Predicting the Future in Science, Economics, and Politics

TO OUR CHILDREN:
May they know peace and join hands with all who seek justice

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And in memory of Paul Williamson, guiding light and workhorse behind this project. Sadly he died before seeing it in print but he remains forever in our inspiration for a better world made possible through rigorous science.

Predicting the Future in Science, Economics, and Politics

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Preface and introduction: overview of why this book matters

Frank Whelon Wayman, Paul R. Williamson, Solomon W. Polachek, and Bruce Bueno de Mesquita

> All public policy presupposes a forecast. (Alan Greenspan[1])
> Life can only be understood backwards, but . . . must be lived forwards. (Søren Kierkegaard[2])

In public policy, as in personal life, we protect ourselves as best we can by making informed choices – let us call the best ones rational choices – between (indeed, among) the options that seem to be available to us. It is one's hope that the choice we make will be for the best, but . . . . If our choice does have some effect, as we hope, then it alters the world, and hence moves us from the present into the future. And we do not know the future; it is the undiscovered country in whose shadow we live. This critical switch to a future frame of reference is especially so about many of our most important choices, such as choices about what to do about the big global problems with long turnaround times, like environmental degradation and nuclear proliferation.

Our best choice requires us to make, then, either explicitly or intuitively, a pair of contingent forecasts, namely: one about how things will be better, in our future, if we take our preferred choice; and the other about how things will turn out worse if we take the alternative, inferior choice before us. It is in this sense that "All public policy presupposes a forecast" – a remark that Alan Greenspan made even before he was Chairman of the Federal Reserve. However, all we have to go on in making such contingent forecasts is any data (or evidence or pattern) that we have detected from how things have been in the past. In that sense, Kierkegaard is right in saying that life must be lived forwards but can only be understood backwards. This book, *Predicting the Future in Science, Economics, and Politics*, is about that reasoning process by which we attempt to understand future contingent forecasts, and how we attempt to guide our decisions by evidence necessarily based on – but hopefully elevated by our reasoning above – past experience. As Richard Alexander said during his preparation of Chapter 4, we humans are the future-seeking organism (Alexander 2005).

The global biospheric system of Earth, emphasized in our book, is the physical, biological, and social context in which, and only in which, humans have evolved to live. It is affected by (nominally distinct) physical, biological, and social processes, and, we contend, can only be understood from an ecological perspective covering, and integrating, the whole range of the sciences. Such a perspective might add empirical content to the term "general systems theory." The limits and possibilities of scientific prediction and explanation of this system's properties are in fact a large part of the context of our book.

To examine this inclusive system, we consider both the relatively continuous variables which have tended to grow incrementally in our lifetimes, such as atmospheric carbon dioxide (CO_2) or the world's human population, and other variables that are more discontinuous, with a history of surprising onsets, such as earthquakes, war, and genocide. Although *Predicting the Future* contains forecasts of surprising phenomena such as nuclear weapons proliferation (Chapter 8) and international armed conflict (in Chapters 9 and 13), our main focus is not the explicit forecast, but rather the method of doing this correctly. (For greater attention to the forecast issue, see Cooper and Layard 2002.)

While it would be useful to be able to predict the future of certain global conditions, such as global warming, nuclear proliferation, and warfare, it would also be useful to know the limitations in the ability to make such predictions. To balance these abilities to predict but also to recognize the limits of forecasts, we must reckon with behavior of complex systems including chaos theory, so our book has contributions from well-known specialists in these areas. Another methodological theme we develop is that, to predict the future, we will need the means to study change over time; this involves incorporating dynamics in addition to comparative statics from one period to the next. There is a broader scope of material that is relevant to this subject of global forecasting and prediction than has been previously considered, and this book touches on several of these elements that we think are relevant, but how exactly they are to be put together remains to be determined (a set of choices and possibilities being examined especially in Chapters 2 and 18).

RATIONALE FOR PUBLICATION, IN THE CONTEXT OF THE LITERATURE OF OUR TIME

Recent bestsellers indicate a trending interest among both authors and readers, a quest for understanding *What the Future Holds* (Cooper and Layard 2002). We have written a book that fills an important gap in the new shelf of books on predicting the future. One reason for the surge in interest in this topic (namely, anticipating the future) may well be that, more than in previous generations, we live in a "revolutionary" epoch (Gore 2013: xv). In this fairly plausible view, held by Al Gore and others, changes in the past have simply not been "as powerful or as pregnant with the fraternal twins – peril and opportunity – as the ones that are beginning to unfold" (Gore 2013: xv). Gore presents six dimensions of change which he believes are unprecedented, especially in their powerful interaction effects with each other, such as the shifting balance between the power of human technology and of the Earth's ecological systems, new biotechnology, and unsustainable growth in human population and pollution flows (Gore 2013: xiv−xv). A second reason for the new interest in predicting the future is that, despite the novel conditions we face, computer modeling and related tools have allowed predictions to become more accurate. An everyday example of this improved predictive accuracy is provided by five-day weather forecasts. The accuracy extends to other areas such as the social sciences. We find some of the recent bestsellers cover the story of accurate forecasts of stock markets and presidential elections. A third reason for the new interest in prediction is that this improved predictive accuracy is not accidental, but stems from better scientific tools (such as computer models) that merit our attention. And yet our understanding of what tools are good, and how the tools can be used together in a synergistic way, certainly needs improvement. We believe our book can help with this.

Thus, our book *Predicting the Future in Science, Economics, and Politics* provides an analytic framework for implementing the approaches advocated in two current *New York Times* bestsellers: Nate Silver's (2012) *The Signal and the Noise* and James Owen Weatherall's (2013) *The Physics of Wall Street*. Silver calls attention to accurate versus inaccurate forecasting and suggests strategies for accurate prediction, based in part on his own success. Weatherall, in one of his main examples, describes the methods used by our Chapter 5 author, the physicist Doyne Farmer, whose Prediction Company found weak signals in noisy data, and combined them to earn good rates of return for its investors. Weatherall advocates using hard science, including physics, and emphasizes that one physics-based hedge fund doubled other returns, while refusing to hire Wall Street insiders. We believe we provide the best of both Silver's and Weatherall's approaches, insofar as we have made salient the idea of "consilience" which unifies knowledge to do these things. Silver's forecasts, on the 2012 election and baseball, rely mostly on large databases (such as many public opinion polls, weighted by Silver on the basis of their likely accuracy). On the other hand, Bueno de Mesquita's (2009) recent popular book – written by one of us – focuses more on short-term consequences of specific policies (for example, what is the effect of US foreign aid to Pakistan, in making Pakistan more helpful in the war on al-Qaida?). It uses game theory as its main method. As mentioned, we are interested in comparing and contrasting several useful methods, including Bueno de Mesquita's and Silver's, and figuring out how they all fit together best in an overall strategy for forecasting. Compared to Cooper and Layard (2002), we focus more on the menu of choice concerning methods for knowing the future, and the advantages and disadvantages of each; they focus more on specific forecasts. Our forecasts are stronger than theirs concerning political risks such as the future likelihood of nuclear weapons acquisition and warfare. Unlike Cooper and Layard, we have hedge fund managers from physics and economics who (in their Chapter 5 on "Using Predictions in an Uncertain World") discuss how to assess the value of future assets, and who had to successfully forecast such things each day in order to make money. Far better than most at explanation involving the unification of science, Wilson (1998, 2000) can only do so much in a given book. He had not, until teaming up with Alexander in this volume (contributing our Chapters 3 and 4, respectively), been able to strongly extend consilient efforts to include the realms of the macro-social sciences such as economics and political science, in whose domains so much of the future is driven.

In short, until now there has not been one comprehensive overview, in a book, of the integration of the sciences into a unified predictive tool, and our volume provides new insights into how one might be constructed, with contributions from leading scholars across many disciplines, and with applications to many problems in global forecasting about conditions affecting the human condition.

It seems a tragic truism that academic research tends to increased specialization as time goes by, whereas the important problems facing humans (such as climate change, the need to cooperate to protect the environment, threats from nuclear weapons) require a synthesis of understanding. For the good of the human condition, this trend should, if not reversed, at least be balanced with efforts to not just cumulate but synthesize understanding. Therefore, we have brought together a group of authors from various disciplines, to reflect on how to forecast the future. We believe the market is increasing, as it is being recognized that long-term trends (population growth, carbon dioxide emissions, nuclear proliferation, war) need to be understood in order to adopt effective policies or even comprehend where we stand and what sort of future awaits us. We believe our book is timely, given the several current *New York Times* bestsellers alluded to above.

Predicting the Future consists of 18 original chapters by prominent scholars developing new techniques to forecast global conditions for business and world leaders. Each chapter is built around cause-and-effect relationships based on empirical evidence that link together to create a unified predictive model to project global economic and political conditions, such as the ecological environment, war, nuclear proliferation, and sustainable development. Both qualitative and quantitative approaches are included. The quantitative range from complex systems studies to game theory to number-crunching of past patterns to assess the likely range of future developments (as, for example, whether stock prices anticipate political turmoil). Original contributions come at the start from the two-time Pulitzer Prize-winning Harvard Professor Edward O. Wilson (also named one of *Time* magazine's 25 most influential Americans), and continue through to Bruce Bueno de Mesquita (named one of *Foreign Policy*'s top 100 global thinkers, and the US cable TV History Channel's "Next Nostradamus") at the end. Overall, this unusual collaborative endeavor of high-level scholars from across the sciences offers a new view into predicting the future.

NOTES

1. From James L. Rowe, "US Statistics," *Washington Post*, July 11, 1976, as quoted in Robert Behn and James Vaupel (1982) *Quick Analysis for Busy Decision Makers*, New York: Basic Books, p. 71.
2. From Søren Kierkegaard, *Journalen* JJ: 167 (1843), *Søren Kierkegaards Skrifter*, Søren Kierkegaard Research Center, Copenhagen, 1997–, Vol. 18, p. 306.

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PART I

The Promise of Global Forecasting

1. Scientific prediction and the human condition

Frank Whelon Wayman

In times of unprecedented prosperity, humanity risks unparalleled destruction. From Hiroshima as bombed in 1945 to Hiroshima rebuilt today, we see an extraordinary range of our era's possibilities, from war's misery to peace and prosperity. Not only nuclear weapons, but global warming and pandemics all threaten their worst while we enjoy some of the best. One might say that we live at the edge of collapse, of plummeting from where we have climbed in 200 years of material progress (and decades of growing peace), back to the hard times that faced all pre-modern human generations. In kinetic and potential energy, from Everest it is just a step – off the edge, you hit Tibet. Specifically, I refer to the Hillary Step, the last great, perilous obstacle to the ascent of Everest. Applying more generally this notion that the higher you go the harder the fall, one might say that modernization, while creating an unprecedented prosperity among the economically developed nations, has left those nations in an artificial and perhaps easily destabilized level of well-being. To avert foreseeable threats, anticipatory plans are surely needed. So we live amidst such ventures as the development and distribution of flu vaccines, to hopefully prevent catastrophes such as occurred in 1918 when the flu turned particularly deadly. Every purposive thing we do is an action now that we take for a better future, based on what we think the future might be like. And increasingly, with new technology, human choice alters the steering mechanisms that are shaping the future of life on the planet.

Our goal in this book is to use some of the modeling techniques from a wide variety of disciplines in the physical and social sciences to explain and forecast global patterns of human behavior. With these tools, we focus on predicting several interrelated variables:

- global shifts in material standards of living, including economic, social, health, and environmental well-being;
- the decline, spread, or altered distribution of war;
- the proliferation of weapons of mass destruction.

Beyond that, even, we hope to harmonize a variety of nominally distinct approaches to provide the basis for a truly scientific approach to the problem of social modeling and forecasting.

This book grew out of a conference, "Illuminating the Shadow of the Future: Scientific Prediction and the Human Condition," held at the University of Michigan in October 2005. We sometimes refer to it as the *Prediction* book for short, especially in those sentences and contexts where succinctness seems at a premium.

While modern life has led to academic specialization, we have written a book that is as interdisciplinary as possible at present, based on the idea of consilience (Wilson 1998), within the context of what we are studying. Hence, we are interested in cross-fertilization of ideas from a variety of perspectives, including not only varieties of political science and economics, but also mathematics, demography, public health, evolutionary biology, and, where possible, even the physical sciences and certain humanities. Beyond that we wish to inquire whether at a higher level these apparently diverse perspectives can be merged into an underlying or some underlying modes of inquiry. While scholars in those fields are not always interested in devoting substantial chunks of time to studying the topics we are exploring, several who do (for example, Lewis Richardson, Jay Forrester, Isaac Asimov) have made a good start in the direction of forecasting. We are interested in any predictive method that works, and that can be applied in a scientific test against evidence from after the date the prediction was written.

Our book is concerned with a number of interrelated global phenomena, including attention to:

1. The degree to which the variation in these conditions in the past has been systematic enough to allow progress in scientific explanation and prediction of past patterns.
2. The degree to which such prediction of the past allows extrapolation to the future.
3. The degree to which forecasting has elements different from static explanation and prediction.
4. The absolute and comparative advantage of competing means of forecasting, including but not limited to:
    a. conventional multivariate regression and analogous methods such as logit/probit;
    b. game-theoretic and choice-theoretic models where strategic interaction may be involved;
    c. prognostications by open-information experts, such as academic area specialists and journalists;

   d. expectations of those with access to classified information, such as government officials;
   e. refinements of the above through Bayesian updating of prior expectations;
   f. dynamic modeling, for example Richardson (see Lynch 2006) and Forrester's (1971) *World Dynamics*.
5. The degree to which methods from the various sciences, mathematical, biological, physical, philosophical, and social, lend themselves to the solution of these problems.

In working out our proposed solutions to these problems, we have tried to strike a balance between, at one extreme, being so broad as to be of little use in this age of specialization, and at the other extreme, of being so specialized as to be of only narrow interest. We believe we have tailored a tapestry that links into a broad-based network of scholars from many academic disciplines, and that allows us to bring them together in a way that will bring fresh insights.

Furthermore, the components are not just the disciplines (from the physical, biological, and social sciences) that people talk about when they discuss interdisciplinary work, but potentially:

- game theory and rational choice;
- evolutionary biology, sociobiology, and reduction and integration of the sciences;
- quantitative empirical work;
- complex systems; and
- computational dynamic global modeling.

We have endeavored not just to lay these out side by side, but also to have leading contributors to each of these important perspectives express how they might, at a higher level of understanding, begin to link up to each other.

OUR VIEW OF PREDICTION IN SCIENCE

Science has been able to advance by being based on three principles: (1) looking for connections between things; (2) studying dynamics rather than static situations; and (3) examining evidence to see if the supposed connections really do help one predict the changes occurring in the subject. For example, Newton predicted where planets would move based on connections between their motion and things that influenced that motion, namely, their mass, the mass of the Sun, the gravitational attraction between massive objects, and the distance between a given planet and the Sun. Newton connected these variables in a dynamic model that differed from the older, static view of science often attributed to Aristotle. And the predictions were falsifiable, meaning that evidence could be used to confirm whether or not the planets moved to exactly where Newton predicted and did so at exactly the time he predicted.

Predictions can be about the present. By "present" is meant a span of time during which the variables of interest may be regarded as unchanging. As is often the case in political or other societal inquiry, the period of one calendar year may be so regarded. Other short or (more usually) longer time periods (for example, decades) may also be regarded as constituting the present. It should be clear that this idea of "present" is judgmental and contextual. One also conventionally regards the present to include whatever moment we, the "observers," "now" occupy. Relative to any such definition of the present, the past consists of those moments in time that preceded the present; the future consists of moments of time that will follow the present. In sum, the terms past, present, and future refer to a threefold stratification based on time.

Using this terminology, we note that predictions are most limited when they only "predict" what is in the present based on other things also in the present. Let us refer to this as the first type of prediction. This happens when the prediction takes the form of estimating the present value of one variable based on its correlation to other variables and on their present values. This is a type of static prediction, in the sense that the variation is across "space" only, rather than across time and space; this has been called "correlational design" (Campbell and Stanley 1966; Cook and Campbell 1979). In contrast, by "forecasting" we mean predictions over periods of time during which the variables are regarded to show changes in value, such that prediction requires that we predict the changes. One form of such forecasting is "postdiction," when information taken from what was once a "past" stratum is used to predict what then was in the present. This form, which we may call the second type, is of greater interest than the first type, for the reason that this second type may be used to test dynamic models. Of course, the power of any such test is limited in that all the data are known a priori. This catch is what Niels Bohr had in mind when he said, "Prediction is difficult, especially about the future." Of course, as Bohr was implying, of still greater intrinsic interest is forecasting from one's own time to the future. Let us call this the third type.

This scientific method of prediction through dynamic modeling of the connection between observed variables can be embodied in one equation, which we can call the dynamic equation. It is that y at $t + 1 = f\,(y$ at t, x

at t, and possibly x at $t-1$). Incidentally, this contrasts to a static model, in which y at $t = f(x$ at t, and possibly some accumulated x from the more distant past to $t - n$, $n = 1, 2, 3, \ldots N$). (In these definitions of dynamic and static prediction, the symbol $t - 1$, in the first equation, is meant to denote x at the immediately prior point in time, but it can be generalized to x at some previous point in time, or at several previous points in time, as in the line $n = 1, 2, 3 \ldots N$.) There are also continuous versions, for example, appearing in the Abelson (1963) derivation of the Richardson "arms race" equations.

Models predict what will happen in the future when they say what will happen at a point after the research has been completed and published. For example, Newton's theory predicts where Mars will be years after Newton worked. Even static models can be predictions of the future if the analyst has an understanding that there are logical reasons for the future to probably be like the past and present. To be relevant to policy, social science models, whether static or dynamic, must be generalizable enough to hold for the future as well as the past in which they were tested.

Prediction is usually thought of as the other side of explanation, but some predictions can be made (and be accurate) even when an explanation is not yet available (for example, Ptolemaic astronomy prior to Newton – see Chapter 16 of the present volume; genetics prior to molecular biology; thermodynamics prior to statistical mechanics). If there is an explanation, that gives us more confidence that the future will be like the past, because we expect the correlation between the predictor and outcome variable to be more stable if we see that there is an explanation for why it has its current value.

Extrapolating from a trend is saying what the future y will be like using only the prior y variable, that is, without bringing in the x variables. Such extrapolation may not be prediction and explanation, because those two things may require some other variable to be the thing producing change in the outcome. If a non-scientific but savvy prognosticator, such as Jules Verne or H.G. Wells, successfully anticipates the future, it is probably best to call that intuitive forecasting rather than prediction, because the prognosticator has not explicitly spelled out the variables that explain the future forecast.

FOUR VARIATIONS

1. It is possible to do dynamic modeling and prediction just regarding the past and present, with implications for the future left implicit. In fact, there is no way to validate future predictions except by testing the

model on historic data, so any model that has met empirical tests has been used to study the past.

2. If the *x* to *y* link is weak and *x* varies unpredictably, yet *y* varies in a relatively stable manner, it is acceptable to just predict future *y* based on past and present *y*. (Demography is a relatively stable *y*.)
3. It is possible to forecast based on intuition. Jensen (1972) has shown that State Department officials and journalists are better than academics at this. It is possible that, in addition to such journalists and diplomats, science fiction authors such as Jules Verne and H.G. Wells and Isaac Asimov, and others who use intuition and logic to anticipate future events, may be better than more academic analysis when the goal is anticipating what the future holds. Hence, H.G. Wells's epitaph is basically, "I told you so" (Wells 1941: Preface). A full consideration of alternative futures has to be open to the possibility that such literary intuitions may have merit.
4. Intuition may also work as input into a mathematical model for forecasting. While Jensen shows you can just forecast with area specialists' raw opinions, Bruce Bueno de Mesquita et al. (1985) uses these intuitions as a basis of a rational choice type forecasting model.

GAME THEORY RELEVANCE

Axelrod (1984), in the *Evolution of Cooperation*, shows how conflict and cooperation predictions and evolutionary dynamics may be affected by strategic interaction. This is more Darwinian than Newtonian. How can game theory become incorporated into predictions to increase their accuracy? Axelrod brings math and computation to what with Darwin had been initially a verbal model. To illustrate the importance of these strategic interactions, Erik Gartzke has emphasized that powerful decision-makers in the global system have their own expectations of what will be effective (often novel) strategies, based on their own intuitions about the future, and that these can confound simple predictions based on past conditions (Gartzke, personal communication).

APPLYING OUR VIEW OF PREDICTION IN SCIENCE TO THE PROBLEM AT HAND

Based on these principles, the purpose of this book is to explore ways to more adequately predict global conditions such as levels of nuclear proliferation, war, and environmental deterioration; and, in this endeavor, the book presents a series of chapters on the prediction of global conditions, and the proper role of "consilience" (Wilson 1998), the quest for reduction and unity of the sciences. Although the predictions made in the book are from the social sciences, a broad foundation is developed for bringing physical, biological, and social sciences together to develop a basis for consilient explanation, from which more broadly informed scientific prediction would be possible.

We seek increased integration, or "consilience," because the most satisfying predictions would stem from explanation, which is often improved by reduction in which we explain one phenomenon (for example, war between states) by moving to a lower level of analysis (for example, the preferences, incentives, and choices of leaders of states). Further, we seek greater scientific unity because of our premise (developed most explicitly in Chapter 18) that to predict global conditions, we need to include a neglected synthesis of the study of particles and energy (physical science), genes (biological science), and interactive choice (social science). To anticipate how this might emerge, we present a schema (Chapter 2) that proposes approximately 100 links between bundles of variables across the "boundaries" of these domains (a matter elaborated in Chapter 15, on the "global state space"). To explore this unity in practice, we convened a group of creative physical, biological, and social scientists, realizing that the actual interactions they fostered or exemplified would supplant any merely conjectural attempt. Some of the synergies might be empirical links between variables across domains, others might be methods or concepts from one science that apply to global prediction in useful ways. The result was a stimulating set of papers, fruitful in the above inquiry and in still others beyond the space of this summation. The presentations from this conference have been captured in the book before you. We think the volume has many potentially important contributions to the desired synthesis, especially the evolutionary roots of rational choice.

THE LITERATURE ON GLOBAL FORECASTING

How does our work relate to other studies of these matters? Systematic, scientific studies of predicting the future of world conditions go back at least several decades. Many of the more technical ones are reviewed in Chapter 2 ("Organizing Diverse Contributions to Global Forecasting," written by Paul R. Williamson). The development of the relevant parts of biological science is covered in Chapters 3 and 4 ("Consilience: the Role of Human Nature in the Emergence of Social Artifacts," and "Darwin's Challenges and the Future of Human Society," by Edward O. Wilson and Richard

D. Alexander, respectively). In an overview here, I will now examine some general perspectives not included in those coming chapters. The purpose is to cover some of the more prominent books that have shaped discussion of these matters, and to add in a few items that we as the volume editors draw on for direction, and that come out of our own intellectual heritage.

Looking back over the development of scholarship on global conditions, one sees that this field emerged in the dangerous context of the four-decade-long Cold War between the US and the Soviet Union. World War II had ended with an ominous prologue to the Cold War, namely, the detonation of the first atomic bombs used to kill human beings, at Hiroshima and Nagasaki. In the four years before that, the conventional weapons of World War II had already killed more people than had died in any modern war. Now the prospect of a possible World War III with nuclear weapons was even more terrifying. When the first nuclear bomb exploded in a test in the New Mexico desert, the month before Hiroshima, the scale of the detonation awed J. Robert Oppenheimer, the director of the scientific lab of the Manhattan Project, leading him to consider the words, “Now I am become death, the destroyer of worlds” (Bird and Sherwin 2005: 309). Within years, the two superpowers, the US and the Soviet Union, possessed tens of thousands of even more powerful weapons, based on the principle of nuclear fusion. For these fusion bombs, the fission process used to destroy Hiroshima was the trigger. The overall destructive energy of the large fusion bombs was 100 to 1000 times greater than Hiroshima. In the Cuban Missile Crisis of 1962, President Kennedy and Premier Khrushchev were alarmed that a nuclear war using these hydrogen bombs might break out. The war plans of the day were that one side would deter the other from attacking, by threatening to counter-attack with its own nuclear weapons. While this deterrence was likely to work to prevent war, it could only work if the two sides were frightened of each other, and that could only happen – according to the logic of the game theorist Thomas Schelling – if there was a “threat that leaves something to chance,” that is, an actual possibility that in certain circumstances the weapons would be used (Schelling 2005). This was perhaps even more dangerous than was understood by deterrence theorists, nuclear scientists, and world leaders in Moscow and Washington. Plans for such threats and possible use were taking place in the absence of the critical knowledge, only revealed in 1982, that a large nuclear exchange between the two superpowers might end almost all life on Earth, through a destructive atmospheric effect called the “nuclear winter” (Turco et al. 1983). Within a decade of that finding, the Cold War would wind down, perhaps partly because President Reagan and Premier Gorbachev came to trust each other during meetings they held to advance their shared hope of assuring that nuclear weapons would never be used. Meanwhile, the fate of the Earth continued to hang in the balance, and some very clever thinkers went to work on the problem of preventing a nuclear holocaust. For example, the psychologist Phillip Tetlock's award-winning book on "what constitutes good judgment in predicting future events" began with his appointment in 1984 to a committee of the US National Academy of Sciences, with the mandate of "rescuing civilization itself from nuclear incineration" (Tetlock 2005: xii). One year after the Cuban Missile Crisis, J. David Singer, co-author of Chapter 8 in this volume, founded the Correlates of War Project at the University of Michigan. One can see how the nuclear winter planetary modeling effort, forecasting what would actually happen in the event of a nuclear war, may have decisively changed thinking in high places (Sagan 1994: 227). Singer attempted to foster more fresh thinking in a book called *Quantitative Indicators in World Politics: Timely Assurance and Early Warning* (Singer and Stoll 1984). As the title suggests, the hope was to build databases that could provide leading indicators of either danger or safe passage ahead. In one chapter in that book, I showed how expert judgments from US State Department officials (or Pentagon officials or professors of international relations) could be used to statistically predict future armed conflict in the Middle East in ways that the officials themselves would not have been able to anticipate (Wayman 1984). This fitted in with Singer's organizing schema of the book, which was to: (1) "identify a particular condition . . . whose social desirability (or undesirability) . . . can be reasonably demonstrated"; (2) "measure with high reliability . . . that condition"; (3) "identify and measure one or more predictor conditions or events that might be expected, in the relevant future, to regularly precede the outcome condition"; (4) "demonstrate the extent to which such an association has obtained . . . in the past"; and (5) "clearly articulate the ways in which some or all policy makers could, if they chose, utilize such predictive indicators to reduce the incidence of inter-state war" (Singer and Wallace 1979: 13). One of the studies in a pioneering volume (Meyer and Brewer 1979) laid out an early scheme very much like ones in use today for monitoring nuclear proliferation. The effort to predict the path of nuclear proliferation is taken up afresh in our Chapter 8.

As the risk of war faded a bit at the end of the Cold War era, attention in global forecasting shifted somewhat from the above security issues to ecological and economic interactions. We might term this new area "political economy." In the area of political economy, the main intellectual paradigms of the 1950s and 1960s were optimistic. It was recognized that there were periodic recessions, and even depressions, that temporarily reduced national and even global material well-being; but it was believed that the general trend was towards growth or improvement in the average person's material standard of living. This complacency, that each generation would be at least a little bit better off than its predecessors, was about to change. Shortly after the first "Earth Day" (April 22, 1970), Jay Forrester in *World Dynamics* (1971) presented the "Club of Rome" view that, contrary to the capitalist and Marxist views of increasing prosperity through industrialization, there were ominous limits to growth that could, if mismanaged, destroy the prosperity that had become widespread in the modern world of the mid-twentieth century. If we glance back for a moment to ancient times, we find that most humans then expected life on Earth to go on as it already was; in modern times, a new view had emerged, that there was material "progress" that would gradually improve living conditions. After Earth Day, in the paradigm shift of 1971, Forrester was introducing the ecological warning that our future might be one of collapse (Diamond 2005) rather than progress. The destructive forces were postulated to be excessive growth of the human population, overuse of raw materials, and excessive pollution. A popular version of Forrester's study (Meadows et al. 1972) proposed a solution that the world could only sustain 8 billion people at a per capita income of $2000 per year in 1970 dollars (and with pollution per unit of income cut to a quarter of its 1970 level). A reply (Cole 1973), titled *Models of Doom*, showed that the Club of Rome model rested on unproven assumptions, but added that it was not possible, as that critique went to press, to replace the Club of Rome model with a "correct" one (because of lack of data, unknown relationships between variables, and so on). Tetlock (2005: 17) reports on an ongoing continuation of this debate, in which Paul Ehrlich, a scholar worried about overpopulation and food shortages, lost a bet to an optimist, Julian Simon. Simon's predictions had turned out to be more accurate than Ehrlich's. Ehrlich paid up, but then claimed that Simon had only won because not enough time had passed: it was as if a man such as Simon had jumped off the Empire State Building and, halfway to the ground, said, "All's well so far." In our Chapter 7 (by Luterbacher et al.), the ongoing debate is addressed over whether a sustainable economy exists or not.

The Forrester *World Dynamics* model, by linking physical conditions (resource scarcity, pollution) to social conditions (sustainable population, material standard of living), was implicitly interdisciplinary, as it crossed the boundaries from physical systems to social ones. Yet it failed to have a political or economic sub-routine. All four of the editors of the present book came together at the University of Michigan, where the Correlates of War Project was meeting weekly at the Mental Health Research Institute (MHRI). This was an interdisciplinary operation, based on the notion of "general systems theory." Attendees at the Correlates of War weekly seminars, besides ourselves, included Anatol Rapoport, a mathematician, peace researcher, game theorist and MHRI staffer; and Karl Deutsch, a political scientist who made monthly visits from Harvard. Deutsch, during a later phase as Director of the Science Center Berlin, became a mentor of Barry Hughes and his International Futures Project (Hughes 1999: xix).

Influenced by this modeling work but not directly making computations, Deutsch intuitively developed his own forecasts on the future of the globe (Deutsch 1977, 1978): the dominant Cold War security issues would be replaced by an emerging security dilemma with a handful of features. While some say the future cannot be known, Deutsch forecast with a high degree of likelihood that: (1) population would grow; (2) the world's people would not only be more numerous, but would be more urban and more literate; (3) the poor would therefore be more aware of how "the other half" lived, and be more demanding; (4) consequently, needs would grow, because what people demand becomes a political need; (5) therefore the gross national product (GNP) per capita, or more fundamentally, the material standard of living, would have to increase; (6) however, we have been trending for the past two centuries toward a phase of "armed equality," in which great powers can no longer win most wars and dominate the globe; (7) nuclear proliferation, a component of that, will continue; (8) on account of the previous two points, it will be impossible to triage the world's population and let the poor suffer – they will attack if desperate; (9) given the need to increase GNP per capita, along with the harmful side-effects of pollution, the most important step toward national security would be the investment of a substantial portion of the GNP in energy conservation, solar energy development, the production of goods with "higher information ratios," recycling without excessive use of energy, and similar technological initiatives. Looking back a third of a century later, it is hard to disagree. However, at the same time as Deutsch, many other "experts" were making foolish projections, so we do not want to put too much faith in "expert" insights. Tocqueville remarkably said, in the 1830s, "there are at present two nations . . . who each seem set out by the will of Heaven to sway the destinies of half the globe – I allude to the Russian and the American." With great ingenuity, he anticipated the world of 1943–90. The trouble is that insight such as we find in Tocqueville's (1956) *Democracy in America* is special, and while we can be amazed at him, as we look back now with hindsight, the problem is that when the predictions are being made by pundits, the record is that most pundits will be wrong. And it is not clear which of them has the right answer till later. What to do? There are at least a couple of possible ways forward.

By coincidence, two of the editors of the present book wondered whether experts, instead of just saying what the future holds in store, could simply be asked to provide some input data that could be used in a more elaborate model to forecast events. In surveys of US State Department officials, Pentagon personnel, and academics, in 1975 and 1981, Wayman (1984) measured their perceptions of hostility or friendship between pairs of actors in the Middle East, and showed that these, as if they were "voices prophesying war," could be used in an interactive model to forecast when future conflict events would follow from, but express different patterns than, past events. Bueno de Mesquita (e.g., Bueno de Mesquita et al. 1985) measured instead the experts' judgments of the relative power of various actors, the preferences of those actors for certain outcomes along certain issue dimensions, and related variables such as the salience of the issues to each actor. He then used computer modeling (for example, in a very simple model of a one-dimensional issue with single-peaked preferences and majority rule, using the median voter theorem we can predict the outcome as the ideal point of the weighted median voter; see Bueno de Mesquita 2014: 101–114). Bueno de Mesquita showed that these expert judgments as modeled forecast the future better than the experts themselves could foresee (that is, when they were asked, "So what do you think's going to happen?" they did worse than the model based on the input of power of each actor, and so on, which they themselves had provided). Succinct and useful summaries of these patterns from Bueno de Mesquita's forecasts, across a wide range of examples, may be found in the periodic press (Lerner 2007; Thompson 2009).

Bueno de Mesquita's work has focused on games in which actors attempt to pursue their own goals, with each actor constrained by what the other actors' choices are likely to be. More specifically, the national leaders are looking out for themselves, and either a small coterie or larger public, depending on the structural span of the needed domestic political power base, from the few to the many (Bueno de Mesquita 2014; Bueno de Mesquita et al. 2003). From this and some particulars of time and place, forecasts follow, so Bueno de Mesquita's study is focused on the choices of key actors.

Forecast success is not limited to just Bueno de Mesquita, or just game theory. Another successful analyst, Nate Silver, has recently focused on the election process by which the most important international actor, the US President, is chosen. In a recent bestseller (Silver 2012), he tells how this data-intensive work of his succeeds, and what distinguishes "the signal and the noise."

The controversies about the accuracy of such studies – and especially about which approaches worked better than others – raised the question how well one could know, with 100 percent focus, the exact path to such a complex future. As research (and computing power) advanced, one approach, taken by Barry Hughes (1999), was to try to compile, from the "best practices" of modelers and data gatherers in different subfields, a large computer model and database which could project for analysts various possible global futures (plural), in the form of "if, then" statements, without saying in which of these directions the world would go. Another approach was to assess how well "best-practice" practitioners, and other highly placed professionals, could do in intuitively predicting the future. Some of these studies of expert judgment focused more on international tensions and the risk of nuclear war; others on what we have called political economy. In a very early rigorous study, Jensen (1972) asked journalists, professors, US State Department officials, and Pentagon officials to predict world events in the next few years. Jensen found little difference in accuracy as a function of level of education of the respondent, or as a function of the assumptions made about the international environment (for example, whether deterrence was stable, whether the Soviet Union was bent on world domination). He did find substantial differences in accuracy from role to role: the State officials did best (43 percent high accuracy predicting up to five years ahead), the journalists came in second (27 percent accuracy), and the academics and the US Defense Department officials fared worst (18 percent accuracy). Of course, one would wonder why experts from some organizations did better, while those in other walks of life did worse. A fellow graduate student of Jensen's, at the University of Michigan, conducted a doctoral dissertation (Mennis 1971), in which he found that State Department officials were more open-minded (as measured by Milton Rokeach's scale) than Pentagon officials, and that this went all the way back to what sort of young high school students applied to Ivy League schools, as opposed to the military academies. This raises the question whether mental style is related to successful prognostication. Eventually, Tetlock (2005) found that there was a cognitive style associated with accuracy in predicting the future. He distinguished between "foxes" and "hedgehogs." The foxes tended to look at things in a subtle, complicated way, and be a bit unsure of themselves; while the hedgehogs tended to think there was a right answer, and that they had it. It turned out the foxes did better at predicting international futures, but were less sure of themselves; so, paradoxically, those who expressed caution were more likely to be right than those who said they had the answer. As an amusing (but also harmful) side-effect, the hedgehogs tend to be popular guests on certain TV shows, because the hosts want to quickly provide their listeners with a take-away right answer before it is time for the next commercial message (Silver 2012: 47–56).

Recent bestsellers indicate that such forecasting ventures, rather than simply being permanently stunted in their potential, are becoming examined increasingly, with more and more interest in the results. This is partly because the predictions have been successful. Bruce Bueno de Mesquita has been praised by officials for providing more accurate predictions than were elsewhere available, and he continues to make predictions in print that can be checked out to see if they come to pass (Bueno de Mesquita 2009 is a recent case in point). It has been said that the two basic "political-economic mechanisms available for coping with present and future are . . . government . . . and markets" (Lindblom 1977: 4). As for politics and government, Silver (2012), previously noted above, showed an uncanny accuracy in statistically forecasting the outcome of the selection of the most prominent political leader, the President of the United States. As for markets, likewise, scientific forecasters, in this case from physics, are attempting to oust traditional analysts from the perch as leaders of hedge funds, by mathematical models of the stock market (Weatherall 2013). In the geophysical world, there has also been progress. In the mid-twentieth century, the distinguished physicist George Gamow wrote a popular book in which he made an earnest effort to explain the fluctuation of the Earth's temperature from the warm age of the dinosaurs to the Ice Ages in which humans first emerged (Gamow 1953). The focus was on variations in such things as planetary orbits and spin, not human-generated atmospheric carbon dioxide (CO_2) levels. Likewise, the Forrester model I have discussed, from 1971, examined overall "pollution" as a variable, and did not comprehend global warming. Except for the conjectures of a handful of scientists, people were not thinking about greenhouse gases yet in those years. Then, in 1978, the *Pioneer 12* mission to Venus confirmed the hypothesis that the metal-melting temperatures on our closest sister planet were caused by "the ordinary greenhouse effect – the surface heated by the Sun and the heat retained by the blanket of air" (Sagan 1994: 225–226). In the early twenty-first century, with growth in geophysical knowledge, it is not difficult to forecast next year's average global temperature based on the input of this year's level of CO_2 concentration in the atmosphere.

Looking at the whole planet, Al Gore (2013) has presented what he sees as several significant twenty-first-century trends, within the general premise that never before has it been more important to be concerned about the future, because never before has our species been facing such rapid change. The first review on Gore's dustjacket is by our first contributing author (Edward O. Wilson, Chapter 3 in this volume). If there is one key to our approach in *Predicting the Future*, it is provided by Gore's focus on what he calls "The Edge," which represents "the emergence of a radically new relationship between the aggregate power of human civilization and the Earth's ecological systems" (Gore 2013: xv, 280–360) One might translate this by saying that the future of the global system increasingly depends on human choices. Only 200 years ago, Lord Byron could still write, "Roll on, thou deep and dark blue Ocean – roll!/Ten thousand fleets sweep over thee in vain;/Man marks the earth with ruin – his control/Stops with the shore" ("Childe Harold's Pilgrimage," Canto IV, Verse 178: Byron 1962 [1812–1818]: 281). Now the temperature and cleanliness of the great commons, the air and the ocean, are affected profoundly by human activity. The physical, biological, and social subsystems of the global system no longer have clear boundaries, but rather interpenetrate one another, with the human social forces increasingly important as drivers of change. This leads us from the previous literature to our own book.

ORGANIZATION OF THE BOOK

After this chapter and Chapter 2, which provide an introductory perspective, *Predicting the Future* continues with the living aspect of the physical basis of the global system. While this is diverse and complex, we focus on living things, because understanding them is the most difficult part of the problem and arguably the most important. The first two substantive chapters (by Wilson and Alexander, respectively) focus on the evolutionary and biological basis of human behavior including human choice. Wilson, in Chapter 3, issues a challenge: "The subject . . . I want to address is the intrinsic unity of knowledge. Does it exist? Or does it not exist?" He then explains how human preferences (involving everything from incest taboos to habitat preference), and some other cognitions, emerge from our evolutionary background. Alexander, in his closely related Chapter 4, outlines the implications of this for human behavior and choice at the global level. Human beings are "the future-seeking organism," (Alexander 2005), but our choices about that are grounded in evolutionary biology. In particular, one explanatory framework for Alexander is that "humans evolving to live in groups" are "a very loosely organized counterpart to the genes living in genomes" (Alexander 2005). For a variety of reasons he explains, individuals in groups do not cooperate as effectively as genes in genomes. This leads to a complex relationship between individual advancement of individual interests and the evolutionary (or survival) benefit of the in-groups in which these individuals are embedded, and which historically struggled against out-groups. Wilson and Alexander raise important questions about the evolutionary basis of rational choice. The remainder of our book is concerned with the applicability of these principles and others at the level of macro-social systems, including the overall global system.

To that purpose, the book turns to topical and/or methodological contributions that may be elements needed in an effective global model. Farmer and Geanakoplos, who made money through successful, scientific financial forecasting, discuss what is the proper discounting function for comparing present and future pay-offs. In Chapter 5, Farmer and Geanakoplos address particularly the problem of how to value the future damage of global warming. Sprinz (Chapter 6) then considers in what ways political institutions deal with long-term problems, including climate change which is his main concern. In Chapter 7, Luterbacher, Rohner, and Wiegandt, with di Iorio (looking at the impact – that is, a "coupling," to use a term introduced in the next chapter – of the natural environment on violent conflict) examine what institutional forms would be needed to avoid what they call the "triple tragedy of the commons," and how failure to create a stable ecological and economic system can lead to armed conflict. Topical examination of future international security problems includes the chapters by Schneider (Chapter 9, on financial markets as early warning indicators of armed conflict), as well as Tago and Singer (Chapter 8, forecasting nuclear weapons proliferation), and Wayman (Chapter 13, forecasting the future frequency of war). All four of these authors have some interesting methods that show success in predicting an important outcome variable (war, violence, nuclear weapons proliferation) that is discontinuous and episodic, and hence trickier to forecast than more continuous variables with lots of auto-correlation, such as population growth. Just as Wilson and Alexander provide a short treatise on human nature, several authors in the latter half of the book examine the nature of the global system. Holland, in Chapter 10, offers some methods for what you might do as an analyst if the system turns out to be a complex adaptive system; because that is going to put severe limits on your ability to forecast, and maybe even require different techniques. Other treatments of global systemic features are offered by Wilkinson (Chapter 12), Williamson (Chapter 14), and Karasik (Chapter 11). As one way to synthesize all this, the innovations to be found in our book are reviewed in the penultimate Chapter 17, by Polachek.

Our even greater challenge was to explore the idea of merging these apparently diverse perspectives into a single, overarching mode of inquiry. In Chapter 2, Williamson takes up that task. He elaborates on the three foundations – couplings, dynamics, and evidence base – that we have said underlie scientific progress. He also discusses how content from different academic disciplines might be linked. Consilient patterns can explain one science in terms of another at a lower level of aggregation (for instance, biology being based on chemistry). Yet it is still vital to find connections and evidence at the higher levels of aggregation, possibly even before there are links that can be found to lower levels explanation. In Chapters 3 and 4, by Wilson and Alexander, respectively, some important illustrations are given of biologically based evolutionary traits that may affect macro-social behavior. The place of this in our book's organizational scheme is outlined in Williamson's Figure 2.1, on reduction and synthesis. Williamson, more generally, in Table 2.2 and Figure 2.1 speculates on how different fields covered in the book may affect each other. This provides a rationale for the scope of the book. In fact, specific instances of what he is talking about make up the bulk of the remainder of the book.

Our last co-editor, Bruce Bueno de Mesquita, takes up these themes in our final Chapter 18 from a choice-theoretic point of view. Choices we would like to make about the future depend on consequences of each alternative, given the constraints that we can call our environment. Part of the function of our book is to bring to the reader's attention which features of the environment are fixed and which are manipulable. Wilson and Alexander point to human traits that can be seen as fixed from the short-run viewpoint, but which in the long run do change and evolve. Before we get that far, we turn now to Williamson's chapter, and then those of our other contributors.

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2. Organizing diverse contributions to global forecasting

Paul R. Williamson

The elements that may contribute to computational global societal–environmental modeling and forecasting – herein simply "modeling" or "global modeling" where clarity permits – take the form of contributions from greatly diverse sources. Some of these (somewhat skewed in the direction of social inquiries) are speculatively indicated by the categories in Table 2.1. This chapter offers a set of themes, set forth below, for connecting such elements. This particular set of ideas is not meant to be unique; there may be, no doubt are, other ways of doing the connecting; nor will the present discussion do more than briefly treat the themes to be considered.[1]

The organizing principle that I propose is that the various elements may be described and compared in terms of the themes. This suggested organization is, thus, a very loose one. It is not a substitute for the ideal of a consistent, coherent, validated, maximally compacted organization of elements, but my suggestion is that the indicated comparative descriptions may help move global modeling in the direction of that ideal.

The rationale for these particular themes is that to do successful global modeling one needs to look, anew, at modern physical science as both exemplar and basis of global knowledge. By "modern," I mean a form that has characterized the inquiries of Isaac Newton and his contemporaries and successors to the present day and which differentiates those inquiries from most scholarly inquiries previous to Newton and, even today in one respect or another, from most social inquiries.

First, though I take human society as the focus of interest, there are more aspects to the global system than humans and human groups. The global system also includes other life forms such as animals, plants, and microbes, and non-living phenomena such as weather, climate, and tectonic plate movements, that are intimately connected with human society. Physics, chemistry, and biology in many of their disciplinary forms are required in order to account for these non-human societal aspects, to whatever extent may be possible.

Table 2.1 Some important fragments potentially contributing to computational dynamic global modeling and forecasting

	Short name	Some current representative proponents	Originator or early proponent(s)
1	Enhanced econometric modeling	Globus project; Hughes; *Luterbacher*; *Polachek*; *Schneider*	Forrester / Meadows; Mesarovic / Pestel
2	Input–output modeling	Duchin	Leontief
3	Earth environmental modeling	NCAR; *Sprinz*; *Luterbacher*	
4	Evolutionary theory / sociobiology	*Alexander*; Axelrod; *Wilson*	Darwin; Wallace
5	Deadly quarrels	Cioffi; *Polachek*; *Singer* / COW project; *Wilkinson*	Richardson; Wright
6	Choice theory	*Bueno de Mesquita* / Smith / Siverson / Morrow	Morgenstern / Von Neumann
7	Linear differential change	Kadera, *Wayman*	Rashevsky; Richardson
8	Non-linear dynamics / complex systems	*Farmer*; *Geanakoplos*; *Holland*; *Karasik*; Mayer; Santa Fe Institute	Poincaré
9	Constrained generating procedures	*Holland*	
10	Cellular automata	Conway	Ulam
11	Homeokinetics		Iberall
12	Non-equilibrium thermodynamics		Prigogine
13	EE control theory	*Karasik*	
14	Feed forward neural nets	*Farmer*; *Karasik* / *Williamson*	Werbos
15	Cyclical neural nets	*Holland*	Hebb; McCulloch / Pitts
16	Social field / spatial theory	*Williamson*	Wright; Rummel
17	World order study	*Wilkinson*	Wallerstein
18	Waiting times analysis	Cioffi; *Tago*/ *Singer*; *Williamson*	Tuma / Hannan
19	Power balance/ transition	Houweling / Siccima; Kadera; Kugler; Lemke; *Wayman*	Organski
20	Graphs / networks	Barabasi; Bonabeau; Maoz	Brams; Alger
21	Demography	Cohen	

Note: Names of contributors to this book are in italic.

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A second reason for looking at modern physical science concerns the role of "modern scientific" style in societal inquiry; which role I take to be very desirable. My premise is that the distinction between "modern" and other versions of science is very important; that it is the modern variant, as demonstrated in present-day physical inquiry, which has led to the great conceptual and practical successes that we attribute to scientific activity. Thus it is the modern variant of physical inquiry that societal inquiry should seek to emulate, in order to give the endeavor its best chance.

A third reason for considering modern science is the prospect that the most powerful form of human societal knowledge may come to be based on a foundation of physical knowledge, just as biology today is increasingly so founded. This basis would fulfill the idea of a fundamental unity among all forms of modern scientific endeavor, Edward O. Wilson's concept of "Consilience," so well expressed in his book of that title (Wilson 1999) and as further developed by him in other places, including his Chapter 3 in this book. My suggestion here is that, in seeking to realize the most effective modeling, we can profit by taking account of the search for consilience and by making its program part of our own.

In the remainder of this discussion I will consider further the second, then third viewpoints, expressed above, on modern science; then briefly return to the first.

STYLE OF MODERN SCIENTIFIC INQUIRY

Three alleged valuable characteristics come to mind. Let us call them:

- couplings;
- empirical validation; and
- dynamics.

Again, these are not meant to be unique or established writ; I readily acknowledge the possibility of alternatives and complements.

Couplings

By "couplings" I mean that factors nominally distinct (because they have distinct names) may, in reality, be causally connected; that is, each may affect or relate to the other, in ways too important to neglect. The transition from classical to modern science involved accepting the idea that "Earth" (supposedly the place of earthly sin and imperfection) and "Heaven" (the place of celestial flawlessness) were not fundamentally different, after all, but were governed by the same laws. So, once the Earth–Heaven distinction was put aside, what Galileo saw in the motions of pendulums and rolling spheres and what Kepler (building on Copernicus and Brahe) saw in the conic sections of planetary orbits could then legitimately be combined by Newton into a single framework, which turned out to be extremely powerful, *inter alia* exactly because of the combination.

In issues of global modeling we see many such domains that legitimately may belong together, even though conventional inquiry may treat them as self-contained. The matrix of Table 2.2 (the exact content of which is largely a product of my imagination) shows about a score of such coupled domains. A dot in a cell matrix represents that the row factor is thought to influence the column factor. (A column factor is identified by a number, which corresponds to the named row factor bearing the same number. More realistically, each displayed factor would be replaced by a bundle of variables; the couplings would be continuous, not dichotomous; and their values would be theoretically and empirically validated to the extent permitted by then-current understanding.)

There are three other points to be made about couplings. First, they fundamentally are opportunistic. That is, no matter that two factors conventionally may be regarded as entirely distinct – for example, governed by entirely different systems of causation – they may be connected if evidence, theory, or conjecture suggests it. Let me put this another way: modern science (physics and its applications) is not “about” some pre-assigned domain. It is about whatever it is about; that is, whatever can be connected together is connected. What started as rolling spheres on an incline now includes (just to pick three out of many) galaxies, tomorrow’s weather, and the molecular basis of living cells. A similar point of view leads to the broad scope of factors named in Table 2.2.

Second, consideration of couplings may well lead to the view that, rather than merely being coupled, the factors in question are the same factor. This happened in the case of the above-mentioned unification of Earth and Heaven; it took the form of Newton’s decision to treat the motion of bodies falling (or rolling, or swinging) on the Earth and the motion of planets and planetary satellites in Heaven (now demoted to “space”) as responding to the same force, namely gravitation. Earthly and celestial motions thus were unified into the same factor. This program of unification has been repeated many times: electricity, magnetism, and optics unified in electrodynamics (Maxwell); electrodynamics and Newtonian dynamics (other than gravitation) unified in special relativity (Einstein); quantum physics and special relativity unified in quantum electrodynamics (Dirac, Feynman, and others); electromagnetic and weak nuclear forces unified in the electroweak force; electroweak and strong nuclear forces

Table 2.2 Possible couplings among variable and problem groups

(All factors to be geo-encoded where applicable.)		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
General health indicators, symptoms	1	•	•			•	•	•	•	•	•		•	•	•		•								•			
Vector-borne disease indicators, symptoms	2	•	•			•	•	•	•	•	•		•	•	•		•								•			
Lifestyle	3	•	•	•		•	•	•	•										•									
Genetic factors – determinants	4	•	•		•	•																						
Epidemiology factors – determinants	5	•	•			•																						
Conventional health system utilization, costs	6	•	•	•		•	•	•	•					•														
Tele-health system utilization, costs	7	•	•	•		•	•	•	•					•														
Demography, population instability	8		•		•	•	•	•	•	•	•	•	•	•	•	•		•	•		•	•	•	•	•		•	
Literacy – illiteracy	9	•	•	•		•	•	•	•	•	•		•	•	•										•			
Food production, malnutrition, starvation	10	•	•	•		•	•	•	•	•	•	•	•	•	•	•						•		•				

Table 2.2 (continued)

(All factors to be geo-encoded where applicable.)		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Land, sea multi-spectral indicators	11		•			•					•	•	•		•		•			•	•	•	•	•			•	•
Urban development – disintegration	12	•	•	•		•	•	•	•	•		•	•	•	•										•		•	
Wealth, wealth distribution, poverty	13			•		•	•	•	•	•	•		•	•	•		•								•			
Investment – disinvestment	14				•		•	•	•	•		•	•	•	•	•	•	•	•		•							
Monetary growth, instability	15			•			•	•	•	•			•	•	•	•	•								•			
Economic growth, instability	16			•			•	•	•	•	•	•	•	•	•	•	•								•	•	•	•
Severe ozone depletion	17	+				+					+													+				
Greenhouse gases	18																			•								
Weather – climate change	19	•	•	•	•	•					•	•	•		•		•		•									
Water flow, ground-water pollution	20	•	•	•	•	•					•	•	•		•		•					•		•			•	•

Deforestation, wetlands factors	21		•			•					•	•							•	•		•	•	•				
Desertification	22		•			•					•	•								•	•	•	•	•				
Species populations, extinctions	23		•			•					•																	
Authoritarianism	24					•	•	•					•	•		•	•								•	•	•	•
Armaments acquisitions, transfers	25													•	•	•	•				•				•	•	•	•
Conventional war, war risk	26	•	•	•		•			•		•	•	•	•	•		•		•		•				•	•	•	•
WMD war, war risk	27	+	+	+	+	+			+		+	+	+	+	•	+	+	+	+	+	+	+		+	•	•	•	•
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27

Notes:
Cell entries represent hypothetical couplings from row entry to column entry. Given column number denotes entry of same row number.

• supposes strong coupling at present;
+ supposes contingent strong coupling – actual coupling only following discrete occurrence of named event.

Source: By permission Global Vision, Inc.

united in the Standard Model. Physicists now seek to unify gravitation and the Standard Model so that a single general force will describe the universe. Global modelers need to be thinking along the same lines. For example, are the phenomena called "politics" and "economics" truly different?

Finally, the third consideration: accepting the program of couplings appears to be psychologically difficult for many. Thinking, again, of the emergence of modern science, Giordano Bruno was burned at Rome in 1600. His heresy included the claim that stars are not holes in the heavenly dome through which shines the light of heaven; rather, that they are luminous spheres floating in a three-dimensional space. Galileo, also, was threatened with dire punishment for his views. The heresy in both cases was to assert connections among domains regarded, by established authority, as properly distinct.

Today, authorities do not burn heretics for exploring fundamental but unconventional connections transgressing established fields; instead they deny them funding, publication, academic appointment, promotion, and tenure. Fortunately these denials work imperfectly, as is well attested by the contents of this book; but still, with such comparatively rare exceptions, the denials have a powerful inhibiting effect on inquiry. What are we missing as a result? Or, phrasing it in the positive, what might be the benefits of a global systemic analog to, or extension of, the beneficial synthesis created by Newton and his contemporaries and successors? Perhaps it will be in the synthesis of the "physical" and the "social"; or of "purposeful" and "non-purposeful" behavior. The knowledge benefits that flowed from past syntheses give good reason to get over the current mentality of resistance to unconventional ways of putting together ideas concerning the global system.

Empirical Validation

The second above-named characteristic of scientific inquiry is empirical validation. This means that ideas about how the world works are to be tested not just against realistic evidence but, moreover, against the most comprehensive body of evidence that is practical, at any particular moment. This implies, in each instance and to the extent that is practical, reliance on reproducible data and on data series, quantitative where appropriate; "reproducibility" meaning that steps have been taken to minimize variations in data due merely to differences in judgment among those who develop the data.

Various relevant inquiries practice the above to varying degrees. The ethos of empirical validation is very well established in conventionally "physical" inquiries; and, there, what is practical is greatly aided by the availability of comparatively vast funding to take measurements and develop them into data. Empirical validation is also well established in parts of economics, and funding for data is available, though on a lesser scale than in physical inquiries. Other parts of social inquiry also pursue empirical validation but in greatly varying degrees. (For example, opinion survey research in the United States receives great emphasis and is said to be comparatively well funded.) The variation seems to reflect variations both in funding and in the receptivity, among the prospective fund recipients, to the idea of data-based validation. Some inquiries appear to reject the idea of doing science; others are quantitative in their use of mathematical models that, however, are tested against empirical evidence to a sharply limited extent or not at all. One conclusion to be drawn is that empirical validation and funding to support it needs to be considered, or reconsidered, and strengthened as appropriate in areas relevant to global modeling where now it is weak, especially in human societal inquiries.

An equally important point, however, is that the diverse relevant fields of inquiry appear usually to be ignorant of the empirical resources in other relevant fields or even of the very idea that empiricism might be appropriate in those other fields. First, it would seem to be the case that practitioners in societal inquiries often are ignorant of the empirical variables, thus the resources, in physical, chemical, and biological inquiries, though one presumes they are aware of the idea of empiricism in physical inquiries. However, it is also the case that both physical and many societal investigators are ignorant of the idea and practice of empiricism in societal inquiries where currently they are found. For example, this book draws extensively on persons engaged in the quantitative, empirically based study of international and national violent conflict, particularly persons in the globally extended community called the Correlates of War project. This project originated (~1960, and continues today, first under J. David Singer and now with the involvement of many of his students) at the University of Michigan – a very well-known place; yet it would appear that the truly extensive data holdings developed, with great care and intellectual integrity, within this project, and the idea of the importance of these data, still remain largely unrecognized by most persons engaged in relevant scientific or policy inquiries. In sum, the appropriate roles of all sorts of empirical evidence in global modeling remain unrecognized, and their uses, fragmented.

Dynamics

By this word I mean simply the following. Given a model and a description of the system of interest at a particular moment in time, can one then infer, from the model, the change in the system to some other moment of time? If so, then one has incorporated dynamics into the model. (One might want to put more into the definition of dynamics but the above seems best for the present purpose; see also Chapter 15 of this volume.)

This third element in the suggested trilogy comes with two points. Most directly, "forecasting" means the ability, given where the system is at some moment, to infer where it will be at future moments (and where it was at past moments) – or to determine that such inference is not possible in the specific given circumstances (as with chaotic phenomena). Thus "dynamics" is the ability to do that for which we ultimately aim, namely scientifically validated forecasting.

The other point is a fundamental point about dynamics. What we know today as the study of differential and integral calculus of real (and complex) variables was initiated by Newton and Leibnitz in parallel with the development of mechanics. (Long before, according to recently uncovered evidence, Archimedes may have preceded them in working on the idea of calculus.) Calculus is a way of studying change; that is, it is a dynamic modeling technique. Newton used it to study the changes in position (the motions) of bodies under the influence of gravitation.

The important feature here is that the above approach to initiating the study of gravitation makes no reference whatsoever to the causes of gravitation. (Apparently this bothered Newton; see Kline 1985.) The point is not to exclude seeking such a cause, initially or later. As noted, and if successful, the above-mentioned search for a unification of gravitation with the Standard Model will give this cause, expressed in terms of gravitation as a special case of some more general ("unified") force.

Now consider two other phenomena: biological evolution, as posited by Darwin; and thermodynamics, as developed by various thinkers in the nineteenth century. In neither case were the "causes" initially understood. Darwin had no idea of the genetic and molecular basis of inherited traits (Wilson 1999); nor were the thermodynamic properties, defined at first in terms of heat flow and entropy, initially understood in terms of molecular motions. In both instances the initial concern was with dynamics, in the sense of changes over time in biological species, and in temperature–volume–pressure of gasses, respectively.

The point is not to exclude seeking causation. Rather, in all three instances the point is that progress in understanding the phenomenon of interest suffered no harm, indeed may have hugely benefited, by initially focusing on dynamics without worrying about causation. This is a very important consideration for societal inquiry, where preoccupation with explaining causes remains preponderant or exclusive, to the near complete neglect of dynamics. (In the field of world politics, for example, work is still routinely rejected on the grounds that the investigators have not explored, or properly explored in the opinion of the reviewers, the “theory” – by which they mean causal theory – on which the findings supposedly must be based.) The issue of this paragraph needs to be understood in all areas.

PHYSICALLY REASONED ASPECTS AND BASIS OF GLOBAL MODELING

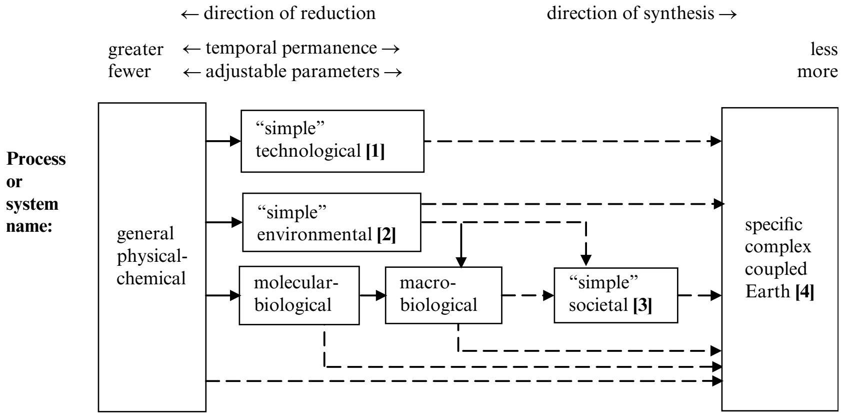
I turn, now, to the third and, briefly, first considerations, mentioned at the beginning, about modern science. As mentioned, the term “consilience” (Wilson 1999) reflects the idea that fundamental physical knowledge can become the basis of all other areas of scientific endeavor. (This and what follows is my own paraphrase or interpretation of Wilson’s idea.) The view is expressed that this has already happened in chemistry and other areas of inquiry conventionally called “physical”; is in the process of happening in biological inquiries; and can be expected, eventually, to happen in social inquiries. (Wilson also distinguishes and includes the humanities in this process of extension and incorporation.) In what follows I will consider some features of the consilience viewpoint that may be significant for global modeling.

First is the distinction between, and roles of, “reduction” and “synthesis.” The former means taking specific systems apart to view their presumed more simple and generally law-like components. Examples might include understanding a molecule in terms of its electrons, ions, and atoms; a living cell in terms of the behavior of its organelles; and a human society in terms of the individual humans that comprise it. Synthesis means going in the other direction: starting with simpler and more general components and deducing the properties of the more complex thing that they comprise. For illustration, the previous three examples can be taken in reverse: for example, deducing the characteristics of a living cell from the properties of its organelles.

The previous example can also be taken to illustrate that, in synthesis, one may need to assume parametric values: additional conditions beyond those logically derived from the properties of the more simple components. Perhaps in the case of a cell, parametric values would include specifying material and energy flows, across the cell wall, that reflect the host organism or other environment in which the cell is situated. The essential point is that, as one synthesizes from simple things to more complex things at the next-higher level, typically it is necessary to assume parametric values not derived from the fundamentals of the lower-level components. Social scientists should take reassurance from the acknowledgment of the necessity of parameters, that is, of characteristics not derived. This acknowledgment is what makes this physical reduction–synthesis scheme, in principle, a realistic aspiration. They, the social scientists, would supply many of the parameter values.

The essence of establishing a "foundation of physical knowledge" lies in gaining the ability successfully to go in both directions – reduction and synthesis – between the complex global system and the simple system found at whatever level of fundamental physics where one decides to stop, and among the levels of varying complexity in between. A representation of how this might look (as with Table 2.2, largely conjectural), appears as Figure 2.1. In the figure, movement to the left, along the lines connecting one process or system to another, represent going to a simpler level with fewer parametric conditions; movement to the right, to a more complex level with a greater number of conditions. In addition, the figure also presents the idea that the more general elements to the left have a greater permanence than elements to the right. For example, what is happening in a specific type of atom is the same today as 100 000 years ago, whereas global human societal behavior has changed drastically (*inter alia*, a global anarchy has evolved to a global system) over the same period. Finally, knowledge to the left is more general, applying everywhere – one hydrogen atom is exactly like all others in the universe – whereas knowledge becomes increasingly specific as one progresses to the right so that, at the extreme, the complex coupled system of Earth today is entirely unique so far as known.

The various pieces are connected in such a way as to suggest how various aspects of knowledge about the global Earth system, represented at the right, might fit, in a hierarchy extending to fundamental physical and chemical knowledge represented at the left. Solid lines represent connections in which logical deduction plus additional adjustable parameters are said to yield the more complex element to the right via a relatively well-known path. Dashed lines signify breaks in the present ability to carry out this idea of movement, using chain of logic plus parametric values, from left to higher right. Movement across such a break reflects that the possibilities of reduction and synthesis are merely presumed, whereas in reality one does not know how to do either at those places. To the right of such a break, everything begins by being parametric, given the present state of knowledge. (One might further differentiate between the "small problematique," the problem of connecting the macro-biological, to the "simple" societal, to the Earth system, on one hand; versus the "large problematique," the problem of connecting all the elements connected by the dashed lines to the Earth system.) At the bottom of the figure, the dashed line directly from physical–chemical to the Earth system is meant to



Notes:
Key: synthesis from general to specific (left to right) is:
comparatively well understood
poorly understood or merely hoped for
Numbered elaborations:
[1] non-biological human artifacts, once created
[2] includes: geophysical, atmospheric, oceanic, near-Earth cosmological
[3] includes: biological aspect of human societies, other animal societies, disease pandemics
[4] societal–technological–environmental–biological–transcendent.

Source: By permission Global Vision, Inc.

Figure 2.1 Complex, coupled earth dynamic modeling in reductive and synthetic context

accommodate the possibility of connections that do not fit into the technological–environmental–biological taxonomy shown. It is further worth noting that only the dashed character of the lines preserves the distinction between "societal" (elements to the right) and "physical" (elements to the left). If the indicated scheme were to be successfully implemented, then that distinction would cease to be well defined.

It is extremely important to recognize that much of current societal inquiry is cut off from below by such logical breaks. Concurrently, however, those breaks are not complete: one way of thinking of the chapters in this volume by Wilson and Alexander (Chapters 3 and 4, respectively) is that they describe efforts now under way which will have the result of synthesizing from molecular- and macro-biological components to the "simple" societal and complex coupled Earth components pictured in Figure 2.1. The latter coupled complexity seems particularly addressed in Alexander's contemplation of the evolutionary and other biological bases of the occurrence of human warfare up to global range. Karasik's treatment of human organization (Chapter 11 in this volume) also appears to suggest a story of transition from "simple" societies to complex global society. Could there be a fundamental connection between the processes described by Karasik and the biological considerations set forth by Alexander?

Equally important is to understand the legitimacy and importance of work that, for the moment, may be physically ungrounded. Drawing on the familiar for an example, I would cite rational choice theory and, currently less familiar, social field theory (originating with Wright 1961), both of which are mentioned later in this book (Chapter 18 by Bueno de Mesquita and Chapter 14 by Williamson). We need to recognize that this work is like the inquiries, mentioned above, into evolution and thermodynamics in their initial periods, and like gravitation still today. These historical examples make clear that scientific understanding does not consist necessarily, or even primarily, in starting at the left of the figure and moving progressively to the right; the physical or intermediate-level grounding can come later. Conversely, there is nothing wrong in working now to find such grounds, even if we do not at first know how. In terms used by Feynman (1965), modern scientific reasoning is "Babylonian," not "Greek."

Finally, returning to the first reason for this look at modern science, Figure 2.1 illustrates that non-societal physical knowledge would take at least two distinct roles in physically grounded global modeling. The first concerns knowledge of aspects of environment or of biological systems that are independent of human activity. Ideal, completely pure examples may be rare; perhaps the above-mentioned factor of tectonic plate movements is one; potential collisions from near-Earth celestial bodies (prior to engineered orbital deflection, if any) is another.

The second, more prevalent, role for knowledge of physical factors occurs where the factor may be affected by human intervention. Examples include climate change, microbial pandemics, and human technology. In such cases modeling the nominally "physical" part may be comparatively simple (for example, computing a ballistic missile trajectory) or, more usually, in reality highly complex in itself (hence the quotation marks when using the word "simple" in Figure 2.1). Whatever the degree of complexity, that degree is enormously further complicated by the factor of human intervention. For example, estimating climate change given a certain rate of industrial greenhouse gas output may be complex; estimating the changes in that rate of output – presumably conditioned by economic–political factors in ways still unknown or imperfectly known – may add a considerable further complication. Returning to another example, above, synthesizing the human invention of nuclear-armed missiles, then their acquisition, then the risks of actual use, would be quite a step beyond ballistic calculations. (That step, however, should be attempted, as it has been in a preliminary manner by Tago and Singer, as described in Chapter 8 of this volume.) In the figure this complication is represented by the merger, at the right, of human societal and nominally physical lines of development.

CONCLUSION

Returning to the opening remarks, the scientific themes and characteristics, such as those mentioned above, may be applied in description and comparison of the various, diverse areas of scientific work pertinent to global modeling. These themes and characteristics are summarized in Box 2.1, part 3 of which adds some further suggestions in addition to those mentioned above. Such descriptions would serve as a primitive means of tying various lines of work together and, perhaps, might suggest more theoretical or functional connections. The editors have tried to do some of that in this volume.

BOX 2.1 SOME SUGGESTIONS FOR PUTTING SCIENTIFIC WORK IN THE CONTEXT OF GLOBAL MODELING

1. Connect work, where possible, to forecasting issues:
   a. Dynamic techniques – Is the underlying model static or dynamic? How is, or how might be addressed, the need for dynamic modeling (as opposed to “static” or “snap shop” modeling)?
   b. What is the empirical domain (or domains) of the topic? How shall the topic concepts be connected to empirical observation?
   c. How does the topic connect to other topics relevant to global dynamic modeling and forecasting, and to their empirical domains?
2. Put work in context of reductive–synthetic context of Earth modeling:
   a. Is the work reductive, synthetic, both, neither?
   b. Does it fit the elements (boxes) in Figure 2.1? If so, which ones?
   c. What is the degree of permanence or longevity of the process or system? What is its characteristic time scale

process or system? What is its characteristic time scale (. . . , hours, days, decades, centuries, . . .)?
    d. What possibilities may exist for connecting the work to other elements?
3. Consider – address in cases where appropriate:
    a. Is the above three-part enumeration, item 1, relevant to more effective forecasting?
    b. How do proposed or conceivable alternative dynamic techniques complement or compete with each other?
    c. What is the role of non-linear dynamics?
    d. What is the necessary or appropriate empirical scope of dynamic modeling and forecasting? Is the Table 2.2 matrix appropriate?
    e. How can Figure 2.1 be improved?
    f. How shall forecasting deal with practicalities, most obvious of which is adequate funding? Are institutional and intellectual insularities a barrier to effecting better global system forecasting? If so, how shall they be addressed?

The key suggestion is that persons working in relevant areas should contemplate their work in relation to global modeling and should adopt the practice of routinely describing and placing their work in such a context using the above (and, no doubt, other) comparative themes and characteristics. (This point of view is exemplified by an ongoing effort by Global Vision, Inc. 2005, using such themes and characteristics, to categorize bibliographical citations and other resources.) Moreover, to the extent that it is practical, dynamic global development activities should strive for sufficient generality to incorporate the various relevant elements or to preserve room for subsequent incorporation. In place of the current fragmentation of many disjoint endeavors, such practices may contribute to the consilience goal, a common global scientific endeavor.

NOTE

1. I have made use of ideas expressed by Bronowski (1976), Feynman (1965), Kline (1985), Layzer (1984) and Wilson (1999). A partly completed list of citations of the work of proponents appearing in Figure 2.1 can be found at http://www.globechange.org/resources_main.php. Another excellent source of links is the website maintained by Brecke (n.d.), http://www.inta.gatech.edu/peter/globmod.html.

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PART II

Human Nature and Prediction

Editor’s introduction to Part II

Frank Whelon Wayman

Edward O. Wilson’s personal interest in the unification of physical, biological, and social science provides an ideal orientation to the themes of our book – a book which aims to integrate diverse scientific efforts to predict the future of the human condition on a global scale. In his 1998 book *Consilience*, Wilson calls for a renewal of the Enlightenment project of combining scientific endeavors to improve human understanding and well-being. From the elegant prose of *Consilience* to the liberal use of partial derivatives in *Sociobiology: The New Synthesis*, Professor Wilson bridges the two cultures of letters and numbers.

Professor Wilson’s *Sociobiology*, published in 1975, was a path-breaking effort to examine the biological basis of social behavior. As he wrote 30 years ago, one might also say today, it “remains to be seen” whether “sociology and the other social sciences, as well as the humanities,” are to be “the last branches of biology waiting to be included in the Modern [neo-Darwinist] synthesis” (Wilson 1975 [2000]: 4). In *Consilience*, two decades later, Professor Wilson continued to contribute to the quest for unification of knowledge, from physics and biology to anthropology and the arts. In Chapter 3, we take that journey with his help, as he writes on human nature (the title of one of his books; Wilson 1978).

Wilson’s chapter is immediately followed by a closely connected contribution, Richard Alexander’s Chapter 4, “Darwin’s Challenges and the Future of Human Society.” These two chapters flow together smoothly, as Wilson and his colleague Richard Alexander take up the issues of the potentially holistic nature of the sciences, pertaining particularly to the biological roots of human nature. Wilson examines this especially in areas such as the formation of altruism in kinship groups, and certain common esthetics of shared taste across all peoples.

In our book, we are engaged in the unfinished task of extending consilience, or “the unity of knowledge” (Wilson 1998). This endeavor can be seen as a renewal of faith in the Enlightenment project. Many Enlightenment leaders wished to use reason and evidence to improve science. They then hoped, through education, to spread the new knowledge for the betterment of all. While the Enlightenment dates to the late eighteenth century, we (along with many others) believe the Enlightenment's project of synthesizing scientific knowledge gained a substantial burst of fresh energy through the publication of Edward Wilson's book *Consilience*. In our book we are examining consilience not only in its own right, but also as a potentially critical component of global forecasting. In the first chapter of Part II, we have important examples of consilient principles at work, in Professor Wilson's views on the East African savannah's place in our ancestral genetic memory, and on the golden mean of complexity in artistic grace. Can even such a promise of consilience that is presented in his chapter, frequently on the relatively micro level, be extended to the macro-social economic, ecological, strategic, and political processes that affect overall planetary conditions? Can this science of a global consilience be constructed to possibly improve prediction itself, even though, as we know from David Hume's *Treatise* and from Niels Bohr, prediction is difficult, especially about the future? One must be realistic about our abilities to do this: the contributors to this book are exceptionally broad-minded for academics, but we each come from a particular tradition. In metaphorical terms, we're all coming out of our own discipline's tunnels. As we venture beyond our empirical starting points we address an academic community that too often is not so much a community as it is a bunch of people doing their own independent thing under a shared University charter and budget. Admittedly, most of the things they do are meritorious, and some have gotten us out of the old pre-scientific life. But I think there's a need for a greater synergy now. It's that synergy we're trying to foster, enhance, and attract attention to. That's somewhat of a contrarian view, because as time goes by in academia it seems we find people are more and more analytic and specialized. To put it in other words, there's not been enough of what Dina Zinnes called integrative understanding or integrative accumulation of knowledge as opposed to just additive cumulation of knowledge in academia.

In *Consilience* (1998: 42), most scientists are compared to "journeymen prospectors." From this metaphor, one might say that scholarship is a bit like deep rock mining. The scholars around us are very well trained to go down a tunnel, very efficiently with folks like them in their specialization, to come back up with some new load of ore and bring it to the light of day. They often have no idea what's going on in the next tunnel over, where some other scholars are working on some other ore. Many of these fine colleagues who are doing this mining are bringing up much needed lignite and even bituminous coal and anthracite. And we can learn a lot from what's going on and what they're bringing up from the depths. But this book is more like an effort to achieve a really substantial net gain and energy from a contained fusion, rather than burning fossil fuels. The input to our intellectual fusion process is not hydrogen, but rather the minds of our contributors. It takes a lot of energy input to enable any fusion process – to create the environment in which it can occur. This input is used to make and maintain a containment vessel, within which we can actually produce energy out of the hydrogen fuel or out of the ideas we've got. We have expended that initial energy because of the great potential payoffs, and now we must persist on the path to reap the rewards.

In Chapter 3, Wilson tries to move us a little bit, as a contrarian, against overspecialization, and tried to do so from the basis of understanding of human nature, reckoning with ideas that go back towards Hume's *Treatise of Human Nature* (1888 [1739]). Wilson had painted a hopeful vision of an integrated science of consilience that would uncover the causal connections between the great fields of human learning, as he called them. Despite the difficulties in pursuing this quest, a new set of threats may motivate us to pursue this effort at synthesis of the disciplines. Why? For one thing, global threats these days are less from the natural forces such as large meteors that seem to have led to past mass extinctions, and more and more from novelties shaped by a human hand, be they invasive species spread by global commerce, pandemics nurtured by human agronomy, nuclear attacks with our species' finger on the button, or global warming from our heretofore thoughtless dumping of carbon dioxide (CO_2) into the atmosphere. In each instance, a comprehensive scientific approach to the forces at work would need to integrate understanding of physical, biological, and social processes. To the implications of that and the search for a consilient science, we now turn to the remaining chapter authors, who ably take up the task. A bridge between Wilson and the others is provided by Richard Alexander, in Chapter 4, where he takes up the question of predictability in evolutionary biology, especially as applied to human sociality. In the end, he asks whether humans will be able to cooperate to cope with problems that affect the entire species, such as global warming, when the solution of such long-term problems requires shared sacrifices among all people, across all groups. Optimistically, he grants that we are "the future seeking organism" (Alexander 2005) but leaves open the question of whether our nature permits macro-level and even global cooperation, when our evolutionary background has been more mixed. As such (without loss of generality), his chapter moves us from Wilson's overarching problem of making biology consilient with sociology, to the application of that effort to explaining patterns of war, genocide, and related characteristics of the human group. One might say that Alexander has extended Wilson's efforts at consilience into disciplines such as political science and international relations, that study human society on a global scale.

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3. Consilience: the role of human nature in the emergence of social artifacts

Edward O. Wilson

The subject explicitly I want to address is the intrinsic unity of knowledge. Does it exist? Or does it not exist? The question is of surpassing importance in both the sciences and the humanities. The evidence that I am going to cite is still fragmentary and in all instances needs better integration into other fragments. Whatever the eventual outcome, this is a subject that invites the attention of the best scholarly minds.

Since the eighteenth century the great branches of learning have been divided – classified – into the natural sciences, the social sciences, and the humanities. Today we have the choice between, on the one hand, trying to make those great branches of learning consilient, that is, coherent and interconnected by cause and effect explanation; or, on the other hand, not trying to make them consilient (Wilson 1998). Surely universal consilience is worth a serious try. After all, the brain, mind, and culture are composed of material entities and processes. They do not exist in an astral plane that floats above and outside the tangible world. Consilience then defines a cause-and-effect explanation across disciplines. Consilience, incidentally, is a term first introduced by the founder of the philosophy of science, William Whewell, in the 1840s, and it has plenty of credibility. It is the mother's milk of the natural sciences. Its material understanding of how the world works and its technological spin-offs are the foundation of modern civilization.

The time has come, I believe, to consider more seriously its relevance to the social sciences and the humanities. I will grant immediately that the belief in the possibility of consilience beyond the natural sciences and across to the other great branches of learning is not the same as science, at least not yet. It is a metaphysical view and a minority one, still, at that. The evidence is fragmentary and in some cases quite thin. But I believe also that it is a matter of practical urgency to focus on the unity of knowledge. Let me illustrate that point with an example (Figure 3.1).

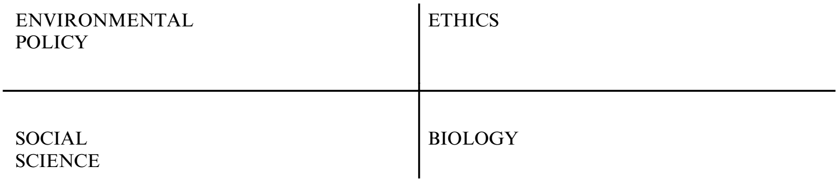

Figure 3.1

Think, as displayed here in Figure 3.1, of two intersecting lines forming a cross. Picture the four quadrants thus created. Label one quadrant here as shown environmental policy, the next ethics, the next biology, and the final one social science. Now each one of these subjects has its own experts, its own language, rules of evidence, and criteria of validation. Think of each one as an island in what consists, particularly, among its practitioners, as largely a sea of ignorance. And now if we focus on more specific topics within each of these quadrants we see how general theory, or philosophy of science, translates into the analysis of practical problems. And we understand that in each case we somehow have to learn how to travel, as in a clockwise direction, from one subject to the next. In a single sentence or two in a discussion we may find it necessary to travel the entire circuit. As an example, if we start with forest management, an entire academic and practical field in its own right, we soon are up against great problems of moral reasoning having to do with resource management and the relation of humanity to the natural environment. And then, of course, in order to really make judgments of a moral nature we must know the environment much more thoroughly than we do in most cases. And as part of that we have to understand the impact of economics and of human nature. What are our desires and our needs? And that leads us back then to how we handle forest management.

Now, move through concentric circles toward the intersection of these disciplines. We approach the intersection where most real-world problems exist, and that is what our central concern is, going out from the specific, from the real world to the abstraction of forms that allow us to handle our knowledge ever more capably and analytically. As we approach that intersection the circuit becomes more difficult and the process more disorienting and contentious. The nub of the problem vexing a great deal of human thought is the general belief that a fault line exists between the natural sciences on the one hand and the social sciences and the humanities and the humanistic social sciences on the other hand; in other words, very roughly between the scientific and literary cultures as defined by C.P. Snow in his famous 1959 Rede Lecture. The solution to the problem, I believe, is the recognition that this boundary is not a fault line. It is not a permanent epistemological division. It is not a Hadrian's Wall, as many might have it, needed to protect high culture from the reductionist barbarians of science. What we are beginning to understand at last is that this line does not exist as a line or a fault at all. It is instead a broad domain of poorly understood material phenomena awaiting cooperative exploration from both sides of that little-known domain.

During the past 30 years four borderline disciplines have grown dramatically in the natural sciences – or more precisely, dramatically in the biological sciences – that bridge this intermediate domain. They are cognitive neuroscience, a good part of brain science; behavioral genetics, identifying the hereditary basis of mental development in process; evolutionary biology, including the aforementioned sociobiology, reconstructing the evolutionary history of mental development and process; and environmental science, describing the physical environment to which humanity is adapted and from which so much of what we might call human nature is derived in the course of that adaptation. And from the social sciences side the bridging disciplines, now growing ever stronger, are cognitive psychology and biological anthropology, and also other fields to varying degrees.

To an increasing degree, cognitive psychology and biological anthropology have become consilient with these four disciplines. In fact they are connected with them now in a system of cause-and-effect explanations. And we all know the exponential or even superexponential progress of genetics and human genetics, including the astonishing take-off during the 1980s of the base pair mapping and gene mapping in the human genome, which is now very far advanced.

Now why is this conjunction among the great branches of learning important? Because it offers the prospect of characterizing human nature with greater objectivity and precision. That is an exactitude that is the key to human self-understanding. The intuitive grasp of human nature has been the substance of the creative arts. It has been the underpinning of the social sciences and the beckoning mystery to the natural sciences, which promise to grasp human nature, whatever it is, objectively. To explore to its depth scientifically, to grasp its ramifications more fully, would be to approach, if not obtain, the grail of scholarship and to fulfill at last the dreams of the Enlightenment. Now rather than let the matter just hang in the air, rhetorically, I want to suggest a consilient definition of human nature and then illustrate that definition with examples of human nature that I hope will be proven heuristic in research – in fact, have already proven so – and I hope are examples of the kind of bridging insights that will be even more heuristic in the future.

Human nature is not a collection of cultural universals, such as the rites of passage that are the products of human nature. Human nature is not the genes that prescribe the universals. Rather, human nature is the collectivity of epigenetic or developmental rules, the inherited regularities of mental development. The rules are the genetic biases in the way we – that is, our senses – perceive the world, the symbolic coding by which we represent the world, the options we open to ourselves, and the responses we find easiest and most rewarding to make. These are just beginning to come into focus at the physiological level, and even in a few cases the genetic level. These epigenetic rules alter the way we see and linguistically classify color. They cause us to evaluate the esthetics of artistic design according to elementary abstract shapes and the degree of complexity. They lead us differentially to acquire fears and phobias concerning dangers in the environment, as from snakes and heights and wolves; to communicate with certain facial expressions and forms of body language; to bond with infants, to bond conjugally; and so on across a wide range of categories in behavior and thought.

Most epigenetic rules are evidently very ancient, dating back millions of years in pre-human mammalian history. Others like the stages of linguistic development are uniquely human and probably only hundreds of thousands of years old.

Let me now spell out several of the examples of these epigenetic rules. When you take a dimmer and you vary light continuously from brilliant intensity to dark, that is how the brain sees it. It sees the continuum. But if you take wavelengths of light, project monochromatic light at one wavelength and then move it back and forth along the spectrum – the visual spectrum – you do not see a continuum of change in wavelength. Rather you see the four basic core colors illustrated in Munsell array.

Now we know, down to the level of the gene, the base pairs that control the assembly of the sensitive pigments of the retina and the mutations that occur to cause color blindness among them, and thence to the retina to the inner neurons that lead to the organizing geniculate nuclei and continue tracking to the optical cortex, and thence to the organizing center with other kinds of information, and out again to information centers in which this information is integrated. We know then what the basis of this color discrimination is. And we know it to the molecular level. That, I believe, is what you might call an epigenetic rule, although this is quite hard-wired.

But now let us move past this circuitry that I have just mentioned to the vocabulary, and to the brilliant Berlin and Kay (1969) experiment, in which native language speakers of some 20 languages were shown the Munsell array. They were asked to point to the position of color terms they intuitively felt in the intensity and wavelength. It comes as no surprise that the points average out among these speakers to the areas in which there is least ambiguity in distinguishing the colors. In other words, there is the least change in perception moving along the spectrum of a changing wavelength. And the fewest selections were made in the most ambiguous areas. In one experiment performed with the Dani people of New Guinea (this is the kind of experiment that I like to cite, that should be repeated over and over again so we can be sure about it) it was possible to test people with two color terms only, essentially dark and light. And when the volunteers were given new terms and then trained in distinguishing those colors, not surprisingly they were found to do best in the areas of least ambiguity; in other words the slowest change in perception across the spectrum. And when the terms were perversely put in the intermediate areas where the change is most rapid and presents the greatest ambiguity, then they did more poorly. And, if they were given a choice of where to put those terms, then they picked the ones with least ambiguity. Now we are getting into an area in which learning is critical in the development of human color vocabularies and where the genetically based developmental rules of languages acquisition apply.

And then here is another remarkable finding. When you compare languages across many, many cultures, by and large when a culture has only crude color distinction – for example two colors like the Dani people, they recognize black and white. If they have three colors in their vocabulary, black, white and red; four: black, white, red, green or yellow; five: black, white, red, green and yellow; and so on. Now this is an astonishing result. There are 2036 different pathways of going from two terms to 11 terms. There are 11 semantically interchangeable color terms among all the cultures in the world; that is, where you can map one on one, one on many, or many on one across color terms of different languages. It turns out that in developing a larger and larger vocabulary, people have just about been limited to 22 of these pathways in the evolution of color language. Again, this is a result I would like to see repeated and checked again and again.

As a second example of epigenetic rules, consider the instinct (I think I can properly call it) to avoid incest. Its key element is the Westermarck effect, named after Edward Westermarck, the Finnish anthropologist who discovered it somewhat more than a century ago. It is as follows; and this has been well confirmed in a remarkable analysis made in Israeli kibbutzes and then again in very careful studies made of Chinese "*simpua*," or the traditional marriage that involved exchanging female infants at – or near – their birth to adoption in other families. Many of the families would go by this *simpua* method to make sure that the son would have a wife. It was found from these studies that when two people live in close domestic proximity during the first 30 months of the life of either of the two people, both are desensitized. They do not know it is happening, but they are desensitized to later close sexual attraction and bonding. They may experiment with sex. But close bonding, and what you could call sexual love: of that they are incapable. This occurs almost without exception. The Westermarck effect has been very well documented, as I said, although the genetic basis and the neurobiological mechanics of it remain to be studied. There is no better example than the two examples I have just given you of information flowing from anthropology down into biology, and raising whole new questions that would not have been asked before of human neurobiology and genetics. In the case of the Westermarck effect, what makes the human evidence the more convincing is that all non-human primates, whose sexual behavior has been closely studied to date, also display the Westermarck effect. Thus the Westermarck effect is a primate trait.

In another wholly different realm, consider the basis of esthetic judgment. Neurobiological monitoring, in particular measurements of the damping of the alpha waves, is a measure of arousal. Measurements of the damping during presentation of abstract designs produced at random by computers show that the brain is most aroused by patterns in which there is about 20 percent of redundancy of elements. Put very roughly, that is the amount of complexity found in a simple maze, or two turns of a logarithmic spiral, or an asymmetric cross. And it may be a coincidence, but it has been proven out of many, many tests, including ones I conducted with every year of Harvard graduates in my class. It may be a coincidence (this is just speculation, but it is a kind of clue that can lead to interesting advances in social science, humanities, and science) that about that same property of the degree of complexity is shared by a great deal of the artwork in friezes, grille work, and then in colophons, logographs, and flag designs. It crops up again in the glyphs of ancient Egypt and Meso-America as well as the pictographs of modern Asian languages. It appears in primitive and modern abstract art. Now I do not want to sound like a UFO (unidentified flying object) proponent, you know, by saying “it’s sited over here” and “it appears over there,” and so on. But I think this is very suggestive.

Now let me emphasize that none of this is proof. And the optimal arousal hypothesis needs a lot more testing. But the universal nature and preponderance of the effect has to be considered very suggestive to some young scholars in the social sciences and the humanities. Let me say that the theory of the arts awaits its Mendeleev. In other words, Mendeleev first put all the information of the chemical elements together and made sense of it out of great complexity and accumulated knowledge.

Now let me come to another aspect, in this case to another form of esthetics. And I would like then to mention biophilia: simply, the love of life; the innate affiliation that people seek with other organisms, and especially in the natural world. This is a subject on which I have worked a great deal (Wilson 1984). And it has now become a minor discipline, particularly within the area of preventive medicine and post-surgical medical practice.

Studies have shown that given complete freedom to choose the setting of their homes or offices, people around the world (this has now been extended to a number of cultures) gravitate, given a choice, toward an environment for their habitation that combines three features, intuitively understood by real-estate entrepreneurs. They are as follows. People want to be on a height looking down. They prefer an open savannah-like terrain with scattered trees and copses. And finally, they want to be near a body of water such as a river or lake. Even if these elements are purely esthetic and not functional, they will, if they have the wherewithal, pay enormous prices to have this view. I was once a guest of the editor of a leading journal of science, who had his doubts about the validity of this approach to human behavior. And the dinner that evening was held in his apartment. He was a fairly wealthy man. And we went out on the open space – his equivalent of his veranda of his top-level apartment – and looked out there. He showed me with great pleasure the view down over Central Park, the savannah, the lake, and we were up on the height.

And people look for two other cross-cutting elements. They want a retreat in which to live and a prospect of fruitful terrain in which to forage. And then the prospect (not always, but very frequently preferred) to put scattered large animals, or statues of them at least, and trees with low, nearly horizontal branches. In short (now if you will allow me to take a deep breath and then plunge where you may not wish to follow; and yet biology is full of stranger events than this), people want to be in these environments, they have the predisposition, they tend to learn to like these choices. They want to be in the environments in which our species evolved over millions of years. That wish to be hidden in a copse, maybe, or against a rock wall, looking out over open savannah and transitional woodland – acacias and other dominant trees of the African environment. And why not? Is that such a strange idea? All mobile, animal species have a powerful, often sophisticated, inborn guide for habitat selection; why not human beings?

This is an important subject of biology, ecology, and behavioral ecology. It is habitat choice. My favorite examples are the mymarid wasps or the fairy flies. These tiny wasps are among the smallest insects in the world. And they specialize in laying their eggs in the eggs of water insects. So the female mymarid wasp, with a brain barely visible to the naked eye, has the capacity and the program to first find the right spot, then mate, proceeding to the water where these insects are found and where their eggs are at the bottom of the water. She digs through the water film, and then uses her wings as paddles all the way to the bottom, searching for the eggs of certain kinds of insects, finds them, and lays her eggs in them. This is what a lot of animal behavior consists of: the habitat preference and search image programmed in them. It is hard to believe that human beings do not have at least a residue of the habitat preference in which our species mostly evolved.

Now how much do we know about the innate basis of such esthetics? Not a lot, and certainly very little about the genetics and neurobiology in particular of the epigenetic rule; not because they have been investigated and found lacking, not because they are technically very daunting, but mostly – simply – because they have not been studied. The right questions have not been asked. Only recently have researchers begun to ask the right questions within the borderline disciplines.

My overall point is that genetic evolution and cultural evolution are closely interwoven. And this is the question of questions in my mind, very rarely addressed directly, of gene–culture co-evolution. We are only beginning to obtain a glimmer of the nature of the process of gene–culture co-evolution. We know that cultural evolution is shaped substantially by biology. I do not think there is much question of that any more. And that much of the biological evolution of the brain, especially the neocortex, has occurred in a cultural context. But the principles and the details form a great challenge in the emerging borderline disciplines to which I have referred. In my opinion, gene–culture co-evolution is a central problem of the social sciences and much of the humanities; and is also, simultaneously, one of the great remaining problems in the natural sciences. Solving it is the obvious means by which the branches of learning can be fundamentally united. And so, in a sense, we would track a trait from a gene at the bottom, through the development, prescribed by the gene, which is just being worked out in more and more detail by the biologists of the organisms, and of the brain of the organism, and then track that post-natally, even pre-natally, as the infant acquires new abilities and begins to learn. The learning is affected by the peculiarities of restraint in the sensory and nervous systems, to certain patterns, to the tendencies of the epigenetic rules. These are profoundly affected by culture but nevertheless sufficiently constrained to produce the cultural universals. Then the success or failure of individuals, and next of group against group in the production of the cultures, bring us down to the gene again, and natural selection at this ultimate level.

In closing let me acknowledge that some critics will question (they have in the past and will continue) whether this conception is correct; whether the program is possible; and whether the major gaps to traverse in the borderland between the natural sciences on the one side and the social sciences and humanities on the other are just too wide and complex to master. The traits in this view are emergent properties that can never be reduced. Perhaps, the critics continue, they even reflect separate epistemologies that cannot be bridged.

Well, what are emergent properties? It is simply those that we have to observe and measure and explain in principles at their own level of organization, because we have not yet been able to break their origin by a reference to lower levels of organization, especially biological organization. And that, of course, is extraordinarily difficult to do, to synthesize and to move across levels of biological organization; but that does not mean it is impossible to achieve.

Once again, it is not too difficult to imagine the interplay of biological and cultural evolution in normal behavior. As we proceed into this intermediate domain, as we discover many things of startling strangeness, remember what J.B.S. Haldane once said: that the universe is not only queer but it is queerer than we can imagine.

To summarize then, biologists, social scientists, and humanities scholars, by meeting within the borderland disciplines, have begun to discover increasing numbers of epigenic rules, such as the ones I have illustrated and speculated on here. Many more rules and their biological processes, I am confident, will come to light as scholars shift their focus to search for these phenomena explicitly. We have seen this happen over and over again in the sciences: from particle physics, the first ones to be identified carefully, to the genes, to endocrinology, to hormones, with more and more examples added exponentially. I am very well aware that the conception of a biological foundation of complex social and cultural structures runs against the grain for a lot of scholars. They object that too few such inherited regularities have yet been found to make the case solid. And that is true. In any case they will add that maybe higher mental processes and cultural evolution are too complex, shifting, and subtle to be encompassed in this way. Well, I do not think so.

Reduction, they also say, rips human thought from its context, is vivisectional. It bleeds away the artist's true meaning. It melts the Inca gold of the humanities. But the same was said by the vitalists about the nature of life when the first enzymes and other complex organic molecules were discovered. The same was said about the physical basis of heredity even as early evidence pointed straight at the relatively simple DNA molecules as the code bearers. And most recently doubts were expressed about the physical basis of mind, even as they are fading before the successes of sophisticated imaging techniques.

In the history of the natural sciences, the common sequence has predictably unfolded from severe philosophical doubt to increasing scientific, realistic, repeatable, and transparent reality. The value of the consilient program, or renewal of the Enlightenment agenda, if you wish, and the interdisciplinary approach to the great branches of learning, at long last appear to have acquired the means either to establish the truth of the fundamental unity of knowledge, or to discard that idea. I think we are going to establish it. The great branches of learning seem destined to meet in this way. And if so, in my opinion then this is going to be a historic event that happens only once.

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4. Darwin's challenges and the future of human society

Richard D. Alexander

> The challenge of Darwinism is to find out what our genes have been up to, and to make that knowledge widely available as a part of the environment in which each of us develops and lives so that we can decide for ourselves, quite deliberately, to what extent we wish to go along. (Alexander 1979: 136–137)

> A hydrogen bomb is an example of mankind's enormous capacity for friendly cooperation. Its construction requires an intricate network of human teams, all working with single-minded devotion toward a common goal. Let us pause and savor the glow of self-congratulation we deserve for belonging to such an intelligent and sociable species. (Robert S. Bigelow 1969, *The Dawn Warriors*)

INTRODUCTION

The Extent of Wars and Genocides

"Human society" is a phrase used to refer to virtually everything about modern humans, presumably living in a civilized manner all over the Earth. But the truth is that we are a frighteningly long way from putting our global human house in order. Leaving aside all other problems, *National Geographic Magazine* (January 2006) reported that 50 million people were killed during the twentieth century in 48 instances of wars and genocides – averages of about 500 000 per year and 1400 per day. Not surprisingly, *National Geographic* labeled the twentieth century, the Killing Century. Other figures, however, indicate 2–3 times as many deaths from wars and genocides in the twentieth century: Scaruffi (2006) estimated 160 million (Sarkees and Wayman 2010; Wayman and Tago 2010).

After a long period of insistence that our pre-industrial ancestors were appropriately characterized as peaceful and gentle nomads, most anthropologists now accept that rates of killing were likely higher in pre-industrial societies than they are today, with 20–30 percent of men dying at the hands of others in their own species (e.g., Ember and Ember 1990). Nevertheless, the number of deliberate killings in wars and genocides since the American Civil War may have resulted in the deaths of more “modern humans” than existed at any single time prior to what Diamond (1997) called humanity’s “Great Leap Forward,” about 50 000 years ago. It is difficult to believe that we will do better in the twenty-first century.

No one has yet found a way to measure satisfactorily the pain, misery, and suffering that also occur during such mass killings, including permanent physical maiming and disablement, and mental and emotional distress from the savageness of war and the wholesale destruction of fellow human beings (for the month of July 2010, ABC News reported that 32 US military personnel had committed suicide during the previous month, 21 of them while on active duty). Current wars may not be typical of pre-historical conflicts, but reports of their effects suggest that the numbers of people damaged significantly by war, though not killed, are many times higher than the numbers killed.

How many people seriously ponder why human groups persistently become involved in wars and genocides? Given our huge and complex brains, our cognitive abilities, and our capacity for fellowship – given our sympathy and empathy, our ability to be consciously thoughtful, and our confidence that, “deep down,” we are all basically kind and generous – how can we participate in or tolerate killings on such a scale? (“We” is not merely you and I, but every human being on Earth.) Why should the numbers of people killed and mutilated in wars and genocides continue, and even increase, rather than diminishing dramatically as what we call civilization continues to develop and “advance”? What other global issue is more appalling?

The Reciprocating Echoes of Intra-Group Amity and Inter-Group Enmity

Alone among all species, we have been designed by our evolutionary history to accept and routinely promote, within our own species, both intense inter-group competition and intense intra-group cooperation and benevolence. Is it possible that we continue this dual design, this uniquely destructive back-and-forth, not in spite of our tendencies to show affection, cooperativeness, patriotism, and loyalty to kin and friends within our own social groups, but because we use such tendencies to win – to engage and defeat other groups? Have we evolved to exploit the amity that helps us see ourselves as kind and benevolent at least partly because it generates and nurtures the enmity we also see as inevitable, and necessary for success in inter-group competition and war?

We overcome or dismiss distressing war experiences by adjusting our post-war minds and activities to peaceful and tranquil preoccupations.

We return to the harmony of our families and our local communities, and think of ourselves once again as "good people." We seek gentle life situations, familiar places and people where we can live cooperatively, and where moral rules approach universality and are well understood, such that we can be confident and secure. But do the extremes of these respites actually take their form because they also prime and equip us for the next seemingly unavoidable competitive or violent episode?

Why are the temporary reliefs of being surrounded by local family and community sometimes contrary to caring on a wide or global scale, rather than a part of such caring? Can it be a heritage from our having become so dominant, ecologically, as a species that we were able to turn our attention to others among our own species as new – and enduring – hostile and competitive forces of nature? Is it that, for whatever reasons, we are inclined to justify our hostile acts as necessary – even inevitable – competitions for resources, for more resources, or more of the highest quality of resources: competitions that we typically glorify as reflecting the highest levels of morality, honor, and virtue because they serve our interests? Even if not all of these attitudes are entrenched, we are surely continuing to live with concepts of ourselves that include avarice, cruelty, and self-serving dismissiveness.

Can we deny that the intensity of cooperativeness and loyalty within mostly small and closely knit social groups not only enables them to be successful in competitions, but as well spawns tendencies to characterize members of other competitive and adversarial groups as inferior, subhuman, stupid, ignorant, misguided, wicked, depraved, and worse. Across much of the twentieth century, newspapers were liberally sprinkled with unmistakably ape-ish cartoons of our adversaries in World War II. Such tendencies have also led to acceptance of absolute authority in moral and religious matters, expressed both in the extreme cooperativeness of the members of groups and in the alienation between competitive groups that regards adversaries or enemies as negative and evil, and often applies vicious derogation to merely "different" groups. In these considerations, what is accepted as "right" or "good" is likely to be whatever best perpetuates the established moral influence and generates willingness to cooperate completely and sacrifice for the members of one's own group (Alexander 1987).

Shouldn't we all like to know a great deal more about how we got to be as we are now – why terribly destructive things keep on happening and are all too often treated as justifiable or inevitable? How did we acquire the consciousness that causes us to regard as essential the all-out intergroup competitions that plague our possibilities of living peacefully; the consciousness that also allows us, all too easily, to step back and dismiss or tolerate the immediately previous ravages of inter-group hostility and war? Wouldn't knowledge of our history and the directions of our evolutionary background help us do something about the almost constant flow of these grotesque happenings?

The uniquely human tendency to engage almost continually in inter-group competitions and conflicts within our own species has spawned the set of evolutionary adaptations that more than any other has shaped the human species and accounts for virtually all of what might be called its major unique traits (Alexander 1990b, 2008). This tendency could not have become paramount until humans had achieved degrees of contentious dominance, involving sizable social groups, which enabled them to gain more by transferring investment in calories and risk-taking in within-species competitions than is apparently the case in any others among the tens of millions of living species.

Darwin (*Origin of Species*, 1936 [1859, 1871]) identified the hostile forces of nature responsible for natural selection, the principal guiding force of the evolutionary process, as predators, parasites, diseases, food shortages, climate, and weather (cf. Alexander 1979: 15–18). These threats primarily involve as worst enemies either other species or non-living forces. Darwin also included within-species conflicts such as sexual and social competition, and he was keenly aware of the importance of inter-group, within-species competition. But humans went a huge step further when they caused inter-group competition and conflict to become (uniquely) the main force of selection on the human species (Wrangham 1999; Alexander 1969, 2009, and references therein).

We have successfully marched our understanding and uses of rules and cooperation from family-like units to the levels of nations and alliances of nations. But we have not concomitantly alleviated the destructiveness of such grand affiliations. Nor have we successfully prevented or reduced the continuing development of ever more dreadful contrivances designed solely for deliberately destroying other humans.

I have emphasized wars and their effects, and brought up the unholy capability and willingness to turn closely knit groups into fighting machines. I believe that what we must seek to understand, and change, is by a large margin the most terrible puzzle of our world. Courts of law routinely settle disputes over careless or even inadvertent deaths or maimings of single individuals for millions of dollars. To say the least, we do not behave comparably toward slaughtered or damaged military personnel or their families, or toward civilians either deliberately or incidentally slain during war, unless we are willing to claim that merely honoring those killed and incapacitated by war is acceptable as appropriate compensation.

SOCIAL CHANGES AND BILATERAL KINSHIP SYSTEMS

Introduction

Bilateral kinship systems became possible when concealment of ovulation by females in multi-male bands of humans enabled recognition of both parents, hence both sets of family relationships, not merely those in the mother's family (Alexander and Noonan 1979; Alexander 1979, 1990a, 2008). Humans in multi-male groups became able to socially learn to recognize variations in genetic relatedness on both sides of the family, and eventually trace and remember the collective genealogies of their social groups. Everyone could thereby maximize the transgenerational persistence of their genes, not merely by producing and tending offspring, but as well through beneficence to both descendant and collateral (non-descendant) relatives (Hamilton 1964). Whether we like it or not, transgenerational persistence of some genes while others are disappearing is the main consequence of organic evolution. And it is what all whole organisms strive for, more or less exclusively, whether or not we humans are fully aware of the effects on ourselves or how they come about (Alexander 1990a). Even if organic evolution is a slow process, we need to consider the long history of cumulative changes that have made us what we are – at least until we learn how to override some of our less admirable tendencies.

Concealment of Ovulation: The Enabler of Within-Group Collaboration

Humans, chimpanzees, and bonobos all live in multi-male groups, but, among extant apes, only humans, in which females do not recognize or blatantly advertise ovulation, are able to discriminate nepotistically among a wide variety of genetic relatives. In most life situations, human males cannot or do not distinguish ovulating females from others that are not ovulating. In multi-male mammal social groups, only with sufficiently and appropriately concealed ovulation can there be high levels of confidence of paternity (recognition of fatherhood), hence strong and lasting parental and spousal bonds, and long-term biparental care. Only in humans with appropriately concealed ovulation have the bonds of parental care and differential nepotism provided the uniquely extensive bilateral systems of kinship that have functioned across history in tightly knit human social groups of up to several hundreds of individuals.

The evolution of durable spousal and parental bonds has enabled a flood of unique features characterizing the human species: the extreme altriciality and long juvenile life of human offspring, the expanded and lengthened learning lives of juveniles, the cessation of production of offspring in mid-life in favor of extensive tending of diverse kin (in women, termed menopause), the uniquely extreme complexity of function and size of the human brain, and the doubling of the adult human lifetime compared to extant ape species (Alexander 1990a, 2008). The dramatically increased lifetime of humans necessarily occurred via slowing of senescence, owing to significant genetic reproduction caused by the rise of assistance to increasing numbers of genetic kin in later life. Increased reproduction, via nepotism in late life, alters evolutionary selection by favoring gene effects that would not have persisted without the significant late reproductive gains that facilitated the extensive kinship contributions and unity of the small groups that have continued to characterize modern humans (Williams 1957; Alexander 1987, 1990a, 2008).

Effects of Incomplete and Adaptively Concealed Consciousness

The elaborate consciousness of modern humans falls short of revealing to us that particular evolved reductions or cloakings of consciousness have enabled us to function more effectively in evolutionary or reproductive terms. But, along with our incredibly keen consciousness, we have evolved to ignore, dismiss, forget, or fail to recognize many life situations or consequences, and this is at least part of the reason for our difficulties in removing effects of our evolutionary background in the interest of solving problems such as war and its violent relatives.

Two categories of problems are involved in attempts to teach people how to understand biological events or phenomena that are not initially conscious. The first consists of items that merely have not been appropriately proximal to conscious-raising possibilities or explicitly alerted to individual consciousness (e.g., our historically inaccessible knowledge of the existence of genes and other microscopic physical and biological structures). This first category includes two possibilities: (1) items that can be easily and quickly taught and learned because such knowledge yields more or less obvious advantages that are often immediately understandable to the generally conscious learner (for example, the usefulness of language and arithmetic); and (2) items that are not learned easily because they are difficult to grasp, even without a history of evolutionary selection against specific conscious understanding (for example, the extent and nature of the physical universe). For such items we have been prone to fanciful and erroneous interpretations.

The second category includes items for which consciousness has been masked or disguised by evolutionary selection. Ovulation, for example, does not have to be concealed consciously to yield bilateral kinship recognition in multi-male groups. No deliberate or conscious efforts to conceal ovulation, or even understanding of such concealment, are required – at least not in the current social environment. Nor should we expect complete inability of modern human females to know about or recognize their own ovulation. Modern women sometimes discover technological or incidental means of detecting ovulation reliably (e.g., thermometers, particular kinds and timing of discomfort or headaches, and other slight or barely noticeable changes). Modern men may sometimes detect ovulation, especially in closely bonded mates. Some reports, however, have indicated that in pre-technological or pre-industrial peoples, neither men nor women were aware of not only the significance of ovulation but also its actual existence and function. Nevertheless they obviously gained the ability to contrive mating opportunities facilitated by effective spousal and parental bonds that have provided accurate recognition of fatherhood (summarized from Alexander 1990a, 2008). It is likely that patterns of sexual behavior between parentally bonded spouses tend to acquire the function of social bonding and as a result assume patterns and frequencies in which ovulation results in pregnancy incidentally.

It is difficult for us to accept that evolutionarily adaptive concealing or cloaking of consciousness could improve our lives. It seems opposite to our sensitivity and pride, and this is perhaps a large part of the reason for our difficulties in finding ways to understand interactions between: (1) closely-knit local groups and their temporary national and international coalitions; and (2) inter-group competitions at all levels.

The astonishing complexity of detailed bilateral kinship patterns in pre-technological human societies studied by anthropologists supports the above arguments and promotes commonality of interests within small social groups (Alexander 1979, 1990a, 1990b, 1991, 2008). Coincidentally, complex features of kin recognition were surely instrumental in the evolution of the unique human intellect (Hamilton 1964; Humphrey 1976; Alexander 1987, 1989, 1990b, 1991). In turn, the bilateral kinship system and the expanding human intellect enabled late-life assistance of both descendant and collateral kin over the production of additional offspring, hence the doubling of human lifetimes, compared to the lifetimes of the 14 ape species that are the closest extant relatives of humans (Alexander 2008).

Consequences of Humans Evolving to be Their Own Principal Hostile Force of Nature

> We really do not know what kind of predators, if any, might have been involved in the steady increase in man's brain size, and, as much as we may dislike the idea, I believe the possibility still exists that man is the only one that could have done the job. (Alexander 1969: 495)

In a 1967 lecture in an international University of Michigan systematics symposium, sponsored by the National Academy of Sciences, I suggested that humans have become their own principal hostile force of nature. So far as I am aware, no other species has done this. To reduce the continuing destructiveness of the human species we must understand what trends take place in the sociality of a group-living species when its groups have become the sources of war – the driving forces of evolutionary change for all the groups in our species. Multiple questions arise, concerning this situation. Will within-species interactions accelerate evolutionary change for unusual reasons; for example effects of inter-group interbreeding, resulting in new combinations of useful traits via winners co-parenting with winners? These are reasons that would not have the same effects in species that run the selective gauntlet against species other than their own. Have social groups, as a result, tended to become rapidly more aggressive, more powerful, more inclined to wage war, and more capable of it? Have there been tendencies for increasingly effective organization of adversarial groups? How can we best influence continuing changes in social organizing and leadership tendencies so as to disfavor persistent and increasingly devastating wars? What relationship is likely to unfold between the repeated waging of wars and the reciprocating returns to our small closely knit groups of kin and reciprocity investors? How many of the observable and not so observable trends of these topics tend to worsen rather than alleviate human destructiveness? How can we influence such trends? Will humans generate unpreventable "echo" systems of deadly warring in which local groups are expanded and increasingly organized by the social, legal, moral, and other behavior systems from families and local groups up to nations and alliances of nations? What relationships are likely to unfold between the repeated waging of wars and the repeated returns to small closely knit groups of relatives championing local and absolute systems of morality?

Large Groups and Global Problems

Inter-group competition has obviously led to ever-increasing group sizes, initially facilitated by parental bonds leading to the unity of bilateral kinship systems in multi-male groups. The continuing evolution of intellect, and the correlated doubling of the human lifetime, compared to those of all our closest relatives among the extent apes, have contributed to the organizing and maintaining of progressively larger, more complex, more powerful groups capable of defending themselves against other such groups (Alexander 1987, 1990a, 2008).

Larger social groups become more difficult to maintain, and are benefited by competent leaders. Leaders in multi-male groups of intelligent humans tend to function as authoritative figures. In turn, morality becomes a prominent unifying theme, further emphasizing internal group harmony and cohesion as well as inter-group differences often leading to competitiveness and war.

Nowadays, apparently for the first time in history, we are acknowledging that we have generated global problems – involving at least war, overpopulation, environmental pollution, human-induced climatic warming, and resource depletion. These global problems can only be solved in ways that will be at least temporarily (and also variably) expensive to everyone; even though in the end far less expensive than if we do not confront and solve them. Reducing or eliminating the waging of war is the one change that potentially can massively reduce expense. The question is: can humans cooperate successfully on a global scale, particularly when different groups retain the tendency to compete; when everyone is likely to suffer temporary and sometimes unpredictable expense in acts of cooperation; and when everyone has strong probability of realizing all too consciously that the effort will be more costly for them than for some others?

There seems to be no evidence that humans have ever behaved as a single global cooperative population. The International Olympic Committee might be held up as a symbolic example. It is surely not trivial that the theme of the Olympics is athletic competition among nations. Most biologists view play as practice in low-cost, restricted situations (for example, a football, soccer, or basketball game) for full-cost situations involving all-out deadly competitions (for example, on a field of war). It is also no accident that, evidently alone among all species, humans play competitively, group against group, almost certainly as unknowing practice models for serious inter-group competition, or war (Alexander 1979, 1987, 1989, 1990a).

Some of us may live long enough to find out what can be accomplished that will lead to global cooperation. The answer, I believe, will be discovered among the biases – both conscious and unconscious – that differential reproduction, the principal and inexorable guiding force of evolution, has produced in us. It is probably more difficult than most people think, but surely not impossible, to go against a long history of adaptive change.

UNDERSTANDING EVOLUTION TO UNDERSTAND OURSELVES

Introduction

I have argued that the fastest and most reliable way to change ourselves in order to reduce the slaughter within our species, solve other growing global problems, and create a more secure, contented, and socially positive human population, is to maximize on a wide scale – in detail, accurately, and at long last – deep understanding of the evolutionary process that has constructed us. We need to know how evolution has affected us as singular, whole, functioning individuals, as social groups, and why evolution has prohibited us from knowing many things about the most important features of our species, and about ourselves as individuals. We seem to have two fruitful strategies: (1) use the components of our evolved within-group cooperativeness to diminish rather than enhance destructive between-group competition; and (2) work consciously against evolved tendencies that lead to global and other dire problems. Unfortunately, efforts with the first of these possibilities have mainly elevated the size and power of competitive groups that we call nations (and alliances of nations) with the result that the potential for destructiveness has become even more appalling.

It is likely that the vast majority of people in the world know little or nothing about organic evolution and the role of evolutionary adaptation in the makeup of their lives. Perhaps most know only the word "evolution," and little else about it. Most of those still not included are almost certainly to one degree or another hostile to the concept of evolution, and either deny that the process exists, deny that it is important, or perhaps regard it as an instrument of some evil force adversarial to their religion, their ethics, or their local group's way of thinking. Most of the tiny number left after all such exclusions, who may not be negative about evolution, are nevertheless unlikely to be experts regarding the evolutionary process and its significance to humans. Finally, even people who understand evolution profoundly often are reluctant to openly deliver honest, detailed, or complete descriptions of evolution and its past, even for the purpose of teaching humans how to get along, how to reduce or eliminate the worst things humans do; perhaps because if evolution operates as it seems to, we might think of ourselves as unable to change the situation. But we can accept that much of what evolution has done to us, and continues to do to us, can be reversed or altered as a result of our ability to use our evolved learning abilities to override our history of natural selection. It is an important aspect of this suggestion that we learn how to deal with what I have termed "cloaked consciousness."

I think of current evolutionary understanding this way: if we could imagine a darkened map of the world, perhaps with different colored lights for different degrees of understanding, those who not only have a deep knowledge of evolution, but as well are willing and eager to consider seriously and openly how it relates to the nature and behavior of human beings, would be represented by an extremely thin scattering around the world of pinpoints of the appropriate lights so tiny that without extreme magnification we could not make the map large enough even to see them. I believe we desperately need to change this situation, so that we can decide how far to go along with, or resist, the results of our history of genetic changes.

Darwin's First Challenge

In the effort to realize the immediately previous considerations, I will go directly now to what I call Darwin's First Challenge, because it is the most general challenge in Darwin's 1859 book *On the Origin of Species*. I will briefly discuss some other challenges and statements, and proceed toward an explanation of the biases that the evolutionary process has generated in our makeup; for example, the specificities of our learning abilities and tendencies and the distribution of consciousness and its absence. Finally, I will attempt to generate an exhaustive list of the general classes of the positive social behaviors of humans, how they fit together to describe and define human sociality, and how the proximate mechanisms underlying social behaviors can help us in assessing the significance of social and benevolent behaviors. These are the relevant vehicles, or background, of our hopes to remake human society as a unified, harmonious world population.

> 1. If it could be demonstrated that any complex organ existed, which could not possibly have been formed by numerous, successive, slight modifications, my theory would absolutely break down. (Darwin 1936 [1859, 1871]: 189)

When Darwin set out the challenges for his theory of how all of life evolved, he was undertaking explanation of one of the greatest profusions of complexity humans have ever had opportunity to consider. In effect, he virtually formalized, or at least reinforced, a particular axis of opposites: on the one hand, science as open and continuing investigation of all cause–effect relations in the entire universe; and on the other hand, religion and patriotism as bastions of morality and authoritative absolutism, and social cooperativeness as essential, therefore sacred. These two routes to knowledge and cooperativeness have continued, and remain adversarial. To solve global problems, we need to explain why the repeated probing of science and adamant adherence to authority-based rules exist in a kind of stalemate, and what we can do to make them compatible.

Darwin's various challenges were mostly in the form of hypotheses that if rejected would destroy his general theory. Hypotheses are surely the most important part of science. Grand and informed hypotheses, of the sort Darwin presented to us so long ago, are the ultimate intellectual stimulants to students of cause and effect in the world at large.

Darwin declared that, under certain conditions that he described, his general theory of life would absolutely break down. He did not say that if complex organs could be formed in ways other than as he indicates, his theory might break down, might have to be modified, or might be weakened or less useful, or any such thing. He did not rest until he had worked out a statement that, if true, would cause his theory, of how the entire world of life had come about, to absolutely break down. Such unequivocal falsification efforts best encourage the testing of scientific ideas. This 150-year-old example is an early such challenge, and surely one of the first clear and truly beautiful ones. Not surprisingly, his theory has never been successfully challenged, or falsified.

For at least three reasons falsification efforts are better than efforts to support a theory (Alexander 1988). First, when we are trying to support our own theory our bias is in the wrong direction. Whether or not we know it, we tend to see support everywhere, and to ignore possible falsifiers. Second, whatever supports our theory may, unknown to us, also be supporting one or several other theories. Third, however well we are able to support a particular theory, there may be another theory, totally unknown to us or not, that is better supported. Even successful falsifying of every theory of which we are aware, except our own, will not mean that the one theory remaining is the right one; unless we try with all our might, and in a continuing way, to falsify it. Even so, scientific or any other kind of investigation cannot absolutely demonstrate that a theory is entirely correct: to get things straight, scientific work must continue indefinitely. With his first challenge, however, Charles Darwin showed us – so very long ago – how best to set up a first-rate scientific investigation and carry it out.

The philosopher Karl Popper is generally given credit for introducing and explaining falsification in science (e.g., Popper 1963). He surely wrote more on the specific topic than anyone else, and explained its nature and importance well. Nevertheless, Darwin was presenting falsification challenges beautifully, with respect to actual, massively important, and ultimately difficult problems, long before 1902, when Popper was born. It is therefore ironic that until near the end of his life Karl Popper regarded evolution as metaphysical. I am not aware that he ever wrote explicitly of Darwin's challenges.

Seeking to falsify hypotheses and theories involves empirical work of various sorts, from merely thinking about already known facts until one or more of them either falsifies relevant propositions at hand or strengthens them by failure to falsify, to extensive and tedious gathering and statistical analysis of previously unexplored quantitative information that can become conclusive data. Nothing makes empirical work more effective than hypotheses of the sort Darwin proposed.

With regard to usefulness, what have by some been derogatorily called "adaptive stories" are potentially no less useful, or honorable, than what the Nobel Laureate Richard Feynman called the "guesses" that constitute the first steps in scientific procedures. As Feynman noted, hypotheses, or guesses, must be tested, and if they do not pass the tests, they must be discarded. The stream of worthwhile scientific discovery thus begins with the generation of grand hypotheses. As crucial as is reliable and thorough testing of hypotheses, it cannot rescue inferior or trivial hypotheses. Nothing is more frustrating and pointless than seeking to test a mediocre hypothesis. Mediocre hypotheses sometimes involve trivial topics, and sometimes have no possibility of being falsified, not because they might be wrong but because they are so constructed, or conceived, as to present only vague possibilities of showing how the premise involved could indeed be wrong.

Whenever we falsify a theory, that theory, or idea, is finished. We must seek another theory if we are to continue trying to explain the problem that stimulated the original theory. When we generate or locate a theory that we cannot falsify, especially about a massive and complicated problem such as the explanation of all life on earth – as Darwin apparently did repeatedly – then we are surely making scientific progress. When efforts at falsification fail consistently, scientists accept the theory, tentatively, and go on to new hypotheses and theories, dependent on the still not falsified theory. Science progresses through the generation and testing of sequences of interdependent theories, leading to increasing understanding of the phenomena being investigated. In a sense the entire body of science remains tentative, because absoluteness is not achievable at any stage. Because science is never absolute, scientists are forever returning to some earlier stage of their investigation, correcting a minor or major error, and proceeding once again. Despite the inescapable frustration of those who try to use results of science that are still in the process of refinement, there is no better way of establishing facts.

In my opinion there should be no quarrel with people who emphasize in their lives the importance of absolute faith. All of us depend now and then, and in some arenas virtually all the time, on information handed to us by others, in various forms and from various sources of authority, whether a holy book, a religious or other leader, a jural system, the constitution and other documents of our organizations or our nation, or simply a commonly understood and accepted local pattern of social precedents. Faith, in this sense, is a necessary – though always tentative – aspect of life because none of us has the time or knowledge to figure out everything for ourselves. Moreover, in some arenas of human life the rules of human social behavior, in particular, are always more stringent than other facts about life; more nearly approaching absoluteness in the sense of universal agreement and universal approbation for missteps or violations. Morality is the parade example. This is true even though, undeniably and also paradoxically, part of the universality and insistence on absoluteness in any moral system stems from the interactions of different groups of people following different and sometimes incompatible sets of "absolute" moral rules (Alexander 1987, 1993). Such seeming arbitrariness can happen because the most important thing about morality often is judged, or accepted, not by the nature of the rules adhered to – not even by fairness or justice – but by the secure knowledge that the members of the group associated with a particular moral system are sufficiently patriotic (cooperative, trustworthy, dependable, willing, and loyal) as to further the interests of the component members and the future of the local and, unfortunately, exclusive group. This circumstance arises out of the dominating influences derived from the universal inter-group competitions alluded to earlier, and responsible for the negativism and horrific slaughter associated with warfare and genocide. Somewhere, sometime, a clever wag was perhaps more on target than he or she realized by saying that, "Justice really means Just-Us."

It is one thing to practice faith in the ways and situations just described, but quite another to use authority to attempt to deny humans the right to discover, describe, and utilize facts about the natural world, or to attempt to restrict the areas in which such investigations of the natural world can proceed. All of us depend not only on faith – which nearly always derives from some kind of accepted or revered authority – but also on facts about the natural world that have been generated or demonstrated during extensive and careful open-minded study and testing. The most serious questions arise when moral authority and scientifically discovered facts seem to clash. Moral rules are preserved as absolutes because it is so important for all of us to know how and when to cooperate willingly, or completely. There is expectation that if any moral rule is broken, or changed, the entire social system of right and wrong might be damaged. Some of these clashes occur because the paradigms underlying our disciplines and beliefs – including both religion and early science – were established so long ago, and so solidly, that new discoveries and their effects are difficult to accept. After all, religion is hundreds or thousands of years old; although philosophy does go back two millenia, the supporting sciences are fairly young:

anthropology is only a century and a half old and other social sciences began to mature a century ago. And yet, not until George C. Williams (1966) wrote *Adaptation and Natural Selection* did we have clear – scattered but convincing – realizations of how natural selection actually works: how evolutionary adaptation comes about.

It is easy for those in power to declare or maintain that some aspect of human existence must be treated as factual, and also difficult for scientists to approach absoluteness in their searches for evidence, reliability, and truth. But everything about life is probabilistic. I admit to puzzlement in the presence of people who claim or believe that every aspect of their lives operates entirely on absolute faith rather than on a compatible mix of faith and personal exploration and investigation, subject to adjustment when new information demands it. I also admit that I am disappointed when people assert (as did at least three of the candidates who most recently sought to gain the presidency of the United States) that they do not "believe" in evolution, even though that process is simple to observe and understand in its basics, and is to all indications universal and ongoing continually among all forms of life. Evolution has been studied extensively and accepted since Darwin by many of the best and most careful minds ever engaged in exploration of the natural world. Denials of well-established realities – because of zeal to maintain adherence to beliefs that may be wildly unlikely, that have been solidly demonstrated to be false or to involve an entirely different topic or basis, or that are being avoided in an untruthful way to woo "voters" – are incompatible with reality. They lead to unnecessary and unresolvable conflicts, both within and between human groups (Alexander 1978). Perhaps we somehow sense that exposing ourselves as having evolved, bringing to light all the details of our evolved motivations and tendencies, laying bare every competitive strategy, would be like revealing all the dark corners in the basements of our personal lives, in the kind of autobiographical exposé Stanley Elkin (1993) declared is unlikely to become public (Elkin referred to "the nasty hoard" in the "secret cellar"). Yet, almost certainly, we must do something of this sort globally if we are interested in understanding ourselves well enough to solve the problems discussed in this chapter.

Returning to Darwin's first challenge, some of my students and fellow biologists have suggested that this challenge is impossible to test because, among all of life's forms, there are far too many complex organs to examine every one to see if each of them matches Darwin's proposition. As a result, these skeptics said, no one would ever try to demonstrate an exception to such a challenge. But Darwin was not suggesting that anyone should be required, or should try, to examine every single complex organ of every individual organism on earth. Instead he was inviting any or all of us to choose just one organ – any complex organ – really, almost any structure or function of life that had to come about in the way that Darwin's first challenge specifies. He was telling us that we can select the one or ones we personally regard as most likely to meet his challenge. Moreover, the challenge continues, precisely the same today as it was when Darwin initially presented it. Barring falsification, it will stand forever. Any skeptic at any time can choose another complicated organ and try again, as many times as is desired or required.

I confess that when I first read this particular challenge of Darwin's, I thought it obscure and trivial. I wondered what was all the fuss about "numerous, successive, slight modifications." Eventually it dawned on me that Darwin was talking about the entire world of life: everything alive and everything that had ever lived. He was telling us one way to identify consequences of natural selection, across the billions of years that life has existed on earth.

It is worthwhile to consider for a moment the immensity of the phenomenon Darwin sought to encompass in his various challenges. Modern systematists estimate that there may be as many as 30–50 million species. Almost any one of these tens of millions of species can be composed of up to virtually countless individuals, each one of which is unique, even including monozygotic twins because of the innumerable internal and external, large and small environmental changes that vary across different lifetimes. Every one of these countless individuals may possess tens of thousands of genes and be made up of as many as tens of trillions of cells. Normally, every body cell carries a complete set of genes and, even though groups of cells are collectively specialized to function within complex arrays of organs and tissues, each cell is by itself a separate machine of incredible complexity, also going through a unique sequence of change as a result of a succession of internal and external environments. The human brain alone is incredibly complex, involving millions of neuronal changes that can occur within a split second, and that provide us with the ability to make uncountable numbers of behaviorally appropriate decisions across our entire lifetimes in an ever-changing and complicated world (consider the number of split seconds and the number of small and large, internal and external environmental variations in a single human lifetime). This staggering parade of innumerable and changing units, combinations, and variations, with – in most cases – each individual beginning from a single fertilized cell, is the foundation from which we must try to understand the immense complexity of life. And, in the end, we must understand the whole organism, not merely its parts, despite the obvious importance of modern reductionistic biology. It is clear that the persisting parts of the organism are designed and coordinated so as to cause every trait expression of the organism to serve its overall genetic reproduction.

Exactly what did Darwin mean by numerous, successive, slight modifications? How did he even come to speak of them? I do not think we can know what was in his mind, and I cannot say whether anyone else has actually taken up this question. Darwin often spoke of traits, and if that is what he meant he surely would have used that word in his discussion of this first challenge. He did not, however, use even the term "variations," but rather "modifications," suggesting that he was thinking of variations that arise somehow, thus becoming modifications. Whatever terms he used, he could not have referred directly to the genes and mutations that underlie traits because genes were not known until around the start of the twentieth century. There is apparently no evidence that Darwin ever knew about Mendel's early work, at least sufficiently that he could have adopted Mendel's term, "factors." He is said to have had a copy of one of Mendel's papers on his desk when he died, but it had never been unwrapped and read.

Anyone who considers traits of organisms that can be easily observed across several to many generations, such as in most domestic animals and plants, could have recognized that trait expressions can change in small increments. Perhaps this is what convinced Darwin to make his challenge regarding numerous, successive, slight modifications. He not only wrote scientifically about a wide array of different "wild" organisms, but also paid a good deal of attention to domestic animals and plants: for example, raising and breeding pigeons and discussing their traits, and their trait expressions and variations. He often used domestic animals and plants in his discussions of changes brought about by natural selection, as well as by "artificial" or human-mediated selection.

It would appear that, by numerous, successive, slight modifications, Darwin was describing how he thought natural selection, or differential reproduction, takes place. In effect, the challenge he issued meant that if complex organs, or whole organisms, have come about in any way other than by natural selection of small changes that persisted – for example, if they came about as a result of creation by "intelligent design" by a supernatural force or being – that process would have worked exactly as he understood natural selection to work. This conclusion, if correct, means that there is no reason for anyone to reject the scientific study of the evolution of life.

Albert Einstein, who spoke of mind pictures and hypothesis testing, completed the general theory of relativity in his brain and tested it there so thoroughly that he was confident that: 'The result could not be otherwise than correct. I was only concerned with putting the answer into a lucid form. I did not for one second doubt that it would agree with observation' (Clark 1971: 259).

> Anonymous: *How did you discover the law of gravitation?*
> Newton: *By thinking about it all the time*. (Frank 2001: 211)

The Components and Structure of the Evolutionary Process

Let us consider for a moment the nature of life and evolution, beginning with gene mutations. Gene mutations are the basic source of modifications of the size and prevalence that makes them the likely candidate for the vast majority of Darwin's numerous, successive, slight modifications (NSSM).

Today we know a great deal about how gene mutations relate to the structures and functions of organisms. Nevertheless, anyone can walk into a bookstore and find more than a few current books revealing that not even the most basic things about evolution are well understood by a good many of those making an effort to discuss the topic (cf. Parens et al. 2008). In 1979 I tried to outline the components and structure of the evolutionary process in *Darwinism and Human Affairs* (Alexander 1979: 15ff.). Whatever may be inadequate in my effort, I doubt that I can improve on that 35-year-old description. I will repeat most of it here because I think everyone who considers the topics in this chapter needs to know what natural selection is all about, and why it is regarded as the principal guiding force in the evolutionary process:

> A theory is said to be a simple set of propositions that provides a large number of explanations. Einstein noted that 'a theory is the more impressive the greater is the simplicity of its premises, the more different are the kinds of things it relates and the more extended is its range of applicability.' Although he was not referring to evolutionary theory his statement could scarcely have applied more appropriately. For all that it purports to explain, evolutionary theory is based on a remarkably simple set of propositions. The process from which it stems derives from the interactions of five basic phenomena:
>
> *Inheritance:* All living organisms (phenotypes) are products of the interaction of their genetic materials (genotypes) with their developmental (ontogenetic) environments; these genetic materials (genes, chromosomes) can be passed from generation to generation unchanged. Without inheritance there could not be cumulative change. [Learning of learned behaviors is cumulative in culture, paralleling cumulative change in the genetic materials.]
>
> *Mutation:* The genetic materials do change occasionally, and these changes are in turn heritable. Without mutations there would be no continuing source of change (in forms lacking culture).
>
> *Selection:* All genetic lines do not reproduce equally, and the causes of the variation may be consistent for long periods. Without selection there would be no direction to cumulative changes.
>
> *Isolation:* Not all genetic lines are able, for various intrinsic and extrinsic reasons, to interbreed freely, and thus continually to re-amalgamate their differences. Thus, some populations cannot interbreed because they are spatially or temporally (extrinsically) separated; others are so genetically (intrinsically)

different as to preclude hybridization. Without isolation there would be but a single species.

Drift: Genetic materials are sometimes lost through accidents, which are by definition random or non-repetitive in their effects on populations. The main effect of genetic drift is to reduce the influence of selection, especially in very small populations; evolution could, of course, occur without drift.

These five phenomena have all been demonstrated repeatedly, and they can be demonstrated at will, as can some of their interactions. No living things have been demonstrated to lack any of them. Hence, they may be described as the *factual* basis of evolution.

The theory of evolution, then, is the proposition that the effects and interactions of these five phenomena, in the successions of environments in which organisms have lived, account for the traits and history of all forms of life. The challenge we face here is how to apply this simple proposition toward a better understanding of human sociality.

Of the five main components of the evolutionary process, natural selection, or the differential reproduction of genetic variants, is generally accepted as the principal guiding force. The reasons for this acceptance are not commonly discussed; it seems to me that there are at least three. First, altering the directions of selection apparently always alters the directions of change in organisms; this indicates that evolutionary change does not depend for its rate upon the appearance of mutations. Second, the causes of mutation and the causes of selection appear to be independent; and, third, only the causes of selection remain consistently directional for long periods, and, hence, could explain long-term directional changes.

Mutations are caused, at least chiefly in the past, by atmospheric radiation or, perhaps, by internal chemical events still poorly understood (Suzuki and Griffiths 1976). Selection, however, is caused by extrinsic phenomena that Darwin termed the "Hostile Forces of Nature": climate, weather, food shortages, predators, parasites, and diseases. This list implies competition for resources, such as food and shelter from the other hostile forces. Accordingly, for all sexual species, we must include competition for mates as a selective factor . . .

The competition involved in natural and sexual selection is not just for the greatest quantity of resources but also for the highest quality. Those organisms will out-reproduce that use the least energy and take the lowest risks in securing the highest quality and quantity of resources and converting them into their own genetic materials.

Because directions of mutation evidently are random with respect to directions of evolution, mutational changes as such are independent of adaptation, or the behavioral, physiological, and morphological fine tuning that organisms exhibit in response to their physical and biotic environments. The same is true of genetic drift, for by definition its causes are without cumulative directional effects on the genetic materials. This means, first, that as evolutionary adaptation proceeds, mutations must increasingly tend to become deleterious, so that their rates of occurrence have likely been selected severely downward. It also means that directional evolutionary change cannot result from either mutations or drift, but must be caused by directional selection . . . When one direction or force of selection is removed from the environment of a species, the necessary effect is to cause other previously opposing forces [of selection] to become more intense or powerful.

These are the reasons, then, for the common tendency to refer to the theory of evolution as the theory of natural selection; we derive them by applying logic to the set of facts known, from experiments and observations, about the phenomena that together make up the process of organic evolution.

So we are led to the next conclusion: *to understand ourselves better from our evolutionary background we must focus our attention on one particular part of the evolutionary process – on the causes and effects of differential reproduction or natural selection.*

Creation Research Scientists and Darwin's First Challenge

At least two approaches could have been made to try to meet Darwin's first challenge: (1) seek a complicated organ – or anything complicated about life, such as individual organisms – and try to demonstrate that it was not put together as a combining of numerous, successive, slight modifications; or (2) claim that a supernatural, all-powerful, everlasting force or being (often considered to be anthropomorphic) could have generated the underlying mechanics that have been demonstrated in natural selection and thereby produced the particular sort of small-step-by-small-step changes that Darwin regarded as universal. In effect, no such process of creation could ever be falsified because there would by definition be no limits on the nature or means of creation caused by an all-powerful and eternal supernatural force. The mere use of the term "supernatural" means that no natural restrictions can be claimed for the creative process. If supernatural creation is indeed the means by which life came about and took its present form, then it cannot be refuted or acclaimed via scientific challenges. All options, both imaginable and unimaginable, will always remain possible.

Some scientists – and others who favor or find acceptable a theory of creation – have continued to try to meet Darwin's first challenge. They have done it in at least three ways. First, the members of an organization prominent in the 1970s and 1980s, who referred to themselves as Creation Research Scientists, initially argued that evolution cannot be studied as a science because it takes so long that it cannot be observed directly. At some point, however, they withdrew this argument, realizing (as had been pointed out by biologists – for example, Alexander 1978) that evolution can indeed be observed directly, because many organisms have very short life cycles, and evolutionary change can be observed across one or a few generations. The Creation Research Scientists subsequently termed this portion of evolution, "micro-evolution," and argued that "macro-evolution" – referring to a term used by biologists and paleontologists for what they see as effects deriving from long-term evolutionary changes – in particular the fragmentary and often disconnected remains of fossils, cannot be studied scientifically because the divergences resulting in such fragmentary remains really do take too long for humans to observe them directly. Scientists and jurists, however, continue to make decisions of great importance on the basis of indirect observation (or circumstantial evidence), including accounting for the gaps in the fossil record that have been the items most questioned by creationists. One way to falsify the argument that the gaps are simply the result of only occasional individuals being fossilized, or of our efforts to locate the fossils that do exist being imperfect, is to show that no progress is being made in closing the gaps among fossils. As long as new fossils continue to be discovered that sometimes tend to reduce or close existing gaps among fossils – and particularly in the face of Darwin's first challenge – it is reasonable to proceed under the assumption that macro-evolution is no more than micro-evolution extended.

Creation Research Scientists failed again when they argued that the existence of different species is evidence of supernatural creation because species differences are too great, and of such a nature that they cannot be produced by numerous, successive, slight modifications. They used the arguments that species differences represent macro-evolution because such differences cannot be observed directly, and because no one has ever turned one species into another or caused one species to become two in the laboratory, or otherwise under direct observation. These arguments do not hold up because different species that live together, mixed individually, yet have never been found to hybridize in the field, can be caused to hybridize in the laboratory, sometimes simply by putting males of one species with females of another and vice versa. This fact has been well known for at least three-quarters of a century, for numerous species, including both vertebrates and insects. Moreover, sequences of controlled backcross hybridizations (crossing hybrids with members of either parent species) and hybridizing hybrids (creating successions of repeated hybridizations, yielding F1, F2, F3. . . generations) have shown many times over that the differences between species are indeed owing to Darwin's numerous, successive, slight modifications (cf. Alexander 1978, 1979: 8ff.). With regard to Darwin's first challenge, differences between members of different species are demonstrably – and likely invariably – of the same sort that occur among genetically different individuals within species. They give no evidence of requiring supernatural explanations. Species are simply populations that have diverged via NSSMs because they were separated in space, time, or both long enough that their differences in accumulated NSSMs prevented them from amalgamating again, either preventing all hybridization or rendering hybrids sufficiently non-reproductive that individuals avoiding hybridization were sufficiently favored by selection.

A second kind of effort to meet Darwin's challenge involved claiming to have discovered organs, or other traits in organisms, that cannot be explained as comprising numerous, successive, slight modifications. Three arguments have been used to make this challenge: (1) noting that under certain circumstances complex organs occur in individuals whose parents show no indication of such organs; (2) claiming that the functions of many organs show that they could not have evolved by numerous, successive, slight modifications; and (3) choosing an organ that is so small, so symmetrical, and seemingly so "entire" in its structure as, on that basis alone, it appears to deny Darwin's challenge.

Consider the first case. An example is cave-dwelling animals, such as fish. When animals continue to live in total darkness for long periods, after a long period of evolution in the light, selection changes direction. One change is that structural and functional losses to the complex organs that we call eyes will not be favored, so that other beneficial effects, having little or nothing to do with the eyes, can be saved at the expense of maintenance of functional eyes. Under this kind of selection, eyes tend to become imperfect, and sometimes may disappear entirely because of changes in one or a few genes that had become key to continuation of the eye. When an eye disappears, however, many or most of the genes formerly involved in its functioning may remain unchanged. Changes in only one or a few genes, among the many contributing in concert to produce a complex organ such as an eye, can eliminate most or all external evidence of the eye. In an entirely dark environment, any genetic event that canceled a useless but calorically and genetically expensive visual organ – especially when it did so as an aspect of improving some other sensory device – would be favored by natural selection. Again, hybridization experiments have demonstrated what has happened. Two parents showing little or no external evidence of eyes can produce offspring that have functional eyes. Even more important, they can produce offspring with eyes in various stages of imperfection, revealing that the complex organs called eyes do indeed evolve through Darwin's numerous, successive, slight modifications. The "sudden" reappearance of an eye in offspring of two eyeless parents can come about because the particular gene mutations causing eyes to disappear may be different in the two parents, so that some offspring of those parents can possess all or nearly all of the original sets of genes responsible for eyes. Hybrids between eyeless cave creatures can end up with differing numbers of "eye" genes, and differences in the particular genes in their incomplete sets of eye genes; and, when they are hybridized, some of their offspring may accidentally wind up with complete sets.

In a second approach, creationists have argued that some complex organs, such as wings, could not have evolved via numerous, successive, slight modifications because they would have been non-functional in their early stages. This argument is falsified by knowledge that organs can begin with one function and generate another function later. For example, wings of birds and mammals are clearly derived from forelimbs, and may have been gliding devices or courtship display devices before they were flying organs. Wings of insects have been postulated to have begun as swimming organs or as dorsal courtship display devices (or possibly both, in sequence) because there is ample evidence that early insects copulated with the female on the male's back. Either of the postulated early functions of mating insects could have involved means of moving their incipient wings prior to actual flying (Alexander and Brown 1963; Kukalova-Peck 1978, 1983).

The third case is different, but equally interesting. The option remains for hybridizing variants within species, or hybridizing different species, to bring out whether or not differences in organs are owing to numerous, slight, successive modifications. Sometimes, however, these options are not easily available because conditions enabling laboratory hybridization for the appropriate species have not yet been worked out. The question may also arise whether an organ results from many or relatively few genes. In the latter case, despite larger effects from individual gene changes, Darwin's challenge still holds, simply because the entire organism has relatively few genes. In such organisms, however, so-called "complex" organs are unlikely to be as complex as in organisms with tens of thousands of genes, yet still come about via numerous, slight, successive modifications.

Darwin was careful to state his challenge with the phrase, "If it could be demonstrated . . .." This challenge does not leave the option of using one's intuition, or merely asserting that the overall appearance or structure of a complex organ can show that it is not owing to numerous, successive, slight modifications. Almost all complex organs, and, indeed, organisms themselves, are unitary in function, hence even if made up of large numbers of NSSMs they may give the impression of having been created entire (see Dobzhansky's statement below). Mere observation of populations of such organisms, across long periods, can however reveal effects of successive mutations in the form of slight changes.

Interestingly, the reverse of Darwin's first challenge is also true: if Darwin is right, then any complex structure or organ of a living creature is necessarily a product of natural selection. This fact becomes an underlying principle that every student of (for example) human behavior must take into account. Thus, if a trait such as net-cost social altruism is claimed to have been demonstrated – say, by experimentation – to be potentially adaptive, then unless that trait can be shown to be "complex," to be a result of numerous, successive, slight modifications, it is likely to be some kind of recent evolutionary accident or novelty; that is, a result of one mutation or a chance combination of a few mutations. If it is indeed a result of numerous, slight, successive modifications, therefore necessarily evolved, then it is, or has been, reproductively functional.

If Darwin's first challenge is correct, then, we can feasibly use hybridization to test all apparently complex traits, believed to be independent of the evolutionary process or to have little or nothing to do with reproductive success (Alexander 2009).

Cooperation and Dobzhansky's Statement on Heredity and Development

To continue this kind of example, consider the statement below. It is not one of Darwin's observations but an explanatory effort by Theodosius Dobzhansky, a Russian who emigrated to the US and became one of the twentieth century's best-known and most important evolutionary geneticists. Fruit flies were his principal research subjects, but he also wrote extensively about human genetics. In the following statement he was participating in a discussion following a series of talks in a symposium in London on polymorphisms in insects:

> Heredity is particulate, but development is unitary. Everything in the organism is the result of the interactions of all genes, subject to the environment to which they are exposed. What genes determine is not characters, but rather the ways in which the developing organism responds to the environment it encounters. (Dobzhansky 1961: 111)

From my first reading of this statement I regarded it as one of the most profoundly important biological observations I have encountered. Heredity is particulate, meaning that the genes mutate separately, they can be shuffled, and they are shuffled every generation in sexual organisms, which includes the vast majority of species. But development – the ontogeny of the individual – is unitary. What does this mean? It means that the genes in a genome have evolved, and are evolving, to cooperate completely (that is, even if they never achieve such completeness). This means that their interests are close to being identical, in the sense of a group with a common goal, while they are functioning within the genome. At some point, part of the reason for this direction of evolution became that genes in genomes could no longer change groups. Once the genome is formed, instances of genes changing groups – thus, in some cases, acting as if "selfishly" within the genome – are sufficiently unusual that they are singled out for special discussion. The major exception is the brief period of meiosis, sexual recombination, and zygote formation in sexual forms (e.g., Burt and Trivers 2006).

In October 2007, the evolutionary biologist Olivia Judson published a brief article in the *Atlantic Monthly* titled "The Selfless Gene." She was, of course, parodying Richard Dawkins's (1976) concept of *The Selfish Gene*. Nearly all of her paper was about cooperation, with the last part taking up what has come to be called "strong reciprocity." But cooperation, even though it involves within-group social beneficence, is not the opposite of selfishness. Cooperation refers to efforts of some kind of group to achieve a common goal. Cooperation is thus a way of competing at a higher level of social organization: competing against others at large by cooperating locally. It evolves because the genes, or organisms such as humans that cooperate, reproduce better in the overall population than those that do not cooperate, so that the genes of cooperators persist longer; and that is precisely why cooperators sometimes become prevalent. "Complete" cooperation is a theoretical extreme in which all of the group members come to have the same interests, either briefly or indefinitely. To the extent that development indeed is unitary, the ultimate situation approached is that every gene in a genome is favored for doing anything and everything that assists any and all of the other genes in enabling the genome (and themselves) to succeed; more accurately, and less anthropomorphically, alleles that do this are favored over others that do it less well. Again, the reason is that this is the way the cooperative genome becomes most successful, with the result that every gene that cooperates in furthering the genome gains maximally in the population at large (that is, is apt to persist longer). That this situation is approximated is indicated by cooperativeness within the genome having become so nearly complete that the genome has evolved, via the process of meiosis, to give every allele in the genome (or nearly every allele) approximately an equal chance to be inserted into the genome of each offspring that is produced during the organism's reproductive activities. This remarkable fact, the origin and elaboration of which apparently remains to be fully explained, is why the phrase "Mendelian ratios" can continue to be useful.

By using the hypothetical example of completely unitary development and (nearly) "complete cooperation" of the genes, I have painted the picture as somewhat simpler than it actually is, because there may always be instances of alleles outcompeting their counterparts, for example via what is called "meiotic drive" (see Burt and Trivers 2006 for a general discussion of cases). But such disruptors of genomes are often like cancer, in the sense that they at first seem to win, but then disappear in favor of cooperators. Unlike cancer, genes evolve to adhere to the developmental program of their organismal host to persist indefinitely. If it were not so, the incredible cooperativeness of the genome, hence the unitary nature of the whole organism, could not have evolved. The evolved and evolving function of the organism is to maximize the transgenerational transfer of its genes.

Cooperativeness thus does not constitute selflessness, even within genomes; its effect is to further the persistence of the cooperator (its genes) by furthering the persistence of the group that shares the cooperator's interests. Nor is modularity in ontogeny an exception to Dobzhansky's unity of development, any more than is the development of multiple separate organs, because typically the entire genome is contained in every cell of every part of the developing organism, so that the same rules of gene cooperation as are essential to the organism's reproductive success, and the indefinite intergenerational persistence of genes, necessarily apply. Although I have been discussing this fact with respect to genes in the genome, it is obviously central to understanding the behavioral cooperativeness within human organizations that structures our lives by the unique, continual, and often incredibly destructive inter-group competition within our species.

Unity of development explains why complex organs and complex organisms can form in ways that cause organs and organisms to have singular functions, no matter how complex they may be; no matter how many successive, slight modifications went into their evolution. In other words, organs and organisms develop – or form – in ways that cause them to look and act as though they were not formed by Darwin's numerous, successive, slight modifications. But every time anyone has studied a complex organ or organism carefully and thoroughly, it has seemed even more likely that Darwin's first challenge is never going to be met. In any case, as already noted, Darwin's first challenge cannot be met by intuition or mere observation, or an argument that the structure or function of an organ simply does not appear to be formed of NSSMs. Whenever any such organ or organism is watched through a few generations, or compared across its species, the evidence of NSSMs becomes apparent through the natural events of living and reproducing, even in the absence of investigations of either interspecific hybridization or induced intra-specific hybridization. If Darwin was right, examining a population of any species across several generations will eventually demonstrate that it is being changed by NSSMs.

Mutations and Darwin's Numerous, Successive, Slight Modifications

Why, in selective terms, are NSSMs so numerous, successive, and slight? Returning to the causes of mutations and selection can remind us that Sir Ronald A. Fisher in the 1958 edition of his 1930 book, *The Genetical Theory of Natural Selection*, noted that if a change (for example, a mutation of a gene) is random with regard to its benefit or detriment for the organism, it is highly unlikely to be beneficial. To imagine otherwise would be the same as expecting that a random change in a complex machine would be likely to improve the machine. Fisher went on to say as well that the larger the effect a mutation has on the structure or function of the organism – on the phenotype – the more likely it is to be deleterious, and to disappear quickly. A mutation that produces only a "slight" modification – that has only a small effect on the phenotype, especially if it has deleterious effects along with beneficial effects – is more likely to last at least a few generations because it is less likely to destroy the phenotype immediately. As a result it has a certain likelihood of lasting even longer, perhaps until the genome and the environment change sufficiently that its deleterious effect happens to become beneficial, or until the deleterious effect has been modified (as by changes in other genes) to essential neutrality (genes causing such modification would, because of that effect, become beneficial). Every genome carries many alleles that have been modified so as to make their deleterious effects become recessive, thereby not affecting the phenotype except when the gene is present in the homozygous condition. It may not be trivial that such alleles, and any others that appear to be non-functional (but may be functional, and in extremely important ways, even if only in rare but significant situations or environments), might be regarded as a kind of accidental or incidental reservoir of NSSMs that remain in a position to spread, and to be modified toward dominance, if their effects should for some reason – such as changes in the environment – become beneficial rather than deleterious.

The question of why Darwin's NSSMs should appear "successively" can also be related to the deleterious effects of most mutations, leading to down-selection of mutation rates. The appearance all at once of multiple or numerous mutations will have the effect of single mutations with large effects on the phenotype, hence "flocks of mutants" will be more likely to die out quickly because the harboring organism will be less likely to reproduce (the same effect is involved in hybridization of members of groups that have been apart long enough to have evolved numerous or large genetic differences). Darwin's use of "numerous" thus also refers to the fact that the effects of individual genes (Darwin's "modifications") are nearly always small. As a consequence, every complex organ or organism is necessarily composed of numerous slight modifications that arrived successively in the organism's genome.

Several years ago, in a small assemblage of faculty from biology, medical genetics, and gerontology, I cited Dobzhansky's statement that heredity is particulate and development unitary, and that every gene likely affects the action of every other gene. Across the table a medical geneticist looked skeptical and finally said, "I don't understand Dobzhansky's statement. Every gene does but one thing, and we know what it is." I replied, "But what if genes do their single 'thing' (meaning being turned on and turned off) in more than a single environment?" Later I realized that environments are both internal and external, and the numbers of small and large, internal and external environmental variations that affect organisms are surely beyond estimating.

If humans have, say, 25 000 genes, and only variables resulting from an individual's genes were considered, the extreme form of the medical geneticist's view would mean that, taking into account all possible arrangements of genes being on or off, humans might result from the states of all genes being turned on or off, yielding two (on or off) to the 25 000 power.

As explained earlier, even this is but a minuscule fraction of the possibilities across a human lifetime ("It is now apparent that each gene may yield a large number of variants in trait expressions"; Silverman 2004). At least in part this figure almost certainly derives from cooperative effects between genes multiplying the potential number of trait expressions in different micro, macro, and internal and external changes in environments. When multiple alleles are present and many loci are heterozygous, the number of different things the organ or organism can do might be increased considerably more. But even these considerations do not give an adequate accounting if what we are told nowadays, for example about the complexity of the human brain, is accurate.

Taking into account the number of genes and their cooperative interactions in the human organism, and the multiplicity of both internal and external environments across the 80–90-year lifetimes of humans, the number of different actions possible in the individual human organism across its lifetime is so incredibly large as to be virtually immeasurable. In this sense, at least, Dobzhansky's implication of evolution changing toward full cooperation of the genes while they are in the genome of the developing organism, makes considerable sense.

Evolution and Culture

> There is every reason to expect a correlation between cultural change and inclusive-fitness-maximizing; if none had existed the capacity for culture could not have evolved by natural selection of genetic alternatives. (Alexander 1971: 106)

Everything said so far explains why evolution is generally a slow process. In particular, the randomness, resulting from the independence of the causes of change (mutations) and the causes of adaptiveness or maladaptiveness of NSSMs, results in change being relatively slow.

At this point an enlightening comparison can be made between the evolutionary process and the process of human cultural change, which I made in detail, originally in 1979, in *Darwinism and Human Affairs*, under the heading "A Comparison of Organic and Cultural Evolution" (Alexander 1979: 73ff.). Unlike organisms in general, humans have evolved ways to complete the need–novelty connection (referring to the fact that environmental novelties lead us observers to identify what we see as adaptive "needs"). Humans are able to imagine novelties or improvements in their tools or activities, then build or practice them in ways that in effect replace Darwin's NSSMs. Because of imagination and foresight – intent and purpose – which probably evolved largely in the context of social performance, humans are able to invent or "create," and build, not only new structures and functions but also new kinds of domestic organisms (by deliberate breeding practices). They are able to do these things because they are able to visualize different situations or devices, create novelties that meet their current needs, and then implement them. They can imagine the effects of their efforts at new creations even before beginning to construct them. They are also able to generate cultural transmission of traits or practices through cumulative learning (including teaching). Their cultural "mutations" need not be only accidentally adaptive, because the process of selection among existing cultural alternatives can be carried out via imagination, foresight, intent, and purpose. Thus, a new kind of plow or computer can be conceived in the human brain and built for its expected usefulness; it can be rejected if it fails or adopted if it works, and it can also be improved repeatedly by the same processes of learning, imagination, and insight that initially enabled it to be conceived and constructed (Alexander 1979: 74). This is a main reason that cultural change can be much more rapid than evolutionary change (see also Flinn and Alexander 1982).

In other words, human imagination can lead to the creation of both inanimate and animate objects in the way that creationists have imagined that the physical and living universes and their contents have been produced. The intelligent designs evident in cultural items created by humans do not have to be produced via numerous, successive, slight modifications – just by the combining of imaginable changes. Additional insights may arise from continuing to compare the ways in which changes have taken place in living and non-living forms.

Even Darwin's first and most basic challenge thus continues to provide insight into the nature of human society. The second of his five challenges is a summary statement about natural selection, followed by three challenges of great interest to students of human culture.

Darwin's Second Challenge

> 2. The only check to a continued augmentation of fertility in each organism seems to be either the expenditure of power and the greater risks run by parents that produce a more numerous progeny, or the contingency of very numerous eggs and young being produced of smaller size or less vigorous, or subsequently not so well nurtured. (Darwin 1871: Vol. 1, p. 319)

In this "seems to be" statement, Darwin is suggesting to us that each potentially parental organism has limitations in the production of offspring, limitations on available calories, and limitations on the likelihood that different degrees and kinds of risks will yield a net return. There is always a trade-off between producing many small offspring that will receive little or no parental care versus a few large offspring that can receive large amounts of parental care. Hence, birds that hide their nests or make them inaccessible to predators have been able to "win" by placing in such nests a few large eggs that are hatched by one or both parents incubating the eggs, with the offspring of some species entirely supplied with food brought to the nest by the parents. Humans, producing but one offspring at a time, are an even more extreme change in the same direction. At a different extreme are fish that produce thousands of tiny eggs and show little or no parental care. In each of these cases, whenever the population is remaining approximately stable in numbers, an average of two offspring per two-parent family survive and reproduce.

Humans are unique among all their primate relatives in producing small lifetime numbers of at first extremely helpless offspring and tending them for uniquely long periods; often, in some fashion, for the parents' entire lifetimes. "Helpless" or "altricial" offspring that have evolved to require enormous amounts of parental care gain by being able to devote high proportions of their calories to growth and development rather than to protecting themselves. Infant altriciality, lengthened juvenile life, and enormous amounts of parental care (and other kin help) thus facilitate early development of the huge social brain (cf. Alexander 1990a, 1990b) and provide opportunities for juveniles to learn how to be socially successful in ways that have enabled living in ever-larger social groups and caused lengthening of the human lifetime to approximately double those of our closest primate relatives (Alexander 2008).

The special message virtually hidden in Darwin's second challenge, however, is even more stark. It is that the phenotype – the organism itself, including its behavior and life pattern – is evolved solely in the context of reproductive success. Everything the organism is evolved to do is part of the reproductive process. As mentioned earlier, one of the biases apparently built into the human makeup is that we are not evolved to be acutely conscious of facts central to our existence, such as the primacy of reproduction; both the production of offspring and the tending of both offspring and non-descendant or collateral relatives. Even more, we are apparently evolved to reject some such traits entirely. Sometimes, at least, the reason appears to be social. Reproduction is the most directly competitive activity of the individuals of any species, meaning partly that cooperation among individuals has not evolved to be nearly as complete – nor as consistent – as with genes in genomes. Individuals that possess a keenly and consistently conscious recognition of the primacy of reproduction in their lives – openly employing and demonstrating intent, foresight, and planning solely to maximize reproduction – will almost certainly either fail, or change so as to reduce consciousness on the issue of all-out reproduction, becoming deceptive about reproduction and their attitude toward it. If complete reproductive intent remained completely conscious, or obvious, it would surely be followed frequently by negative responses, detection of any deception, suspicion of unrestricted competitiveness (that is, evidence of a deficient morality), and, most likely, serious social rejection. Social rejection in our species, as well as many others, can lead to ostracism, and even murder or execution that could be considered justifiable by the social group. It is not that we cannot escape such strictures, but that, sometimes at least – and perhaps paradoxically – we are more capable of escaping them if we know about them and why they exist. In a social species made up of individuals capable of executing long-term plans, no individual is likely to gain by being too obviously conscious in planning to out-reproduce its associates. Reproductive competition across generations does not result in "winning" in the form of an eventually stable and final achievement; it is instead an endlessly continuous and open competition. The consequences, given our continuing sociality and our growing consciousness about precisely how we have evolved, are difficult to forecast.

As is discussed further below, evolution has produced several general biases in the social makeup of humans. These biases must be identified and taken into account during investigations of what humans do socially, and what they either do not do, or cannot do. Methods of judging whether acts are assumed to be adaptive can be generated by effects of hybridization and examination of proximate mechanisms of social behaviors (Alexander 1987: 13–20).

With the next three challenges Darwin moves us directly into the problems involved in the analysis and understanding of human sociality, in particular raising questions about what is typically referred to as altruism. How do we take up the topic of apparently selfless, beneficent behaviors toward others – not just between species but within species – and even, in a sense, "within" ourselves (in the sense of conscious motivation)? If, as

Darwin's second challenge (above) implies, the answer is to be couched in terms of every organism competing to secure the greatest amount of the highest possible quality resources, and then using them all for its own reproduction – sometimes via cooperative interactions within small groups that compete with other such groups – it will not be easy to understand all the details of human social behavior.

As suggested in the statement that introduces this chapter, the argument is not that we cannot do anything but what evolution has primed us to do, but rather how we can identify and then deal with the biases evolution has installed in us, some of which are poorly understood, while others tend to remain outside our consciousness for either accidental or evolutionary reasons.

Three Additional Darwinian Challenges

> 3. If it could be proved that any part of the structure of any one species had been formed for the exclusive good of another species, it would annihilate my theory, for such could not have been produced through natural selection. (Darwin 1936 [1859, 1871]: 201)
>
> 4. Natural selection will never produce in a being anything injurious to itself . . . no organ will be formed . . . for the purpose of causing pain or doing an injury to its possessor. (Darwin 1936 [1859, 1871]: 201)
>
> 5. . . . some naturalists believe that many structures have been created for the sake of beauty, to delight man or the Creator . . . or for the sake of mere variety . . . Such doctrines, if true, would be absolutely fatal to my theory. (Darwin 1936 [1859, 1871]: 146)

These three challenges require careful analysis. It is easy to misinterpret what Darwin must have meant, and to conclude (erroneously) that he was wrong.

A main point to be understood for all three of these challenges is Darwin's use of the term "for the exclusive good of another species." The meaning is that such a tendency would not serve the interests of the individual possessing the structure. In statement (4), Darwin is not referring to acts that have beneficial effects even though they cause pain as a side-effect. He is not saying that organisms will evolve to do nothing at all likely to cause pain. He is rather saying that organisms will not evolve to cause themselves pain, or hurt, in the absence of any available or possible countering effects. The same is true of his statement (5) about beauty. He is surely not discussing instances in which a viewer chooses the beautiful individual or the beautiful tool because of the usefulness associated with the perception of its beauty; because of what is meant by the old adage, "Beauty is as beauty does." Instead Darwin is referring to beauty that has no practical application whatever. We can evolve to see as beautiful something that is useful, even if only because seeing it as beautiful inspires us in one way or another. But natural selection cannot cause objects to change to meet our standards of beauty solely because we like them, even though humans can change features such as those regarded as beautiful, using human-generated or so-called "artificial" selection. Beauty does not evolve because it causes us to admire it for no functional reason, and we do not evolve to see beauty when it has no relationship to our own evolved functions.

Similarly, when Darwin says that an organism cannot evolve to do anything injurious to itself, he apparently meant doing anything that solely hurts itself; something that has no other function. Thus he could even have meant, by "hurt," the reduction of reproductive success.

Pain, too, evolves when it is useful. Pain that is suffered because some part of one's body has been damaged is generally (but not always) functional. When we are injured or wounded, pain at the appropriate location guides us to tend and protect the injury, thus hastening its healing, as well as reminding us to avoid the same pain later. That such pain is evolved seems obvious from the fact that parts of our body that have no history of repeated healing (such as the interior of the brain, injuries to which, in pre-technological, pre-medical times, would tend always to be fatal), have not evolved significant pain sensors.

Without the pain that relates to healing we would surely be in trouble a good deal of the time, even from minor wounds. That horses, for example, do not easily heal injured or broken legs is related to the fact that horses are prey animals that rely heavily upon quick speed to escape dangers and are likely to "run over" anything in their paths. When predation is consistently intense, slower or obviously crippled individuals are sought out and eliminated, thereby reducing or removing the possibility of evolving the ability to recover. This is at least in part why, in a recent example, the broken leg of the valuable racehorse Barbaro in the US resulted in the horse being euthanized, despite a remarkable investment of time, effort, and modern veterinarian expertise.

Consider the pain of childbirth. It is reasonable to assume that this pain is caused by the severe displacement of bones and tissues in the mother's pelvic region. Two possibilities exist, and each may be real in particular instances. Childbirth pain may occur because the infant is sufficiently large – in humans, especially the infant's head (its brain) – to cause pain by disrupting tissues or straining bone structure in the region of the emergence of the newborn. But this pain did not evolve because of that problem; the predictability of its eventual appearance was in place before childbirth became as difficult as it is in many or most modern women. For natural selection to remove the pain of childbirth, yet retain the large head and brain, would presumably require such serious alterations of the pelvic region that reproductive success would in some way be reduced. Natural selection has taken women to extremes in birthing large infants (and infants with large heads) because of benefit to the infant itself, and for that reason benefit to the reproduction of the mother (Alexander 1990a). Similarly, if admiring a prospective mate as beautiful means admiring features that are likely to make a prospective mate the best possible match for the admirer, then features predicting reproductive success have evolved to be seen as beautiful rather than the perception of beauty evolving independently of any indication of reproductive success.

Regarding beauty, Darwin (1936 [1859, 1871]: 147) wrote as follows:

> If beautiful objects had been created solely for man's gratification, it ought to be shown that before man appeared, there was less beauty on the face of the earth than since he came on the stage. Were the beautiful volute and cone shells of the Eocene epoch, and the gracefully sculptured ammonites of the Secondary period, created that man might ages afterward admire them in his cabinet? Few objects are more beautiful than the minute siliceous cases of the diatomaceae: were these created that they might be examined and admired under the high powers of the microscope?

Evolution-Based Biases in the Social Actions of Humans

Now we can consider whether social acts evolve to be selfless, partly by taking into account biases we can expect to find in the social behavior of humans, biases planted in us by the process of evolution. Then I will discuss what I see as an exhaustive list of the general kinds of social behaviors evolved in the human species. I will also discuss the use of proximate mechanisms of social behavior in humans to help identify the likely consequences of different human social acts, particularly in deciding whether net-cost altruism is prevalent or evolved. I would argue that all social scientists will be better equipped to conduct experimental studies of social acts – and to develop the deep understanding of humans that surely will be required to solve the massive and global problems of humanity – if they contemplate lists such as are presented below and adjust their approaches to take into account the manners in which evolution has constructed our human characteristics.

Following are four evolution-based biases in human social acts, from Darwin's challenges. Again, I am not arguing that we cannot escape these biases. Instead I am suggesting we will be better able to escape them if we know about them and understand their basis and significance:

1. Evolved human interests are expected to be solely reproductive; natural selection is differential reproduction, meaning adding to the intergenerational persistence of genes in whatever combinations they regularly assume.
2. All evolved acts are presumably constructed by natural selection so as to serve the actor's interests (that is, can be termed self-interested), whether "self" refers to genes only, genes that give rise to competing individuals, genes that give rise to integrated (and competing) groups of individuals, or any combination of the three possibilities.
3. Not all acts or efforts will have evolved to be either conscious or completely understood. Failures of acts to be conscious may have come about: (a) incidentally because there is no benefit to their being conscious; or (b) by selection because there is a net detriment arising from their being conscious. For either alternative we humans have an enormously difficult task in working out how to deal with our inability to distinguish truly selfless acts from acts that we and others may erroneously term selfless. Much of learning and teaching (training, education) consists of bringing into our consciousness phenomena that for one or the other of the two above reasons have not been conscious.

   Acts that do not serve the actor's reproductive interests are presumably not evolved, rather are evolutionary accidents or mistakes. Such acts, for example, can take place in evolutionarily novel environments. Included are deliberate deviations from evolved acts, because conscious knowledge brought about by scientific understanding constitutes a novel environment. Evolutionary accidents and mistakes are not necessarily likely to come about because of numerous, slight, successive modifications, and when they do it is likely because some aspect of the environment has changed in a way that makes a previously expressed adaptation useless or negative.
4. The intense and pervasive role of within-species inter-group competition in human evolution has uniquely shaped human social behavior at both individual and group levels, yielding not only sympathy and empathy, but the corresponding potential for extreme inter-group competitions, including tendencies of local pride and fellowship that facilitate extreme patriotism and xenophobic tendencies.

BUILDING BLOCKS OF HUMAN SOCIETY

The following list of possible positive social actions by humans is an effort to be complete, meaning that, regardless how many different kinds of individual actions can be discovered, each should fit into one or another of the general categories represented by the list that follows. The purpose of making this list is to show that the number of classes of positive social interactions is not indefinitely large, and that not all are entirely obvious; collectively, however, they are the explanations of our evolutionary background. As a result, human society is not easily understood except by taking into accurate account the particular biases caused by our background in differential reproduction. All but three of the possible social actions listed below are consistent with a history of cumulative differential reproduction. The second social action has become equivocal, hence less useful, because of the different ways humans have regarded it. The fifth and thirteenth are inconsistent with a history of cumulative differential reproduction. It is not that these three actions (*asterisked below) cannot be carried out; we are free to use them, appropriate to our own considerations.

1. Ecological Mutualism

Ecological mutualism is a reciprocal, low-risk, shared interaction that often arises between co-resident species and becomes profitable to each party. Such interactions can begin either with the extraction of benefits by one species via parasitism, or by no-cost one-way benefits (commensalism) utilized by one species via benefits from the other. Mutualism exists when each partner becomes a valuable and reliable resource to the other. Mutual benefits can become elaborate because the risk of withdrawal is low as a result of consistent co-residence of potential mutualists, and is weighed against benefits returned from the partner. In mutualism neither partner suffers a net loss by providing benefits to the other, and the low risk from the outset tends to cause the traits involved in the mutualism to become phenotypically obligate. Mutualism can thus flourish without requiring foresight or risk assessment of the sort involved in human social reciprocity.

An example of interspecific ecological mutualism involving humans could be their interaction with dogs, if the interaction actually came about in approximately the following way (the example is valid, as given, even if the dog–human interaction actually came about in a different sequence). Suppose that dogs gained by beginning to approach human groups and feed upon the leavings from meals made up of animals hunted and partly consumed by the humans. At first, humans may have neither gained nor lost from this interaction. Apparently, dogs eventually began to stay around human settlements, became accustomed to humans, and started to respond aggressively (territorially) to predators such as big cats or other animals dangerous to themselves – and ultimately to humans. These behaviors, beneficial to the dogs, would also tend to benefit humans, at the least warning them of danger. At some point humans began to promote the benefits of their association with dogs by deliberately providing food and other rewards to keep the dogs around. Dogs would gain from becoming increasingly tolerant of humans, and increasingly familiar with, or beholden to, particular individuals or families, the latter leading to within-group competition of both humans and dogs. At some point dogs must have begun to follow humans on their hunts, and to interact in other ways that immediately favored humans, or that humans could adjust or manipulate to their own benefit. The association, as I have just described it, would have taken place at first by accident, serving only one of the two participants but also not particularly costly to the other. Gradually both participants became contributors to the interaction, and each benefited from it. Obviously, additional kinds of beneficent acts, such as are typical of deliberately modified different breeds of dogs today, were added to the dog–human mutualism (via mainly Darwin's "numerous, successive, slight modifications" in dogs and almost certainly via mainly considerable learning or "cultural changes" in humans). The dog–human mutualism is not obligate, but thousands of other mutualisms have become so.

2. Altruism*

"Unselfish concern for the welfare of others" (*Webster's Unabridged Dictionary*). Because of the implication of assumed or intended selflessness, with insufficient attention to possible return benefits (as occur in mutualism, cooperation, nepotism, and direct and indirect social reciprocity – see below), and because of the possibility of evolved misconception and self-deception regarding motive, altruism has become an ambiguous and misleading term, not easy to use in efforts to analyze social behavior (see cooperation, below). Dictionary definitions of selfishness and altruism do not necessarily take into account that: (a) humans did not evolve to be keenly conscious of the probability of compensatory returns from all social investments; and (b) consciousness can be adaptively cloaked or concealed.

3. Social Beneficence

Acts costly to benefactors and likely to benefit recipients, with or without returns to self or self's relatives (directly or indirectly). Social beneficence can be a positive benefit to the benefactor, or it can be accidentally altruistic (see #4 and #5 below).

4. Net-Gain Social Beneficence

Social beneficence that involves overcompensating returns via mutualism, cooperation, nepotism, or direct or indirect social reciprocity.

5. Net-Cost (or Net-Loss) Social Beneficence (Net-Cost Altruism)*

Social beneficence without overcompensating returns. Such acts may occur, either by mistake or accident, or deliberately, despite even conscious knowledge that they cannot lead to gains, in terms of differential reproduction. But the tendency to carry them out, or elaborate them (except as practice, especially by juveniles and "beginners"), cannot evolve via Darwin's numerous, successive, slight modifications. Note the relationship to altruism (#2 and #3 above), which by its usual definition, also cannot evolve.

6. Social Investment (or Investment Beneficence)

Social beneficence treated, or regarded, as likely to yield (later, or eventually) overcompensating returns, regardless whether the beneficent individual or the cooperative gene is "aware" of the reliability of compensating return.

7. Nepotism

Social beneficence passed directly or indirectly to accurately (but not necessarily consciously) identified genetic relatives. The return is via reproduction of genes identical to those of the benefactor by immediate descent in the helped individual. Genes are likely to persist only if they are reproduced (multiplied).

It is essential to realize that even quite large bilateral kinship systems (or kin groups) can be comprised entirely of socially recognizable genetic relatives, including in-laws (Alexander 1990a, 1990b), which in large kin groups typically reproduce with relatives. Spousal and parental bonds arise (or are coerced) within such groups, most often with cross-cousins, either first or more distant cousins. In such cases all members of the kin group can eventually evolve to be prepared continually to assist any individual within the kin group because there will be genetic returns from aiding the reproduction of relatives (or in-laws) when individuals living in kin groups are competitive with other less closely related groups. The universality of relatedness in such groups, generated genealogically, establishes an equivalent to Hamilton's "genes identical by immediate descent." This social situation, which for numerous reasons is unlikely to be so precise throughout the kin group as to follow Hamilton's Rule (see #8) in all respects, might be misinterpreted as pure altruism or net-cost social beneficence, and perhaps regarded as proof of either willing cooperativeness or "goodness" (altruism*). In-laws, even if unrelated to their marriage partners, can be included in this evolved beneficence within kin groups, without changing what has just been said, because, as noted, they are linked to the large group of relatives via the reproductive effort that connects them genetically with members of the kin group. Here, as elsewhere (for example, in direct and indirect reciprocity in social groups that have evolved to utilize the benefits of social reciprocity), there is no reason to believe that, for evolved adaptiveness to be involved, genetic returns must be consciously anticipated or consciously calculated, by beneficent individuals, or even perceived by observers.

8. Hamilton's Rule

All else being equal, organisms are expected to evolve to treat genetic relatives according to their degrees of relationship in genes identical by immediate descent (Hamilton 1964).

Social proximity, and patterns of social interaction consistent with genealogies, rather than recognition of trait variations reflecting genetic differences, are what (at least typically) allows the evolution of ability to learn (consciously or not: Alexander 1979, 1990a, 1991) to classify different relatives accurately according to genes; hence the engagement of differential nepotism, as in all human societies, and the rise of the complex kinship systems of all studied human groups. I have argued that differential nepotism to multiple relatives of differing degrees – in the manner according with Hamilton's Rule – can come about (in any organisms) only via evolved patterns (including effects of evolved opportunities) and biases of learning abilities and tendencies. The success of some ants in carrying off larvae from other colonies, or species, to be "willing (non-reproductive) slaves" in their own colony, is a demonstration of such learning or tolerance. So far, complex patterns of differential nepotism that would accord precisely with a full-blown version of Hamilton's Rule (for example, including virtually all available relatives, even distant cousins) are approached only in humans, although other primates have probably not been investigated sufficiently to make adequate comparisons. There are multiple categories of imperfect social learning that may appear to be differential nepotism but are not evolved as such, and do not require social learning of different relatives (Alexander 1990b, 1991).

Hamilton's Rule can be extended to account for sterility in the workers and soldiers of eusocial forms. The example is worth citing here because it demonstrates the extremes to which nepotistic beneficence can be extended. Thus: if the trait of sterility can be carried without being expressed, then if those who express it help sufficiently those who carry it without expressing it, the trait itself can be advanced by natural selection (Darwin's idea; Darwin 1936 [1859, 1871]: 238; Alexander et al. 1991).

9. Direct Reciprocity

Direct reciprocity occurs when benefits are returned from recipients of the initial beneficence. In all forms of social reciprocity, whether or not conscious and deliberate, the beneficence involved is appropriately termed social investment, investment beneficence, or temporary altruism (meaning that overcompensating returns are expected; again, not necessarily consciously). Unlike in mutualism, there tends always to be a risk of failure to return social beneficence, because return beneficence can be optional and may occur only after significant delays, which may result in changes in the social situation.

10. Indirect Reciprocity

Indirect reciprocity occurs when benefits are returned from parties other than recipients of the initial beneficence (for example, groups promoting beneficent or heroic acts; observers seeking reciprocal interactions). Returns from a single act of social beneficence can involve both direct and indirect reciprocity. Indirect reciprocity can occur in extremely diverse and complex, subtle and unexpected interlacing of interactions (Alexander 2005, 2006; see below). Reputation is one of the important ways in which knowledge of a potentially good partner in reciprocity can be identified and engaged, but it need not be a necessary element in indirect reciprocity.

11. Cooperation

Group action to bring about a common goal – any of the above social acts except net-cost beneficence, which cannot evolve via Darwin's "numerous, successive, slight modifications" – and some forms of what is called altruism. Cooperative acts thus evolve as self-interested competition by individuals via levels of organization higher than the individual. They pay off to the participants when the interests of cooperative individuals become sufficiently similar as to more than compensate, within the population at large, for whatever inter-individual competition occurs within the group.

As with other species, humans can evolve to provide social benefits that will result in net benefits to the donor without conscious perception of the complete interaction by either (any) party. An example is selflessness (in cooperation) within groups from which no individual can emigrate, meaning that the interests of all group members have become identical and anyone who fails to contribute to the success of the group – regardless whether all other individuals behave similarly – increases the likelihood that all will perish. This situation can occur with genes in genomes and with groups of humans, including humans when they are in dire situations such as war.

12. Self-Interested Behaviors

In evolutionary terms, any acts that serve the reproductive interests of the actor (that is, the transgenerational persistence of the actor's genes), including all of the above social acts except net-cost social beneficence and some forms of what is called altruism.

13. Alternatives to Self-Interest*

Evolutionary mistakes (including deliberate deviations); any net-cost social beneficence; any efforts at self-interested acts that fail to increase the actor's reproductive success (including via returns to genetic relatives). Self-interest includes: (a) return benefits to self's phenotype; and (b) benefits to self's genes, whether to genes residing in self, or genes residing in genetic relatives of self.

Recognition of the differences among acts of social beneficence with differing prospects of returns has probably evolved, and adjusted the relative frequencies of the different acts in human sociality. Such recognition need not be conscious to potential social investors, or to any involved parties.

Complete cooperation, approached for example by genes within the genome, is self-interested if the reproductive fate of the group (such as the genome) is identical to that of every cooperator; hence, of every member of the group (such as different genes in the same genome or the different individuals in a military squad on a dangerous mission). Complete cooperation may never be achieved, except as visualized end-results of directions of evolutionary change; it is the continuing direction of evolutionary change that should be our focus. Whenever group members consistently cannot change groups, as when genes are functioning within genomes, selection will tend to favor complete cooperation, in which every individual's fate can become inseparable from that of the genome (because more effectively cooperative mutants will successively prevail over less cooperative mutants). Compare genomes in which the genes are always evolved to cooperate (asexual forms), or shuffled each generation (sexual forms), with the contrasts of dramatically fluctuating intensities of patriotism (that is, cooperation approaching completeness) in humans in separate, adversarial groups: such cooperativeness is extreme (as extensions of within-group amity) when kin groups, clans, or nations are at war; mild when inter-group conflict is minimal and, correspondingly, when intra-group conflict is most intense.

14. So-Called "Strong Reciprocity": Is It Real?

> recent experimental research has revealed forms of human behavior involving interaction among unrelated individuals that cannot be explained in terms of self-interest. One such trait, which we call strong reciprocity . . . is a predisposition to cooperate with others and to punish those who violate the norms of cooperation, at personal cost, even when it is implausible to expect that these costs will be repaid either by others or at a later date.
>
> We show that under conditions plausibly characteristic of the early stages of human evolution, a small number of strong reciprocators could invade a population of self-regarding types, and strong reciprocity is an evolutionary stable strategy. (Gintis et al. 2003: 154)

A sizable group of students of social behavior has recently generated a significant literature regarding social experiments, the results of which they believe require a new term, "strong reciprocity" (e.g., Gintis 2000; Fehr and Henrich 2003; Bowles and Gintis 2003; Gintis et al. 2003; and references cited in Hammerstein 2003): "Strong reciprocity means that people willingly repay gifts and punish the violation of cooperation and fairness norms [when the act of punishment is costly to the punisher] even in anonymous one-shot encounters with genetically unrelated strangers" (Fehr and Heinrich 2003). Fehr and Heinrich (2003) add that, "This chapter provides ethnographic and experimental evidence suggesting that ultimate theories of kin selection, reciprocal altruism, costly signaling, and indirect reciprocity do not provide satisfactory evolutionary explanations of strong reciprocity." They argue that these theories "can rationalize strong reciprocity only if it is viewed as maladaptive behavior, whereas the evidence suggests that it is an adaptive trait."

I have suggested (Alexander 2005) that there are multiple possible solutions to the so-called "strong reciprocity" phenomenon, as derived by the experiments of the above authors, that must be explored before we are required to accept the tendencies they regard as unexplainable via the "ultimate theories of kin selection, reciprocal altruism, and the risks of costly signaling and indirect reciprocity" (Fehr and Heinrich 2003; see also Burnham and Johnson 1992). The proponents of "strong reciprocity" as an independent form of social activity need to be certain that the phrase "at risk" is not more accurate than "at personal cost." It is all too easy to assume wrongly that there is no possibility of return benefits in interactions that take the often subtle and sometimes disguised or concealed expressions of indirect reciprocity.

The comment that "interaction among unrelated individuals . . . cannot be explained in terms of self-interest" (Gintis et al. 2003) needs explanation. It is not the saving of self that drives evolution, but the saving of genes – the transmission of genes (of self or identical to those of self) – to the next generation. In some situations the greatest number of genes is saved by assisting genes carried by distant relatives, or by assisting non-relatives in high-risk indirect reciprocity (Alexander 1979, 1987, 1990b, 1993, 2005, 2008).

The apparent claim that strong reciprocity involves personal cost, or net-cost altruism, suggests violation of Darwin's first challenge (see above) either: (1) because strong reciprocity does not fit the criteria of an evolved complex organ of sociality; or (2) because it is after all formed by numerous, successive, slight modifications and does not fit the claim of voluntary personal cost, as when it is regarded as implausible to expect that these costs will be repaid either by others or at a later date.

Reviewing Indirect Reciprocity

Indirect reciprocity is surely the most difficult of all human social interactions because of: (1) the diversity, complexity, and indirectness of sources of returns; especially among non-relatives (because there is less predictability in the patterning of responses to reciprocal as opposed to nepotistic social actions); and (2) the effects of adaptively cloaked or muted consciousness.

Indirect reciprocity is often subtle and deceptive, both consciously and non-consciously. Almost no positive or punishing social act can remain entirely free of social consequences; essentially all of our social rules – and the perceptions of observers – reinforce this reality. As a result, a thorough understanding of indirect reciprocity will require a detailed science of its own. Such a science requires painstaking attention to all possibilities of unexpected positive and negative responses to every positive or punishing social act.

Returns from indirect reciprocity may take at least three major forms (Alexander 1987: 94): (1) the beneficent individual may later be engaged in profitable reciprocal interactions by individuals who have observed their behavior in directly reciprocal interactions, or by others informed by the observing individual or by the actual beneficent individual (the 'reputation' or 'status' of the investor is enhanced, to their ultimate benefit); (2) the beneficent individual may be rewarded with direct compensation from all or part of the group (such as with money, or a medal, or social elevation as a hero); and (3) the beneficent individual may be rewarded by simply having the success of the group within which they behaved beneficently contribute to the success of their own descendants and collateral relatives. For example, when the canoe is headed for a deadly waterfall everyone in the canoe is likely to gain by paddling as hard as possible, which can cause every individual in the canoe to be rewarded by their behavior; selflessness, or net-cost altruism, need not be involved. Unlike genes in genomes, humans, in particular, are not expected to remain in tightly knit social groups for the entire lives of all participating individuals; when the canoe has been beached successfully, everyone may go their own way and perhaps pursue similar jeopardies with different groups of individuals.

Leaving aside maladaptive accidents or errors, I can think of at least three other possible adaptive (indirect reciprocity) explanations for what some authors in this volume call "one-shot" social investments: (4) the return may be to the beneficent individual's relatives or friends, and the nature of social information spread as a result may be such as to make this kind of return consistent with reciprocity being self-serving; (5) the investment may serve the individual practicing how to engage in reciprocity adaptively, as with individuals who practice while alone for success in, say, being humorous, or in developing a useful conscience, or any other social behavior (that is, as a way of learning how to invest socially in a more rewarding – more profitable – way). This is not reciprocity per se, nor is it evidence of net-cost beneficence; rather, it is investment that can improve the individual's later engagement in social reciprocity. In my experience we do this kind of thing all the time, and I regard it as an essential part of knowing how to behave socially in one's own interests. For several decades I consistently practiced my biology lectures while driving to the university. An alien, or a member of another species, observing my behavior, might believe that I was displaying net-cost frivolous behavior, or revealing some kind of mental disturbance, lacking in any beneficent return. Because of such possibilities, special care must be taken in interpreting social investment, especially by rapid and resolute learning of career-oriented pre-adults (such as were employed by those occupied with "strong reciprocity"). Juvenile individuals, "practicing" moral behavior, may carry out learning propositions that occur much less often in adults. Who can say how frequently an exceedingly polite student may respond with what appears to be a net-cost act of politeness, with no available responder, or on the other hand deliberately use knowledge of how a question was asked to amuse fellow students and show his or her evidence of superiority?

An example of social behavior, relevant to this discussion, can be illustrated by a true story. A distinguished entomology professor and close friend was for years my best discussant (and critic) of propositions regarding human social behavior. On one occasion, he told me that on his walk to the Museum of Zoology that morning he had noticed a butterfly larva (caterpillar) moving across the sidewalk. Believing that the caterpillar had fallen from its host plant, and that it was moving in the wrong direction, the professor said he picked up the caterpillar and carefully placed it back on its host plant. At the end of the story he said to me, "Now, Dick, wouldn't you agree that was an act of pure altruism?" I replied, "It might have been – until you told me about it." He and I eventually agreed that the caterpillar may not have been helped at all. Because of the season, and its observed size, it was almost surely full-grown, therefore likely seeking a suitable location for pupation rather than having fallen off the host plant from which it was departing.

It is not necessary for an individual who carries out an act of the above sort to tell anyone at all about it – except himself – to keep it from being an act of "pure altruism." Anyone who thinks about their own beneficent behavior with respect to others can be expected to "practice" doing the kinds of things that will yield returns in social rewards, including (but not solely) reputational effects. As practice, an act of net-cost altruism can even yield a pleasurable response in the actor, especially if they regard the practice as likely to contribute positively, and even much later, to their own ability to perform socially. Of course we practice – often alone and sometimes in the presence of others unlikely to respond appropriately – at such things as music, humor, politeness, honesty, upcoming performances, and many other kinds of social efforts.

Fehr and Henrich (2003), citing Gintis (2000), argue that, when groups face such extinction threats as "wars, famines, and environmental catastrophes," then "neither reciprocal altruism nor indirect reciprocity can sustain the necessary cooperation that helps the group survive the situation because the shadow of the future is too weak." This argument seems to be cast in terms of the overall situation; for example, the war as a whole. But wars are fought not by entire armies as masses of unorganized individuals, and not as independent individuals. Armies tend to function as absolute dictatorships and, particularly on the battlefield, individuals are constrained in ways that do not provide opportunities to behave according to personal inclinations. During my brief military experience (basic training as an infantry rifleman followed by service as an entomologist, 1951–53), my training company was informed publicly, via loudspeaker and while arrayed in ranks on the parade ground, that anyone who disobeyed a command on the battlefield could be summarily shot dead, either from the front or from behind. There is little room for personal concern about "the shadow of the future" in such a situation.

In situations in which the interests of group members are identical, or nearly so, individuals (as with genes) can act (function) appropriately without the ability – or even tendency – to remember the relevant past or predict the relevant future. Genes accomplish this because genes functioning in genomes have had a long and consistent history of identical interests, or near-identical interests; the reason for Dobzhansky (1961) to argue that development is unitary (cf. Alexander 1993).

I suggest that: (a) humans learn a very great deal about the adaptive way to behave in virtually every social situation; (b) humans possess great ability to change back and forth quickly between significant within-group competition and extreme patriotism, or within-group cooperation (see also Lahti and Weinstein 2005); and (c) close and constant social interaction and the vigilance of moral systems enforces such quick and decisive changes. Humans are too flexible, and too capable of policing, and of enforcing moral behavior, to be explained solely, or even primarily, in terms of proportions of purely selfish and strongly reciprocating individuals.

Finally, (6), social investment may be part of an individual's effort explicitly (either consciously or unconsciously) to elevate the general level of reciprocity in society. Thus, generous donations to people affected by a disaster, or efforts to enlist in the armed forces at the onset of war, can have snowballing effects on donations or rates of enlistment that raise the level of social investment generally, and may benefit the individual by various indirectly reciprocal returns. Whenever the general level of social investment is raised, all persons had better pay attention and act wisely, or they may lose by being viewed as laggards, or as self-serving and stingy. It is not necessary, however, that the reputation of an individual contributing to the rise in social investment in indirect reciprocity be involved. Such donations can be entirely anonymous and without conscious anticipation of returns, and the donor can still gain, individually, as whenever their interests are sufficiently close to those of the entire group.

General changes in levels of beneficence, or risk-taking with acts of beneficence within a society, if they are adaptive, are adjustments of systems of indirect reciprocity (or nepotism). Anyone who carries out acts that raise the level of beneficence within a society can be investing in indirect reciprocity. There may often be significant risks – and frequent losses – involved in individual attempts to change society toward a greater level of beneficence. But, obviously, there can also be huge benefits, in the form of rewards directly to the social beneficence pioneer, or to the anonymous pioneer in the particular form of a generally more beneficent society which may: (a) increase the likelihood of a healthy persistence of the society harboring the pioneer's circle of kin; and/or (b) yield an outright bias of benefits to the kin of the social pioneer.

It seems to me undeniable that selection has favored flexibilities in individual humans via the patterning of learning skills and biases, flexibilities that have allowed individuals to perform appropriately along all of the axes in the kinds of experiments being described to test for strong reciprocity. Individual humans have been influenced differently by personal social (learning) histories, affecting both whether they return kindnesses in one-shot anonymous encounters and whether they punish violations of cooperativeness and fairness. I regard it as undeniable that individual humans can possess both of these tendencies and capabilities, and can act on them in rapid alternation or virtually simultaneously. I also suggest that most individual humans are capable of changing their behavior between "strong" and "not-so-strong" reciprocity (social beneficence) as they pass through different life situations affecting whether those alternative behaviors are adaptive. Acceptance of this possibility can be inferred from Fehr and Heinrich's (2003) sentence, "This logic applies to genes, cultural traits, or both in an interactive process." At least it does so if the statement includes that individuals can change between the different situations, treat different individuals differently in the same situation, and assume these stances along a more or less continuous axis. I would also argue that the importance of these kinds of skills and flexibility, and their potential for opposite behaviors evolving in the different situations just described, are the most likely explanations for the general nature and extremeness of the human brain and the overall complexity of human sociality. Should these things be true, it seems fairly clear that (risky) investments in ordinary direct and indirect social reciprocity are being described. This conclusion does not preclude using the phrase "strong reciprocity" as the authors have used it, but it does suggest that direct and indirect reciprocity, and nepotism – as originally known to most evolutionary biologists – are all together capable of explaining what is being discussed, so long as we include, when appropriate, that for various reasons in each of the situations just described, individuals showing so-called "strong reciprocity" may simply be behaving maladaptively.

Probably, no one doubts that what appears to be net-cost beneficence can evolve when the beneficence is channeled to entities with interests common to those of the original benefactor, or to entities whose interests incidentally or accidentally cause them to benefit the original benefactor because of the beneficence. The question seems to be whether or not net-cost beneficence can evolve in the absence of returns, or is only an incidental or accidental effect of evolved (hence, in some sense, even if unconscious, calculated) social investment when no return occurs or is likely. If the action is adaptive, then there will be returns to the beneficent individual's genes. Otherwise, we have to be puzzled by use of the word "reciprocity" in the term "strong reciprocity."

In the absence of the extremely careful, meticulous, and time-consuming analyses obviously required to test the experiments said to demonstrate social behaviors regarded as both adaptive and contrary to self-interest, I can only suggest that if so-called strong reciprocity is truly reciprocity, and therefore potentially adaptive, it is almost certainly an aspect of indirect reciprocity, and as such it can be explained using existing social theory (Alexander 1987, 1993, 2005).

USING PROXIMATE MECHANISMS TO INTERPRET RESULTS OF EXPERIMENTS WITH HUMAN SOCIAL BEHAVIOR

> Natural selection cannot produce pleasurable responses to acts that consistently cause net expense to an organism, because pleasure leads to efforts to seek out and repeat acts. Pleasure signifies benefit, therefore attraction and repetition. Displeasure or pain signifies detriment, therefore avoidance. (Alexander 1987: 26ff., 110–114).

Pleasure and displeasure (or pain) are proximate mechanisms affecting, respectively, positive and negative responses to life experiences. Natural selection favors pleasurable responses to acts with positive effects (net-gain social beneficence), causing such acts to be sought out and repeated. Net-cost social beneficence, as with other investment mistakes or deviations from evolutionarily appropriate actions, yields displeasure or pain, including efforts to avoid and escape repetitions. These proximate responses may be useful in facilitating current studies of social beneficence by assessment of expectations of experimental subjects. Their use, however, will require careful analysis that takes into account participants' skill or competence in different circumstances to assess both the risk of no returns and the possibility of unexpected or particularly generous return benefits (that is, those worthy of serious risk-taking), in particular via indirect reciprocity.

If a participant in a social experiment demonstrates a pleasurable response following an act regarded by the investigator as net-cost beneficence, the investigator must somehow reconcile this response with his own interpretation. We should not expect that net-cost beneficence will yield a pleasurable response.

Thorough understanding of social beneficence will likely require the development of a detailed science of indirect reciprocity, because of an evolved inadequacy of conscious acceptance of the rewards of indirect reciprocity, as well as evolved resistance to the suggestion that social beneficence is only accidentally or incidentally expressed (meaning not evolved), except in situations involving reliable returns. This suggestion does not mean that net-cost beneficence (or any other behavior) cannot become prevalent as a deliberate deviation from evolved tendencies. It does mean that, whatever evolved tendencies might enable such deviations, they did not evolve as a favoring of net-cost beneficence, or as a response to evolutionarily novel situations. Such tendencies could have evolved, however, as a willingness to risk almost certain net-cost beneficence in desperate situations.

There is much yet to be worked out in the convolutions of indirect reciprocity and cooperativeness, and how they are reflected in our conscious and non-conscious motivations; perhaps there is no more difficult proposition in understanding ourselves socially. For these reasons it will not always be a simple matter to measure proximate mechanisms and assess their direction of expression as a test of alternative motivations in game theory and other social beneficence experiments. Nevertheless, these are potentially useful methods, and perhaps essential, in efforts to understand the meaning of results in such experiments.

CONCLUDING REFLECTIONS ON GLOBAL COOPERATION

Consider the two above propositions, in relation to combined effects of global problems such as war, environmental pollution, resource depletion, and overpopulation, and how or whether humans will ever be able to cooperate on any universal project, especially if they necessarily yield varyingly uncertain levels of at least temporary net expense to every participant. All humans, whether individuals or groups, are evolved to compete, even as cooperators at multiple sub-global levels. Perhaps this problem cannot be resolved without a sufficient number of the participants recognizing consciously that a special kind of cooperativeness – or at least enormous risk – must be engaged. Some participants must expect to lose permanently, compared to others, in order to produce universal benefits that will prevent catastrophic results to the entire world population of individuals and genes. There may be no precedent for this kind of "global" (in essence, one cooperative group) behavior across the entire history of the human species. The conditions of cooperation, or willing risk-taking or self-destruction that take place in military combat or with so-called suicide bombers, are not precisely parallel. There, decisions often must be made instantly, and there is as well a rich background of both urging and coercion to heroism. Included are potential rewards to family

– or self when death can be avoided – and manipulation to further patriotism. The imposing of authoritarianism in military situations includes the threat of being executed summarily when an order is refused, or of ignominious imprisonment, with potentially disastrous consequences for the offending individual's family or clan. These possibilities are real, because when the chips are down, even in democracies the military deliberately takes a form approaching that of an absolute hierarchy and morality. Moreover, the relevant question is whether it has been adaptive to accept willingly the edicts of authoritarian figures, particularly in times of inter-group conflict. If it has, then we can explain as indirect reciprocity, or coercion to complete cooperation, what Bowles and Gintis (2003) referred to as "common behaviors in warfare as in everyday life [that] are not easily explained by the expectation of future reciprocity." The lure of possible social returns via indirect reciprocity, sometimes involving promised rewards from supernatural forces after death, sometimes involving moral consequences to families (e.g., Alexander 1989: 464), also attests to the potential adaptive value of risky social investment. The "future reciprocity" need not accrue to the beneficent individual to be evolutionarily adaptive. In general, only genes and learning accumulate changes and persist across generations, and the learning only because of the presence and functioning of the genes.

As the quote at the start of this chapter indicates, whatever degrees or kinds of cooperative behavior we are able to accomplish in the future need not accord with every detail of our evolutionary history, even though we are unlikely to be able to change ourselves fully, or well, in directions contrary to our evolutionary backgrounds unless and until we are fully understanding of those evolutionary backgrounds. It is a most important example that we will surely be required, in some sense or to some extent, to view the members of our entire species as we view today's surrogate kin groups, local communities, and nations of patriots. The question is: in the presence of even potential conspecific adversaries, will such a global attitude ever become anything other than too much to ask?

> As long as there are sovereign nations possessing great power, war is inevitable. (Albert Einstein)

> Kindness and generosity arise spontaneously when the otherness of others goes away. (Barry R. McKay, August 3, 2007: Letter to the *Ann Arbor News*, Ann Arbor, Michigan)

If only we could devise an effective way to tackle the question – and generate the solution – of how to make "otherness" go away!

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PART III

The Value of the Future

Editor's introduction to Part III

Frank Whelon Wayman

We now come to Part III of the book on "The Value of the Future." In Chapter 5, Farmer and Geanakoplos discuss this in terms of discounting for the future, offering a critique of, and alternative to, how this is conventionally handled in economics. They see a number of advantages to their method and derivations, and believe also that their method is a representation close to how discounting is actually done in financial markets.

While cast as a general model, the Farmer and Geanakoplos approach has manifest applicability to the debate over what and how much to expend to reduce the degree of global warming. As Sprinz points out in his chapter (Chapter 6, "Long-Term Policy Problems: Definition, Origins, and Responses"), environmental problems such as global warming are among the class of problems, such as old age insurance, infrastructure investment, and so on, in which it is especially important to think about the future. Sprinz looks at the relationship of government to many long-term, intergenerational problems, including social security for the elderly, budget deficits, and especially environmental problems.

In studying our human ecology, Luterbacher, Rohner, and Wiegandt, with di Iorio (Chapter 7) begin with the "tragedy of the commons." The phrase refers to a particular sort of analysis of the reasons for damage to the environment. Diagnosis of the tragedy then may suggest a course of remedial action, from which would come potential solutions to environmental problems. In their chapter, Luterbacher et al. present a theoretical argument about collective goods and the impediments to solving environmental problems. With that basis, they then are in a position to consider the potential linkages between resource scarcity and armed conflict. Luterbacher et al. summarize their discoveries with the catchphrase, "the triple tragedy of the commons."

Since an important application of these chapters is to environmental protection, how do we as editors characterize the nature of these environmental challenges before us, and, based on that, how do these chapters fit in to what is needed in this area? Summary points would seem to be:

1. The environmental calamity is not a short-term crisis, but a long-term problem (some exceptions are mentioned in Chapter 6 by Sprinz).
2. The gravest environmental threats – global warming, loss of species diversity, and ozone layer depletion – are global and regional problems. These rarely correspond to the spatial and temporal domains of political systems.
3. Within existing political systems, environmental issues are usually fought over in bureaucratic or pressure group arenas in which the most powerful actors are the organizations – private or public – which have modernized the economy and built the capabilities of the state's military apparatus; these organizations fight for their own goals and define the national goals as identical to their own (Enloe 1975; Denzau and Munger 1986; Hall and Wayman 1990; Bueno de Mesquita et al. 2003).
4. The environmental and energy crises are occurring in a context of political and economic inequality, in which it is difficult to separate arguments over justice from arguments over efficiency. Consequently, potential remedies are often denounced as unfair, and debate over this has the effect of complicating or delaying action. Meanwhile, activities harmful to the environment are often shifted to poor, enabling jurisdictions (sometimes termed "pollution havens"). Yet the effects (as in global warming) can remain worldwide.
5. Environmental problems are a particular class of long-term problems with public goods aspects: namely, they are problems that cannot be adequately addressed without scientific models that necessarily are based on debatable assumptions and imperfect information, and that baffle the median voter, leading at times to denial, apathy, or uncertainty (a problem discussed by Alexander in Chapter 4).
6. A further impediment to using government to protect the environment is that much pollution is caused by government and quasi-governmental agencies. The Platonic question arises: "Who will guard the guardians?"

These six problems make it difficult to protect our home – our "pale blue dot" – in the otherwise uninhabitable and barren expanses of neighboring space.

POSSIBLE REMEDIES

Many solutions to environmental problems have been proposed and some have been implemented. Farmer and Geanakoplos provide a fresh way of thinking about the merits of these solutions. Then, Sprinz points to pros and cons of "sugar daddy" and other possible remedies to intergenerational problems such as global warming. Luterbacher et al. call attention to a Swiss mountain version of sustainable development, and draw specifically on the work of Partha Dasgupta and also of A.C. Pigou, an economist perhaps not as well known to our readers as his work merits.

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5. Properly discounting the future: using predictions in an uncertain world

J. Doyne Farmer and John Geanakoplos[1]

In this chapter, we have chosen to address a broad issue concerning social prediction, namely concerning the role of utility. First, we present some new work concerning the temporal discounting of utility. This work then provides one piece in a more general context of additional comments regarding the limitations and proper use of the utility concept.

UTILITY – FUTURE DISCOUNTING

Turning, first, to the issue of temporal discounting, as the reader may know, the normal way of addressing the present value of the future is through a discounting function (see Box 5.1).

BOX 5.1 DISCOUNTING THE FUTURE

- How does one compare having something today with having it tomorrow?
- Standard approach is to use exponential discounting:

$$U(t + \tau) = e^{-r\tau} U(t).$$

- Natural because it is time-invariant.
- No arbitrage.

Let us suppose you have some notion of utility and you have some money you can spend now; for which you get a certain utility if you do. Now suppose somebody offers to take your money and give you, instead, some (greater) amount of money five years in the future. How do you trade those things (keeping your money or giving it to the other person) off against each other, so as to choose between them? The conventional answer is, there is some discount function you apply, which typically is an exponential function, that tells you what the trade-off should be, thus allows you to compute the present value of that five year future alternative so it can be directly compared with the value of money, now. This function is given by:

$$U(\tau) = e^{\Theta(t-\tau)}\, U_0(t),\ \tau \geq t,\ \Theta > 0 \tag{5.1}$$

where $U(\tau)$ is the value at the present moment t of the money (or whatever good is at issue) that will be available at some future moment τ, $U_0(t)$ is the value if the item were available immediately at the present moment t, and Θ is the discount rate.

This exponential utility is hard to argue with for a couple of reasons. One is, you just test it. You put your money in the bank; they will give you an interest rate; you get more money later on. And so, obviously, there is that trade-off there.

Secondly, this utility function (5.1) is time-invariant. This means the following: suppose we shift from the present time t to a different present time $t + \Delta t$, with a corresponding shift from τ to $\tau + \Delta t$ in the future time from which the utility is to be discounted. If no material change in the situation has occurred, this means the utility of the good if immediately available is unchanged:

$$U_0(t + \Delta t) = U_0(t). \tag{5.2}$$

Then we should find that the discounted utility, evaluated over the correspondingly shifted future time $\tau + \Delta t$, should be unchanged also. From equation (5.1) we find:

$$\begin{aligned} U(\tau + \Delta t) &= \{\exp \Theta[(t + \Delta t) - (\tau + \Delta t)]\}\cdot U_0(t + \Delta t) \\ &= \{\exp \Theta[t - \tau]\} \cdot U_0(t + \Delta t) \\ &= \{\exp \Theta[t - \tau]\}\cdot U_0(t), \end{aligned} \tag{5.3}$$

as desired, the final step from equation (5.2).

However, if one replaces the exponential form on the right with some other discounting form then, in general, one is going to have the property that the utility being computed, going forward, is changing all the time even when there is nothing else happening that ought to lead to a change.[2] So exponential utility, on the other hand, is at least consistent; we will compute the same utility to every step. Say one replaces that with a power law, it will not do that.

Now the other thing that is very natural about this utility function is that it is arbitrage-free. That is, if we specify not a utility discount function but some other discount function, like say a power law, and we gave you, and anyone else who wants it, a loan with that power law, then you could buy the loans, hold them, and sell them during the period when their equivalent exponential interest rate is at a maximum, to other people who did not realize that. And the market will adjust the prices of all those loans in such a way that you will actually get back to an exponential utility function.

Concerning the issue of discounting utility, we may say accurately that the above is standard. And it has been used quite forcefully (we would say) by many economists to argue that, for instance, we should not worry too much about global warming because it takes 100 years to hit us. That is not very soon; so let us concentrate on something else like boosting the economy, because we will make more money which we can put in the bank; then we will have all that money to deal with global warming later. (Okay, we are stylizing the argument a little bit; see Box 5.2.) The other argument is, you know, that technology grows so fast, the gross domestic product (GDP) is growing so fast, we will have the power to take care of that stuff in the future because technology always takes care of stuff. (Just look at those stupid guys who wrote *Limits to Growth*; Meadows et al. 1972. They predicted all this gloom and doom stuff and technology is still winning. So, you know, it's the old elevator going down: the cord breaks, but so far so good at every floor.)

Okay, so what is wrong with that? Well, several things. One, there is a clue, which is that normal people do not actually use this discounting function. Maybe normal people actually know something that economists do not know. (It would not be the first time.) Closely related, another indication of something screwy going on is that those who do use it, truncate

BOX 5.2 RESULT OF EXPONENTIAL DISCOUNTING

Under exponential discounting with realistic interest rates, the far future is not worth much: for example, with an interest rate of 6 percent, 100 years out discount factor is 0.0025. This is widely used by economists to argue that we should put very little energy into worrying about phenomena such as global warming that create problems in the far future.

Table 5.1 Sensitivity of discount factor to interest rate

	Discount (present value of 1), from 100 years in the future		
% interest rate	10	5	1
discount factor	5×10^{-5}	7×10^{-3}	0.37

it. They typically say, well, we use exponential discounting out to say ten years, then we assume no value after that. Maybe (in addition to increasing the price to earnings ratio) that is justifiable: discounting is not like an invariant thing; the manager could die; the infrastructure of the company could go away, and so on.

Another thing wrong is that exponential discounting is nasty, if one cares about something like the environment. If we take a typical interest rate, even say 6 percent, 100 years out the discounting factor is 0.25 percent. So, if global warming costs $1 trillion then, maybe it only costs us $2.5 billion now; the discounting factor is huge. Thus, if you believe exponential discounting, to argue that we really ought to pay attention to global warming, you need to believe that global warming is getting exponentially worse at more than 6 percent, that it is actually beating this rate.

The third thing wrong with exponential discounting is that it is extremely sensitive to the rate that you pick. Looking at Table 5.1, one sees that the discount factor, 100 years out, is hugely variable depending on what rate one picks, ranging from 1 percent, where we are talking about a 40 percent discount, to 10 percent, where we are talking about a discount that is a tiny fraction of a hundredth of a percent.

A fourth thing, a key consideration that none of the above takes into account, is that interest rates are not constant, they actually vary. If you look out in the world, interest rates are a financial instrument, changing all the time, just like all the others. In fact, if you take the data and apply a unit root test to ask whether this is a random walk, it is very hard to show that interest rates are not following a random walk. People on Wall Street who price mortgage bank securities have to hedge them so that they are immune to changes in interest rates; so they have to have a model for pricing interest rates, for which they must take into account the fact that interest rates change all the time. At the conference from which this chapter is derived (Farmer and Geanakoplos 2005), the discussant Solomon Polachek brought up the issue of risk, meaning uncertainty in forecasting (see also Chapter 17 by Polachek in this book). Where interest rates are concerned, you have to actually forecast uncertainty or your forecast will be very poor.

And so, what we now will do is examine what is known as the binomial random walk interest rate model, which is just a standard model that is used all over the place on Wall Street (by firms such as Ellington Capital Management). We will show that if you take that model seriously it actually gives a very non-exponential interest rate (so that, again, maybe we who intuitively use a much more long-lived discounting function actually know something that the environmental economists who use constant interest rate, exponential discounting, do not).

How does this model work? We define it recursively, as follows. Let $\mathrm{x}(t)$ be the evaluation of an asset and $r(t)$ the interest rate, both functions defined at time t from the present moment (so that $r(t - 1)$ is the interest rate in the previous period). (Note the shift in notation from before, with $t \geq 0$ now denoting the same thing as $\tau - t$ in equations (5.1) through (5.3), above; namely the elapsed time counting the present moment as 0; and $\mathrm{x}(t)$ takes the place of U, in denoting value.) Now the model assumes that, in each period, the interest rate r changes multiplicatively. You take the interest rate in one period and multiply it either by a factor one plus the parameter $\varepsilon > 0$ or multiply it by a factor of one over the quantity one plus epsilon:

$$r(t) = \{1 + \varepsilon, 1/(1 + \varepsilon)\} \cdot r(t - 1), \tag{5.4}$$

where either the first or the second of the two quantities within braces is chosen with equal probability.[3] Thus the interest rate can either fluctuate up or down. So if you want to get from the valuation in one period to the evaluation in the next period, under some interest rate $r(t)$, you simply multiply something like this:

$$\mathrm{x}(t) = [1 + r(t)] \cdot \mathrm{x}(t - 1). \tag{5.5}$$

Now imagine we have an asset and we assign a value $\mathrm{x}(t)$ to it at some point t in the future. (In the present context, assigning future value raises another issue, which we do not attempt to resolve here. Suppose, relative to, say, climate change, we did this for the Earth. What is the Earth worth in the future? $30 trillion? $100 trillion? We do not know.) What we want to know is the expectation $\mathrm{E}[\mathrm{x}(0)]$ of the discounted value at the present moment, taking account of the fact of variable interest rates. Therefore, using the (now variable) discount rates in our utility function, we start with $\mathrm{x}(t)$, the value of which, at time t, we assume to be known, and go backwards in time in a binary tree (each branch representing one of the equally probable sequences of interest rates, each step in each such sequence given by one of the two alternatives of equation (5.4), above). So we have to average over the outcomes at the bottom of that binary tree to understand how to properly discount this asset that we have in the future at time t.

So that you can see how the model works, we apply it below to two cases, $\mathrm{N} = 1$ (where we work backwards one step from $t = 1$) and $\mathrm{N} = 2$ (where we work backward two steps from $t = 2$). Turning to the first of these, $\mathrm{N} = 1$, from equation (5.5), we have $\mathrm{x}(1) = [1 + r(1)]\cdot\mathrm{x}(0)$, from which:

$$\mathrm{x}(0) = \mathrm{x}(1)/[1 + r(1)], \tag{5.6}$$

where we have taken the $1 + r(1)$ term on the right-hand side of (5.5) and put it underneath the $\mathrm{x}(1)$ term in (5.6). In accordance with the above, the expectation $\mathrm{E}[\mathrm{x}(0)]$, is found by assigning a probability of 1/2 to each of the two possible values of $r(1)$, as given by equation (5.4), corresponding to the two possible alternate routes by which $\mathrm{x}(1)$ was reached from $\mathrm{x}(0)$:

$$\mathrm{E}[\mathrm{x}(0)] = \mathrm{x}(1)\cdot(1/2)\{1/[1 + r(0)\cdot(1 + \varepsilon)] + 1/[1 + r(0)/(1 + \varepsilon)]\}. \tag{5.7}$$

Note, within the braces, {. . .}, on the right there is one term corresponding to one outcome, the path where interest rates go up (where we multiply by $1 + \varepsilon$), and another term corresponding to the other outcome, the path where interest rates go down (where we divide by $1 + \varepsilon$). The coefficient 1/2 assigns the (equal) probability of 1/2 to each of the two branches. So we now have the expected discounted present value in terms of the known (or presumed) future value $\mathrm{x}(1)$, in the case where there is just the one step to $t = 1$.

Turning to the second case, $\mathrm{N} = 2$, we have the more complicated situation corresponding to the four possible, equally probable alternative routes. In two steps, first from $t = 0$ to $t = 1$, then from $t = 1$ to $t = 2$, the alternatives are: (1) both steps take the multiplication branch $(1 + \varepsilon)$; (2) first step takes multiplication, second step takes the division branch $1/(1 + \varepsilon)$; (3) first step takes division, second step multiplication; (4) both steps take the division branch. When these four alternatives are taken into account and assuming, again, the value of the final step, $\mathrm{x}(2)$ in this case, is known, the present expectation is given by:

$$\begin{aligned}\mathrm{E}[\mathrm{x}(0)] = \mathrm{x}(2)\cdot(1/4)\{&1/[1 + \mathrm{r}(0)\cdot(1 + \varepsilon) + \mathrm{r}(0)\cdot(1 + \varepsilon)^2 + \mathrm{r}(0)^2\cdot(1 + \varepsilon)^3]\\ &+ [1/[1 + \mathrm{r}(0)]\cdot[[1/[1 + \mathrm{r}(0)/(1 + \varepsilon)] + [1/[1 + \mathrm{r}(0)\cdot(1 + \varepsilon)]]\\ &+ [1/[1 + \mathrm{r}(0)/(1 + \varepsilon)]]\cdot[1/[1 + \mathrm{r}(0)/(1 + \varepsilon)^2]]\}.\end{aligned} \tag{5.8}$$

In the above, within the braces on the right, the first line corresponds to alternative (1), above; upon expansion the second line corresponds to alternatives (2) and (3); the third line corresponds to alternative (4). The details of this result are shown in the Appendix to this chapter.

In general, for case N there are 2^N alternative branches, so that expressions corresponding to equations (5.7) and (5.8) for $N > 2$ become rapidly more complex; so it is complicated. All we want to do here is to show the function of effective interest rate versus time that we get from using an annual volatility of 15 percent, that is, $\varepsilon = 0.15$, and doing discount calculations E[x(0)], corresponding to the above examples, for values up to N – many steps, $N = 1200$. By "effective interest rate," we mean the rate obtained by inserting E[x(0)], x(t), and $t = N$ in the standard discounting model, equation (5.1) above, and solving for the corresponding interest rate (which then is given by $r = -(1/t) \cdot \log\{E[x(0)]/x(t)\}$, "log" denoting the natural logarithm).

The resulting function empirically fits the form shown in Figure 5.1 as a power law with an exponent that is very close to one:

$$r(t) = A \cdot (t - t_0)^{-q},\ q = 0.95,\ \varepsilon = 0.15, \tag{5.9}$$

where t_0 is a reference time corresponding to "now" and A is a scaling constant.

Evidently the effective rate drops in the future, which corresponds to a

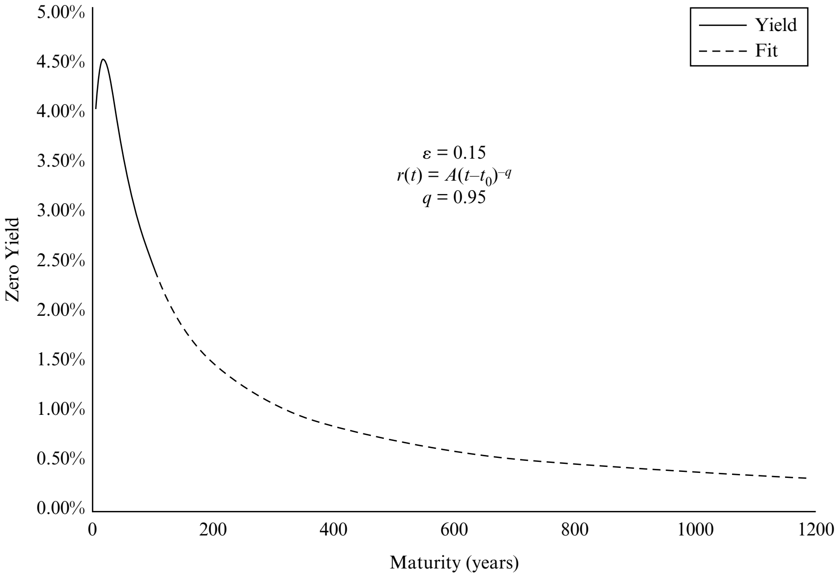

Figure 5.1 Yield as a function of maturity

larger discount fraction; that is, greater value is placed on the future than the value computed in the standard discounting model of equation (5.1). This is shown, in Table 5.2, in terms of the relative drop in utility (the ratios E[x(0)]/x(N) in second and third columns; N in the first column) for the two models.

Table 5.2 Comparison of discount functions, 15 percent annual volatility

Year	Binomial rate model	Constant rate model
10	0.66	0.67
50	0.15	0.13
100	0.05	0.02
500	0.008	2×10^{-9}
1000	0.005	4×10^{-18}

You can compare utilities going out from the binomial model, where you are averaging over these interest rates, to those under the constant model; and you see where it starts to make a big difference: it really makes a difference at, say, 1000 years out, where you get somewhat reasonable utilities still left whereas the world is worth literally nothing after 1000 years, if you believe in exponential discounting. The result is roughly consistent with the kind of thing that, it has been observed, people appear actually to do.

Interestingly, if you crank the volatility up to 30 percent you see something that gets pretty wild. You start to see these differences quite manifestly at 100 years, and the utility function actually reaches a minimum and goes up again, as shown in Table 5.3.

Table 5.3 Comparison of discount functions, 30 percent annual volatility

year	Binomial rate model	Constant rate model
10	0.62	0.67
50	0.38	0.13
100	0.41	0.02
500	0.54	2×10^{-9}
1000	0.54	4×10^{-18}

Now, you say, wait, that's got to be crazy. It probably is. We are not trying to argue that the binomial model – though it is the standard on Wall Street – is the best way to do this. What we are trying to argue is that exponential discounting is clearly wrong: it is not even rational on the terms that it is proposed to be rational and it is actually a hard problem. (Probably the anomaly here is due to the fact that the lower interest rates, when you make this kind of averaging, end up getting a big weight because in the sum, as you go out, the scenarios where interest rates get quite low dominate the valuation. In reality there is probably some kind of barrier that prevents them from ever getting that small.) We merely want to point out that it is a state-of-the-art problem to model what the discounting function ought to be, and to deal with uncertainty.

UTILITY: LIMITATIONS AND PROPER USE

Now we want to talk about some problems that we see with the concept, itself, of utility (see Box 5.3). We do not think this, in its present use, is a good concept for scientific inquiry.

BOX 5.3 OTHER PROBLEMS

- Does not take factors that determine real utility into account.
- Only utility of living individuals:
  - no direct utility for future living people;
  - no direct utility for plants and animals.
- Utility analysis as presently practiced should only be used as an upper bound.

First, in a proper theory, one ought to have experimentally verifiable things that remain so, in another context, without one having to remeasure all the parameters on the new set of things. Typically, however – the way utility is used – it has got free parameters in it. Then you go take your target data and you fit those free parameters on the target data; and when you come to a new set of target data, you fit the parameters all over again. It is symptomatic – that the parameters are that much up in the air that they cannot be measured a priori – that there is something wrong with the basic concept. If utility were really valid, we ought to be able to measure it. We ought to know those parameters before we ever go test our expectations from psychological experiments.

Apropos, and just to make a pitch for something that we think is really interesting and unexploited, there is the theory of happiness and economic happiness. There are some economists who are actually taking psychologists seriously, looking at what utility really seems to depend on. Granted, they have to do things like use questionnaires, and so on; but what they see is quite a different picture than just money. People are not very good at understanding what is really giving them utility. Actually we see a hint of that in Luterbacher et al.'s Chapter 7 in this volume: people care very much about what their peer group does and where they are relative to the peer group; they care very much about where they are in relation to where they were over some sliding window in the past; and they care very much about social relationships and their environment. Where wealth comes in is about fifth, in terms of imparting utility.

There is another, very disturbing, thing about utility as currently it is used. One of us (Farmer) was in an environmental economist conference (as a fly on the wall) a while back. He was just appalled. The participants gave no direct utility for future living people; they were only allowed utility based on how much pleasure they give us. (It is true, for those of us who have kids, that our future living people give a lot of positive utility; but we think it should be more than that.) Nor was any direct utility given for plants, animals – none of that. The point is, utility should only be used as an upper bound of the appropriate discount rate and it should always be stated that way because the standard suite of assumptions are not scientific assumptions. They are religious assumptions.

NOTES

1. What we are going to talk about is the outcome of an extended dialog between the two of us, over the last ten years, concerning hedge funds, which both of us have had experience in creating; however, we did it in completely different ways. One of us did it by flying exactly in the face of what one is not supposed to be able to do, from the point of view of economic theory, and finding patterns where they are not supposed to exist. The other did it by doing economic theory differently (and better, we think) than the other economists were doing it, and making predictions that way. So we had a very constructive long-term dialog. The novel result we also present here, concerning models for discounting future utility in an uncertain world, is an outcome of that dialog.
2. Editors' note: this is because, for "nothing happening" to lead to no change, the chosen function must at all times give the same fractional discount for a fixed time – say, for one year – into the future. That latter property implies a negative-exponential function.
3. This, by the way, preserves the expected geometric mean of the interest rate, given by:

   $E[(\Pi_{i=1}^{n} r_i)^{1/n}] = \{\{(1+\varepsilon)\cdot r(0)\}^{n/2} \cdot \{[1/(1+\varepsilon)]\cdot r(0)\}^{n/2}\}^{1/n} = \{(1+\varepsilon)\cdot[1/(1+\varepsilon)]\}^{1/2} \cdot [r(0)^{1/2}]^2 = r(0)$,

   where $i = 1 \ldots n$ denotes the sequence of n – many successive interest rates, thus showing the expected mean always to equal the value r(0) on the right, for arbitrary n.

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APPENDIX: DERIVATION OF EQUATION (5.8)

(Note: this appendix was provided by one of the editors.)

From equation (5.5) we have $x(1) = [1 + r(1)]\cdot x(0)$ (as before) and $x(2) = [1 + r(2)]\cdot x(1)$. Combining these two shows $x(2) = [1 + r(2)]\cdot[1 + r(1)]\cdot x(0)$ which, upon solving for $x(0)$ gives:

$$\text{(A1)}\ x(0) = x(2)/[1 + r(2)]\cdot[1 + r(1)] = x(2)/[1 + r(1) + r(2) + r(1)\cdot r(2)].$$

From this, using equation (5.4), above, and assigning equal probabilities to the branches, we conclude:

$$\begin{aligned}
&\text{(A2)}\ E[x(0)] = x(2)\cdot E\{1/[1 + r(1) + r(2) + r(1)\cdot r(2)]\}\\
&= x(2)\cdot(1/4)\cdot\{1/[1 + r(0)\cdot(1 + \varepsilon) + r(1)\cdot(1 + \varepsilon) + r(0)\cdot r(1)\cdot(1 + \varepsilon)^2]\\
&+ 1/[1 + r(0)\cdot(1 + \varepsilon) + r(1)/(1 + \varepsilon) + r(0)\cdot r(1)]\\
&+ 1/[1 + r(0)/(1 + \varepsilon) + r(1)\cdot(1 + \varepsilon) + r(0)\cdot r(1)]\\
&+ 1/[1 + r(0)/(1 + \varepsilon) + r(1)/(1 + \varepsilon) + r(0)\cdot r(1)/(1 + \varepsilon)^2]\}\\
&= x(2)\cdot(1/4)\cdot\{1/[1 + r(0)\cdot(1 + \varepsilon) + r(0)\cdot(1 + \varepsilon)^2 + r(0)^2\cdot(1 + \varepsilon)^3]\\
&+ 1/[1 + r(0)\cdot(1 + \varepsilon) + r(0) + r(0)^2\cdot(1 + \varepsilon)]\\
&+ 1/[1 + r(0)/(1 + \varepsilon) + r(0) + r(0)^2/(1 + \varepsilon)]\\
&+ 1/[1 + r(0)/(1 + \varepsilon) + r(0)/(1 + \varepsilon)^2 + r(0)^2/(1 + \varepsilon)^3]\}.
\end{aligned}$$

In the above, the four lines within braces, $\{-\}$, on the right correspond, in same order, to the four numbered alternative routes enumerated in the paragraph preceding equation (5.8), above.

6. Long-term policy problems: definition, origins, and responses

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Long-term policy issues are becoming a challenge for many industrialized and industrializing countries alike. This applies to environmental problems (such as global climate change), financial issues (such as public debt or public pension plans), or public health (long-term care for the elderly). In the following, I will define the population of long-term policy issues, discuss which policy problems may qualify, explore the reasons why they exist, and summarize policy designs to cope with them. Long-term environmental problems will serve as the main focal point of the discussion. These include global climate change, where the stakes are anticipated to be very large. Another issue is the construction, now, of homes and businesses on vulnerable shorelines, where rising sea levels and increasingly severe storms might make it virtually certain that in a generation or two, a catastrophe will occur. I begin the discussion with this example as presented in *The Economist*:

> A government might, for instance, want to discourage building in areas prone to hurricanes. So it warns citizens that no compensation will be given for houses in such areas should disaster strike. If people believe the warning, they will not build. But if they expect (as history suggests they should) that the government is likely to soften its stance and pay for hurricane damage after all, they will ignore the warning. Before the fact, the government wants to stop building; afterwards, it wants to compensate those who have suffered. Mr Kydland and Mr Prescott refer to such conundrums as "time consistency problems." (*The Economist* 2004)

It appears that we are surrounded by long-term policy problems. Public and private pension plans for the elderly are currently redesigned so as to close the gap between implicit and explicit entitlements given out in the past and the ability to actually honor those financial obligations; public debt sharply restricts the opportunities for politicians to enjoy the fruits of the pork barrel in countries such as Germany, Japan, France, or Italy even before the onset of the financial crisis in the early years of the twenty-first century. Public healthcare systems seem to be stretched in many industrialized countries; global climate change, if unabated, may lead to severe sea-level rise and subsequently dislocate substantial parts of the earth's population that lives in proximity of the coastal areas. Could even the 2005 Hurricane Katrina point to the emergence of a long-term policy problem?

Sustainability, interdependence, globalization, and other terms have made a career by being imprecisely used. In the following sections, I first define long-term policy problems in general. Subsequently, I outline three explanations that shed more light on potential sources of long-term policy issues, followed by a discussion of policy options to cope with long-term environmental problems. Throughout this chapter, I shall draw on examples from the field of global environmental politics. I close with an agenda for future research on long-term environmental policy challenges.

DEFINING LONG-TERM POLICY ISSUES

Before elaborating the mechanisms that generate long-term public policy challenges, it is useful to define core terminology. Long-term policy challenges will be defined as public policy issues that last at least one human generation, exhibit deep uncertainty exacerbated by the depth of time, and engender public goods aspects both at the stage of problem generation as well as at the response stage.

First, a long-term problem exists only if the mechanism creating it leads to substantial adverse effects for at least a human generation of 25 years or if the remedy would take an equally substantial amount of time. Global biodiversity may offer us a potent example: if species of flora or fauna become extinct and have no functional proxies, both the species and the functions they fulfill for ecosystems could be lost forever. Even ambitious research and development efforts may find it difficult to create functional proxies, for instance by genetically modifying still existent organisms.

Second, deep uncertainty, "a situation where the system model and the input parameters to the system model are not known or widely agreed on by the stakeholders to the decision" (Lempert 2002: 7309), refers to the breadth of parameter values that we may contemplate. For example, there is considerable uncertainty regarding the price of carbon offsets under various choices of policy instruments, and we have no experience with accurately predicting the price of carbon offsets for a 50 percent emission reduction over the next half-century or the value of any natural resource or ecosystem.

Third, public goods aspects of long-term policy problems relate both to the generation of long-term policy challenges as well as ways to respond to them. Quite often, long-term policy challenges are generated by externalizing some cost to the public, both contemporaneously as well as inter-temporally. For example, if historical carbon emissions already lead to uncompensated climate-related impacts today, then some past decision-makers will have benefited, knowingly or unknowingly, from carbon releases at the expense of present generations. In addition, curbing future emissions is a public goods problem by itself in a mostly decentralized world. Those countries serving as leaders in international climate policy may not witness immediate benefits for themselves, and future benefits may be quite uncertain, thereby tempting only a small range of countries to venture into global public goods production – and others to free ride.

Overall, long-term policy problems pose a rather difficult class of challenges that are beyond the scope of single parliaments and political as well as bureaucratic tenures in office, and yet many have escaped comparative research so far.

Some environmental issues can be easily solved: water can be purified with considerable ease and often at affordable cost; species can be reintroduced if they are still existent somewhere (for example, seed banks or zoos); classical air pollutants can be filtered, severely polluting chemicals replaced by less toxic ones, and so on. Climate change, loss of biodiversity, depletion of the stratospheric ozone layer, and desertification are perhaps the most prominent examples of global environmental challenges. In the case of climate change, the multi-decadal release of emissions of greenhouse gases (principally carbon dioxide, methane, and nitrous oxides) are still effective long thereafter and alter the state of the atmosphere. A shift of most energy systems from substantial reliance on fossil fuels to renewable energies will easily take a human generation or longer. Various aspects of biodiversity are of an equal long-term nature, with species extinction representing the ultimate irreversibility.

Overall, long-term policy challenges are not unique to the environmental field, yet long-term environmental policy challenges are likely to stay with us for decades to come. As a consequence, they are likely to influence the long-term policy agenda, especially if voters become more aware of how central they are to their quality of life.

THE POPULATION OF CASES

There is a range of policy areas where first suspicion points to classification as a long-term policy issue. I have elaborated three criteria above. Some countries or geographic or political entities are able to cope sufficiently well with specific long-term challenges, while others are not.

In order to topically qualify as a long-term policy problem, we should therefore focus on the modal or median situation across countries or the world at large. In the following, I will discuss a few prominent policy areas and provide a first approximation on whether they fall under the rubric of long-term policy challenges or not. This topical overview will include comparative and international political economy, energy and environmental issues, violent conflict, major societal changes, demography and public health, as well as a residual category.

First, within the fields of comparative and international comparative political economy, monetary institutions are often mandated to control inflation, in the field of fiscal policy large-scale subsidy programs (for example agriculture and rust belt industry adjustment programs) qualify, structural unemployment exists in many industrialized countries, and mandatory public pensions systems are in actual trouble or projected to become so in honoring previously granted explicit or implicit entitlements.

Not all of these problems qualify as long-term policy issues. Within a human generation, monetary institutions have managed to cure hyperinflation, although this may lead to severe industrial restructuring and substantial transfers of wealth within (and sometimes between) economies. Within the fiscal policy stream, providing breathing space for former leading sectors (coal, steel, agriculture) by way of large-scale and enduring subsidies often qualifies as a long-term policy issue. And even market transformation: the creation and nurturing of Airbus by European governments over 30 years to change the airline industry for aircraft carrying more than 100 passengers is a good example; it also appears to have some common good characteristics as it liberated a monopolistic market dominated by Boeing from lack of technological progress. Creating and maintaining public infrastructures is certainly a long-term policy challenge as many public sector budgets are unable to keep infrastructures in good shape. Structural unemployment is the likely result of both regional policies to shield electorally important industries from further decline as well as the rigidities of collective bargaining arrangements which often do not readily respond to the business cycle and changes in the industry structure. Structural unemployment is certainly a long-term policy problem in much of Europe. Finally, the level of real public debt and the servicing of interest payment as well as repayment of the principal prove to be a problem for some countries even before the financial crisis in the early twenty-first century. At the very least, highly indebted countries that honor their obligations lose considerable freedom to embark on new costly public policy programs. For example, the second-largest item of the German federal budget is servicing the federal debt. Such countries are forced to downscale other expenditure programs or increase revenue by taxes to embark on new policies; otherwise, they run the risk of sovereign default. Russia and Argentina have come close to this over the past decade. Public debt may be a borderline long-term policy issue as fiscal discipline (that is, no new public net debt) combined with moderate economic growth could limit the problem considerably.

Second, environmental, energy, and natural resource issues as well as access to raw materials could be considered long-term policy challenges. Perhaps climate change serves as the most enduring environmental problem, but biodiversity and desertification are likely to follow suit. In the case of climate change, the multi-decadal release of emissions of greenhouse gases (principally carbon dioxide, methane, and nitrous oxides) are still effective over half a century later and alter the state of the atmosphere; a shift of the energy sector from substantial reliance on fossil fuels to renewable energies would easily take a generation or longer. Availability of and access to natural resources, as far as they are slowly depleting (such as oil, gas, or coal), are not long-term problems from an energy standpoint. All of these could be replaced by a low-carbon energy system built on renewables (wind, solar, biomass) and some studies suggest this could be achieved even at negative economic cost. Raw materials (excluding energy resources) are largely not long-term policy problems insofar as international markets work with reasonable efficiency and substitutes are often available – at a cost. The preservation of large-scale commons, such as Antarctica, pollution of outer space and cultural landscapes, qualify as long-term policy challenges.

Third, demographic and public health issues qualify as long-term public policy problems. Demographic changes, both the first demographic transition (to larger surviving families) and the second demographic transition (to smaller surviving families) represent long-term policy challenges. The first transition essentially led to a substantial increase in demand for natural and human-made resources which some advocates responded to by advocating zero population growth; and the second transition mostly poses a problem by way of the strain it may put on pay-as-you-go systems created in some "modern" welfare states over the past century. Long-term public health challenges become perhaps the most visible as modal parts of whole generations are becoming overweight and subsequently prone to a range of costly diseases. Preventions to be taken against virulent viruses (such as SARS and avian flu) require essentially the maintenance of a public health care system as well as more specific treatments even if there are no pandemics occurring in a specific time interval. The recent emergence of resistance against standard medical treatments (for example, in cases of malaria and some strains of flu) poses a challenge where our hope must be placed on medical innovation and smarter prescription policies.

Fourth, violent conflict between and within societies has plagued humankind for millennia. To the degree that violent conflict has long-term origins and/or long-term effects, it falls under the rubric of long-term policy issues. Cycles of war associated with international power transitions serve as the most prominent cases. The spread of terrorism as well as the enduring incentives for some countries to develop weapons of mass destruction as well as nuclear deterrence – which have enduring consequences for interstate relations – add to the proliferation of long-term policy issues.

Fifth, societies undergo a range of internal transitions or transitions involving close neighbors. Religious transitions, such as the Reformation in Europe about four centuries ago, still had a discernible impact on the European party system in the twentieth century. Migration and societal integration issues qualify more easily, as value and behavioral patterns of migrants and ethnically cohesive groups may well be enduring beyond a generation, but it substantively depends on the political and cultural context as to whether this is a more continuous process (such as in the USA) or a more discrete challenge (such as immigration into Western Europe over the past three decades).

Finally, a sixth group of issues is rather heterogeneous, but may also qualify as long-term policy challenges. Among these, corruption and organized crime across substantial segments of society in developed and developing countries alike pose a sincere risk to the sustainability of democracies.

In conclusion, not all problems that we initially considered are indeed long-term policy problems, but there is no paucity of those likely to honor the three definitional dimensions outlined further above. In the remainder of the chapter, I will focus on long-term environmental problems, to illustrate how we might think about these intergenerational problems in general. Not all environmental problems are long-term problems. An oil spill that is promptly and completely cleaned up, for instance, would be an environmental problem, but not an intergenerational one. Nonetheless, a number of the environmental problems deemed most important by scientists (for example, global warming and loss of species diversity) are long-term problems, so the environmental area is a significant one to consider.

WHY LONG-TERM POLICY ISSUES ARISE

Why do long-term problems arise? In essence, there are three major explanatory routes. First, the time inconsistency problem may loom and not allow for consistent policy-making over time; second, even if multiple generations are included in decision-making, a coalition of older generations and segments of younger generations may support intergenerational redistribution; and third, the distribution of risk and votes may be conducive to the rise of long-term policy issues. In the following, I shall briefly sketch these three perspectives and offer response options in the context of global environmental politics in the subsequent section.

In their seminal work on time inconsistency, Kydland and Prescott (1977) demonstrate that optimal choices at one point in time may be at odds with optimal choices taken at future points in time. Policies may be designed such that one policy rule is administered in the first period; for example, encouraging low inflation by way of wage restraint. However, at a later point in time, it may be the best policy to actually permit some degree of inflation so as to reduce short-term unemployment. More generally, governments are tempted to renege on earlier promises. "The suboptimality arises because there is no mechanism to induce future policymakers to take into consideration the effect of their policy, via the expectations mechanisms, upon current decisions of agents" (Kydland and Prescott 1977: 481).

For example, if it is not forbidden to build houses on flood plains, people will build houses in such locations while anticipating that the government will ultimately build dams so as to protect them or compensate them for flood damages incurred. This example was actually mentioned by Kydland and Prescott in 1977 (Kydland and Prescott 1977: 477), well before Hurricane Katrina damaged New Orleans and surrounding areas. Expectations about future policies impact on current behavior. Thus, these problems resemble moral hazard problems with a long-term time dimension. It would have been preferable to forbid erecting housing in such areas and stick to the announced rule of no dams and no compensation. Had such an announcement been perceived as credible, no houses would have been built in risk-prone areas, or only been built by risk-taking investors, and governments would have been saved from paying compensation.

A second perspective on why long-term policy challenges may arise originates from models of intergenerational redistribution. For example, Tabellini (1991) builds a simple two-generation model where the parental generation lives for two periods while the children's generation only lives for one period, that is, they overlap for one period when they also take common decisions. While both generations receive initial endowments financed through government bonds, the parental generation also receives unequal amounts of non-storable output, and it can bequeath parts of its wealth to its offspring. By assumption, this transfer of wealth is only possible by way of government bonds, while both generations are taxed.

Since the parental generation commands a first-mover advantage, it can issue debts, but it faces the risk that the children's generation reneges on repaying those bonds in the second period. In his model, Tabellini (1991) demonstrates that a coalition of parents and wealthy children supports the issuance of public debt, although this has intergenerational redistributional effects. The logic supporting the finding that wealthy children favor not to repudiate debt is that they would otherwise endanger their bequests. Furthermore, repayment of debt is broadly distributed among the children's generation and thereby intragenerational redistribution occurs. For the findings to hold, the debt originally issued must be large enough and sufficiently widely spread so that a coalition of parents and children supports such a policy and does not renege on servicing the debts.

Applied to the environmental field of pollution, the parental generation may be interpreted as the generation that has built the industrial infrastructure that leads to negative environmental externalities which are subsequently passed on to the children's generation. Even if the children's generation might muster a majority against polluting infrastructures among itself, it is plausible that a coalition of large parts of the parental generation with the disproportionally benefiting members of the children's generation might muster a majority that does not allow for reasonably fast policy change. Furthermore, infrastructures are often built for long time frames and are inherently difficult to replace.

A third perspective is offered by Stone (2009) who suggests that agent-specific risks are unequally distributed. Given the need for majoritarian support (for example, in "first past the post" electoral systems) or de facto supermajority requirements in international institutions, public goods are suboptimally supplied. As a result of the skewed distribution of risks and votes, we are likely to witness suboptimal states of the environment, especially with global environmental problems.

In his writing, Stone himself (2009) offers climate change (besides international financial stability) as a superb example to illustrate his model. Much of the recent waves of climate impact research indicates (for example, by way of illustrative maps) the projected changes of droughts, harvests, species composition, ocean sea levels, and so on. These differences are often regionally explicit and vary considerably around the world. Once we combine these differences in expected levels of climatic impacts with the absence of widespread support among the G20 of major countries and economies behind ambitious and implementable climate policy goals, it becomes apparent that we are witnessing an undersupply of protection against climate change. The protection of biodiversity offers similar perspectives due to the unequal distribution of biodiversity hotspots and the varying capacities and enthusiasm for the protection of biodiversity.

In summary, the time-inconsistency challenge, the intergenerational transfer of externalities, and the combination of unequal distribution of environmental risk in the face of (super)majority requirements for ambitious policies are three mechanisms that let us better understand why long-term environmental policy issues arise.

RESPONSE OPTIONS

Given the existence of long-term problems, it is beneficial to know from which menu of options policy-makers could make selections. This exploration comprises select response options, including:

1. the "sugar daddy" solution;
2. delegation of authority;
3. transparency; and
4. liability.

Sugar Daddy Solution

Perhaps the most straightforward solution is to buy out the constituency that accounts for the problem. I shall coin this the "sugar daddy" solution[2] in an allusion to proposals by the European Commission to compensate the European sugar beet industry for downsizing under conditions of falling prices on the world market for sugar cane. In this particular case, the adjustment is essentially financed by third parties, namely the taxpayers of the European Union (EU) in return for lower consumer prices. In essence, an external financier who is capable of solving the long-term policy problem has to be found.

Is this a plausible solution in the environmental field? The global environmental governance system as well as multilateral and bilateral green aid add up to modest amounts (Najam et al. 2006; Hicks et al. 2010: Chapter 2) and are largely targeted to developing countries. Overall, it is unlikely that any of the major long-term environmental problems, such as biodiversity, climate change, or soil degradation, can be solved by third parties footing the bill – worldwide or for developing countries.

Delegation of Authority

The second response option has been foreshadowed by Kydland and Prescott (1977) when they proposed the creation of political institutions that follow rules over time and which are detached from day-to-day political pressure:

> The implication of our analysis is that policymakers should follow rules rather than have discretion. The reason that they should not have discretion is not that they are stupid or evil but, rather, that discretion implies selecting the decision which is best, given the current situation. Such behavior either results in consistent but suboptimal planning or in economic instability . . . There could be institutional arrangements which make it a difficult and time-consuming process to change the policy rules in all but emergency situations. (Kydland and Prescott 1977: 477–487)

The adherence to rules and its positive implications for government credibility had a substantial impact on the design of institutions for monetary policy, especially the rule-based expansion of monetary aggregates that many central banks adhere to following the 1970s period of stagflation. In the environmental field, the idea of an energy agency that manages carbon emissions and secures energy supply has been suggested (Helm et al. 2003). Such an agency should be governed by conservative carbon bankers in analogy to Rogoff's "conservative central banker" in the monetary policy area (Rogoff 1985).

Credible commitment by independent institutions could also be useful for other air pollutants such as ozone-depleting substances that negatively impact the stratosphere, or for determining the number and types of fish that can be caught during a harvest period. Delegation of authority, however, does not seem easily applicable to issues such as the issue of biodiversity which simultaneously deals with securing the survival of species, whole landscapes, diversity of species, and so on. This can potentially be generalized to a range of environmental issues where a multitude of proximate causes rather than one class of proximate causes (for example, pollution emissions) are at work.

In general, wherever the credible pursuit of just one rule or the non-conflicting pursuit of multiple rules leads in the desired direction, the delegation of authority to independent institutions and decision-makers can increase the credibility of commitment to long-term environmental policies.

Transparency

Environmental reporting on the international scale has become both more prevalent and more regular during the past decades. Regular reporting is a major tool to enhance transparency by providing information to broader audiences that are thereby enabled to hold decision-makers inside and outside of governments accountable for their (in)activity (Gupta 2010b). While governments often commission national environmental reports, companies increasingly create their own (sometimes multinational) environmental and corporate social responsibility reports. Furthermore, a range of network-based reporting initiatives has flourished (for a recent overview, see Gupta 2010a). Climate change even became the topic of a major report by Transparency International.[3] Of more direct relevance to the issue of long-term environmental policy are environmental reports by supranational and international organizations that cover broader sets of countries or the world at large.

In general, these reporting activities cover the state of the environment, explain the causal mechanisms behind longer-term past trajectories, as well as provide an outlook into the future and may offer select guidance on how to cope with pertinent environmental challenges. In the following, two such regular initiatives will be summarized, namely those by the United Nations Environment Programme (UNEP) and the European Environment Agency (EEA).

Over the past one-and-a-half decades, UNEP has produced four Global Environment Outlooks (GEOs) which have covered both the environmental regions and major classical environmental themes. The latest incarnation, Global Environment Outlook 4 (UNEP 2007), uses a traditional classification by environmental media (atmosphere, land, water, and biodiversity) as well as cross-cutting sections on vulnerability (worldwide maps), and governance issues. In the pursuit of integrated assessments, GEO is supported by a data portal.

In comparison to the global mission of UNEP, the EEA is tasked to harmonize and lead the European-wide work of environmental agencies of EU member countries as well as those of Iceland, Liechtenstein, Norway, Switzerland, Turkey, and potential future West Balkan members. Much of its work rests on standardized procedures for data and their European-wide evaluation through the shared environmental information system as well as related data centers. Every five years, the EEA is tasked to provide a synoptic overview of its environmental reporting by way of its "State and Outlook" reports. Much like UNEP's GEO reports, it reviews the state of environmental media, yet in much finer thematic resolution. It is supported by a range of supplementary reports, an overview of the "megatrends" which drive global environmental change, and select country reports (EEA 2010).

Both reporting activities are time- and resource-intensive undertakings that aspire to provide a data-based grand overview of the state of the environment for their respective geographic coverage (with the EEA supporting the European regional component of GEO), and they shed light on potential policy priorities. These reporting activities may be the best we have at this point in time, yet they also seem to be suffering from lack of simpler metrics of transparency. For example, the field of inter-temporal public liabilities, a measure of the net indebtedness of public authorities (in terms of net public debts and the costs of the modern welfare state over the next century) has generated easy-to-communicate aggregate results that policy-makers may consider in preparing their policies in view of mounting public financial obligations (Raffelhüschen 2002: 84, 86). Would an environmental decision-maker, looking at the plethora of data and graphs across the various environmental media and potentially cross-cutting themes, gain a succinct overview of the state of the environment, past achievements, and the (finite) priorities to be tackled in the future? Relevant indices have to be developed in order to provide decision-makers with a succinct overview, a dashboard displaying our current attainment, as well as benchmarks for "perfect" policy performance in order to allow for policy evaluation. Such indices and benchmarks would facilitate communication with broader audiences as well as create a foundation for the non-arbitrary derivation of policy priorities to manage long-term environmental challenges.

Compensation

It is astonishing to see the difference in liability and accountability that chief executive officers (CEOs) of private firms face as compared to political decision-makers. Politicians and bureaucrats essentially face only the threat of not being re-elected or not being reappointed. Private sector CEOs have to fear being sued for civil damages (implying a threat to their private wealth) and being subject to criminal law and imprisonment. For example, recklessly sending a private company into bankruptcy normally constitutes grounds for exploring personal liability of private sector CEOs. Politicians rarely face such threats in advanced industrial societies, although the scope of their decisions may easily trounce those of the private sector. This could lead politicians to be more risk-taking than they would be in the case of more adequate rules of liability (Sprinz 2005).

Liability for public decisions of an intergenerational nature has at least been considered in a US court case of environmental non-governmental organizations (NGOs) against the Overseas Private Investment Corporation and the Export–Import Bank. At issue are those decisions of both entities that have climate impacts on US cities. By 2009, both banks had agreed in a court settlement to take climate concern into account in their future decisions. To provide insurance against the effects of earthquakes, the California Earthquake Authority has built a publicly backed private insurance system that allows for homeowners to insure against damages that are likely to occur over longer time intervals in earthquake-prone areas. To avoid undue moral hazard, policyholders must normally accept a 10–15 percent deductible.

Long-term environmental impacts will occur. A specific form of "insurance" could be the creation of structured compensation funds for damages not avoided. In the areas of transboundary nuclear impacts as well as oil spills from tankers, compensation systems have been created, and the market for compensating oil spills is frequently used (a detailed perspective is offered by Sprinz and von Bünau 2011). Generalizing on work with Steffen von Bünau in the area of climate change (Sprinz and von Bünau 2011), let me suggest a fourfold architecture:

1. Derivation of an ambitious benchmark (for example, no exceedance of the 2°C change in global mean temperature for global climate change since the onset of industrialization; halting the loss of species in the field of biodiversity).
2. A court-like adjudication procedure that links causes with effects (for example, greenhouse gas emissions with climatic impacts; habitat fragmentation with lack of sustainable reproduction).
3. A simple formula that links responsibility with contributions to a compensation fund (for example, share of emissions determines share of compensation in the area of climate change; fixed shares to hosts of biodiversity of ultimate proceeds from access to genetic resources of biodiversity under the Nagoya Protocol; Secretariat of the Convention on Biological Diversity 2011).
4. An actor or group of actors which initially endows the compensation fund (for example, a major green donor country, or an environmental NGO, or an environmentally concerned industry group).

While any such structured compensation systems raise the issue of unilateralism, credibility, and generalizability, they offer a constructive alternative to appearing empty-handed later on in the absence of building up a compensation fund.

In conclusion, I have considered four possible solutions to design institutions to deal with long-term environmental problems: the sugar daddy solution, delegation of authority to independent institutions, transparency, and compensation have been briefly considered. The broader set of possible response options and the invention of completely new options ought to be the privilege of further research.

AN AGENDA FOR RESEARCH

Given the early stage of research on long-term environmental policy, I suggest three overarching questions which would greatly benefit from sustained research due to their generic character, namely: (1) how to overcome the time-inconsistency problem in practical political life; (2) whether democracies and decentralized political systems can successfully pursue long-term environmental policies; and (3) institutional design options to prevent and recover from undesirable long-term policy outcomes.

First, the time-inconsistency problem relates to the choice of optimal rules at time t0 to actual rule adherence at t1 when political circumstances might have changed and rule adherence at t1 might not be optimal for decision-makers at that point in time. The possibility of this happening creates incentives to doubt the rule's credibility at time t0. For example, Europe wished to halt biodiversity loss by 2010 although many of the biodiversity hotspots are located outside the EU. It is all too easy to criticize a political actor for holding on to ambitious goals and yet it is also sometimes too easy to promulgate ambitious political goals whose impact can only be evaluated far in the future. While the work by Kydland and Prescott provided the academic rationale for the creation of independent central banks, it is unlikely that a forceful World Environment Organization will materialize in the near future. Thus, we are left with multilateral governance. While the world has harnessed new insights from the solution to the domestic time inconsistency problem, the equivalent of Kydland and Prescott's solution at the decentralized international level remains an open challenge. Building decentralized and voluntary compensation systems for damages or for the maintenance of environmental quality is merely a first step in this direction.

Second, it is often doubted that democracies can pursue long-term policies due to the structured length of terms of the legislative, executive, and judicial branches.[4] Moreover, decentralization of authority, as is typical with global environmental issues, may pose additional challenges to governance. The former aspect refers to electoral terms in office. Political or legal careers in high office rarely last multiple decades. Winston Churchill's career as a democratic leader may be an exception, yet it perhaps provides some clues as to why he could survive and return to office. He often held principled policy positions, accepted being out of office when such positions did not garner sufficient support, and was returned to office when such positions became attractive to the (s)electorate. Churchill opposed the Munich agreement of 1938 when many, such as Neville Chamberlain, thought that "peace for our time" was secured. In turn, he was a credible choice of democratic leader to withstand the German onslaught on Britain during World War II. The same dual clocks of relatively short-term electoral cycles (Churchill was voted out of office during the Potsdam conference of 1945) and long-term policy goals (withstand Germany during World War II) should be simultaneously modeled to see under which conditions time-limited democratic governments can survive and which characteristics their leadership personnel would have to offer to successfully pursue long-term policies.

Furthermore, how can political systems with decentralized political authority pursue ambitious long-term environmental problems? The German federal constitution (Grundgesetz), for example, grants authority for protecting nature to the *Länder* (states) such that the German federal government may face implementation hurdles at the level of EU directives on nature protection issues. Conversely, around 20 major countries plus the EU are needed for any long-term international strategy on climate change to have an appreciable impact. It therefore remains an open question how grander political designs, if any, can reconcile decentralized political authority with the successful pursuit of long-term environmental challenges, given the time-inconsistency challenge mentioned above and the domestic and international political challenges discussed elsewhere (Hovi et al. 2009).

Third, long-term environmental issues may engender a quest for institutional response options to prevent unwanted outcomes or to recover from such outcomes after prevention has failed. The term "prevention" refers to the avoidance of an unwanted outcome. By contrast, "recovery" refers to having already reached the unwanted outcome, followed by subsequent attempts to substantially improve the state of the environment. This may include aiming for a return to a more desirable status quo ante.

Preventing biodiversity loss is, in the extreme, an impossible goal to pursue. We simply have no complete inventory of all species. We may lose species even without knowing that they ever existed. Nevertheless, halting the loss of biodiversity espouses some conceptual clarity: prevent losing a good (material and immaterial). The suggestion for the creation of "conservation systems" (Steinberg 2009) presents a forward-looking perspective. The required characteristics for conservation systems to be successful are demanding. Can we derive a finite, relatively small set of design principles that allows us to move a desirable state of a specific environmental object (landscape, river shed, or species) through an infinite "time tunnel"? Do design principles vary by spatial or temporal resolution?

A range of coastal and high seas fishing grounds were overfished during the second half of the twentieth century, particularly in the North Atlantic, and serve as a good example of the recovery perspective which may take decades or longer. The focus of research ought to be directed toward how long-term sustainable yields and rich abundance in species can be substantially improved from an undesirably low level. Scholarly interest should be directed to institutional design options which might combine, for example, solutions to the time-inconsistency problem with solutions to the decentralization challenge in authority for open-sea fisheries.

Climate change can be seen as a combination of prevention and recovery modes. Article 2 of the United Nations Framework Convention on Climate Change explicitly directs member countries to "prevent dangerous anthropogenic interference with the climate system" (UNFCCC, Article 2). The Copenhagen and Cancun agreements of 2009 and 2010 lend credibility to the 2°C goal as a representation of the ultimate objective of global climate policy.

Unfortunately, we are unlikely to prevent severely overshooting this goal given current emission reduction policies around the world. Moreover, we have to consider the recovery challenge. While there is plenty of research on both mitigation (prevention) and adaptation (akin to recovery) to climate change, the appropriate mix between both and the reciprocal strategic impact between them remains an open question for research.

The list of research challenges outlined above is suggestive, yet certainly not exhaustive. Finding convincing answers would undoubtedly advance our knowledge on how to manage long-term environmental challenges more wisely for present and future generations alike. XPRIZEs have been created to establish whether private business can build spacecraft that fly 100 km above the earth (prize awarded), and whether extremely fuel-efficient cars with more than 100 miles per gallon gasoline equivalent can be built (prize awarded). These large prizes intend to create entrepreneurship to pursue goals with potentially widespread benefits to the public. Perhaps some of the research questions outlined above on the management of long-term environmental issues are worth an XPRIZE themselves?

NOTES

1. The first and the last substantive sections of this chapter originate, largely verbatim, from my editorial contribution to the special issue of *Global Environmental Politics* on the theme of long-term environmental policy (Sprinz 2009a, "Long-Term Environmental Policy: Definition, Knowledge, Future Research," *Global Environmental Politics* **9**(3): 1–8, reprinted by permission of the publisher, MIT Press) and Sprinz (2009b). Select aspects of the sections in between have appeared earlier in highly condensed form (Sprinz 2008). For comments on an earlier draft, I am grateful to Jana Ollmann.
2. "Sugar Subsidies: Beet a Retreat," *The Economist*, 23 June 2005. Available at http://www.economist.com/printedition/PrinterFriendly.cfm?Story_ID=4112150, accessed 09 June 2011.
3. Transparency International's (2011) *Global Corruption Report: Climate Change*.
4. See also Sprinz and Aklin (2011) for a discussion and empirical results on the long-term effect of democracy on per capita carbon emissions.

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7. Explaining and predicting future environmental scarcities and conflicts[*]

Urs Luterbacher, Dominic Rohner, and Ellen Wiegandt, with Sébastien di Iorio

THE PROBLEM IN PERSPECTIVE

It is well established that unregulated property structures create incentives to overuse natural resources (Hardin 1968). The overuse of natural resources, in turn, creates scarcities, leading individuals and households to try to appropriate more resources for themselves by, for example, producing more children (Nerlove 1991; Dasgupta 1995). The result is an increase in population that further aggravates scarcities. The absence of regulations and predetermined dispute resolution schemes, along with growing scarcity, leads to incentives to appropriate resources by force. Armed conflicts ensue among rival bands whose leaders try to take advantage of the situation. This has been called the "tragedy of coercion" (Konrad and Skaperdas 1999).

A synthesis of interactions resulting from the absence of regulation, the exacerbation of scarcity, and the ensuing conflict constitutes a "triple tragedy of the commons" which describes the failure to achieve collectively optimal levels of population, resource use, and political power. We present our preliminary views on the causal mechanisms of this tragedy within a formal theoretical framework and then illustrate them through some empirical analyses and dynamic simulations.

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[*] The editors would like to dedicate this chapter to the memory of Ellen Wiegandt, well-published analyst of Alpine ecosystems and sustainable development. "O gentle child, beautiful as thou wert, Why didst thou leave the trodden paths of men too soon?" (Percy Bysshe Shelley, *Adonais, An Elegy on the Death of John Keats*).

BASIC QUESTION

We take as the starting point Garrett Hardin's (1968) contention that weak or absent regulatory frameworks are the source of environmental scarcities. In other words, what matters is not the degradation of the environment per se but the incentive structures that in the long run lead to an inferior social outcome. It is the incentive structures that are at the origin of the overuse of environmental resources. Hardin thought that the absence of a private property system is specifically at the root of environmental deterioration. However, a subsequent empirical literature demonstrates that a balance between people and resources had been achieved in many parts of the world without recourse to private property structures (McCay and Acheson 1987). Moreover, Hardin had presented a "commonsense" argument, limited to the very narrow context of cattle herding on a meadow whose access is open to everyone. This open access feature leads then to overgrazing. A formalized version of Hardin's reasoning and a generalization of his approach was presented later by Dasgupta and Heal (1979). Their work shows that Hardin's presentation is a special case of a situation where individual incentives lead to socially inferior outcomes. They also insist that many of these incentive structures do not permit the development of long-term retaliation strategies to help foster cooperation.

To understand the problem raised by Hardin, one must look at the general question of how regulatory structures (such as property rights) can be initiated. As suggested by Dasgupta and Heal's analysis, some regulatory structures might not bring about optimal results. Some might be too restrictive to permit innovation and development; others might be too loose and imprecise to protect natural resources. In both cases, and especially in the latter one, conflicts are likely to develop. To show the existence of the linkage between "the tragedy of the commons," regulatory schemes, and conflict, we begin with the formal analysis developed by Dasgupta and Heal, applying it, with some significant modifications, to our central question.

The Dasgupta and Heal theory assumes the availability or production of two goods, one private and one collective, within a socio-economic system. Private goods exclusively affect the utilities (or preferences) of an individual purchaser up to the amount that he consumes. Collective goods, however, influence the utility of that same individual not only up to the quantity he consumes but also up to the amount consumed by all other individuals of the group. The formalization of these notions can now be presented.

FORMAL ASPECTS: COLLECTIVE GOODS

Assume N individuals (or households) in a particular social group g. Let x_i represent the quantity of the private good consumed by individual i and $g_1, g_2, g_3, \ldots, g_i, \ldots, g_N$, the amounts of the collective good used by individuals $1, \ldots, i, \ldots\ldots, N$. Thus one has:

$$u_i = u_i(x_i, g_1, \ldots, g_i, \ldots, g_N) \tag{7.1}$$

An important special case of 7.1 is:

$$u_i = u_i\,(x_i, \sum_{j=1}^{N} g_i) \tag{7.2}$$

That is, individual (or household) i's utility depends on the total quantity of the collective good consumed, purchased or produced by everyone. A crucial assumption resides now in the definition and specification of u_i.

Many models of rational behavior assume that utility functions are either risk neutral or risk averse. This is often done for mathematical convenience, to simplify complex issues. Experimental psychologists and even observers of animal behavior, however, have noticed that risk acceptance often characterizes choices when a decision-maker is faced with the prospect of losses (Stephens 1990). Risk aversion and risk-preferring behavior are regularly seen together within the same individual, and various attempts have been made to explain their joint appearance. The principal analyses of hybrid risk attitudes are Battalio et al. (1990), Battalio et al. (1985), Camerer (1989), Fishburn and Kochenberger (1979), and especially Kahneman and Tversky (1979). In particular, Fishburn and Kochenberger (1979) show that the majority of individuals have an everywhere increasing utility function $u(x)$, where x is a measure of gains and losses that increases more than proportionally for small or negative x and then less than proportionally for relatively high values of x. Many individuals are thus risk averse over gains and risk preferring over losses. This notion can serve as a theoretical justification for the contention elaborated by Hirshleifer (1991) that the poor have a comparative advantage in appropriation, obviously a more risky way to acquire wealth than capital accumulation through savings. In general, this type of utility function leads to very different but also quite plausible bargaining behavior as compared to traditional models.

A natural extension of these considerations is to represent an average decision-maker's utility function by an everywhere increasing S curve in x which adequately expresses the mix of risk aversion under gains and risk preference over losses.[1] An S-curved utility function does not just obtain as a result of psychological analysis. It may also result from productive

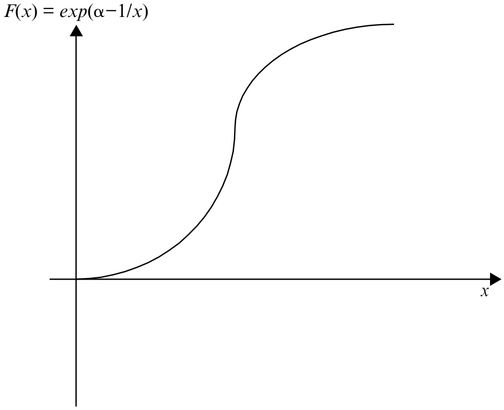


Figure 7.1 *S-shaped utility curve*

processes which exhibit first increasing and then decreasing returns to scale. If an individual agent is a producer and derives utility from the way they produce then they will also have an S-shaped utility function. This case will be discussed later.

Without loss of generality we can then present the following risk averse/risk preferring (S-shaped) utility curve as shown in Figure 7.1.

The utility function u_i is defined here as a marginally increasing then decreasing function of both the x_i and åg_i of equation (7.2). It makes sense that, since the arguments x_i and åg_i will be expressed in terms of values ranging from 0 to infinity, this kind of utility function starts at 0. Let us further assume that either all individuals are identical or very similar in their preferences or that agent *i* represents a median decision maker that sets the tone for what is happening in society. Consistent with this hypothesis, u_i can be rewritten as:

$$u_i\,(x_i, \sum_{j=1}^{N} g_i) = exp(\alpha - 1/x_i + -1/\sum_{j=1}^{N} g_i) \qquad (7.3)$$

The function $exp(\alpha - 1/f(x))$ has precisely the S curve characteristic associated with prospect theory (Figure 7.1). One should also notice that both private and collective goods are essential for the utility of agent *i*, as it should be. If the value of one of the goods goes to zero, the value of the whole utility function goes to zero.[2]

Now assume that initially individuals have one unit of the private good x_i, and none of the collective good g_i. Agents are however able to convert the private good into the collective good at a rate p^s. If $s = 1$, the private good can be transformed into the collective good proportionally, if $s < 1$, the conversion takes place more than proportionally, if $s > 1$, less than proportionally. If, for instance, g_i stands for national defense, then s represents a measure of society's ability to mobilize resources for war (the lower is s, the greater the possibility to mobilize resources).

Agent i in society g can therefore maximize u_i as defined in (7.3) subject to a budget constraint:

$$p^s g_i + x_i \leq 1 \tag{7.4}$$

Several types of equilibria can be considered here. If all agents in society maximize utility in the same way i does, based upon some expectation they have on how much of the collective good every other agent produces or purchases, a particular kind of Nash equilibrium obtains for the society in question, which we will call a society market or anarchic equilibrium. Such an anarchic equilibrium constitutes a particular mix of a pure competitive equilibrium for private goods and a non-competitive but decentralized one for collective goods. Such a society market or anarchic equilibrium will obtain, as mentioned previously if every agent anticipates the purchase or production of the amount of collective good $\hat{g}$ by every other agent. For agent i, the problem is then to maximize:

$$exp\{-1/x_i + -1/[g_i + (N-1)\,\hat{g}]\} \tag{7.5}$$

by choosing x_i and g_i subject to the budget constraint (7.4). The necessary (and eventually sufficient since the utility function will after being initially convex become concave) conditions for an optimum will be:

$$Max\{exp\{-1/x_i + -1/[g_i + (N-1)\hat{g}]\} + l_i(1 - p^s g_i - x_i)\} \tag{7.6}$$

At the anarchic equilibrium, one can assume that $g_i = \hat{g}$ and thus $x_i = \hat{x}$. From the first-order conditions, we therefore have:

$$N\hat{g} = \frac{\hat{x}}{\sqrt{p^s}}$$

using again the budget constraint (7.4), gives for respectively $\hat{g}$ and $\hat{x}$:

$$\hat{x} = \frac{N}{\sqrt{p^s}+N} \text{ and } \hat{g} = \frac{1}{(\sqrt{p^s}+N)\sqrt{p^s}} \tag{7.7}$$

which is what every agent in the society under consideration is ready to produce or purchase as his bundle of private and collective good. One can notice here that if N is large and p^s relatively close to or equal to 1, every agent keeps most of their endowment in private goods and only a very small fraction is devoted to the collective good. However, our formulation of the utility function as S shaped has the advantage of establishing a relationship between the conversion rate p^s and the purchase or production of both private and collective goods. Thus, if p^s is relatively small, the voluntary provision of a collective good can become relatively high even with large N. Moreover, the expressions above show that, under some kind of "increasing returns" in the acquisition of the common good – that is, when the conversion rate p^s is relatively low (at least smaller than one) – the purchase or production of the collective good is relatively cheap and thus allows for a relatively large g per agent even if they consume or produce high amounts of the private good x. This illustrates the possibility that under circumstances of very low conversion rates, the production of both private and collective goods might be relatively high, which has then of course an incidence on the situation of a given society with respect to others.

Is such an anarchic equilibrium Pareto efficient? To answer the question one has to treat g as if it were another kind of private good and considered by agent i as if he was alone and thus maximizes:

$exp\{ -1/x + -1/Ng\}$ subject to the same budget constraint $p^s g + x \leq 1$.

The Pareto optimal solution $(\tilde{x},\tilde{g})$ can be found readily as:

$$\tilde{x} = \frac{\sqrt{N}}{\sqrt{p^s} + \sqrt{N}},\ \tilde{g} = \frac{1}{(\sqrt{p^s} + \sqrt{N})\sqrt{p^s}} \text{ and thus, } \tilde{g} = \frac{\tilde{x}}{\sqrt{N}\sqrt{p^s}} \tag{7.8}$$

Quite clearly, the anarchic equilibrium is not Pareto optimal. It reflects here the "tragedy of the commons" outcome where the absence or minimal provision of the collective good (here regulation) leads to a socially undesirable outcome. In fact, the difference between the anarchic equilibrium and the Pareto optimal value is:

$$\sqrt{p^s}\frac{1 + \sqrt{N}(\sqrt{N} - 2)}{N} > 0 \text{ for all } N > 1, \tag{7.9}$$

provided only positive values for the terms under the square root signs are considered. Expression (7.9) tells us that the anarchic equilibrium is identical with the Pareto optimal outcome whenever $N = 1$ as one would expect since it corresponds to the case where there is just one member of society, or in terms of property rights one owner who has then the incentive to provide for himself in an optimal way.

Is the anarchic solution thus always suboptimal? Not necessarily. If an efficient market can be established that includes all externalities, a Pareto optimal (a so-called Lindahl) equilibrium will obtain (Dasgupta and Heal 1979: 44–52). However, the creation of such a market implies the creation of an organization, a collective good, to define, then protect and guarantee Pareto optimality (for example in the form of property rights) for that market (Luterbacher 1994). The organization of such a market involves potentially considerable costs. If one wants to create a market for the collective good, another collective good is necessary to organize it, and so on. The situation leads to an infinite regress. It is difficult to imagine the creation of an efficient market for defense for instance. In most cases such a market will turn into a racket for protection because property rights will be neither well defined nor protected, since the use of force will make the temptation to extract rents from people one is supposed to defend, hard to resist.[3]

Given the necessity of at least an initial organization for the provision of a collective good, alternatives to externality markets have to exist in order to allow societies to move toward Pareto optimality.[4] This is the case with tax equilibria where societies agree or are forced to maintain collective goods with regular mandatory contributions.[5]

Unlike markets that do not presuppose any form of organization to solve collective good problems, the authority to tax assumes the existence of a social order that is ready to collect and enforce the collection of mandatory contributions in various forms by the members of society. However, as in the case of markets for externalities, the power to tax is far from obvious and requires the possibility to punish recalcitrant members. The imposition of taxes on a society is difficult without the consent of at least some of its members; and usually requires the existence of a relatively important level of transactions in some form of “numeraire” that can then be taxed. Political entrepreneurs can only overcome the first difficulty if they want to avoid seeking consent, when they can rely on their own private sources of revenue.[6] However, even in this case, the collective good could at least initially be supplied at a suboptimal level. The second difficulty, which can be illustrated by a significant reduction in the number of taxable transactions, is almost impossible to overcome without a reorganization of the social order.[7] Usually the organization of defense as one of the initial collective goods has the advantage of solving both the protection problem and the taxation problem since it gives to an authority both the means to use force toward the outside and the power to enforce tax collection. Is taxation thus a way to compensate for the absence of Pareto optimality in an anarchic equilibrium? The answer is quite clearly yes as long as the taxation is “Pigouvian,”[8] that is, if it is explicitly meant to correct for the Pareto inferior outcome represented by the anarchic equilibrium. We will thus also consider here a subsidy t that a social authority will give on the purchase or production of a unit of collective good by agent i and τ a tax (lump sum) that the authority imposes on i in terms of his private goods.[9] Agent i in the absence of any market for externalities maximizes:

$$u_i\,(x_i, \sum_{j=1}^{N} g_i) = exp(-1/x_i + -1/(\sum_{j \neq 1}^{N} g_j + g_i)$$

subject to:

$$(p^s - t)g_i + x_i \leq 1 - \tau \tag{7.10}$$

and where of course agent i chooses only x_i and g_i. By analogy with previous results, we get at equilibrium, assuming that $\overline{p}^s = p^s - t$:

$$N\overline{g} = \frac{\overline{x}}{\sqrt{\overline{p}^s}} \tag{7.11}$$

To get to the Pareto optimal result (7.8) with $\widetilde{g} = \frac{\widetilde{x}}{\sqrt{N}\sqrt{p^s}}$, the net price $\overline{p}^s$ that an agent must pay for the externality should be $\overline{p}^s = \frac{p^s}{N} = \frac{Np^s}{N^2}$. Indeed, introducing this expression into (7.10) leads to the Pareto optimal value (7.8) restated above. Thus the authority must set the per unit subsidy of the collective good at $t = \frac{(N - 1)p^s}{N}$. The authority must also set a lump sum tax on each agent again with the purpose of reaching Pareto optimality as defined by the values of $\widetilde{x}$ and $\widetilde{g}$ in (7.8). This lump sum tax τ, is thus:

$$\tau = \frac{\sqrt{p^s}(N - 1))}{N(\sqrt{p^s} + \sqrt{N})} \tag{7.12}$$

One is now able to compute total authority expenditures and revenues on this basis. Total expenditures or subsidies for the collective good are:

$$N\widetilde{g}t = \frac{N}{(\sqrt{p^s} + \sqrt{N})\sqrt{p^s}}\;\frac{(N - 1)p^s}{N} = \frac{(N - 1)\sqrt{p^s}}{(\sqrt{p^s} + \sqrt{N})} \tag{7.13}$$

Total revenues are:

$$N\tau = \frac{N(N - 1)\sqrt{p^s}}{N(\sqrt{p^s} + \sqrt{N})} = \frac{(N - 1)\sqrt{p^s}}{(\sqrt{p^s} + \sqrt{N})} \tag{7.14}$$

which is of course the same as (7.13).

In other words, under Pigouvian taxation principles, total expenditures equal total revenues and the collective good budget is balanced and leads to Pareto optimality, which establishes the taxation equilibrium. Expression (7.14) allows computation of the optimal size in terms of N of a coalition necessary to establish a Pareto optimal tax equilibrium. This size is given by:

$$\frac{\partial N\tau}{\partial N} = \partial\frac{\dfrac{(N-1)\sqrt{p^s}}{(\sqrt{p^s}+\sqrt{N})}}{\partial N} = 0$$

Which solution (for a maximum) eventually leads to:

$$N = -2\sqrt{p^s}(-\sqrt{p^s}+\sqrt{p^s-1})-1 \text{ or} - 2\sqrt{p^s}(-\sqrt{p^s}-\sqrt{p^s-1})-1$$

where the second solution leads to higher values. One gets then N as a function of p^s increasing either exponentially if $s > 1$ and logarithmically if $s < 1$. This reflects the notion that if the transformation rate from a private to a collective good can be done cheaply (in some sense with increasing returns to scale), then the required coalition to establish it is much less important than when it can only be done at great expense (with decreasing returns).

Clearly, this analysis establishes the importance of numbers of people in the creation of collective-good-providing coalitions. More are necessary if the collective good is relatively expensive, fewer are needed if the collective good is cheap. However, there might be differential prices and thus costs within a society: one group might have cheaper access to collective goods than another which can lead to its domination. Moreover, if two or several groups have cheaper access to collective goods such as defense, armed conflict between them for the control of other resources might erupt. If such collective goods are still relatively expensive, then numbers matter and competitive recruitment efforts by each group will occur. Demographic processes may play a major role in providing subpopulations from which recruitment efforts can be undertaken. We now examine their evolution, their links to resources, their depletion, and their impact.

DEMOGRAPHIC PROCESSES AND RESOURCE DEPLETION

A population problem may occur on a particular delimited area when rates of population growth are overly high. For example, the growth rate of the sub-Saharan African region is between 2 and 3 percent per year, which should lead to a doubling of population in approximately 30 years. This can be thought of as an increased pressure upon the environment's carrying capacity since land and resources cannot be expanded at will. Demographers and economists have shown that bargaining theory can be applied to reproductive decisions inside the household (Lestaeghe 1986; Simon 1986). Indeed, the costs of bearing and rearing children are not equally shared by men and women: pregnancy entails forgone work-capacity and an increased probability of dying. Besides, caring for children is time-consuming and imposes material restraints on the disposal of income. Furthermore, in regions such as sub-Saharan Africa, one can expect "reproductive free-riding" on the part of men since the costs of rearing children can be spread (or shared) among kith and kin (Dasgupta 1998).

Dasgupta (1993, 1998) provides two answers to the possible divergence between decisions at the level of the household that seem rational and their effect on society as a whole. The first is that households get the wrong incentives because of inefficiencies in the relative pricing of various goods and services. The second is that each household imposes negative externalities onto others. One source of externalities has been put forward in the previous comment on open access resources: because of lack of restrictions to entry, open access to the resource provides an incentive to produce too many children since parents do not have to bear the full costs of rearing them. Another basis for externalities is simply the social environment: individual behavior can be dictated by norms and culture. Societies may have acquired customs and mores that favor high fertility rates. Such norms stem traditionally from historic conditions involving high mortality rates, low population densities, and high probabilities of war. However, they tend to survive as part of a community's identity even when the rationale for their existence has disappeared. In such circumstances, each household's utility is a function of its own actions and of the average actions of all others; that is, as long as all households seem to respect the norm, no one has an incentive to move away from it. For example, sub-Saharan African fertility regimes seem to a large extent affected by customs like low age at marriage, polygyny, weak conjugal bonds, and strong kinship support systems for children of the community (Lestaeghe 1986). Moreover, such social arrangements favor males, who get a disproportionate incentive to engender children since they only partially incur the costs of rearing them. The basic conclusion is that society as a whole can be stuck at a suboptimal Nash equilibrium with households producing too many children (and knowing it) because no one has a unilateral incentive to depart from this accepted pattern of behavior. As underlined by Dasgupta (1993), this is a typical coordination problem involving a multiplicity of Nash equilibria which can only be addressed through the regulatory activity of the state.

One puzzling feature of the sub-Saharan African demographic regime is that fertility rates have only begun to react to declining mortality rates.

This can be explained by Dasgupta's first hypothesis: children must be seen as goods providing various benefits to the household. Obviously, the first motivation for having children may be that they are an end in themselves. However, from the viewpoint of their parents, children may be considered as productive assets: given the constraints on saving in rural areas, children represent insurance for their parents in old age. More importantly, children in rural areas are an income-yielding asset. When agricultural output is low, energy and water prohibitively expensive (because of lack of basic infrastructure), and the possibility of investing in capital non-existent, people need to engage themselves in complementary activities such as collecting wood, monitoring cattle grazing, or fetching water. Children are therefore essential as workers for the survival of their family. Clearly, a positive feedback sets in: to the extent that property rights are ill-defined, high fertility rates imply further stresses on the environmental-resource base, which in turn give incentives for expanding the family, which will increase the depletion of the resource. Hence, resource scarcity and development are intrinsically related: investments in infrastructure in order to reduce for example the price associated to basic commodities such as fuel or water would decrease the value of children as income-earning assets. Similarly, increased savings and investment opportunities would lessen the need for children as a sort of insurance. Nevertheless, development programs thought to assure growth and modernization can also exacerbate resource degradation in the absence of clearly defined property rights.

Indeed, as stressed in Dasgupta and Heal (1979), no dominating strategy is available to actors operating in an open-access type of situation. Thus, the Prisoner's Dilemma is not an apt metaphor for such circumstances. However, one can clearly see that whereas no producer has a dominant strategy to keep on extracting more, no one can oppose a credible threat to prevent others from doing it. Hence, the behavior of actors in an open-access type situation is closer to that of players in a Chicken Game. The corollary of the absence of credible threats is the existence of an intense competition for the first move: the first mover enjoys a durable advantage over his opponent; this in turn yields a subgame perfect Nash equilibrium where gains (or losses) are disproportionately distributed in favor of the first. Given the asymmetry at the equilibrium, it is extremely difficult to reach another outcome, thus patterns of behavior exhibiting strong inequalities can easily be maintained over long time periods. Moreover, entitlements to the products in managed common-property systems across the globe have mostly been based on private holdings: such institutional arrangements tend therefore to replicate the inequalities in terms of wealth among participants at the level of resource use. Hence, even when access to a common pool resource is restricted, it is likely to provide the privileged with greater parts of the benefits. To be sure, the asymmetry in resources and capabilities provides the latter with credible threats when it comes to devise collective agreements to control the exploitation of the environmental base. Besides, one need not assume asymmetric players (for example elite versus non-elite) to obtain a stable unequal distribution of benefits accruing from the exploitation of the resource: such agreements are easily supported by specific types of retaliatory strategies (Dasgupta et al. 2005). Moreover, as scarcities occur (the availability of arable land diminishes) the bargaining power of certain population groups is altered by changes in relative prices: actors with few resources may put a premium on the short term. Indeed, in such instances, small parcels of land may be sold to powerful landowners to obtain liquidities rapidly. Furthermore, as competition intensifies, it becomes perfectly rational for individuals to overexploit the commons in order not to be the last one without resources to tap (Dasgupta and Heal 1979). Thus, resource scarcities may lead on the one hand to overuse by their users, and on the other to competition for appropriation between peasants and between peasants and landowners. Finally, the impact of the environmental resource base's depletion over customary rules and norms needs to be considered as well: as land becomes a commodity through market operations, it ceases to be ruled by customary norms and restraints (André and Platteau 1998). Actors are therefore more inclined to overexploitation and short-term calculations. This mechanism both illustrates and gives an answer to the paradox raised by examining the work of different authors concerning the relationships between environment and conflict: scarcities and abundance of resources are in the short term part and parcel of the same dynamic. Overabundance exists because incentives are present for more resource appropriation even when the price of the resources plummets because the opportunity cost of labor is cheap compared to what can be gained by selling it. However, it is precisely this overexploitation that leads eventually to scarcities.

Can one find these processes within the theoretical framework that was presented above? The answer, as we will now see, is clearly positive.

FORMAL ASPECTS: POPULATION

If overuse of resources at first leads to population increase, then incentives must be present within the formal structure that produce that outcome. To show that this is the case we will analyze two expressions that are derived from our formulation: (1)The individual utility of the representative agent within an anarchic equilibrium must increase with the growth in N, the population. (2) The gap between the anarchic equilibrium and the Pareto optimal situation where resources are not overused should increase as N rises. Both these conditions are fulfilled. The partial derivative of the utility function u_i (under anarchy or open access) with respect to N:

$$\partial u_i/\partial N = \partial\, exp\{-1/x_i + -1/[g_i + (N-1)\,\hat{g}]\}/\partial N = 1/N^2(p^s + \surd(p^s)$$

is always positive.

The gap between the anarchic (open access) equilibrium and the Pareto optimal situation is:

$$\sqrt{p^s}\frac{1+\sqrt{N}(\sqrt{N}-2)}{N}.$$

Its partial derivative with respect to N is: $(N-\sqrt{N})\sqrt{p^s}\frac{1}{N^{\frac{5}{2}}}$

which is always positive for $N > 1$.

We thus can reproduce the paradox described earlier: there is an individual incentive to increase N even though a greater N deteriorates the overall social situation. What are the consequences of these processes for conflict?

There exists a well-developed literature about the "resource curse," the negative impact of natural resources on economic growth. This literature is largely empirical, and only a few of the contributing scholars do not only test for the negative impact of natural resources on growth, but also inquire how natural resources can influence growth. Most of the papers which treat particular relations focus on economic aspects such as the Dutch disease, which refers to the impact of natural resources on relative prices and on the terms of trade. Some articles, however, have found empirically that one reason why natural resources tend to decrease growth is the risk of conflict, political instability, and poor institutional quality (see Baland and Francois 2000; Gylfason 2001; Ross 2001; Sala-i-Martin and Subramanian 2003; Bulte et al. 2003).

Only a handful of scholars have yet attempted to measure empirically the direct link between natural endowments and civil unrest. Most of these scholars have used a case-study approach and have found that natural resources have been an important reason for conflict within a particular country (see, e.g., Frynas and Wood 2001; Englebert and Ron 2004; Angrist and Kugler 2005). However, few cross-sectional country statistical studies have been performed so far. A notable exception is Ross (2004), who concludes that some natural resources such as oil increase the risk of civil war, whereas the existence of other kinds of natural resources such as gemstones and drugs increases above all the length of conflict.

Collier and Hoeffler (1998) conducted an econometric study about the likelihood of civil war and came to the conclusion that the effect of natural resources on the risk and duration of civil war is non-monotonic:

> The possession of natural resources initially increases the duration and the risk of civil war but then reduces it . . . In effect, possessing natural resources makes things worse, unless you have plenty of them. The effect is again quite strong. At the means of other variables, a country with the worst amount of natural resources has a probability of war of 0.56 as against one without natural resources of only 0.12.

A few theoretical papers have attempted to explain why an endowment in natural resources can result in conflict. An interesting contribution by Skaperdas (2001)[10] shows that a higher availability of rents from resource production leads to more competition among warlords, which ends eventually with more resources being wasted on unproductive arming and fighting. Furthermore, Skaperdas shows that rents from natural resources like oil, gas, timber, or diamonds, or even foreign aid, can crowd out "ordinary" productive activities in an economy. Reuveny and Maxwell (2001) and also Grossman and Mendoza (2003) show through a dynamic analysis that natural resources can lead to conflict.

Another important consequence of the abundance of natural resources has been described by Tilly (1992): political entrepreneurs (or in our case warlords) are less dependent on tax revenues, if they operate within an area rich in natural resources. Because they can completely rely on rents and do not need tax revenues, they are not forced to seek consent, which is required for an operating taxation system. As a result, the democratization process does not take place.

Even though all these papers provide interesting insights into the link between natural resources and conflict, several important problems remain unsolved. Our model attempts to address some of those challenges. First, all the mentioned papers take the stock of natural resources as exogenously given and ignore resource exploitation issues. To fill this gap we explicitly address the exploitation question with the help of production functions for natural resources showing crowding. Second, our model is characterized by multiple equilibria, where one of them corresponds to a so-called "fighting trap." We will point out the difficulties of getting out of such a trap. This illustrates also the linkages between resource scarcities and conflict.

FORMAL ASPECTS: FIGHTING

The objective of the model is to explain a representative agent's choice between producing and joining fighting forces in an unstable country. This perspective can help clarify the conditions under which the emergence of a society with competing warlords (as sometimes occurs in developing countries) is more or less likely than the building of a politically stable and economically developed society. Moreover, we link the question of warlord competition to the issue of natural resources. We start from the following assumptions:

- Assumption 1: We assume a primitive society with N identical individuals, who can be symbolized by one representative economic agent.
- Assumption 2: The representative economic agent has the choice of how much time they want to allocate to production and how much to fighting.[11] In our model this will be represented by a decision to optimize by using a certain proportion of their time to produce and thus to contribute to a stable political regime and by using the remaining time to establish a "warlord society" through fighting.
- Assumption 3: The individual choice of the representative agent is linked to the aggregate decision of the society. If our representative economic agent achieves a higher expected value by fighting, and vice versa, we can expect that this outcome will eventually hold for the society as a whole. We can draw an analogy here to Schelling's (1971, 1979) binary decisions in an aggregate framework: the decision by one individual is conditioned by what all others are doing. So for instance if everybody drives to work it makes sense from an individual point of view to take public transportation because the roads are crowded. However, if most people take public transportation it is again worth driving. As shown by Moulin (1982 [1986]), this condition can lead to stable or unstable Nash equilibria at the level of the whole society.
- Assumption 4: Every agent is a producer/fighter and at the same time a consumer. The framework is the one of an economy, in which initially no trade with the outside is taking place but then eventually the economy opens up to trade.
- Assumption 5: If the agent becomes a fighter, they can make an initial gain at the beginning of the period by exploiting some of the natural resources. By contrast, becoming a producer demands an initial commitment, an investment. This initial investment can be for example the cost of education, or in a more agricultural society the cost of creating tools and machines for further development of productive activity.
- Assumption 6: The only choice made in this society is one between fighting and productive activities. We thus ignore for the moment the

> question of how warlords emerge or how they organize their armies. We assume that in an environment where lots of people are willing to fight or where our representative agent devotes most of their time to fighting the emergence of warlords capable of organizing armed bands is more likely. Our model presents necessary but not sufficient conditions for organized internal conflict.

We want to find the level of producing/fighting which maximizes the utility of a representative agent. The model is a static, one-period model, in which the representative agent is a utility-maximizer who chooses an individually optimal level of producing and fighting.[12]

The representative agent has the following aforementioned utility function:

$$u_{pf} = \int_{i=1}^{n} c_i^D, \tag{7.15}$$

where c_i^D is the demanded amount of a variety of the only consumption good.

For convenience, all goods produced under a regime of "warlord" or "stable political regime" production can be seen as varieties of one single good, where each of them gives an identical level of utility to the representative agent.[13]

As our locally non-satiated representative agent is at the same time the only producer and consumer in our competitive economy, and as all relative prices are positive, the aggregate demand for every variety of our commodity must equal its aggregate supply. Since we have only one agent, and by assumption initially no international trade takes place, we get:

$$c_i^D = c_i^S, \tag{7.16}$$

where c_i^S is the produced (and supplied) amount of commodity i.

As the utility function is strictly monotonic in all varieties of the consumption good, and the agent basically consumes what he produces, we can focus exclusively on the production function of the goods. In order to maximize his utility, our agent simply maximizes production.

Every variety c_i^S has an identical production function, akin to the utility function (7.3) presented earlier:

$$c_i^S = \exp\left(a - \frac{\theta}{p} - \frac{\pi}{q}\right) \tag{7.17}$$

where a = parameter, p = portion of time allocated for producing, q = portion of time allocated for fighting, θ = parameter expressing the gain of producing, π = parameter expressing the gain of fighting.

This production function exhibits at first increasing then decreasing returns with respect to the arguments p and q. This expresses the plausible assumption that initial increases in the levels of respectively fighting or producing activities will generate more than proportional returns in the production good c_i^S but then eventually, with further increases of p and q, less than proportional output will appear. If everything that is produced is consumed agent i has simply the utility function $u_{ipf} = c_i^S$. This utility function is similar to the S-curve preference functions we introduced earlier. This production/utility function is subject to the constraint:

$$(1 - b)q + (1 + k)p \leq 1 - t + k \textit{ with } t >> b \tag{7.18}$$

By definition, $p + q \leq 1$ since both variables represent parts of a total endowment. However, the initial commitment (analogous to a tax) for becoming a producer, called k, and b, the initial gain (analogous to a subsidy) of turning a producer into a fighter, will also affect the endowment as a whole.[14] The "subsidy" to the fighter usually has to be more than compensated through a tax on the total endowment, t, which is assumed to be considerably greater than b. Similarly, the commitment taken by a producer, k, which is a net contribution to the total endowment, has to be accounted for. All these considerations are represented in the constraint (7.18).[15]

Thus, we assume that there are two ways of producing a particular good. Either the agent can choose the "stable political regime" production technique under which they have to make an initial commitment in order to get a higher return in the long run or they can choose the "warlord" production technique, which refers to the low-technology capability of exploiting natural resources in areas controlled by the armed forces and gets an initial boost from the switch to fighting.

The terms θ and π correspond to the elasticity of producing and fighting, or to put it differently, to the impact of a marginal change in the amount of production and fighting time on the output.

The link between the outputs of the two rival production techniques is summarized in equation (7.19). The decision-taker is myopic and only takes the short and medium run into account. As he ignores the future externalities of overexploitation, he has incentives to extract more than the social optimum of natural resources:

$$\theta = \pi(1 - \phi) + y \tag{7.19}$$

where $\phi = xE - z$; where y = ordinary production in case of producing, z = short-run gain of overexploitation, E = externality of the overuse of the natural resources (positive number), x = extent up to which the externality can be internalized if the agent is a producer (number between 0 and 1).

It is a priori difficult to determine whether $\theta > \pi$ or $\pi > \theta$, as the latter, π, benefits in the short run from the gains of the overexploitation of natural resources (z) and as the former θ implies regular production and efficiency gains from the better internalization of the externality. The short-run gains from overuse correspond to the increased quantity of natural resource exploitation, whereas the gains of better internalization of the natural resources correspond to a higher sale price (as less is produced) and to a more efficient exploitation of natural resources. The influence of y, ordinary production, is ambiguous: if we have $y < \theta$, then we are in a "normal" situation. We will first assume that the overuse of natural resources is quite an important factor and that accordingly θ is smaller than π.

The values of x and y depend on the following factors (by assumption property rights protection and the possibility of joining an international cartel become only real options in the case of the "stable political system" production technique).

$$x = x(p_M^{+}, p_P^{+}) \text{ and} \tag{7.20}$$

$$y = y(p_P^{+}) \text{ and} \tag{7.21}$$

$$p_M = p_M(p_P^{+}) \tag{7.22}$$

where p_M = probability that an international cartel of producers of the natural resource takes place (number between 0 and 1), p_P = probability that the rule of law and property rights are protected (number between 0 and 1).

We can see in equation (7.20) that if the representative agent chooses to be a producer rather than a fighter, a gain due to the internalization of the externality, xE, is possible, if an international cartel of the producers of the particular natural resource takes place or if the property rights are better protected than in the warlords case. An international cartel fights the price-depressing effect and restricts the quantity (less overuse) to keep prices high.[16] A good level of property rights protection assures a more efficient exploitation of natural resources. In addition, as described by equation (7.21), a high level of property rights protection may also favor the "regular" production y.

Equation (7.22) stresses furthermore that a society with a certain control of the quantity produced (due to the protected property rights) is more likely to form an international cartel with other similar societies.

Using (7.17) and (7.18), we get the following production maximization problem:

$$\underset{p,q}{Max}\ \exp\left(a - \frac{\theta}{p} - \frac{\pi}{q}\right) \text{ subject to } (1 - b)q + (1+k)p \leq 1 - t + k, \tag{7.23}$$

and from (7.19) after transformation $\pi = \frac{\theta - y}{1 - \varphi}$.

This can be expressed by the following Lagrangian:

$$L = \exp\left(a - \frac{\theta}{p} - \frac{\pi}{q}\right) + \lambda(1+k-t-(1-b)q-(1+k)p) + \mu\left(\pi - \frac{\theta - y}{1-\varphi}\right) \tag{7.24}$$

Calculating the partial derivatives of L with respect to p, q, λ, μ (the first-order conditions) gives us equation (7.25) after rearrangement:

$$\frac{\pi}{q^2} = \frac{\theta}{\frac{(1 + k - t - (1 - b)q)^2}{(1 + k)^2}} \tag{7.25}$$

After rearranging (7.25), we can distinguish two possible equilibria (all other possibilities violate the restriction $0 \leq q \leq 1$) which we obtain by taking the square root on both sides. We get:

$$q_1 = \frac{1 - t + k}{1 - b + \sqrt{\frac{\theta}{\pi}}(1 + k)} \text{ and} \tag{7.26}$$

$$q_2 = \frac{1 - t + k}{1 - b - \sqrt{\frac{\theta}{\pi}}(1 + k)} \tag{7.27}$$

As expected, a higher b and a higher k result in a higher chosen level of fighting activity, since the first partial derivatives of (7.26) and (7.27) with respect to b are:

$$\frac{\partial q_1}{\partial b} = \frac{1 + k - t}{\left(1 - b + (k + 1)\sqrt{\frac{\theta}{\pi}}\right)^2} \text{ and} \tag{7.28}$$

$$\frac{\partial q_2}{\partial b} = \frac{1 + k - t}{\left(1 - b - (k + 1)\sqrt{\frac{\theta}{\pi}}\right)^2} \tag{7.29}$$

These are always positive, provided $t < 1+k$. In addition, it can also be shown that the first partial derivatives of q_1 and q_2 with respect to k are positive. They are:

$$\frac{\partial q_1}{\partial k} = \frac{1 - b + t\sqrt{\frac{\theta}{\pi}}}{\left(1 - b + (k + 1)\sqrt{\frac{\theta}{\pi}}\right)^2} \text{ and} \tag{7.30}$$

$$\frac{\partial q_2}{\partial k} = \frac{1 - b - t\sqrt{\frac{\theta}{\pi}}}{\left(1 - b - (k + 1)\sqrt{\frac{\theta}{\pi}}\right)^2} \tag{7.31}$$

The equations (7.30) and (7.31) are always positive if $1 \geq b + t\sqrt{\frac{\theta}{\pi}}$.

Interesting consequences appear, when θ and π, the elasticities of producing and fighting, or to put it differently, the impact of a marginal change of the amount of production and fighting activity on the output, are considered.

In the case of the "good" equilibrium q_1 (where q is low), an increase in θ decreases q (the partial derivative of q with respect to θ is always negative). This seems intuitive for a situation in which incentives work properly. By contrast, for the "bad" equilibrium q_2, the so-called "fighting warlords trap," a greater value of θ actually increases q (the partial derivative of q with respect to θ is always positive). The equilibrium value q_2 is a "high" conflict outcome, where a great proportion of the population has an incentive to engage in fighting rather than producing through more conventional means. This means that when fighting is generalized in our model, even an increase in the elasticity of traditional production will not only leave the situation unchanged but will push an even higher proportion of the population into fighting. The society in question is then caught in what can be called a "fighting warlords trap."

However this process has a limit which is given by the ratio $\frac{\theta}{\pi}$. If θ is greater than π, then the denominator of the fraction which determines q_2 becomes negative and thus q_2 itself is negative, which contradicts our assumptions. Thus, if $\theta > \pi$ only the q_1 solution is possible. The ratio $\frac{\theta}{\pi}$ constitutes thus a bifurcation which establishes the possibility of such a "fighting warlords trap." Increasing θ substantially through better internalization of the natural resource externality or greater capacity to produce without fighting will make the "warlord trap" equilibrium impossible.

Thus, the higher the profits made with natural resources under a stable political system regime are relative to those made under a system of competing warlords, the less likely is the latter to occur. Also a higher value of the regular production (exclusive of natural resources) makes the emergence of a liberal democracy more likely.

Further, higher probabilities of an international cartel for the natural resource, *Pm*, and of an operating property rights protection and rule of law system, *Pp*, increase the likelihood of a liberal democracy outcome by increasing x and y in equation (7.19). On the other hand, higher immediate gains from fighting, b, and higher initial commitments for producing, k, increase the risk of civil war.

If the immediate gains from natural resources, b, have a clearly negative impact on democratization and the establishment of the rule of law, the impact of π depends on the values of several other parameters. To deal with those, recall that equation (7.19) expresses θ in terms of $\pi\theta = \pi(1 - \varphi) + y$.

This relation illustrates the idea that if the gains of the natural resource exploitation technology under a regime of warlordism, π, are bigger than the gains of production in a stable political system, θ, it is because of the bigger quantity of natural resources exploited, due to overuse.

Clearly, these bigger gains from the warlordism exploitation technology are not sustainable in the long-run because of the negative impact of over-exploitation. From an evolutionary point of view the gain from exploiting natural resources, π, should approach zero in the long run.

It is interesting to see what the implications of extreme values of π are on the level of q. If we replace θ by its value defined in relation (7.19) we get the following equations:

$$q_1 = \frac{1 - t + k}{1 - b + \sqrt{\frac{\pi(1 - z + xE) + y}{\pi}}(1 + k)} \tag{7.32}$$

$$q_2 = \frac{1 - t + k}{1 - b - \sqrt{\frac{\pi(1 - z + xE) + y}{\pi}}(1 + k)} \tag{7.33}$$

For a very small q, we get, in the square root found in the denominator of the above fractions, almost just the standard (as opposed to the resource) production, y, divided by a very small number, which results in the value of the square root becoming increasingly large. We have thus:

$$\lim_{\pi \to 0} q = 0 \tag{7.34}$$

By contrast, as π approaches infinity, y/π becomes very small within the square root, which leaves:

$$\lim_{\pi\to\infty} q = \frac{1 - t + k}{(1 - b) \pm \sqrt{(1 - z + xE)}\,(1 + k)} \qquad (7.35)$$

Thus, within the framework of the present model, a very low level of natural resources decreases the risk of a civil war outcome to close to zero, whereas for medium and high levels of natural resources we obtain higher levels of q. But the relationship between π and q is not monotonic. These implications are in accord with the empirical findings of Collier and Hoeffler (1998).

The resulting ambiguity could indicate that too huge an abundance of natural resources has a negative impact on political stability and development if the resources are easily accessible (high b). If taking full benefits from the natural endowments requires an important investment (low b), as is for example the case for oil, the risk of civil war is smaller. This could explain why most of the oil-producing countries have more or less stable regimes despite huge amounts of natural endowments.[17] However, the fact that we get multiple equilibria is an interesting feature of the present model. It indicates that it might be possible for a society to get stuck in a "fighting trap," escape from which requires specific policy measures and possibly international cooperation.

We can see that a pure "stable political system" equilibrium with a low level of fighting is only feasible if the additional gains from such a regime are more important than the commitment required in terms of the initial investment of producing, k, and the opportunity cost of the immediate gain of becoming a fighter or a bandit, b. In other words, a democratic society can only stay peaceful and stable if it offers a perspective for the future, a kind of "American Dream" to its members. This is the case in a meritocratic society in which higher education and job opportunities are available for anybody who is willing to work hard enough to succeed. Conversely, if the expected gains of being honest are smaller than the immediate gains of being a criminal (or fighter), people tend to become criminals.[18]

By and large, we can see that overexploitation of natural resources is, among other factors, due to the impact of the absence of an international cartel and to a lack of property rights protection. Both problems are enhanced by warlord competition within a society, which up to a certain point is more likely to occur in areas where big quantities (or highly valued amounts) of natural endowments are easily accessible. Essentially, we have to deal with a vicious circle of natural resources leading to fighting activity, which leads to an overuse of natural resources, where the profits made are used for further fighting and so on.

How do these findings link up with population dynamics? The crucial relationship is again the equation that relates the choice to produce or to fight to natural resource use and production:

$$\theta = \pi(1 - \varphi) + y$$

If φ, which expresses the degree to which the society is unregulated and property rights are left unprotected, is assimilated to the difference between the anarchic equilibrium and the Pareto optimal situation established in our initial model we have a way to analyze whether population growth under the anarchic equilibrium also increases the value of q, the optimal choice for fighting as opposed to producing. Such an analysis will show if our model which represents the choice between fighting or producing is capable of expressing the notion that an increase in population under anarchic conditions leads to a greater proportion of choices to join warlords instead of producing. As established before, the optimal choice leads to two values in terms of the proportion of activities devoted to fighting as opposed to producing: a high one, a "bad" equilibrium; and a low one, a "good" equilibrium outcome. We will concentrate our analysis on the high one and ask whether an increase in N leads to an increase in q_2. Quite clearly this is the case under the specific conditions that $N > 1$ which is obvious and the ordinary productive activity $y > \theta$. This condition implies furthermore that:

$$\varphi = \sqrt{p^s}\frac{1 + \sqrt{N}(\sqrt{N} - 2)}{N} > 1 \text{ for } \pi > 0.$$

What this means is that overproducing and overexploitation of natural resources has to take place in order for a demographic increase to eventually produce more fighting activities. In other words all population increases do not lead to these detrimental results. According to our model, only those that are linked to resource overuse and depletion are likely to generate civil wars and warlord societies.

DYNAMIC ASPECTS

The dynamics of open access or unregulated social systems can be conceived as the interaction between a resource stock and a population that uses it. If the resource stock is finite it will eventually be depleted. It is however possible to deplete it at an optimal rate which should allow timely

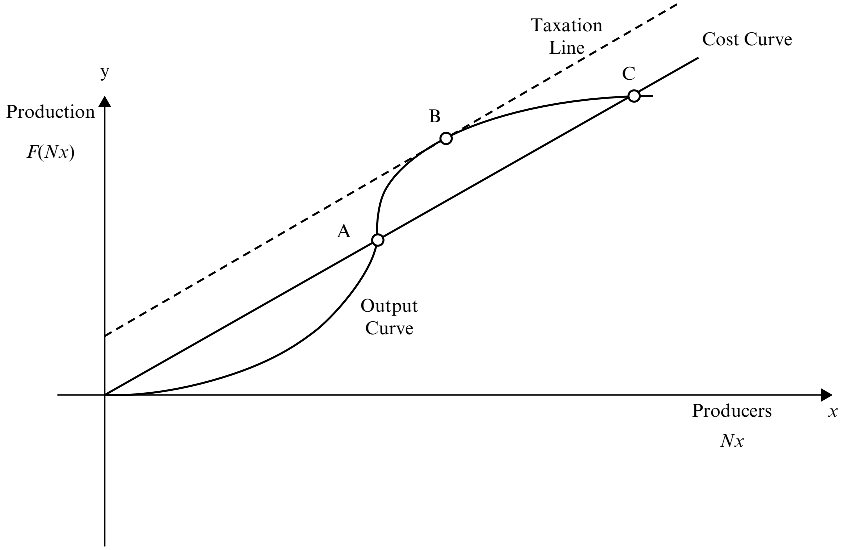


Figure 7.2 Production and costs as a function of number of producers

switches to the use of other resources. If the resource is renewable, the particular dynamics of its evolution will have to be taken into account, especially given the fact that the population will use it. Let us imagine that in a simple production system that relies on a renewable resource (such as fishing), the cumulative production can be represented by an S-shaped curve, while cumulative production costs can be expressed as a straight line if constant unit costs per individual producer are assumed. The production issue in an open access system can be illustrated by the graph in Figure 7.2.

Figure 7.2 shows that up to A, marginal productivity is higher than average productivity but that the output curve is lower than the cost curve. In other words there is an initial investment to be made in terms of sunk costs in order to reap the benefits of greater outputs, which are achieved after point A. The problem, in terms of a collective good creation, is to convince (or to force) enough producers to participate in view of the condition that average product (which motivates producers always in a collective good situation) is lower than marginal product.

After point A, the problem is opposite in the case of Figure 7.2.[19] Output outstrips costs and surpluses are generated which reach their maximum at point B where the slope of the output curve is equal to the marginal cost. If more and more population producers with their inputs are allowed into the process, the maximum at point B is passed, the whole surplus is dissipated at point C, and one is faced with the familiar tragedy of the commons. It can be noticed that if a Pigouvian tax is imposed on production proportional to costs then maximum profit can be reached at point B, which can then be interpreted as a tax equilibrium.

In the absence of taxation and regulation however we can formulate the above considerations in terms of two dynamic differential equations, which describe, firstly, the evolution of the resource stock with the basic assumption that it grows subject to its own natural dynamics minus what is being produced (that is, extracted from it):

$$\frac{dz}{dt} = H(z) - F(z, Nx) \tag{7.36}$$

where z is a variable that represents the resource stock and $F(z,Nx)$ a cumulative production function similar to the one in Figure 7.2 which takes into account the amount of productive input x provided by N users so that one has Nx.

Secondly, the evolution of the number of inputs x, which is proportional to profit, defined as revenue minus cost, a dynamic that reflects exactly the process leading to surplus dissipation in Figure 7.2:

$$\frac{dNx}{dt} = \mu q(F(z, Nx) - pNx) \qquad (7.37)^{20}$$

where x again represents input per producer, $F(z, Nx)$, a production function, q the price of the product and p the cost of a unit of input and where μ is an adjustment constant between revenue and cost in terms of additional inputs x. In other words, equation (7.37) tells us that new entrants (represented here by more inputs) will move into this productive activity as long as profits can be made. This occurs of course because no limits are placed on engaging in that activity exactly as assumed also in Figure 7.2. Equations (7.36) and (7.37) are in fact general forms of the Lotka–Volterra equations which describe in mathematical terms evolutions of prey and predator populations. In general if one deals with a subsistence type economy, we can consider a relatively fixed input so that we can set $x = 1$ such that only the dynamics of N, the population matter. Clearly, left to themselves these dynamics will usually lead to resource exhaustion and hence population collapse. Such population collapses are also often preceded by conflicts, as for instance in the case of Easter Island.[21] We can assume, based upon the theoretical reasoning included in our previous model, that such conflicts erupt when individuals find it more attractive to appropriate by force rather than to produce. We can readily see how a combination of the dynamic formulations suggested above and the static models developed previously can account for the empirical evolutions of collapsing or severely conflict ridden societies (such as for instance Rwanda). An illustration of a conflict situation can easily be derived from the above relations. Assume that a resource stock is the object of a competition between two groups which we can designate as populations N and M. Their respective production functions based on the resource z can now be designated as $F(z, N,M)$ for population N and $G(z, M, N)$ for population M. We can assume that the productive activities of either N or M might interfere with each other (usually negatively) and thus the production functions should include the size of the other population as an input. Keeping our previous assumptions, we have:

$$\frac{dz}{dt} = H(z) - F(z,N,M) - G(z,M,N) \tag{7.38}$$

And respectively:

$$\frac{dN}{dt} = \mu q(F(z,N,M) - pN) \text{ and} \tag{7.39}$$

$$\frac{dM}{dt} = \nu k(G(z,M,N) - sM) \tag{7.40}$$

We assume that ν and k stand for the second population M for their speed of adjustment and their price respectively. From equation (7.38), we can now replace $G(z, M)$ and $F(z, N)$ by their values and introduce these into equations (7.39) and (7.40) which gives:

$$\frac{dN}{dt} = \mu q\left(H(z) - \frac{dz}{dt} - G(z,M,N) - pN\right) \tag{7.41}$$

and

$$\frac{dM}{dt} = \nu k\left(H(z) - \frac{dz}{dt} - F(z,N,M) - sM\right) \tag{7.42}$$

We can now make the following assumptions connected to conflict. Let us assume that the resource stock z is changed from a variable increasing (or decreasing) quantity to a fixed amount z^*. As a result we can reinterpret $H(z^*)$ as a fixed amount of z^* available for use. Since z^* is fixed, it makes sense to posit that:

$$\frac{dz}{dt} = 0$$

We are then left with the following differential equations:

$$\frac{dN}{dt} = -\mu q G(z^*,M,N) + \mu q[H(z^*) - pN] \text{ and} \tag{7.43}$$

$$\frac{dM}{dt} = -\nu k F(z^*,N,M) + \nu k[H(z^*) - sM] \tag{7.44}$$

If now $G(z^*, M, N)$ and $F(z^*, N, M)$ are Cobb–Douglas type production functions: $M^\alpha N^\beta$, then (7.43) and (7.44) become:

$$\frac{dN}{dt} = -\mu q M^\alpha N^\beta + \mu q[H(z^*) - pN] \text{ and} \tag{7.45}$$

$$\frac{dM}{dt} = -\nu k N^\delta M^\gamma + \nu k[H(z^*) - sM] \tag{7.46}$$

These are generalized forms of the dynamic Lanchester (1916) concentration or dispersion combat equations which describe the evolution of two population groups (or armed forces) opposed to each other in a violent confrontation. In particular, when $\beta = \gamma = 0$, $\alpha = \beta = 1$, we get a form of Lanchester's square law, where troop concentration leads to more than proportional casualties on enemy forces and when $\beta = \gamma = 1$, $\alpha = \beta = 1$, we get a form of Lanchester's linear law where dispersed forms of combat lead to proportional casualties on the other side. We can therefore establish how competition for a resource can lead directly to an armed conflict when the resource is finite. We should thus be able to apply some forms of the Lanchester combat equations to conflicts connected to resource scarcities.

EMPIRICAL ANALYSIS

These latter considerations lead to the question of the empirical evidence behind our formulations. While our ultimate goal is to simulate conflicts that might occur as a result of resource overuse in order to permit predictions of future confrontations, we will present at first some cross-sectional empirical data that support our ideas. A dynamic simulation of a resource-based conflict will then be carried out. For this we chose the case of Rwanda where between 500 000 and 800 000 people were killed in 1994.

The cross-sectional research should at least provide some evidence for the following. First, if property rights and regulatory frameworks work properly to protect resources, demographic incentives should work correctly and not lead to uncontrolled expansion. In particular, the desired level of children per household should be shown to adjust to the perspective of achieving a given degree of wealth in the future. Second, demographic variables and political regime characteristics should be linked. Third, linkages between some demographic and geographic variables and internal conflicts should be demonstrated.

There is some anecdotal evidence for the first type of linkage in particular in the demographic history of France. The introduction of well-defined property rights and a civil code as a result of the French revolution and Napoleon's reforms seem to have led the country into an era characterized by both the demographic transition and slow population growth even though France remained essentially an agricultural economy. More systematic analyses were carried out in the Swiss Alps by Ellen Wiegandt (1977; see Appendix 7.1 below) who showed, with the help of statistical investigations, that parental wealth was a strong predictor of the number of children. Relatively wealthy parents had more children than poorer ones. Clearly, if this is the case, incentives are present that internalize the costs of having children since family size will be commensurate with wealth or landed property and thus population will be prevented from expanding in an uncontrolled way.

The second linkage, between political and demographic regimes, also receives empirical support from the work of Rana Crevier (2005) who undertook linear multivariate regressions showing the relationship between type of regime (more or less autocratic) and demographic variables. The most significant results are reproduced in Appendix 7.2. They point quite clearly to the importance of one key demographic variable, the fertility rates, in explaining regime type. Crevier shows that the higher the fertility rate, the more autocratic the regime. Obviously other variables such as religion and the general status of women within the given society also play a role. In general, higher status for women is correlated with less autocratic regimes.

The third relationship between geography and demography has been examined more closely with the help of the Uppsala–PRIO (Peace Research Institute Oslo) internal conflict data set by Sébastien di Iorio (2005). Here, the density of population related to the surface of arable land seems to be the best predictor of internal conflict (results in Appendix 7.3).

Putting these empirically based relationships together, we can hypothesize that there may even be a temporal sequence implied by these linkages. In a first stage, strong demographic expansion would lead to political difficulties that in turn lead to autocratic regimes. In a second, these autocratic regimes would eventually collapse as the children produced by the demographic expansion reach adulthood and contribute to an excessive population density. The scarcities resulting from population pressure on resources could lead to civil strife, ultimately overturning the regime.

Rwanda represents a case where such a sequence might have been at work. We will now analyze it.

Rwanda has had a very difficult history of social and economic relations even before independence in 1962. Tutsi minority resistance to the government was at first unsuccessful because the government of President Juvenal Habyarimana was able to promote agriculture, the main economic activity of the country, through substantive extensions of the areas under cultivation at the expense of marshes and forests but also through the reoccupation of plots abandoned by segments of the fleeing Tutsi population. Eventually this policy reached its limits and was especially unsuccessful at checking population growth. Rwandan agriculture has always been prosperous thanks to favorable climatic and ecological conditions. As noted by Prunier (1995), "the whole country looks to some degree like a gigantic garden, meticulously tended, almost manicured resembling[22] more the Indonesian or Filipino paddy fields than the loose extensive agricultural pattern of many African landscapes." The agricultural development strategies implemented by the government bear a considerable responsibility for the scarcities that occurred from the mid-1980s onward. Indeed, caloric production per capita increased by 22 percent between 1965 and 1982, only to fall back to its 1960s level in the last decade of the century (André and Platteau 1998). To the extent that the per capita production of food crops followed the same pattern (ibid.), one must question the strategy set up by the Rwandese authorities. In particular, the relation linking the abundance of natural resources and the form of social and political controls it implied seems critical to understand the dramatic events that took place in 1994.

Two policies that were put into place stand out. First, the government's strategy mainly promoted developing new land and decreasing fallow land, resulting in increasing returns being based overwhelmingly on land extension (by clearing forests and draining marshes). The limits to such a strategy were reached as population densities eventually converged across the country, as compared to the wide disparities that prevailed until recent times (André and Platteau 1998). Moreover, the production technology remained highly traditional and faced severe problems of erosion and soil mining (due to the utilization of forested and pasture land for cultivation). The second aspect is the emphasis put on food self-sufficiency, illustrated by the fact that the country's per capita exports are among the lowest in the world (André and Platteau 1998), proscribing the abandonment of low-yielding, traditional crops.[23] Thus, in the face of a sustained population growth of well over 3 percent per year, it is not so surprising that famines reappeared by the late 1980s in several areas (André and Platteau 1998).

Land in Rwanda was mostly communally owned. Well-defined property rights were never established and the population was led to believe that the government and not individuals was the provider of land. In fact, in Rwanda, given official policies, the government was probably seen as the provider of land of last resort, especially if more could be appropriated from weaker minority groups. Given such expectations, demographic incentives worked in the wrong direction: the population was led to believe that the possibilities to cultivate land were limitless and thus more children were produced. In accordance with Demsetz's ideas, a land market eventually developed when population growth and density led to land scarcities. Such a market has seen a rapid increase in activities in the area studied by André and Platteau.[24] They report that although parcels of land cannot be sold under a critical threshold of 2 hectares, transactions increased substantially. This implied a wide set of consequences similar to what one would find in a black market: inequalities in access to land rose, and conflicts among family members over inheritance increased dramatically, along with disputes over land. Worth noting is the fact that "many land parcels were sold under distress conditions and purchased by people with regular non agricultural income"(André and Platteau 1998: 28), which shows that those who did not have the possibility to earn additional sources of income fell into a sort of poverty trap: by selling their land they lost the ability to get out of poverty. In addition this black or grey form of buying and selling land implied the erosion of traditions and customary rules, because, as a good, it became independent of such notions. Thus, one can see that scarcities in resources have tended to magnify inequalities through (illegal) market operations.

Rwanda has been characterized by a strong authoritarian tradition coupled with the clan organization of power (Prunier 1995). The key people surrounding President Habyarimana (whose assassination is considered to have set in motion the genocide) were all members of the same clan or belonged to the same region (Prunier 1995).

The organizers of the coup d'état formed a small group belonging to the regime's political, military, and economic elite, who had once been close to the president and whose goal was to stop democratization (Prunier 1995). While they benefited from the involvement of the Presidential Guard – to the extent that it provided a highly organized group capable of targeting selected individuals and groupings – it is clear that the main agents of the genocide were the peasants themselves. As Prunier puts it, "their [the organizers'] efficiency in carrying out the killings proves that these had been planned well in advance . . . but it would not have been enough had it not been for two other factors: the capacity to recruit fairly large numbers of people as actual killers and the moral support and approbation of a large segment – possibly a majority of the population." Thus, the costs of organizing and sustaining an uprising had been considerably reduced by:

(1) the scarcities of land and opportunities of off-farm income; and (2) discursive strategies that served to mobilize high numbers of poor, unemployed and uneducated young men without any prospect of inheriting land. The capacity of the state to address the demands for relief coming from the bottom of society was low, since per capita gross domestic product (GDP) fell by 34 percent between 1986–90 and 1994–98, whereas the price of food rose by 21.49 percent in 1994–98. It should be noted that the prize coveted by the plotters was political power, whereas peasants acted out of strong grievances: "all these people who were about to be killed had land and at times cows. And somebody had to get these lands and these cows after the owners' death" (Prunier 1995). Hence, the issue of ethnicity should be considered more as an instrument in the hands of decision-makers than a cause of the conflict. The underlying and ultimate reason is more likely to be found in the combination of resource scarcities and declining state power. Indeed, one should note that the Hutu and Tutsi are not tribes but social groups inside the same culture (Prunier 1995). This had allowed mixed marriages and prevented the separation of dwellings. Thus, people had lived together and side by side all the time. The fact that "intra-ethnic" killings nevertheless took place is an indicator of the political (as opposed to ethnic) feature of the crisis.

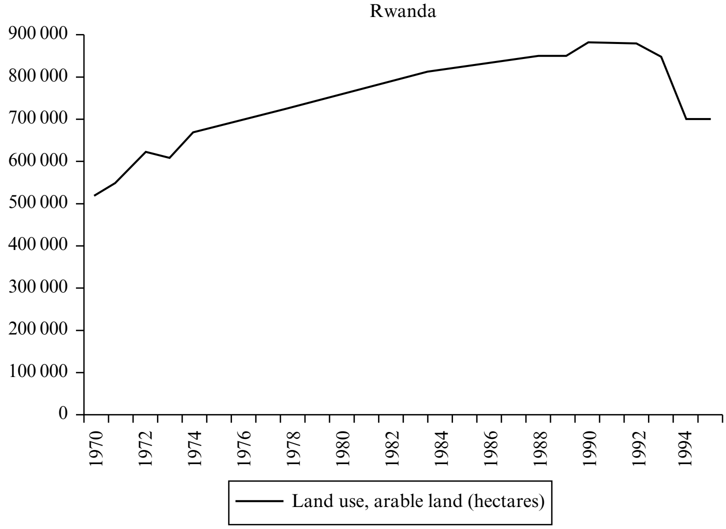
SIMULATING THE CONFLICT AND GENOCIDE

To summarize the scenario suggested by this historical narrative, we can say that the conditions set up at independence led to expectations of increased land availability either through appropriations from minority groups or through gain from marsh draining and deforestation. As a result, birth rates exploded and a demographic expansion took place. These trends are illustrated in the following graphs. Firstly, Figure 7.3 shows the increase in available arable land as the Rwandan government cleared marshes and forests to expand the total area. However this expansion comes to an end in the late 1980s and even a decline starts taking place in the early 1990s.

The demographic expansion is visible from Figures 7.4 and 7.5 which show population increase as well as the persistence of a high population growth rate until 1994.

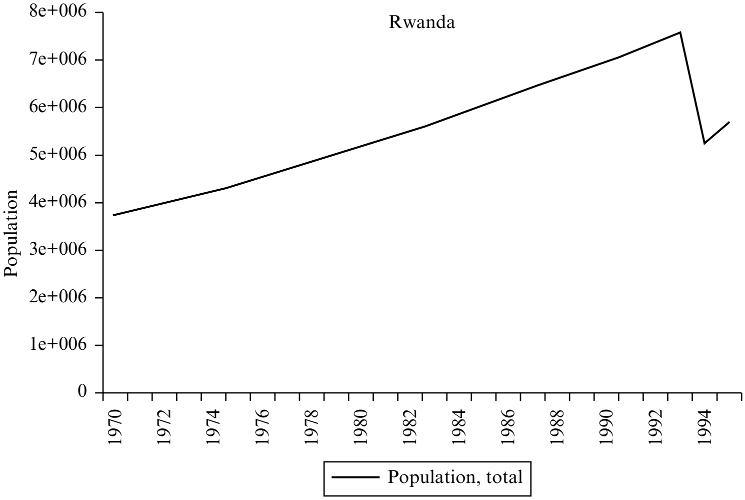
A last illustration of these trends can be presented in the form of the population density of rural areas which also increases considerably from 1970 on (Figure 7.6).

Given these trends and the kinds of incentives that prevail, land resources are eventually all used up and a violent confrontation between two competing groups, which can be described in terms of Lanchester



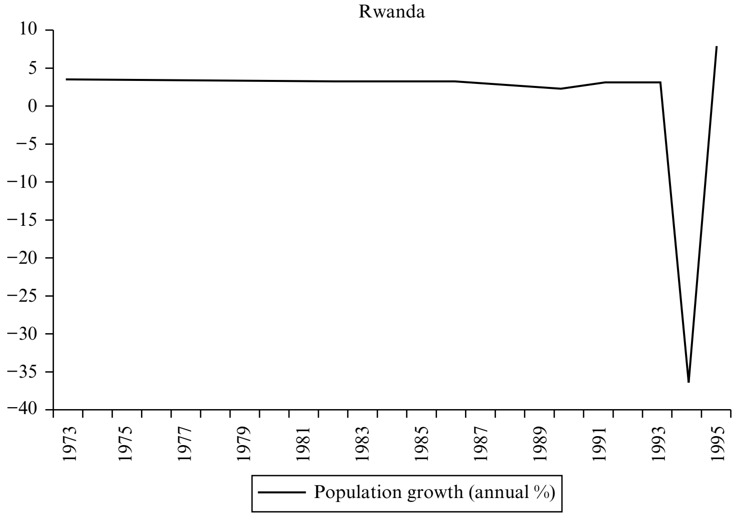
Source: World Bank.

Figure 7.3 Total arable land surface in Rwanda



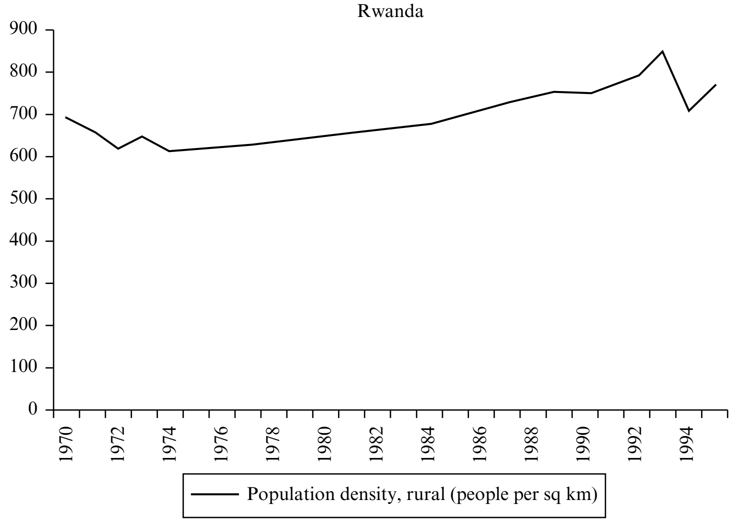
Source: World Bank.

Figure 7.4 Population expansion in Rwanda, 1970–1995



Source: World Bank.

Figure 7.5 Population growth rate in Rwanda, 1970–95



Source: World Bank.

Figure 7.6 Population density in rural areas, Rwanda 1970–1995 combat equations, will start. The work presented here is not the first to use Lanchester relations to simulate the situation in Rwanda, from about 1990 when fighting between (mostly) Tutsi rebels and (mostly) Hutu Rwandan government troops[25] intensified, to 1994 to 1995 when the Rwandan genocide took place.[26]

In contrast to other attempts, our work relies on the considerations introduced by Deitchman (1962) in an article that develops a theory of the application of the Lanchester relations to guerrilla warfare. In his theory of combat, Lanchester evoked the two already discussed notions of concentrated and dispersed fighting. Deitchman (1962) presents the strategic situation of guerrilla fighters in the following way. The guerrillas are usually dispersed over a territory which forces government or occupying forces to attack them in a dispersed way, for instance by blanketing a whole region with search-and-destroy missions, artillery fire, or even massive bombings. Guerrilla forces on the other hand can attack targeted governmental or occupying forces in a concentrated way, which they do mostly by using ambushes. In addition, guerrilla fighters depend largely for their survival and the continuation of their efforts on the existence of a part of a population that supports them and provides them with a base for recruitment purposes. There is thus a fundamental asymmetry between the guerrillas, who fight in a concentrated way, and the government or occupying troops that have to undertake dispersed combat operations. This situation has two important consequences. On the one hand, being forced to fight in a dispersed manner, government or occupying forces will inevitably hit civilians who have nothing to do with the guerillas, and exert some form of "collective punishment." This will often turn the population that the guerrillas claim to represent even more against the government or the occupier.[27] Another way to weaken guerrilla forces is to shrink the fraction of the population that supports them through violent action up to and including genocide. Such behavior aims either at intimidating and scaring the population close to the rebels and eventually when the genocide stage is reached to diminish the size of the group who might join guerrilla forces. What might trigger such extreme actions? In our view essentially the fear that otherwise rebel groups will get even stronger and take power. We can thus establish the following assumptions for our combat and "Genocide" scenario.

The Rwanda situation can be described as a typical Deitchman guerrilla combat model where Tutsi rebels are dispersed but fight the government troops in a concentrated fashion through ambushes. They recruit from about 10 percent of the total Rwandan Tutsi population (estimated at about 650 000 in 1990 as opposed to 6 800 000 Hutus). Their initial size is estimated from various sources, especially Jermann et al. (1999), at 5000 in the beginning of 1990. Government troops (mostly Hutus) are estimated at 40 000 and recruitment possibilities for them at about 100 men per week. Tutsi rebels can inflict much heavier losses on government troops than vice versa.

The following scenario may be envisaged from 1990 on, consistent with our earlier narratives. The resource crisis due to the overall population expansion leads the (Hutu-based) government of President Juvenal Habyrimana to put more pressure on Tutsi-controlled land. This leads to an increase in recruits for the Tutsi rebel army which grows rapidly in size. Given the heavy losses this force can inflict upon government troops, parity with the Hutu forces is reached at the end of 1992 and Tutsi fighters continue to deplete them and achieve superiority. Maximum superiority is achieved for Tutsi forces in the spring of 1994. This can be considered in a way as a triggering event for the genocide of the Tutsis and moderate Hutus, which begins in April 1994. In other words, it is assumed here that what triggers the genocide is an attempt on the part of government forces to reduce their differential with the Tutsi fighters. In that sense, the bombing of Rwanda's President Habyarimana's plane on April 6, the apparent triggering event, manifested (whether it was due to Tutsis or extremist Hutus is still unclear) the weakness and loss of control at the top. This then, in the view of Hutu extremist and government forces, called for drastic action to reduce the recruitment base of the Tutsi fighters.

Based upon these assumptions, the following Lanchester-type relations can be set up:

$$\frac{dtutsif}{dt} = par1pottr - par2\,gov\;tutsif$$

$$\frac{dgov}{dt} = -\,par3\,tutsif + par4$$

$$\frac{dpott}{dt} = par5pott - par6\;par7govpott^{28}$$

$$pottr = 0.1pott$$

$$par6 = 1\;if\,(par8gov - tutsif) < 0$$

$$0\;otherwise$$

where *tutsif* stands for Tutsi fighters, *gov* for government forces, *pott* for Tutsi population, *pottr* for recruitment base from Tutsi population. *par*1 . . . *par*8 represent various constant parameters. Three of these deserve further explanation: *par*4 represents the drafting of 100 people per week by the government army which was initially trained and supplied by French forces present in the country; *par*5 is the rate of increase of the Rwandan population which can be calculated from demographic data up to 1994; *par*6 represents a logical (Boolean) variable with value 1 when the critical differential mentioned above, between government forces and Tutsi fighters, is reached and 0 otherwise. This critical value has been estimated on empirical grounds at the point when Tutsi fighters are equivalent in numbers to 2.5 government forces. *par*6 represents in some sense the "genocide" parameter.

One can notice that the above differential equations constitute a "typical" Deitchman asymmetric form of the original Lanchester equations with reinforcements where the guerilla (Tutsi) fighters are attacked by government troops in a dispersed way whereas Tutsi forces fight in a concentrated fashion. This relatively simple model gives then the following results expressed in graphical form in Figure 7.7.

It has to be pointed out here that reliable combat data for Rwanda are extremely difficult to get. In particular, a monthly evolution of the number of fighters is practically impossible to evaluate. Nevertheless, the swiftness

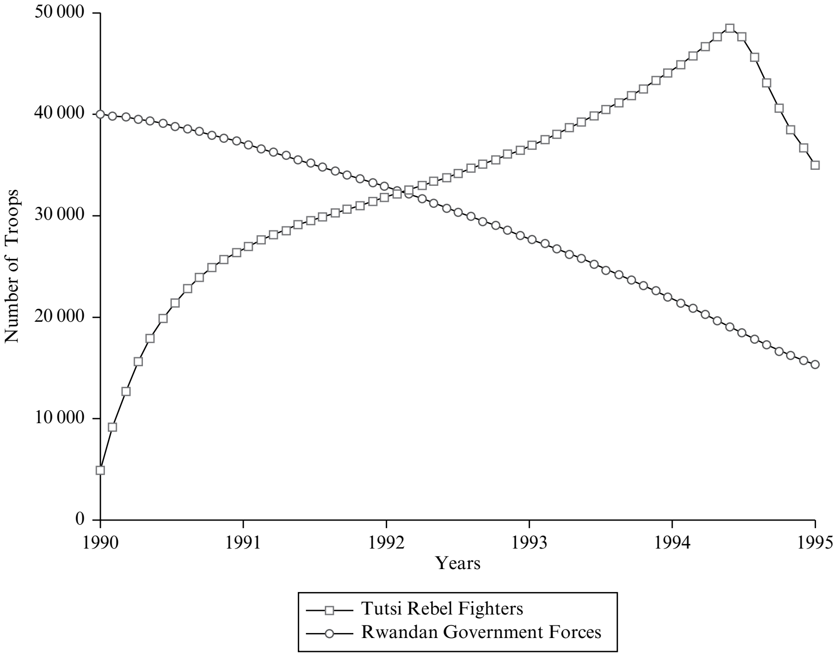


Figure 7.7 Evolution of numbers of Tutsi rebels and Rwandan government forces

of the Tutsi rebel response after the start of the genocide suggests a relatively effective and superior military force to which allies from Uganda, Burundi and the Congo might have contributed. This conclusion derives from our model and is represented in the graph of Figure 7.7. One should also notice that the 2.5:1 superiority of the Tutsis which triggers the genocide is close to a 3 to 1 ratio which traditional analysts link to a victorious outcome for the force that achieves it. Despite the genocide (and maybe because of it) Tutsi superiority is still there at the end of 1994, explaining ultimate Tutsi victory and conquest of power.

Some reliable data exists only for the pace of the genocide and its final magnitude of about 500 000 people. Figure 7.8 represents what we can reproduce here solely with the help of our model and without any ad hoc assumption based upon exogenous factors. However more empirical investigations will have to be carried out as more data becomes available.

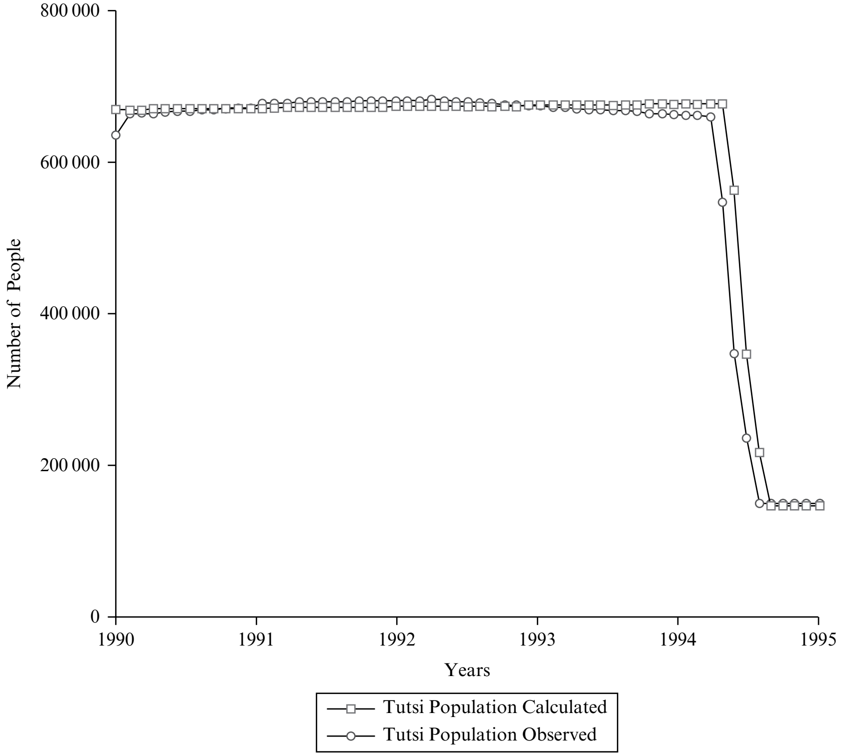


Figure 7.8 The Rwandan genocide: Tutsi population calculated and observed

CONCLUSION

We have tried here to shed some light on the complex linkages between environmental conditions and trends and the issue of conflict. Through an analysis of some basic aspects of the relationships between natural resources, demography and institutions and an analysis of the existing literature, the Homer–Dixon hypothesis of a direct causal linkage between environmental scarcities and conflict was rejected. However, the importance of crucial institutional settings was emphasized. The "political tragedy" affects the "economic tragedy" through the negative impact of conflict on property rights protection, which can lead to overexploitation. The economic tragedy is enhanced by the "demographic tragedy" which is also due to the absence of well-defined property rights and contract enforcement. The economic "tragedy of the commons" influences the risk of conflict through the externality losses from resource extraction. As in the case of mineral resources such as diamonds or oil, the potential short- and medium-run gains of extraction are immense, but the externality losses are small because exclusion is possible. Such goods make it profitable for the elite to launch and then stick to a suboptimal "warlordism" production method. For non-exclusive and renewable resources such as tropical wood or fish, the main problem is overuse. These goods, however, do not appear to have such a harmful impact on political conflict, with the exception of situations like Rwanda where land distribution itself becomes a major issue. Because the main problem in the end is not environmental but institutional, mostly institutional strategies and policies should have the biggest effect in the avoidance of outcomes where environmental scarcities, together with demographic expansion and crowding, lead to violence and warlord-dominated societies. This does not take away from the importance of technical improvements to agriculture such as the development of more drought-resistant crops or the building of dikes and levees as well as of reservoirs, both to prevent floods and to store water, in order to ensure agricultural productivity at a high level despite climate change. The biggest task however is to maintain cooperation and prevent conflict in societies most vulnerable to change. This requires specific policy measures such as worldwide agricultural liberalization to enhance the value of farm-produced output and to encourage the institution and protection of well-defined property rights. In addition such measures as cartel encouragement for scarce and valued natural resources, protection of existing property rights, reduction of the costs of agricultural and industrial production in the developing and organizing of embargoes against warlord-type production can help set societies on the path of the rule of law. These are formidable but not insurmountable tasks, especially if they are undertaken on the basis of a large consensus by democratic industrialized states.

Above all, it is necessary in the future to identify, so that they may be avoided, the positive feedback mechanisms triggered by environmental scarcities that can come about either from an increase in population or the overuse of resources. These are the mechanisms that can lead to major conflicts within and between societies and that should be curtailed. We have been trying to present here some of the empirical analyses and methodologies that could make, in addition to the theoretical considerations we outlined above, these trends toward positive feedback mechanisms more identifiable.

NOTES

1. The S curve analysis and its application to conflict has been initiated by Dacey (1998; Dacey and Gallant 1997). The formulation used here for the critical risk ratio is based on losses, whereas the formulation used in Dacey is based on gains. These formulations are logically equivalent.
2. In other words, one can never completely substitute private goods for collective goods, and vice versa.
3. For example, the Carthaginians before Hannibal and the Romans in the late stages of the Western Empire were racketed by mercenaries as a result of political turmoil and the decline of the state and imperial organization.
4. One should here remember that Pareto optimality does not mean equity. Pareto optimality can result in a very unequal distribution of power and wealth in a society.
5. Dasgupta and Heal (1979: 54) point out two cases where tax equilibria exist whereas Lindahl equilibria do not. Moreover, the two equilibria are equivalent only if institutional costs are zero, a most unlikely situation.
6. Tilly in particular, emphasizes this point.
7. This point is made by Pirenne (1980 [1937]): the reduction in taxable trade, both domestic and international, due to the Moslem conquests and raids on the Mediterranean coastline brought the Frankish Merovingian Dynasty down and resulted in the new Carolingian dynasty. Further invasions and transaction reductions signaled the quick end of this new dynasty and its replacement by Western European feudalism.
8. After the British economist Alfred Pigou (1932).
9. If $t < 0$, the subsidy is in fact a tax and if $\tau < 0$, the lump sum tax becomes a subsidy.
10. For an alternative treatment see Skaperdas and Syropoulos (1996).
11. The concept which we call "fighting" in the present contribution is similar (and can be regarded as interchangeable) to the one of "appropriative activities," as it is sometimes called in the conflict literature.
12. It would surely also have been interesting to focus on learning issues in a dynamic framework, or to put more emphasis on the interaction between the different agents. However, in the present contribution the emphasis is put on the link between natural resources and the fighting–producing decision.
13. As opposed to the previous utility function which referred to the choice between public and private goods, this one refers to the choice between fighting and producing and is thus labeled u_{pf}. The two utility functions are obviously linked, a fact that we will invoke below.
14. The framework of the constraint is inspired by Dasgupta and Heal's (1979) similar reasoning for the case of public goods.
15. We can see from this budget constraint how we could overcome the restriction posed in Assumption 6 and make our model necessary and sufficient for the explanation of warlord activities: the warlord is the one who organizes the taxation of resources to distribute the initial subsidy to fighters.

16. Empirical cases of such international cartels include the OPEC or the coffee cartel until the 1990s.
17. A sad exception is Angola.
18. Following a "rational choice" approach, we do not consider factors like social norms and conventions.
19. This is due to the particular shape of the output curve and the slope of the cost curve. A continuation of increasing returns after A is perfectly conceivable for a while even if the assumption of the S-shaped output curve is maintained.
20. This general formulation is due to Dasgupta and Heal (1979: 122, 134). Obviously if taxes corresponding to the scarcity rent of the resource and an "entry" fee to start using it are charged then the problem of overuse disappears. The dynamics of equations (7.36) and (7.37) are represented more explicitly in an article by Brander and Taylor (1998) describing sustainability problems on Easter Island over time. They exhibit a long-term (low-frequency) population resource cycle analogous to those suggested by Volterra (1931), Lotka (1925) or Kostizin (1937) for animal populations.
21. We refer again to Brander and Taylor (1998).
22. The purpose of this short comment is not to go through the complex process which led to the genocide. It rather aims at highlighting the influence of land scarcities and population growth on the emergence of the conflict.
23. As emphasized by André and Platteau (1998), most studies focus on productivity issues while neglecting the social impacts of the commercialization of agriculture.
24. One can reasonably generalize the findings of the study since the area under consideration, as one of the largest and most important, was particularly involved in the outburst of violence in 1994.
25. We are perfectly aware of the fact that both the rebels and the victims of the genocide included also so-called moderate Hutus, something that the literature we cite also points out. For the sake of convenience we will however refer to the rebels and victims as Tutsis and the government troops and killers as Hutus.
26. Work done by Jermann et al. (1999: 132–136) constitutes a first attempt to use this technique. However, their representation of the combat interaction is based on very ad hoc formulations driven by particular events which weaken the theoretical coherence of the Lanchester relations that they use without achieving a better rendition of actual events. Nevertheless their work is useful in providing an initial framework and some basic data.
27. On the other hand, if the population attributes the blame to the guerrillas, the government's popularity could then increase.
28. This whole system was simulated with the help of the SPARE dynamic simulation package developed at the Graduate Institute of International Studies, Geneva.

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APPENDIX 7.1 INHERITANCE AND DEMOGRAPHY IN THE SWISS ALPS, BY ELLEN WIEGANDT: STUDIES OF A SWISS AGRARIAN ALPINE COMMUNITY IN THE NINETEENTH CENTURY

Table 7A.1 Family size and wealth

	< 2% total wealth	> 2% total wealth	
Families < 4 children	23	6	29
Families > 4 children	8	18	26
	31	24	

Note: Yule's Q = 0.792 χ^2 Significance < 0.001.

Source: Weigandt (1977).

Table 7A.2 Regression of father's wealth – son's wealth as determined by father's wealth:regression summary

Degrees of freedom	R	R square
86	−0.75	0.56

Source: Weigandt (1977).

Table 7A.3 Regression of father's wealth – son's wealth as determined by father's wealth:coefficients

	Estimated value	Standard error	T value	Significance
Constant	1.07	0.19	5.75	< 0.0001
Father's wealth	−0.79	0.08	−10.42	< 0.0001

Source: Weigandt (1977).

APPENDIX 7.2 REGRESSION FOR ALL COUNTRIES THAT HAVE A MOSLEM POPULATION, BY RANA CREVIER

Table 7A.4 Model summary

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.849[a]	0.721	0.511	0.738

Note: a. Predictors: (Constant), unemployment rate FEMALE, GDP per capita (USD) 2003, total fertility rate, 2000-2005, percentage of population that belongs to any Islamic sect, school life expectancy (expected # of years of formal schooling)-FEMALES, PERCMEN

Source: Crevier (2005).

Table 7A.5 ANOVA[b]

ANOVA[b]

Model	Sum of Squares	df	Mean Square	F	Sig.
1 Regression	11.240	6	1.873	3.438	0.055[a]
Residual	4.360	8	0.545		
Total	15.600	14			

Notes:

a. Predictors: (Constant), unemployment rate FEMALE, GDP per capita (USD) 2003, total fertility rate, 2000-2005, percentage of population that belongs to any Islamic sect, school life expectancy (expected # of years of formal schooling)-FEMALES, PERCMEN

b. Dependent Variable: my freedom index

Source: Crevier (2005).

Table 7A.6 Coefficients[a]

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 (Constant)	14.557	6.124	0.885	2.377	0.045
percentage of population that belongs to any Islamic sect	5.425E-02	0.017		3.275	0.011
PERCMEN	–0.443	0.139	–1.763	–3.186	0.013
total fertility rate, 2000–2005	0.795	0.230	0.925	3.461	0.009
school life expectancy (expected # of years of formal	0.501	0.149	1.188	3.356	0.010
schooling)-FEMALES GDP per capita (USD) 2003	1.426E-04	0.000	1.211	2.437	0.041
unemployment rate FEMALE	–4.19E-02	0.027	–0.295	–1.532	0.164

Note: a. Dependent variable: my freedom index.

Source: Crevier (2005).

APPENDIX 7.3 RESULTS OF REGRESSIONS BETWEEN A VARIETY OF DENSITY VARIABLES AND INTERNAL STRIFE AS MEASURED BY THE UPSALA–PRIO DATASET, BY SÉBASTIEN DI IORIO

The results from our statistical model tend to support the claim that resource scarcities – as measured by population density relative to the productive surface – have an influence on the risk of armed conflict. The coefficient of this variable has a Wald statistic equal to 4.617 which is significant at the 0.05 level (95 percent confidence level). The whole model is significant at the 0.01 level according to the model Chi-square statistic. We see a positive relationship between population density and the risk of conflict, a unit increase in this variable produces a 1.091 increase in odds of conflict to occur. In this model, agriculture value added (that is, productivity of the agricultural sector) is not very robust but scores better in explaining conflict onset than gross domestic product (GDP) growth.

Table 7A.7 Variables in the equation

		B	S.E.	Wald	ddl	Signif.	Exp(B)
Etap 1(a)	Population_density_rural_people_per_sq#_km_of_arable_land	0.087	0.041	4.617	1	0.032	1.091
	Agriculture_value_added_per_worker_constant_1995_US$	−0.086	0.051	2.838	1	0.092	0.918
	GDP_growth_annual	0.042	0.060	0.475	1	0.491	1.043
	Constant	−46.679	22.461	4.319	1	0.038	.000

Notes:
a. Variable(s) entered at etap 1: Population_density_rural_people_per_sq#_km_of_arable_land, Agriculture_value_added_per_worker_constant_1995_US$, GDP_growth_annual.
B is the estimated coefficient with standard error S.E., the ratio of B to S.E., squared, equals the Wald statistic. If the Wald statistic is significant (i.e., less than 0.05) then the parameter is useful to the model. Sig is the significance level of the coefficient and Exp(B) is the "odds ratio" of the individual coefficient.

Source: Sébastien di Iorio (2005 data set).

The conclusions we can draw from these preliminary results tend to support the "demographic pressure" argument which, simply put, addresses armed conflicts by looking at demographic and environmental indicators rather than economic or political regime types of parameters. However, these results are not fully robust and need to be taken with great care since refinements of the model are clearly needed in order to put forward definitive claims.

PART IV

Some Problems Addressed via Modeling

Editor's introduction to Part IV

Frank Whelon Wayman

Forecasting the future is especially difficult when predicting rare events such as volcanic eruptions, earthquakes, nuclear weapons acquisition, or war. In this part of the book, we examine methods for making such predictions. If a predictor variable rarely changes much, and tends to persist, then it can be used to predict something that otherwise might be quite surprising. Tago and Singer (Chapter 8) use this insight to predict nuclear proliferation. For example, rivalries between sovereign states (such as the Franco-German rivalry of 1870–1945, the US–Soviet rivalry of the Cold War, or the Indo-Pakistani rivalry since their independence in 1947) tend to be very persistent, and to be strong predictors of nuclear weapons proliferation. Tago and Singer show that such a focus can successfully predict nuclear weapons proliferation in the past, and yield forecasts about likely future nuclear programs. Their forecasts, for developments two decades out, will gradually be verified, or not, with the benefit of hindsight. The Israeli destruction of what appears to have been a Syrian nuclear facility in September 2007, for instance, is indicative of a hotspot that could be predicted by Tago and Singer from the model in their chapter (based on Syria's rivalry with Israel, etc.).

Another possibility is that social groups can sense something collectively that portends trouble. Schneider, in Chapter 9, shows that financial markets have some promise in forecasting armed conflict, and we think there may be possible refinements of his method that will eventually show how movements of particular stock groups (that is, specific industries, not entire countries' markets) may be even better predictors of war, should future scholars follow up on Schneider's lead.

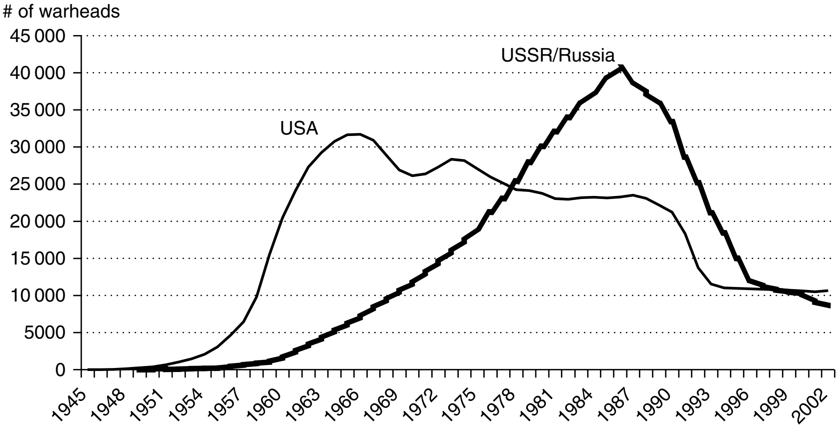
8. Forecasting nuclear weapons proliferation: a hazard model

Atsushi Tago and J. David Singer[1]

INTRODUCTION

From the original test of the first atomic device in the New Mexico desert on July 16, 1945 to the present day, the creation, testing, and deployment of these weapons has generated an extraordinary amount of discussion, debate, speculation, and research. On the positive side, we are told that by dropping the very primitive first two bombs on Hiroshima and then on Nagasaki in August 1945 the US was able to bring Japan to surrender and thus avoid the costly island-hopping campaign that could have taken more than a year and perhaps at the cost of thousands of American and Japanese fatalities. In addition, these bombings served to send a "message to Moscow" and thus make the Union of Soviet Socialist Republics (USSR) a more tractable diplomatic partner. Then it followed that the US monopoly and later weapon superiority would function as a deterrent to Soviet strategies of expansion. In due course, however, the Soviets acquired their own nuclear capabilities such that the next half-century became a period of mutual deterrence, keeping the bipolar rivalry, one of proxy wars and recurrent probes, and thus producing a Cold War standoff while avoiding World War III. And out of that stand-off came the eventual collapse of the Soviet empire, the end of the Cold War, and the emergence of what became a US global hegemony in the 1990s. In addition, the steady development of nuclear technology brought to the world the possibility of cheap, clean, and safe energy for industrial development and scientific research.

Against this reassuring narrative, we can tell a more contested story, in which the early chapter shows the US drive for an atomic monopoly and the rejection of a pragmatic partnership with the USSR, leading to a costly and dangerous armed rivalry. This rivalry, of course, brought with it such near disasters as the Cuban Missile Crisis of 1962, the extent to which the Soviets and Americans intervened in and corrupted many third-world societies, paralyzed any diplomatic creativity on the part of the North Atlantic



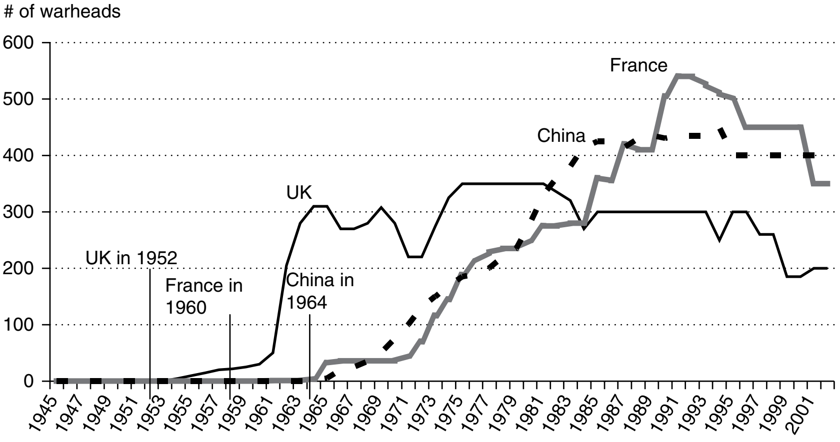
Source: Natural Resources Defense Council's Nuclear Data Archive.

Figure 8.1 Vertical proliferation by the United States and USSR/Russia

Treaty Organization (NATO) or Warsaw Pact allies, and most crucially, purged both the two dominant societies of any possible coalitions that might move them away from their rigid, infantile security policies, while at the same time assuring that the United Nations (UN) system would remain weak, underfunded, and marginalized during a period in which the need for global governance was dramatically evident.

But perhaps most alarming to the global community has been the steady increase in the stockpile of nuclear weapons that the US, USSR, the UK, France, and China have produced and deployed. As shown in Figure 8.1 and Figure 8.2, this virtually unbroken sequence from 1945 until 1971, when the Non-Proliferation Treaty (NPT) came into effect, saw a vertical and horizontal proliferation process that began with the US followed by the Soviet Union in 1949, the UK in 1952, France in 1960, and China in 1964. By then, the worldwide stockpile of deliverable atomic and nuclear bombs and warheads had reached nearly 40 000,[2] enough to lay waste to the entire Earth. Moreover, in addition to the near-miss over Soviet missiles in Cuba (preceded, of course, by those deployed by the US in the UK, Italy, and Turkey), there were scores of accidents stemming from an extraordinary mix of individual, organizational, and electro-mechanical malfunctions.[3]

The trend toward the proliferation of nuclear weapon states and weapon stockpiles was far from orderly. At least a dozen states initiated efforts to acquire such weapons. Israel joined the nuclear weapons club in 1966. Argentina and Brazil went to the brink of acquisition before their



Source: Natural Resources Defense Council's Nuclear Data Archive.

Figure 8.2 Vertical proliferation by the UK, France, and China

agreement vis-à-vis the Treaty of Tlatelolco, followed by their accession to the NPT in 1995 and 1996. There was the remarkable behavior of South Africa, which by the mid-1980s had six or seven weapons, but which in 1991 publicly reversed course, renounced these weapons, and subsequently announced accession to the NPT. Even today, the picture is far from clear, with Libya apparently now committed to abstain; Iraq occupied by the US coalition forces; Iran negotiating under highly ambiguous conditions; and North Korea holding out, driving a hard bargain vis-à-vis China, Japan, the US, and South Korea, and quite likely already having several primitive devices.

SCIENTIFIC PREDICTION OF NUCLEAR HORIZONTAL PROLIFERATION

Given this dramatic and far from reassuring half-century, the question is whether the human race may yet find a way to avoid nuclear Armageddon or some equally tragic but less extreme version. Our major concern in this chapter is the extent to which the continued acquisition and "improvement" of their nuclear forces on the part of the five major, original weapon states will encourage others to join the nuclear club. Before turning to those historical findings that might shed light on the future, an obligatory digression is in order. Whereas most students of world politics accept the premise that any increase in the number of such states (not to mention non-state actors) or their nuclear weapon inventories increases the probability of these weapons being fired in anger or accident, we find a handful of dissenters. We identify them here but decline to evaluate their arguments; they are all too visible, articulate, and contested elsewhere.[4]

Thus, let us turn to the central query: to what extent has vertical proliferation by the original five nuclear weapon states led to the increase in number of new nuclear weapon states? With the dataset we have assembled, and its statistical analysis, what can we say about the future of the proliferation? In particular, who may follow the states on the brink, such as North Korea and Iran, by starting a new nuclear weapons project? How can we reduce a risk of further proliferation? We answer the questions by utilizing a scientific approach, which is elaborated in the next section.

Defining Populations

There are three groups of states in our study. The first includes those 66 states in our "risk set" that we consider as latent or potential nuclear weapons states by dint of the capacity of their nuclear energy reactors or their research reactors, as reported to the International Atomic Energy Agency.[5] As compiled in its Power Reactor Information System or the Research Reactor Data Base, we show in Table 8.1 these 66 states and the years between 1943 and 1996 in which they were first classified as latent nuclear weapon states.

The second group is the smaller subset consisting of those 17 states that by our calculation did at some point begin a serious and systematic program dedicated to the actual domestic acquisition of nuclear weapons. Then, there are those seven states that initiated such a program, but by our best estimate have not (yet) produced or acquired deliverable nuclear weapons. We list them in Table 8.2 along with the years in which they began and later terminated such efforts, while recognizing the uncertainty in regard to some of the dates.

Finally, there are the remaining ten states that we know or believe have actually acquired deliverable nuclear weapons, showing our best estimates as to the decision dates as well as the actual acquisition; as to South Africa, the dismantling of its small stockpile occurred in 1991–92 as verified by the International Atomic Energy Agency (IAEA), and of course the North Korean dates remain a matter of conjecture.[6] Our best estimates are shown in Table 8.3.

Having specified these three groups of states, we next assemble them into the two populations that will constitute our database or spatial–temporal domain for the purpose of our statistical analyses. The first of

Table 8.1 Latent nuclear weapons states and their year of inclusion

Year classified	Latent nuclear weapon states
1943	USA
1945	Canada
1946	USSR
1947	UK
1948	France
1954	Sweden
1955	West Germany
1956	India, Belgium
1957	Czechoslovakia, Brazil, Romania, Denmark, Switzerland
1958	Poland, Argentina, Australia, Yugoslavia, China
1959	Hungary, Italy, DP Congo, Norway, East Germany
1960	Venezuela, Austria, Israel, Netherlands, Japan, DR Vietnam
1961	Egypt, Taiwan, Spain, Bulgaria, Indonesia, Portugal
1962	Finland, Turkey, South Korea
1963	Philippines
1964	Greece
1965	North Korea, Pakistan, Columbia, South Africa
1967	Iran, Iraq
1968	Mexico
1974	Chile
1977	Thailand
1978	Peru, Uruguay
1981	Libya
1982	Malaysia
1984	Jamaica
1986	Bangladesh
1989	Algeria
1991	Kazakhstan, Uzbekistan, Belarus, Latvia, Armenia, Ukraine, Lithuania
1994	Ghana
1996	Syria

Source: IAEA, http://www.iaea.org/DataCenter/datasystems.html.

these consists of the 66 latent or potential weapon states and the number of years in which each enjoyed that status (2355 state-years). These will be the state-years in the "risk-set" that we observe as we seek to ascertain which factors best account for whether they actively attempted to cross the threshold and move from technologically potential to the start of a nuclear weapons program. The second spatial–temporal domain will consist of those 17 states that in our judgment had at one time or another begun to

Table 8.2 States that began a program but did not acquire nuclear weapons

State	Began	Ended	Source
Taiwan	1967	1970	(1)
South Korea	1971	1977	(2)
Iraq	1973	2003	(3)
Iran	1974	?	(4)
Argentina	1976	1990	(5)
Brazil	1978	1990	(6)
Libya	1978	2004	(7)

Notes and sources:

(1) The Defense Ministry presented a proposal for a nuclear weapons program in 1967. See Albright, David, Frans Berkhout, and William Walker (1997) *Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities and Policies*. London: Oxford University Press for SIPRI, pp. 366–368.

(2) SIPRI (n.d.) *South Korea Country Profile: Past Nuclear Policies*, http://projects.sipri.se/nuclear/cnsc3kos.htm, accessed May 8, 2004.

(3) Hamza considers 1973 as the critical year in which Iraq started negotiations to buy nuclear reactors from France. See Hamza, Khidhir (2000) *Saddam's Bombmaker*. New York: Scribner.

(4) Iran created the Atomic Energy Organization in 1974; the Atomic Energy Organization of Iran (AEOI) and Defence Ministry are believed to have started a nuclear weapons program at military sites. See Albright et al., *op. cit*., pp. 352–356.

(5) Rodney and McDonough judge 1976 is the year the military junta decided to develop a nuclear power plant to build weapons. See Rodney, W. Jones and Mark G. McDonough (1998) *Tracking Nuclear Proliferation: A Guide in Maps and Charts, 1998*. Washington, DC: Carnegie Endowment for International Peace, p. 223.

(6) Redick, John R. (1996) "The Evolution of the Argentine-Brazilian Nuclear Rapprochement," paper presented at Argentina and Brazil: The Latin American Nuclear Rapprochement Conference, sponsored by the Shalheveth Freier Center for Peace, Science and Technology, and the Institute for Science and International Security, May 16, Nahel Soreq, Israel.

(7) "Libya Made Plutonium, Nuclear Watchdog Says," *Washington Post*, February 21, 2004, p. A15.

produce and stockpile nuclear weapons (540 state-years). More precisely, we seek here to ascertain: (1) which factors best explain which states initiated a program that could later produce nuclear weapons; and (2) what differentiates the ten which go over the brink from the seven which did not, but remained in the threshold category.

Considering the Factors

Given the long list of factors that have been suggested as possible explanations for the proliferation of nuclear weapons – why some states began to

Table 8.3 States that actually acquired nuclear weapons

State	Decided		Acquired	
	Date	Source	Date	Source
UK	Sept. 1941	(1)	Oct. 3 1952	(A)
USA	Jan. 1942	(2)	July 1945	(A)
USSR	Feb. 1943	(3)	Aug. 1949	(A)
France	Dec. 1954	(4)	Feb. 1960	(A)
Israel	1955	(5)	1966	(B)
China	Jan. 1956	(6)	Oct. 1964	(A)
India	1964/1972	(7)	1974	(A)
South Africa	1971	(8)	1979	(B)
Pakistan	Jan. 1972	(9)	1986	(C)
North Korea	1962/1982	(10)	1999	(D)

Sources:

(A) *Bulletin of the Atomic Scientists*, March 1993.

(B) Cohen, Avner (1998) *Israel and the Bomb*. New York: Columbia University Press, p. 232 for Israel; Rodney and McDonough, *op. cit.*, p. 243 for South Africa. Those two nations did not publicize their nuclear possession.

(C) Cirincione Joseph (with Jon B. Wolfsthal and Miriam Rajkumar) (2002) *Deadly Arsenals, Tracking Weapons of Mass Destruction*. Washington, DC: Carnegie Endowment for International Peace, Chapter 12.

(D) Pakistan's top nuclear scientist, Abdul Qadeer Khan, told interrogators he was shown three nuclear devices at a secret underground nuclear plant when he visited North Korea in 1999. See Sanger, David E. (2004) "Pakistani Says He Saw North Korean Nuclear Devices," *New York Times*, April 13, Section A, p. 12, Column 3.

(1) Churchill and his military chiefs of staff decided to give priority to nuclear weapons and launched the project. Clark, Ronald W. (1961) *The Birth of the Bomb: The Untold Story of Britain's Part in the Weapon that Changed the World*. London: Phoenix House, pp. 74–94.

(2) Franklin Delano Roosevelt (FDR) authorized a National Defense Research Committee to develop nuclear weapons. Nichols, Kenneth D. (1987) *The Road to Trinity*. New York: William Morrow & Co., p. 34.

(3) The State Defense Committee decided to develop nuclear weapons. Holloway, David (1994) *Stalin and the Bomb: The Soviet Union and Atomic Energy, 1939–1956*. New Haven, CT: Yale University Press, pp. 88–96.

(4) Pierre Mendes-France authorized a nuclear weapons program on December 1954. Sublette, Carey (n.d.) "France's Nuclear Weapons: Origin of the Force de Frappe," http://nuclearweaponarchive.org/France/FranceOrigin.html, accessed May 8, 2004.

(5) Albright et al. consider 1955 the year hiring nuclear scientists (Albright et.al., *op. cit.*, p. 258).

(6) With Soviet assistance, nuclear research began at the Institute of Physics and Atomic Energy, and a gaseous diffusion uranium enrichment plant in Lanzhou was constructed. Nuclear Threat Initiative (n.d.) "China's Nuclear Weapon Development, Modernization & Testing," http://www.nit.org/db/china/wnwmdat.html, accessed May 8, 2004.

(7) The first plan was authorized by Shastri in late 1964; Indira Gandhi authorized a nuclear test in 1972. See Perkovich, George (1999) *India's Nuclear Bomb: The Impact of Global Proliferation*. Berkeley, CA: University of California Press. We use the year 1964 for the analysis.

Table 8.3 (continued)

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(8) In late 1970 to 1971, South Africa started to design facilities for production of weapon grade uranium at Pelindaba. See Albright et.al., *op. cit.*, pp. 379–378.

(9) Pakistan started a nuclear weapons program in 1972 by Bhutto. See Kahn, Saria (2002) *Nuclear Proliferation Dynamics in Protracted Conflict Regions: A Comparative Case Study of South Asia and the Middle East*. Aldershot: Ashgate, p.117.

(10) South Korean intelligence reported new construction at Yongbyun in 1982; however, North Korea had started its serious research activities in early 1960s. See Barnaby, Frank (1993) *How Nuclear Weapons Spread: Nuclear-weapon proliferation in the 1990s*. London: Routledge, p. 95. We use the year 1982 for the analysis.

develop a program and then went on to test and produce the weapons, or began but did not pursue it all the way – those to be evaluated here are far from obvious. It would be reassuring were we able to rest our multivariate model on prior research findings, but the sad fact is that despite the importance of the question and the number of discussions in the literature, we find few aforementioned data-based studies.[7] Among them, Singh and Way's and Jo and Gartzke's studies are the most comprehensive research and suggest that we need to include variables such as "great-power military alliance," "participation in ongoing enduring rivalry," and "industrial capacity threshold." We are going to include those variables, and thus this chapter serves as a robustness check of the two studies by using a different dataset and coding rules. Worth emphasizing here is that there is no need to include in our model any indicator of a state's capacity to go nuclear. That is, we need not test for the so-called "technological imperative" or "industrial capacity threshold" inasmuch as our two analytical populations already include only these states that had that capability. First are the 66 that were so defined by the IAEA, and second are the 17 that became even more capable as a result of actually launching a weapons production program.

Our first factor, then, is the one that originally inspired this investigation, even though its inspiration is more political than scholarly: vertical proliferation. This can be measured in terms of the number and the quality of warheads, their distribution as to strategic or tactical, offensive or defensive, long-range or short-range modes of delivery, and so forth. For the sake of simplicity and comparability, we utilize the total number of warheads held by the five original "rogue" states each year from 1945, transformed into their natural logarithm equivalent to reduce excessive reliance on the necessarily imprecise figures. Also, it is reasonable to assume that the level of vertical proliferation in a given year *t* will influence a state's decision on nuclear development within the following three years. Thus, we use the moving average of the past three years' observations, for year t; the natural logged number of warheads at years $t - 1$, $t - 2$ and $t - 3$ are added and then divided by three. By doing so, we obtain a less fluctuating figure in the three years before t and thus capture more clearly the incremental changes.

Turning to the second plausible incentive for a state to either begin a nuclear weapon program or actually carry such a program to fruition, we shift from a generalized system-level aggregation of nuclear capability to a more limited and specifically dyadic factor. Here the question is of how severe is the enduring rivalry a state is involved in. A more precise version of this argument would specify that the rival be nuclear armed, but that would be a bit of a redundancy, as any nuclear potential state must necessarily anticipate that another nuclear potential state that is a rival will go nuclear even if it has not done so early in the rivalry. Our indicator is that used by Diehl and Goertz and requires that the protagonists experience at least six militarized interstate disputes within 20 years;[8] to qualify as a militarized interstate dispute, parties must have explicitly threatened, mobilized, deployed, or used force short of war. We used their basic rivalry level (BRL) score, which is also transformed into their natural logarithm equivalent in order to reduce excessive reliance on the necessarily imprecise figures, and it enables us to capture how much hostile rivalry a state experiences.[9] Again, we consider that using the three-year moving average of the BRL scores gives a less fluctuating indicator of accumulated threat perception.

Turning to a third incentive that should be expected to lead to the beginning of a weapons program or the actual acquisition of these weapons, we again focus on military security. In this case, at the state level of aggregation, there is the question of whether the state actually experiences at least one interstate war while enjoying the nuclear potential status. By war, we mean sustained combat between the official armed forces of at least two sovereign states and culminating in at least 1000 combat-related fatalities.[10] Given the dichotomous indicator of yes or no here, a moving average would not be appropriate; thus we use a simple three-year lag such that for each observation at t, we score yes or no at $t - 3$.

We now turn from what might be three of the more cogent incentives toward the horizontal proliferation of nuclear weapons capabilities to a pair of quite credible disincentives. The first of these disincentives is the presence of a nuclear umbrella, in which the potential proliferator enjoys the assurance that a nuclear armed major power will come to its aid if faced with a nuclear threat; it enjoys some reasonable assurance that it will not be the victim of nuclear blackmail. We regard the US and the USSR as these nuclear armed major powers, and use the Correlates of War (COW) Formal Interstate Alliance Dataset (Version 3.03: 1816–2000) to code the level (type) of formal alliance commitment. We assume that an entente is the weakest commitment, a neutrality or non-aggression pact is next, and that a defense pact is the strongest commitment of a nuclear umbrella (here we also use a simple three-year lag such that for each observation at t, we score a value at $t - 3$).

As we move to our second inhibiting factor and look to the state level rather than the dyadic, we address membership in the non-proliferation regime. Here, the hypothesis is that a state that signs on to the NPT can feel sufficiently secure; especially in light of UN Security Council resolution 984 (1995), in which all of the nuclear weapon states commit to act immediately in the event that any non-nuclear signatory becomes "the victim of an act, or object of a threat of, aggression in which nuclear weapons are used" – and thus need not seek to acquire an independent nuclear deterrent of its own. In other words, the non-proliferation regime is assumed to provide sufficient security – as well as discourage against leaving the NPT regime – to inhibit further horizontal expansion of the nuclear weapons club. We consider that taking a one-year lag is the most appropriate way to code NPT signatory status because any security assurance of the five permanent members, at least in principle, is provided just after a state signs the treaty; and that there is no need to assume that it requires three years to take effect.

Procedure

Having identified our two outcome variables and our five predictor variables, we next proceed to explain our estimation procedure. We have right-censored data inasmuch as an observation's full event history is not observed; that is, a technologically capable state in 2001 may acquire nuclear weapons in 2005 but our data do not capture this information, and our data structure requires us to incorporate the time-dependent pool of states, which means that the number of states to decide on nuclearization over time (once a state decides to change its policy at a given year t, it will not be in the pool for the calculation of the probability at year $t + 1$; also different states become technologically capable and start a nuclear weapons program in different years) may be difficult to model without the right technique. Thus, in order to deal with such special conditions regarding our data, we are strongly motivated to use an event history analysis.[11] Particularly, we use the Weibull model.[12]

We are interested in knowing with what probability a state changes its status of nuclear weapons development at a particular time point, given that it reached that point without having yet changed that status. Such a probability can be composed of two parts; the baseline probability (baseline hazard) of changing status, as well as the effects of our predictors against the hazard rate. If our predictors are expected to have an effect on duration, then the hazard is specified as:

$$h(t) = h_0(t)e^{\beta X}$$

where $h_0(t)$ is known as the baseline hazard[13] and β is a vector of the estimated coefficients and X is the matrix reflecting our actual observations. The predictor variables affect the rate of transition through the $e^{\beta X}$ term, while the basic rate of transition is captured in $h_0(t)$.

In reporting estimation results, the estimated coefficients β and percentage change in the hazard ratio are used. Here, the percentage change in the hazard ratio[14] allows us to report what percentage of increase/decrease occurs when examining the effects of our two binary variables (interstate war involvement and NPT signatory status) and change between them.[15]

Findings

First off, as Table 8.4 indicates, we find that the vertical to horizontal proliferation mantra just is not borne out. As a matter of fact, as the original five declared nuclear states warhead totals continued to climb since World War II, for each standard deviation increase, the probability of additional states initiating a weapon development program was reduced by about 39 percent, and the actual acquisition probability was further reduced by 87 percent. This might be counter-intuitive and opposite to the conventional contagion argument, but a closer look should help to explain these results. For the period up through the mid-1980s, when the total number of warheads reached its peak, additional proliferators may have concluded that there was no way that they could keep up with or compete with the five major powers; that is, the huge stockpile of nuclear warheads might have deterred the potentials. Further, the majors, who came to appreciate the danger of horizontal proliferation as they stockpiled their warheads, became fearful of nuclear competitors and employed strong efforts to discourage any new members of their club. Such efforts resulted in the NPT of 1968 which by 1972 included 33, or 76.7 percent, of the 43 remaining technologically potential nuclear states.

What has had a positive impact is not the overall vertical proliferation of warheads worldwide, but the experience of the individual potential members of the club. To illustrate, one standard deviation change in the severity of their enduring rivalry raises the probability of their starting a nuclear weapons program by 107 percent. More specifically, Iran and Iraq were involved in a severe enduring rivalry (their mean basic rivalry

Table 8.4 Event history analysis of nuclear weapons program and actual weapons acquisition

	Initiation of Weapons Program			Acquisition of Nuclear Weapons		
	Coefficient	Standard Error	Percentage change of Hazard Ratio	Coefficient	Standard Error	Percentage change of Hazard Ratio
# of warheads (natural logged)	−0.307	0.109	−39%**	−0.509	0.190	−87%**
Enduring Rivalry	0.418	0.132	107%**	−0.025	0.170	−5%
Involved in Interstate War	0.414	0.726	51%	0.459	0.919	58%
Security Assurance	−0.191	0.195	−25%	−0.982	0.378	−82%**
NPT Signatory	−0.906	0.682	−60%	−3.590	1.332	−97%**
Constant	−1.968	0.733	(n/a)***	−4.894	1.616	(n/a)**
p		1.06			3.67**	
# of Total Observations		2355			540	
Log likelihood		−50.7			−0.8	

Notes:
Estimated with STATA 8.0 (streg, weibull).
** = significant at .05 level (two-tailed test).

score is 112, which is well above the average BRL score of 81.4) that led to a prolonged war as well as the initiation of nuclear weapons projects in the 1980s. Israel with its rivalry score of 142 vis-à-vis Jordan developed its nuclear weapons devices in the 1960s. North Korea, which now appears to have several nuclear weapons, and South Korea, which began a nuclear weapons program in the 1970s, experienced a mean BRL score of 125. Finally, India and Pakistan whose intense enduring rivalry gives the mean BRL score of 105, both ended up as nuclear weapons states.

This leads, however, to the remarkably large difference in the impact on initiating a weapon development program on the one hand, and the actual testing and production of such weapons on the other. The explanation need not elude us. In an enduring rivalry, the decision-makers will need to find a prudent policy consonant with their material capabilities and their security situation, and launching a development program offers the opportunity to generate a fairly credible warning without committing to a far more costly and less easily reversed move. But when it comes to going over the brink, there is the tension between the momentum factor that would propel them to stay the course (reflected in the highly significant p value of 3.67), and the counter-considerations. These latter are, first, the material costs which appreciably exceed those of the development program, including the natural resources, the energy requirements, the industrial infrastructure, the skilled personnel, and all the other opportunity costs. Probably more compelling have been the political and security costs, beginning with the increased provocation-to-deterrence ratio vis-à-vis the rival, the likelihood of becoming a regional pariah, and the threats and blandishments of major power allies. In a similar vein, getting into an interstate war – as far as the direction of coefficients is concerned – also raises the probability of both beginning the program and actual acquisition of the nuclear weapons. But as we see in Table 8.4, the figures fall far short of the 0.10 level significance threshold.

Turning to our possible disincentives, having a security treaty assurance from either the US or the USSR reduces the probability of actual acquisition of nuclear weapons (–82 percent) but does not significantly reduce the incentive for starting some sort of nuclear weapons development program. This is consistent with the well-known historical cases in which the US strongly opposed the nuclearization of Taiwan and South Korea by threatening to cut their security and economic assistance.[16] Also, this may be applicable to the case of Libya, to which the recent mix of threats and blandishments seems to provide sufficient basis to forgo the nuclear option, at least for the time being.

Finally, the most striking predictor variable in our model is being an NPT signatory, which decreases the probability of going nuclear by about

97 percent with a high statistical significance, even though this coefficient is not statistically significant when it comes to initiating a nuclear development program. This should not, of course, be overinterpreted as a causal factor; it may well be that those who have signed on are the states that have already decided to forgo weapon acquisition, or alternatively, will have withdrawn prior to beginning the weapons program. This may well turn out to explain the ambiguous behavior of North Korea, which claims to have withdrawn in April 2003, and Iran.

Let us take a closer look at some of the historical cases in light of these statistical findings, beginning with the three that decided to go nuclear from 1966 (Israel) through 1974 (India) to 1986 (Pakistan). The explanation emerges quite clearly from our statistical findings. As to Israel, it experienced one or more enduring rivalries every year from independence on, and did not enjoy the putative assurance of a major power nuclear umbrella. Turning to the next proliferator, India, we find a decision equally consistent with our statistical model; there has been the enduring rivalry with China from 1950, and that with Pakistan from 1947 to the present day, and the absence of any major power assurance certainly fits our model. Finally, Pakistan has been involved in an enduring rivalry with India over 50 years and the 1954 Southeast Asia Treaty Organization (SEATO) commitment from the US was terminated in 1977, leaving it without the assurance of a nuclear umbrella.

To recapitulate our general findings, it is clear that vertical proliferation on the part of the major nuclear powers has so far exercised a negative impact upon the number of potential members of the club.[17] When it comes to involvement in an enduring rivalry, that factor has a statistically significant impact on the initiation of a program, but almost none at all on the decision to cross this actual threshold. And while a war experience has a positive effect on both program initiation and actual acquisition, that effect is modest and far from statistically significant. As to the allegedly inhibiting factors, a nuclear power's treaty assurance does not do much to dispel the desire to launch a development program, but it appears to play a strong and statistically significant role in deterring the ultimate decision. Similarly, accession to the Non-Proliferation Treaty played only a minor role when it came to launching a program, but a powerful and statistically significant role in deterring the ultimate decision.

Preventing Further Horizontal Proliferation

Finally, before concluding, let us move to obtain some policy implications. In particular, we are interested in the effects of being a member of Non-Proliferation Treaty as well as major-power alliance commitments. Do

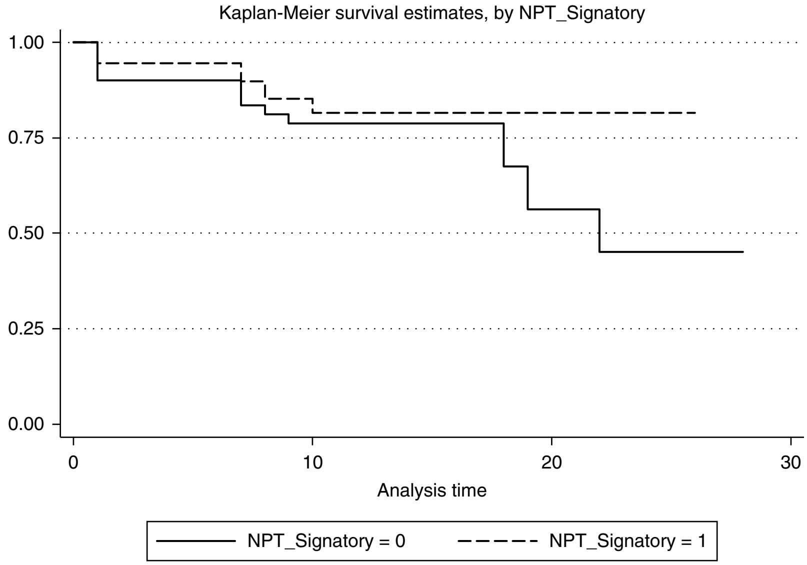
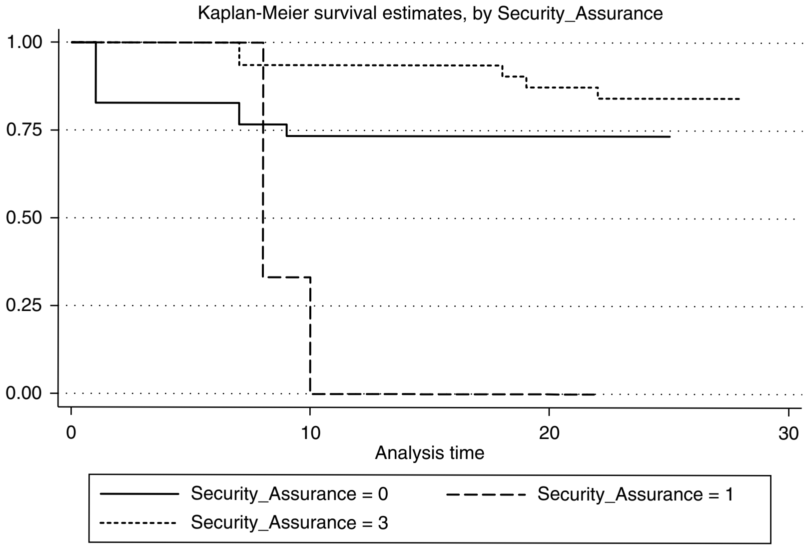


Figure 8.3 Estimated survival function of initiation of nuclear weapons program: by NPT status

diplomatic attempts to keep a risk state in the NPT regime help to reduce a chance of further horizontal proliferation? Do alliance commitments to a risk state increase a probability of not initiating a nuclear weapons development?

Figure 8.3 and Figure 8.4 show estimated survival functions of starting a nuclear weapons program, calculated for different NPT signatory status and different security assurance status, respectively. It is clear from Figure 8.3 that being in the NPT makes a sharp difference after 20 years in the risk set. It is therefore probably meaningful to try persuading a state not to leave the NPT, for prevention of horizontal proliferation. But unfortunately, it will take a long time (20 years) to see a significant effect of this factor in preventing a state from going nuclear. On the other hand, Figure 8.4 suggests that a defense pact with the US or the USSR or Russia mildly contributes to reduction of the likelihood of proliferation, while an entente with them does not help at all (rather, it increases the chance of starting the weapons program). Overall, the figures seem to suggest that there is no simple diagnosis for policy-makers to stop horizontal proliferation. But one thing clear from this study is that we need to work hard to maintain the NPT regime, and major powers need to provide a nuclear umbrella for states under a high security threat; in particular, an involvement in an enduring rivalry.



Note: Security_Assurance equals to 0 stands for no commitment, equals to 1 stands for entente, and equals to 3 stands for defense pact.

Figure 8.4 Estimated survival function of initiation of nuclear weapons program: by major power alliance status

CONCLUSION

This chapter was an attempt at scientific prediction of nuclear proliferation. Theoretically speaking, we basically confirmed what Singh and Way as well as Jo and Garztke found in their *Journal of Conflict Resolution* articles in 2004 and 2007, respectively. It must be noted that our study was a sort of robustness check of their articles by using a different dataset and coding rules vis-à-vis nuclear proliferation and capability control. It is reassuring that the external threat environment turns out to be a key correlate of nuclear proliferation in our study as well. Furthermore, we confirmed that the NPT signatory status matters in reducing a chance of horizontal proliferation. The finding implies in particular that departing from the NPT regime is a significant sign of a state preparing to cross the Rubicon and thus we must probably be alarmed by any attempt to move away from the NPT treaty.

As clear – and perhaps even compelling – as these findings may be, a major question remains. It indeed seems that the NPT status had functioned well vis-à-vis actual acquisition of nuclear weapons and we are thus facing, for the time being, a fairly small number of nuclear weapon states as compared to the number of potentials. After the original burst of weapons acquisition by the original five – all major powers and permanent members of the UN Security Council – between 1945 and 1964, only five states actually joined the club during the following 22 years. With close to 200 sovereign states, of which 53 had the industrial and technological capacity, the addition of so few proliferators is quite remarkable. Is it, as T.V. Paul has argued, that prudence is finally in the saddle? Going nuclear is expensive in material terms and even more expensive strategically; on the one hand, a new nuclear state would become a regional pariah, a possibly lucrative object of hostility. At the same time, it could discover how little security mileage comes with nuclear weapons capabilities. If the prestige and status of going nuclear is diminishing and its strategic utility is increasingly limited, going nuclear may no longer be an attractive option.

But the picture may nevertheless be less assuring than it appears. In addition to the current ambiguous status of Iran, there are the six states of "nuclear strategic concern" (Libya, Taiwan, Serbia-Montenegro, Algeria, South Korea, and Egypt) as defined by SIPRI and First Watch International.[18] Then there is the awesome problem of accounting for – no less controlling – the demobilized and dismantled warheads from the Soviet inventory along with their widely dispersed weapons-level uranium and plutonium and the associated technology. Despite the concern generated by this mess and the Nunn–Lugar and other programs, much remains to be done.[19] Then we face the consequence of Abdul Quadeer Kahn's entrepreneurial activities, and the more recently identified exports of moderately enriched uranium from North Korea, and what seems to be Iran's effort to expand the definition of the "nuclear club."[20] Also of concern is the extraordinary number of states that are utilizing nuclear energy reactors for electrical power (37 states with 441 plants) now that the enrichment of such materials to weapons grade has turned out to be more feasible than was believed in the early days of the Atoms for Peace Program.[21] Given those pessimistic facts, social scientists, in particular students of International Relations, are obligated and probably strongly encouraged to conduct more scientific studies on nuclear proliferation, which would guide us to a world without nuclear weapons.

NOTES

1. This chapter was originally commissioned for this book. Subsequently published by Tago in his own university's law review, it appears here with their permission. Originally

published as J.D. Singer and A. Tago (2012), "Predicting the Horizontal Proliferation of Nuclear Weapons," *Kobe University Law Journal* **45**: 51–68. Permission for reprint is obtained from the Graduate School of Law, Kobe University.

2. In 1967, the United States possessed 30 893 warheads, the USSR possessed 8339 warheads, the UK possessed 270 warheads, France possessed 36 warheads, and China possessed 25 warheads; including 18 of Israeli's maximum capable warheads, there were an estimated 39 563 nuclear warheads in the world. Natural Resources Defense Council, Nuclear Data Archive, Table of Global Nuclear Weapons Stockpiles, 1945–2002. http://www.nrdc.org/ nuclear/nudb/datainx.asp.
3. Sagan, Scott D. (1993) *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*. Princeton, NJ: Princeton University Press.
4. Sagan, Scott D. and Kenneth N. Waltz (1995) *The Spread of Nuclear Weapons: A Debate*. New York: W.W. Norton; Bueno de Mesquita, Bruce and William H. Riker (1982) "Assessing the Merits of Selective Nuclear Proliferation," *Journal of Conflict Resolution* **26**(June): 283–306; Shai Feldman (1982) *Israel's Nuclear Deterrence: A Strategy for the 1980s*. New York: Columbia University Press. Less assertive, but still critical of the "proliferation is dangerous" idea are Gray, Colin S. (1999) *The Second Nuclear Age*. Boulder, CO: Lynne Rienner; and Berkowitz, Bruce D. (1985) "Proliferation, Deterrence, and the Likelihood of Nuclear War," *Journal of Conflict Resolution* **29**(April): 112–136.
5. Editor's note: a caveat should be mentioned. Using nuclear reactors as an indicator of nuclear weapon capacity may be approximate because, *inter alia*, uranium enrichment (increasing the proportion of isotope U-235) is a possible second path to bomb development which can be followed independently of the nuclear reactor indicator criterion (that is, independent of plutonium production in a nuclear reactor). In one case, China, comparison of Table 8.1 with Table 8.3 and its footnotes suggests that their uranium enrichment route (via gaseous diffusion) started in 1956, two years before the year 1958 when the present study lists the beginning of a nuclear reactor program in that country. That difference might be regarded as a bias in the waiting times data. On the other hand, the one other case of which the information allows a definite conclusion is South Africa, which does fit the reactor criterion, having started a reactor program (1965) before starting uranium enrichment (1971). Further, from Table 8.1 it appears that the reactor criterion includes all the parties that have been claimed to have nuclear weapon development programs, thus including any having uranium enrichment programs; although if so, the relative timing is unclear for all but the two cases (China and South Africa). Finally, though bias may be present, it probably is slight when compared with the inherent uncertainties that any weapon program criterion would have (Paul R. Williamson).
6. We analyzed the data without North Korean's weapons acquisition years but it did not change the results.
7. Meyer, Stephen (1984) *The Dynamics of Nuclear Proliferation*. Chicago, IL: The University of Chicago Press; Singh, Sonali and Christopher R. Way (2004) "The Correlates of Nuclear Proliferation: A Quantitative Test," *Journal of Conflict Resolution* 48(December): 859–885; Jo, Dong-Joon and Erik Gartzke (2007) "Determinants of Nuclear Weapons Proliferation," *Journal of Conflict Resolution* 51(February): 167–194.
8. Diehl, Paul F. and Gary Goertz (1999) *War and Peace in International Rivalry*. Ann Arbor, MI: University of Michigan Press; Goertz, Gary and Paul F. Diehl (1995) "The Initiation and Termination of Enduring Rivalries: The Impact of Political Shocks," *American Journal of Political Science* 39(February): 33.
9. We calculated the highest value of BRL for a given year if a state is in more than one rivalry.
10. Datasets for interstate war and formal interstate alliance are available at http://cow2.la.psu.edu/.
11. Box-Steffensmeier, Janet M. and Bradford S. Jones (2004) *Event History Modeling: A Guide for Social Scientists*. Cambridge: Cambridge University Press; Hosmer, David W. and Stanley Lemeshow (1999) *Applied Survival Analysis: Regression Modeling of Time to Event Data*. New York: Wiley.

12. The data was analyzed with a Cox proportional hazard model, but the results do not change meaningfully.
13. In the Weibull model, $h_0(t) = pt^{p-1}$, where p is called the shape parameter, which captures the tendency of the hazard rate to increase (p is positive) or decrease (p is negative) monotonically over time. To be precise, we use the so-called time-varying covariate (TVC) data; the hazard ratio for the Weibull with exogenous TVCs is given by: $h[t|\, x(t-)] = e^{-\beta X(t-)}\, p[e^{-\beta X(t-)}t]^{p-1}$, where the notation $t-$ denotes that the change in the covariate is observed prior to t. See Box-Steffensmeier and Jones, op. cit., p. 105.
14. Percentage change in hazard ratio (HR) = 100*[exp(β) − 1]; Allison, Paul D. (1984) *Event History Analysis: Regression for Longitudinal Event Data*. Beverly Hills, CA: Sage, p. 28.
15. When examining the effects of our continuous variables, we use one standard deviation change for the number of warheads (1.48 for starting a program and 2.18 for the acquisition of weapons), the BRL score of enduring rivalry (2.07 for starting a program and 2.06 for the acquisition of weapons), and the strength of a security alliance (1.45 for starting a program and 1.31 for the acquisition of weapons).
16. As for South Korea, see Paul, T.V. (2000) *Power versus Prudence: Why Nations Forgo Nuclear Weapons*. Quebec City, Canada: McGill-Queen's University Press, pp. 120–124; for Taiwan, see Albright, David, Frans Berkhout, and William Walker (1997) *Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities and Policies*, London: Oxford University Press for SIPRI, pp. 366–368.
17. One note must be made for this finding though: we do not argue that the vertical proliferation helps to stop horizontal proliferation in today's world. Rather, vertical proliferation in the current situation would enhance horizontal proliferation by (re-)stimulating possible developers' incentives to be armed with nuclear weapons and legitimating their projects (this is because the vertical proliferation makes a threat to the developers and it is a clear violation of article VI of the NPT).
18. SIPRI and First Watch International (n.d.) "Countries of Nuclear Strategic Concern," http://projects. sipri.se/ nuclear/index.html, accessed May 8, 2004.
19. Nuclear Threat Initiative (n.d.) "The Global Threat," http://www.nti.org/e_research/cnwm/threat/global. asp, accessed May 8, 2004.
20. Sanger, David E. (2004) "The North Korean Uranium Challenge: Possible Shipment to Libya Raises Disarmament Alarm," *New York Times*, May 24; Dareini, Ali Akbar (2004) "Iran Toughens Stance on Nuclear Program," Associated Press, June 13.
21. World Nuclear Association (n.d.) "World Nuclear Power Reactors 2002–04 and Uranium Requirements," http://www.world-nuclear.org/info/reactors.htm, accessed May 8, 2004.

9. Forecasting political developments with the help of financial markets

Gerald Schneider

INTRODUCTION

It is a truism to say that forecasting political and economic trends continues to be a booming business (Sherden 1997). Within academia, however, many still conceive of prediction as a less noble task than explanation. The wide range of attitudes, between attraction and skepticism, leveled at professional forecasters can even be found among those who have transformed forecasting from an obscurantist business associated with astrology, crystal gazing, and "propheteering" into a key part of "normal science." The example of Oskar Morgenstern, one of the founders of modern game theory, illustrates this ambivalence nicely. In one of the earliest treatises on economic forecasting he stated apodictically: "Economic prognosis is . . . impossible because of objective reasons" (Morgenstern 1928: 108, own translation). Yet, this co-founder of game theory and leading strategic analyst continued to publish on the topic and evaluated for instance the random walk thesis together with Nobel laureate Clive Granger (Granger and Morgenstern 1970).

Nevertheless, the acceptance and popularity of prediction as an academic endeavor vary greatly across social scientific disciplines. While the combination of explanation and prediction is the natural way to do research in demography or econometrics, political scientists are generally still hesitant to engage in this seemingly dirty business. One of the traditional reasons for this unwillingness has been the inaccuracy of standard techniques like opinion polling to forecast specific developments such as election outcomes.

Forecasting political events, however, no longer warrants this approach. The development of two techniques – betting markets and expert interview-based decision models – has considerably changed the predictive accuracy of attempts to forecast the outcomes of political decision-making. In this chapter, I present an approach that marries some of the advantages that these two approaches offer. I test whether the collective information that financial markets contain can be used to predict both political developments and individual political events. To this end, I review recent contributions to the so-called Condorcet Jury Theorem which argues that collectives are better able to recognize the true state of the world than individual experts. I argue that financial markets can function like juries which discuss the available evidence in order to reach a correct decision (Coughlan 2000).

I use the political developments in the Levant, which has been, as we sadly all know, one of the most conflictive regions of the world throughout the past 60 years, to evaluate the predictive potential of financial markets within a political context. As severe political events such as the confrontations between Israel and its neighbors often have repercussions in the economies of the warring parties and elsewhere, we should expect that well-trained brokers serve as quasi-policy experts who build up scenarios over alternative political risks (Schneider and Troeger 2006a, 2006b). The anticipation of significant political events should, as a consequence, find its reflection in the price of securities and the buying and selling decisions that the financial intermediaries make. If a certain economically relevant event does not come as a complete surprise, it is thus *ex ante* contained in the price of a particular security. We can consequently conceive of financial markets as the aggregate opinion on the likelihood of alternative political scenarios that the financial intermediaries develop. The aggregate decision that traders make should be relatively accurate, not least because of the costs of faulty predictions. In contrast to interviewed policy experts who only occasionally have to fear a loss of reputation, financial traders will lose money if their decisions rely on erroneous political information. Yet, information from financial markets is not always useful for predictive purposes. The approach that I present here is not valid for the prediction of political developments: (1) which are economically not highly salient; (2) for which relevant decision-making information is restricted to a few policy insiders; and (3) in which many individual events come as surprises.

Using standard econometric techniques, I test the relative predictive accuracy of naive autoregressive models in predicting political events with competing models that contain information from financial markets. The evidence assembled shows that information from stock markets sensibly improves the predictive accuracy of models that largely rely on the auto-regression of the series under examination to produce forecasts. The lagged development of the Tel Aviv Stock Exchange allows me to predict the level of cooperation in the conflict between Israel and the Palestinians the following day more precisely than with an alternative model that just takes the lagged political interactions into account. Because violent events come much more often as a surprise than cooperative developments, the inclusion of financial market information does not improve the accuracy in the prediction of the daily level of conflict in the Middle East.

I organize this chapter as follows: I first review recent developments in the literature on political forecasting and develop a typology that allows me to see when a particular approach is adequate. Next, I present the research design and empirical evidence. I conclude with some recommendations and warnings on the technology that is introduced through this chapter.

A TYPOLOGY OF RESEARCH STRATEGIES IN POLITICAL FORECASTING

The traditional forecasting approach in the social sciences is based on econometrics and thus on the different scenarios that one can obtain from running competing statistical models. Yet, the predictions that a researcher is able to develop are as good as the information that is fed into the regressions. The requirement of a sound empirical footing of any forecast is particularly relevant for the analysis of key social or economic trends that are heavily influenced by a multitude of arcane decisions in various political settings. As neither reliable dynamic nor detailed micro-level information is obtainable for most decision-making processes, political econometrics often only resorts to crude macro-level indicators that do not vary much over time. Unsurprisingly, models of developments that are heavily shaped by political decisions, but rely on this limited empirical basis, often only provide shaky forecasts, as the experiences with the World Future reports of the 1970s and 1980s amply tell. The limited usefulness of macro-quantitative political data for predictive purposes is the reason why forecasts of political events frequently pursue different research strategies nowadays. They particularly base their predictions on information from individuals, be they explicit experts, quasi-experts working in another decision-making environment, or samples of the general population.

If political analysts base their predictions on judgmental information, they have to make two fundamental choices. The first decision relates to the question of whether or not the purpose of a research endeavor is the prediction of a single event or of a particular political development, which is simply a number of related events. A second consideration is whether the information gathered from few or many people is deemed to be more accurate for the particular forecasting problem under consideration. If one combines the decisions made along these two dimensions, one can distinguish four ideal types of judgment-based political forecasts, which I introduce in Figure 9.1.

		Purpose of Forecast	
		Prediction of development	Prediction of single event
Source of information	“Few” individuals	*Delphi method*	*Game and decision theoretic forecasts*
	“Many” individuals	*Financial markets*	*Opinion polls/ Prediction markets*

Figure 9.1 Ideal types of political forecasts with information from individuals

Predictions Based on Few Individuals

Single or small groups of experts are frequently used to predict scenarios for the development in a particular area. One of the key methodologies used is the Delphi method. The basic trick of this technology is to ask experts through repeated questionnaires what their opinion on a specific scenario is. Several authors have questioned the accuracy of this approach – “Delphi is undeserving of all of the attention it has received” (Armstrong 1978: 410) – while a recent survey comes to a more positive evaluation (Rowe and Wright 2001). Two particularly troublesome aspects of the approach are that the experts have to achieve a consensus and that the process through which they arrive there is not explicitly modeled.

This problem is circumvented in the forecasting approach that Bueno de Mesquita has introduced based on his expected utility approach to decisions on war and peace. Within this model-based framework, the opinion of the expert is only used as an input for a forecasting tool that has its foundations in decision and game theory (e.g. Bueno de Mesquita et al. 1985; Bueno de Mesquita 2002). This approach has been applied to a variety of issues and also to some evaluations by like-minded scholars (Bueno de Mesquita and Stokman 1994; Stokman and Thomson 2004).[1] The relative predictive accuracy of the models is impressive. Feder (1995; see also Ray and Russett 1996) reports a success rate of 90 percent for the analyses that the US Central Intelligence Agency (CIA) had commissioned. In a recent evaluation of the predictive accuracy of this and related game-theoretic models, other approaches based on standard bargaining models, however, performed slightly better (Thomson et al. 2006; Schneider et al. 2005).

The main advantage of the forecasting approach pioneered by Bueno de Mesquita is that the level of expertise that is required from an interview partner is modest and only relates to an evaluation of the present. Hence, game-theoretic models that are used to produce forecasts rely on the estimates that the interviewed expert provides with regard to the actors' preferences, power, and the importance they attach to the various contested issues. As Bueno de Mesquita (2002: 69) argues, the validity of the expert judgment is a less crucial aspect than one might think: "it turns out that the vast majority of specialists basically view this information in the same way." To search for detailed information that only a few experts can provide seems particularly adequate for the analysis of decision-making situations where the informed public is unable to locate the intentions and the power of key decision-makers. Yet, the incentive of the expert to deliver precise information is modest, and the interviewer has often no real chance to verify how accurate the expert estimates are. As I will argue below, there are thus certain situations in which the reliance on a pool of less qualified experts rather than some selected key informants seems desirable.

Predictions Based on Many Individuals

The main reason as to why financial market information should improve forecasts for some political developments depends on the costliness of the decisions that traders make. A broker includes relevant economic and political information when deciding about selling or buying a particular security. If a financial market depends heavily on political decisions, traders build up expectations about the likelihood of certain scenarios in the political realm. A typical example is whether or not a left-wing or a right-wing party will be elected into government in an upcoming election. As the announced economic policies of these competing political forces differ, neglecting the possibility that an election might be more or less favorable to particular financial transactions is highly risky. Even if market participants are not completely "rational" in the technical sense of the term, they will try to anticipate important political events and developments. A large number of studies have shown in this vein that markets systematically include relevant information from an ongoing electoral campaign (e.g. Leblang and Mukherjee 2005). In addition, I have shown in collaborative work with Vera Troeger that world stock markets have reacted systematically to escalatory and de-escalatory moves in three conflicts throughout the 1990s (Schneider and Troeger 2006a, 2006b). As some of the events are easily foreseeable, like upcoming party congress speeches or meetings between heads of states, it would be irrational for traders to refrain from partly anchoring their current buying and selling decisions on an anticipated political event that will have economic repercussions.

The Condorcet Jury Theorem (CJT) provides a theoretical rationale for my assertion that a large number of non-experts can on some occasions provide more accurate forecasts on political developments than the average individual expert. In my view, financial markets function like large decision-making committees that have to decide between competing hypotheses about the future. To deal with this form of belief rather than preference aggregation, the reliance on the CJT seems especially appropriate. The CJT states, in its canonical version, that the competence of a group in recognizing p, the true state of the world, is larger than the average individual competence. Further, this collective capability approximates 1 if the size of the committee grows. Large committees like the traders assembled in a financial market would accordingly be able to reach almost "correct" decisions in situations where the decision-makers share the same fundamental preference, but receive different information about the state of the world.[2]

It should be noted, however, that the CJT does not generally hold. Berg (1993) showed that the collective competence might be smaller than that of the average individual if the individual beliefs are correlated. Furthermore, the collective does not increase its competence if the number of marginally competent individuals (p slightly larger than 0.5) increases (Paroush 1998). In a world of strategic rather than "sincere" traders, the collective wisdom can be more erroneous than the average individual decision (Austen-Smith and Banks 1996).[3] As Feddersen and Pesendorfer (1998) demonstrate, unanimity and thus the consensus opinion to which herding traders refer might be the worst decision-making rule from an informational perspective. Their hypothesis that a curvilinear relationship between the decision-making quorum and the error probabilities exists, receives empirical support in the experiments by Guarnaschelli et al. (2000). Yet, Coughlan (2000) qualifies this result and shows that unanimity is the most information-efficient decision-making rule if a jury faces the risk that a mistrial occurs – no unanimous decision is reached – or if its members are able to communicate their private information.

I assume for my empirical application along these lines that financial markets can be conceived of as a collective decision-making body that also evaluates those political processes that are important for the development of the securities. Even though the traders are far from being well-informed experts in a certain election, a militarized dispute between two states, or the economic policy-making process of a certain country, they have considerable incentives to inform themselves about the possible outcomes of important collective political decisions. Most importantly, they talk with each other about the different scenarios so that the anomalies of judgment aggregation uncovered by Austen-Smith and Banks as well as Feddersen and Pesendorfer (1998) do not matter. If traders refrain from building sensible forecasts about important political developments, they jeopardize the value of securities they are trading with and possibly also harm their personal careers. If a political process is thus relatively easy to understand and economically relevant, they will build up collective forecasts that can be used to predict the ups and downs in the political arena.

Obviously, markets can be wrong in their assessments. In an early application, Bueno de Mesquita (1990) uses the money market discount rate as an indicator for the anticipated costs of conflict to evaluate the expectations contemporary agents had over the confrontations between Austria and Prussia in the nineteenth century. Analyzing the Seven Weeks War and the crucial battle at Königsgrätz, he writes:

> This reinforces the widely reported observation that Prussia was expected to lose the war . . . the expectations in the financial markets were updated to take account of the new information revealed on the battlefield – that the market had underestimated Prussia’s chance of victory. The prewar fears of postwar inflation or of defaults on money instruments by a defeated Prussia were allayed by Prussia’s decisive victory. (Bueno de Mesquita 1990: 44–45)

This chapter pursues a similar line of inquiry and asks whether stock market data can be used to forecast the political climate of the Levant. This conflict, which has been dominated by the confrontation between Israel and the Palestinians throughout the past six decades, certainly belongs to the category of disputes that have consequences for the world economy (Schneider and Troeger 2006a) as well as individual sectors (e.g. Fleischer and Buccola 2002; Schneider and Troeger 2006b). As the developments within this conflict region are well reported, several researchers have attempted to forecast escalations for the various dyads (e.g. Schrodt and Gerner 2000). These forecasts, however, are largely atheoretical. Based on a variety of methodological tools, these applications typically use past information from this conflict region to predict future patterns of interaction. This chapter moves beyond the tradition of solely relying on autoregressive models to produce predictions by including information from a collective quasi-expert – the stock market – in the regression.

RESEARCH DESIGN

This chapter examines whether aggregate financial market indicators improve the predictive accuracy of time series models that only rely on the characteristics of the series itself. For this purpose, I will use a key index of the Tel Aviv Stock Exchange, the TA 100, to evaluate whether financial traders can be conceived as a collective decision-making body which assesses the probability of different political scenarios in the Levant. The application aggregates the TA 100 data at the daily level and regresses it on two indicators of Levant conflict: sum of cooperation and sum of conflict. I have used the data on Levant conflict that was collected by the Kansas Event Data System (KEDS).[4] This prominent collection of event datasets has already served as the empirical basis for some predictive inquiries (e.g. Pevehouse and Goldstein 1999; Schrodt and Gerner 2000). As is common with event data, the events identify the "sender" and the "target" of a cooperative or conflictive act within a dyad of political actors. The outcome variables used in this chapter summarize the information across all relevant dyads in the Levant from January 1, 1990, to June 30, 2004.

To predict the daily level of cooperation and conflict, I will use autoregressive moving average (ARMA) (1, 0) and EGARCH (1, 1) models. The former approach includes an autoregressive parameter to predict the mean of cooperation and conflict. The latter technique is based on a standard tool within financial econometrics, the generalized autoregressive conditional heteroskedasticity (GARCH) models due to Bollerslev (1986) and Engle (1982; see also Beck 1983).

The usage of a GARCH model is appropriate because the error variance of the conflict and cooperation series varies over time.[5] Hence, in an intensive political conflict like the one going on in the Middle East for more than six decades, events of a particular type often come in clusters so that periods of high volatility follow periods of low volatility. This simply means for the conflict in the Levant that "bad days" in the form of a bomb attack are most likely followed by another violent episode in the next time period, while a cooperative gesture typically triggers another conciliatory move the next day. The canonical GARCH (1,1) model uses two parameters, the error coefficient α and the lag coefficient β, in the conditional variance equation that is added to the prediction of the mean of the series under examination.[6]

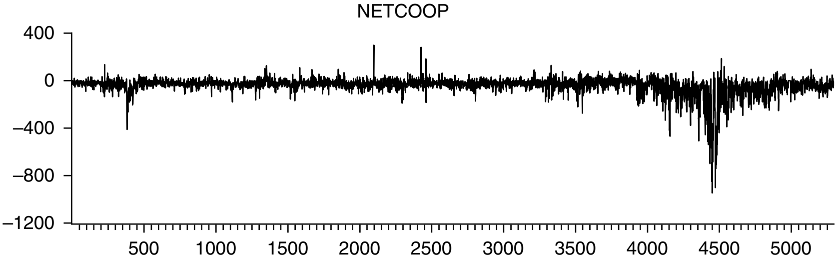
GARCH models assume a symmetric effect of positive and negative errors on the volatility of the series. To control for asymmetric responses in the variance to positive and negative developments, I will examine the appropriateness of a modification of the GARCH model, the so-called exponential general autoregressive conditional heteroskedasticity (EGARCH) approach developed by Nelson (1991).[7] The assumption of asymmetric responses was appropriate in a related inquiry in which we attempted to predict the reactions of stock markets to both cooperative and conflictive events in three conflicts (Schneider and Troeger 2006a, 2006b).

The stock market variable is differenced because high-frequency financial data, such as daily stock market indices, exchange or interest rates, are almost always driven by stochastic processes.[8] The stock market information is included in the mean equation of the models that test the main conjecture of this chapter; I include in all models an autoregressive term to predict the sum of conflict or cooperation that occurred the next day within the overall conflict region. The statistical models also include the lagged variable "bad day" for the calculation of the variance equation. This is in line with the expectation that particularly conflictive events increase the uncertainty of the traders with the effect that the volatility of the series grows. Note that the estimations refer to the same number of cases so that the statistical models are truly comparable. Summary statistics of the data used for the analysis can be found in the Appendix.

THE PREDICTION OF THE DAILY SUM OF COOPERATION AND CONFLICT

Conflict in the Levant has followed a largely erratic pattern throughout the period under observation. Figure 9.2(a) depicts the daily net sum of cooperation, which stands for the difference between the absolute values of cooperation and conflict. Sparks of cooperation are visible in the mid-1990s when the Oslo Peace Process stirred the hope of a permanent settlement between Israel and the Palestinian Liberation Organization (PLO). The Madrid conference of October 1991 did not lead to a similarly positive eruption of cooperation; this mediation attempt by the USA and the USSR took place at the end of the conflict between the Western-led alliance against Saddam Hussein which also – together with events associated with the first Intifada which was then waning out – instigated considerable turbulence in the Levant. The magnitude of these largely conflictive

(a) Net daily cooperation (Goldstein scores)



(b) TA100

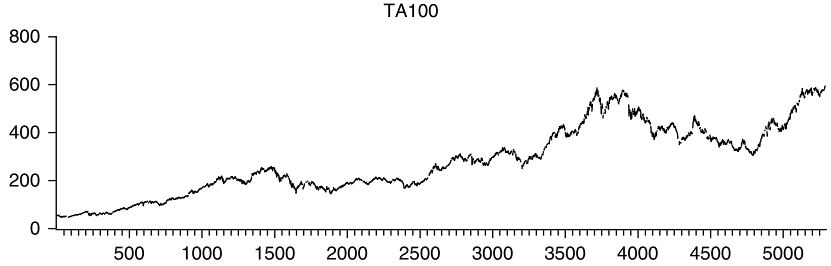


Figure 9.2 Conflict and cooperation in the Levant and the Tel Aviv Stock Exchange, January 1, 1990 to June 30, 2004

clusters of events, however, never reached the magnitude of conflict that the second Intifada brought to the region. The visit of Ariel Sharon, who was then leader of the Likud party, to the Temple Mount was among the catalytic events in this confrontation.

In contrast to the conflict data the stock market series depicted in Figure 9.2(b) shows a clear trend. The TA100 has grown steadily throughout the 1990s, interrupted by a short downturn in 1993. Similar to the world markets, the TA100 peaked shortly after the beginning of the new decade. An abrupt fall was followed by a short recovery and a longer crisis. The Tel Aviv stock exchange, however, rebounded again in early 2003.

As the political and the financial series are visually not related in any meaningful way, we need statistical tools to estimate the impact of lagged cooperative and conflictive events on the TA100. To this end, I present in Table 9.1 the results of four ARMA (1,0) and EGARCH (1,1) models. The dependent variables are the daily sum of cooperation across all dyads in the region and the equivalent measure for the daily level of conflict, which is coded negatively. The full models that I calculated for all different outcome variables include the differenced and lagged stock market

Table 9.1 The impact of the lagged stock market exchange on conflict between Israel and the Palestinians, January 5, 1990 to June 25, 2004 (ARMA (1,0,0) and EGARCH (1, 1) models)

Dependent variable	Conflict	Conflict	Conflict	Conflict	Cooperation	Cooperation	Cooperation	Cooperation
Model	Full AR model	Reduced AR model	Full EGARCH model	Reduced EGARCH model	Full ARMA model	Reduced ARMA model	Full EGARCH model	Reduced EGARCH model
Mean equation								
Constant	−66.63***	−66.66***	−74.90***	−74.90***	34.33***	34.35***	36.38***	36.07***
	(6.83)	(5.68)	(1.43)	(1.43)	(1.59)	(1.59)	(0.75)	(0.77)
Diff(TA100)	0.15		−0.08		0.17		0.32***	
$t - 1$	(0.17)		(0.12)		(0.11)		(0.09)	
AR (1)	0.83***	0.83***	0.78***	0.78***	0.64***	0.64***	0.71***	0.70***
	(0.003)	(0.003)	(0.02)	(0.02)	(0.007)	(0.007)	(0.02)	(0.02)
Variance equation								
Constant			−0.82***	−0.82***			−1.89***	−2.02***
			(0.29)	(0.29)			(0.44)	(0.45)
Bad day $t - 1$			0.19***	0.19***			−0.12***	−0.11**
			(0.05)	(0.05)			(0.03)	(0.03)
δ_1			−0.57***	−0.57***			0.47***	0.44***
			(0.03)	(0.03)			(0.03)	(0.03)
δ_2			-0.10**	0.95***			−0.11***	−0.09***
			(0.04)	(0.04)			(0.03)	(0.03)
β			1.05***	0.88***			1.27***	1.27***
			(0.04)	(0.03)			(0.06)	(0.06)
N	2550	2550	2550	2550	2550	2550	2550	2550
Log-likelihood	−13889.07	−13889.30	−1364.01	−1364.01	−12213.18	−12211.10	−12001.87	−12006.37
AIC	27786.13	27784.60	27312.02	27276.70	24434.36	24434.21	24019.73	24026.74
BIC	27809.51	27802.13	27358.78	27317.60	24457.74	24451.74	24066.49	24067.64

Note: ***, **, and * denote significance levels at 1%, 5%, and 10%. Entries are parameter estimates and robust standard errors.

information; the reduced ARMA and EGARCH models, by contrast, only use autoregressive parameters.

The results reported in Table 9.1 clearly demonstrate that the stock market can be partly used to predict political developments in the Levant. However, this is only the case for cooperative events, not conflictive ones, and even there, the results are not always completely convincing. The divergence in the capacity of the stock market to predict well across different types of events certainly does not come as a complete surprise. In general, conflict is harder to predict than cooperation. If surprising conflictive events like bombings were foreseeable, they would not happen – or at least not that often. The relationship between the lagged and differenced TA100 series and the cooperation series means that traders anticipate cooperative events before they are actually going to happen. The calculations suggest that the substantive effect of a one-point rise in the main Tel Aviv stock market index is followed by a 0.32 increase in the sum of cooperation across all Levant dyads the next day. A similar, but somehow reduced and statistically only marginally significant effect, is observable for the autoregressive model.

The analysis also shows that both conflict and cooperation are highly autoregressive processes. Furthermore, there is strong evidence that the cooperation and conflict series share some of the characteristics of the high-frequency data typically analyzed in financial econometrics. The parameter estimations for the variance equations in the EGARCH models show that particularly bad days increase the volatility of the conflict series and decrease the variance with regard to the net sum of cooperative events. This latter result can easily be explained through the tendency of severe events to render cooperation less likely, thus reducing the level of cooperation and, simultaneously, the volatility of this series. The first d-parameter in the estimation of the cooperation series similarly indicates that conflictive shocks have a strong effect on the series variance.

The analysis conducted so far leads to the question of whether or not one can predict particular events well with the approach pursued in this chapter. I will try to do so in the following through the usage of simple forecasting models that try to predict the level of cooperation that happened the next day. I will compare the predictive accuracy of the EGARCH (1,1) and the autoregressive models that either include the stock market information or do not. The events that I have selected for exploring the ability of stock market data to deliver point predictions for political events are the salient cooperative events listed in Schneider and Troeger (2006a) and some of the key cooperative events that happened outside their period of examination from 2000 to the end of June 2004.

Table 9.2 reports the predicted values of the four models and the real sum of cooperation that was observed on a particular day. Note that I have chosen the next day with a forecast in cases where the Tel Aviv stock market was closed on the day during which a particularly cooperative event happened.

The attempt to forecast individual cooperative events with four different statistical models largely confirms the earlier reported result that the EGARCH model with the lagged stock market information provides the most accurate forecasts. In eight of the 12 chosen events, its point predictions came closest to the real sum of cooperation. However, the inclusion of the financial market series does not make much of a difference as the atheoretical EGARCH model came up seven times with either the best or the second-best forecast. In general, the predicted values underestimate the level of cooperation that occurred on these particularly significant days. The mean average error of the forecasts is thus, to put it more technically, quite considerable. This does not, however, undermine the general message of this chapter, according to which a pool of quasi-experts – like the traders on a stock market – can in some instances be used to forecast political trends and events.

CONCLUSION

Forecasting political developments has for a long time been left to area experts, mediagenic academics or the infamous taxi-driver that the busy journalist selected for his journey from the airport to the downtown hotel. Fortunately, some recent methodological advances allow us to move beyond this dire state of affairs and to make forecasting a routine part of academic inquiry in the social sciences. This chapter adds to this emerging literature by trying to systematically predict conflictive and cooperative patterns of interactions in the Levant, one of the regions in which the interactions between the various political forces are among the most volatile in the world.

The goal of this chapter was largely theoretical rather than methodological. I particularly attempted to show that political forecasting should rely on the judgment of many rather than a selected few experts in situations in which large collectives build an opinion on a particular political development. In my view, this is particularly the case for decisions on war and peace that affect the lives and well-being of many individuals. In the case of the Levant, one of the appropriate juries to gauge systematic forecasts is the financial community. As escalations and de-escalations on the Levant have important political and economic repercussions around the world, I

Table 9.2 Point predictions of AR-model and the stock market model

Cooperative Event	Actual sum of cooperation	Prediction (full ARMA model)	Prediction (reduced ARMA model)	Prediction (full EGARCH model)	Predicted (reduced EGARCH model)
Madrid peace conference (October 30, 1991)	40.7	***29.9***	*28.4*	**35.9**	28.4
Secret Agreement in Oslo announced (August 30, 1993)[1]	51.5	31.01	*30.71*	**37.11**	***36.1***
Israel and PLO sign Oslo I agreement (September 13, 1993)	112.2	***45.0***	**45.9**	*34.5*	36.1
Israel and PLO sign "Gaza-Jericho First" agreement (May 4, 1994)[2]	59.5	***12.01***	12.21	*10.31*	10.9
Israeli and PLO negotiators in Taba achieve partial agreement (August 11, 1995)	64.9	49.7	*49.6*	**51.8**	***51.4***
"Summit of the Peacemakers" at Sharm el-Sheikh (March 13, 1996)	63.6	***30.5***	*30.0*	**31.2**	30.2
Israel and PA sign Wye River Memorandum (October 23, 1998)	120.3	68.4	*67.9*	**72.8**	***71.2***
Israel and the PA sign Sharm el-Sheikh Agreement (September 4, 1999)[3]	34.8	*28.9*	28.9	***36.4***	**36.1**
Camp David summit begins (11/7/00)	76.7	34.0	34.6	***35.1***	**36.1**
Camp David summit ends in failure (July 25, 2000)	52.3	***36.3***	36.3	**36.3**	*36.1*
Abbas to become first Palestinian Prime Minister (March 19, 2003)[4]	28.1	50.6	*51.2*	**35.22**	***36.1***
Roadmap peace plan launched (April 30, 2003)	120.4	***44.1***	*42.5*	**47.0**	43.7

Table 9.2 (continued)

Cooperative Event	Actual sum of cooperation	Prediction (full ARMA model)	Prediction (reduced ARMA model)	Prediction (full EGARCH model)	Predicted (reduced EGARCH model)
Sharon orders a plan be drawn up to remove Gaza strip settlements (February 2, 2004)[5]	37.8	35.2	*34.4*	**38.1**	***36.1***

Notes:

Best prediction in bold, second-best in bold and italics, worst in italics. The cooperative events listed in Schneider and Troeger (2006a) and in a BBC chronology on the Middle East conflict were used as sources.

1 Actual and predicted values from August 31, 1993.
2 Actual and predicted values from May 5, 1994.
3 Actual and predicted values from September 7, 1999.
4 Actual and predicted values from March 21, 2003.
5 Actual and predicted values from February 3, 2004.

can assume that financial markets try to anticipate the change of tide in this conflict region.

I have used recent research on the Condorcet Jury Theorem to argue that we can perceive financial markets as collective deliberative decision-making bodies whose predictions can be more accurate than the forecasts of individual policy experts. The usage of GARCH and simple autoregressive models has confirmed that we can use the lagged stock market information to forecast political developments. In particular, the analysis has shown that financial markets forecast cooperative events, but not necessarily conflictive ones. Hence, although we might rely on financial markets to predict positive developments, the financial community is often not good at predicting what security services, the military, and the media are also especially bad in auguring: violent conflict.

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NOTES

1. Since expert judgment is only used as a data input, the empirical basis could also consist of macro-political information. I have pursued this alternative strategy to test the predictive accuracy of a game-theoretic model in an application of competing bargaining models on international economic negotiations (Schneider 2005).
2. The CJT assumes: (a) that the average competence p exceeds 0.5; (b) that their judgments are independent of each other; and (c) that they "vote" for one state of the world in a sincere fashion. See Grofman and Feld (1988), Young (1988), and Lada (1992) for introductions.
3. The main assumption behind this counterintuitive result is that the signals that committee members receive about "reality" are at least partly private. A strategic voter has, in this implicit voting model, an interest to cast the decisive vote, while a sincere jury member always follows the private information he or she possesses. Technically, the Austen-Smith and Banks models means that sincere voting is generally not a Nash equilibrium and the collective ability to choose the "correct" solution is less than the average individual ability.
4. The machine-coded event dataset, of which I have used an update from 2004, was screened for possible coding errors before the analysis. A few events, like for instance a report on a soccer game, were excluded from the dataset that was used in the analysis. A more recent Levant dataset can be found on the KEDS website (http://www.ku.edu/~keds/, last consulted May 16, 2006).
5. Engle (2001) is one of the many introductions to these modeling tools.
6. Formally, the conditional variance equation in the GARCH (1,1) model takes the following form: $\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2$ here ω is the GARCH constant.
7. The conditional variance equation of the E-GARCH model looks as follows:

$$\log(\sigma_t^2) = \varpi + \delta_1\left|\frac{\varepsilon_{t-1}}{\sqrt{\sigma_{t-1}^2}}\right| + \delta_2\frac{\varepsilon_{t-1}}{\sqrt{\sigma_{t-1}^2}} + \beta\log(\sigma_{t-1}^2)$$

   Asymmetry can be observed in case δ_2 differs significantly from 0.
8. As the respective tests statistics have shown, neither unit-root (Phillips–Perron and Dickey–Fuller tests) nor co-integration (Johansen test) problems hampered this analysis.

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APPENDIX

Table 9A.1 Summary statistics of variables

Variable	Observations	Mean	Standard dev.	Minimum	Maximum
Conflict	2550	−68.4	87.3	−1049.6	0.0
Cooperation	2550	34.5	34.5	0	399.6
Net cooperation	2550	−33.5	73.5	−946.0	280.9
Bad day	2550	0.05	3.9	−38.31	213.0
D(TA 100) $_{t-1}$	2550	21.7	74.1	−199.4	263.1

PART V

The Global System and the Possibilities of Prediction

Editor's introduction to Part V

Frank Whelon Wayman

This volume has given two perspectives in evolutionary biology (Chapters 3 and 4), focusing on human nature, and it then moved on to an ecological perspective of the place, the security, and the welfare of humans in their changing environment (Chapters 5, 6, and 7), but we have not yet addressed the nature of the global system in which humanity must find its present and future home. In Chapter 10, John Holland takes up the role of complex, adaptive systems, and their likely nested existence within other complex adaptive systems that exist at a higher order of magnitude in spatial domains (like bacteria within the bodies of higher organisms). While Holland explicitly refers back to Chapter 3 and 4 by Wilson and Alexander, respectively, his chapter raises the question of how a system such as an ecosystem might evolve if the important components of it are adapting either through learning or natural selection. More generally, Holland is concerned with the issues that are raised by the possibility that the global system is itself a complex adaptive system. These are themes first brought up in the book in Chapter 2, in which Williamson discussed the global system as made up of elements that were social, elements that were biological, and elements and subsystems that were physical (such as the weather and climate). While the weather and climate are not primarily adaptive systems, the social and biological subsystems overwhelmingly are.

Holland's model is a plastic model which can operate at a high level of generality to discuss dynamics of systems. In our book, we are able to deal with the application of such a model to specific environments, such as the interstate political systems of historic civilizations, examined by Wilkinson. More specifically, it is the power structure of the global system and its regional civilizations that is taken up in the chapter by Wilkinson (Chapter 12). In contrast to Wilkinson, Holland's focus is primarily conceptual rather than empirical. His effort is to synthesize ideas across disciplines to come up with ideas for thinking about innovation and related processes that alter the future in non-linear ways. Wilkinson presents a highly data-driven work. He gives us his measures, at ten-year intervals, of all human history over some 5000 years, specific counts of how frequently different subsystems of the global political system were a-polar, multipolar, bipolar, unipolar, hegemonic, or imperial. The data on transitions between these systems indicate that systems tend to stay the same (are autocorrelated), or if they change, tend to revert to their most immediately previous form. In other words, these are not adaptive systems. The future is in this sense like the past. But in a larger sense, over time, the subsystems merge. Over the millennia, the some dozen human civilizations gradually merge with each other, until all that is left is the global phase of central civilization.

Another way of viewing what Wilkinson has done is as follows. One way to forecast the future is to gather a lot of data from the past, and then, relying heavily on the data and perhaps a bit less on deduction, make an effort to extrapolate the data trends into the future. J. David Singer, a practitioner of this approach, once said, "One should not forecast further into the future than one's data run into the past" (personal communication). Singer's data, from the Correlates of War Project he founded, run from 1816 to the present – about 200 years. So he took his own dictum seriously. This approach of Singer's is a sensible one. Projection into the future is basically extrapolation, and one would not want to extrapolate too far. If one had ten years of data, it would be daunting to extrapolate out 200 years into the future. But if one had 200 years of data, such as Singer gathered, perhaps one would be on a sound basis in extrapolating a trend a decade beyond the present. In this chapter, Wilkinson does Singer's trick, but goes one better: to Wilkinson, 200 years of data is a mere trifle. He has nearly 5000 years of data on the state of the international (or world) system.

A side-product of Wilkinson's analysis is a refutation of Waltz's (1964) famed treatment of international systems. Waltz says that the bipolar form is more stable, but Wilkinson shows that bipolar systems are no more stable than any other. Waltz had also viewed international systems as primarily bipolar or multipolar. If the system had been multipolar from 1495 to 1945, and bipolar from 1945 to 1990, what would be next? If bipolar systems were more peaceful (as Waltz contended) would post-1990 be more war-prone? (His disciple Mearsheimer, 1990, once warned: "we will soon miss the Cold War.") We are reminded of an anecdote. One of our colleagues, testifying to a Congressional subcommittee, said to the chairman, "Congressman, that is inaccurately stated. If accurately stated it would be wrong. And, were it not wrong, it would be irrelevant." Somewhat the same is going on here. It is inaccurate to say that bipolar eras are more peaceful because the bipolar period has been shown to be more war-prone than multipolarity. Wilkinson suggests that the system is more likely than not to revert to what it had been, but that it could become several other things (unipolar, imperial, a-polar, and so on).

Another scholar, Huntington (1996), had forecast the "clash of civilizations." There may be something to Huntington's claim, but it strikes us as very useful to keep in mind Wilkinson's alternative view: that civilizations are not homogeneous religi-ocracies, but heterogeneous groups of people defined as simply those in persistent interaction with each other – and over time those interactions have swallowed civilizations, not conserved them.

In Holland's view (as in his Chapter 10), complex, adaptive systems such as the global system have elements in common with games like chess and with computer programs. These feature "perpetual novelty," in which one rarely sees the same thing twice – two grand masters would virtually never play exactly the same chess game against each other. In computer programming, his field, Holland has been known to observe (personal communication) that bugs can be hard to find, because major twenty-first-century programs have so many options that it may take a long time before a user chooses the exact sequence and combination of options that lead to the bug. Insofar as the global system is like that, we can only have, from our present vantage point, "glimpses of the future," because we have not yet seen all the behaviors of which the global system is capable. Of course, this is because the entire repertoire of people's decisions, and other events, have not yet all occurred, that would (had they all occurred) reveal the many outcomes that the global system is capable of manifesting. Prediction and forecasting must be cautious, because when conditions change to what we have not yet experienced, surprising outcomes often result. Despite these potential shortcomings of forecasting, Wilkinson was able (in Chapter 12) to find that some important features seem to have persisted in the world over thousands of years: about a dozen distinct civilizations have converged into one, and as one traces variations in power concentration in these civilizations, one finds that it is most likely to remain as it currently is; and if it does change, it is most likely to revert to what it had been immediately before; so, for instance, if it had gone from hegemonic to bipolar, and now it stops being bipolar, it is likely to revert to being hegemonic, rather than becoming something else, like multi-polar or non-polar.

But, what does the global system consist of, fundamentally? Aside from the chapters we have been discussing, of Holland and Wilkinson, what is the common subject matter they share, when they discuss the global system?

At the basic level, all would agree: a system is a set of interacting parts, with feedback. For example, a house with heating or air conditioning, and a thermostatic control of them, is a system. In the climate where we wrote this book, in the winter in the northeastern United States, houses have furnaces and thermostats, and when the temperature in the house drops below a certain trigger point, the thermostat sends a signal to the furnace to restart and warm up the house. When the house then reaches another trigger point, at a higher temperature, the thermostat sends another signal to shut off the furnace for a while. So the feedback to the furnace is the signal to turn on or off. In this, the house has been simplified down to the important components, and their interaction over time. Likewise, in the global system, one must characterize the forceful, important components, and then describe their interaction, to get to the fundamental properties of the system.

The first widely used scientific measures of such a modern interstate system were devised by the Correlates of War (COW) Project at the University of Michigan. The COW scholars measured the economic, military, and demographic capabilities of the world's sovereign states, and then examined their interaction in military alliances (Wayman 1984). Properties of the broader global system, beyond just the interstate system, are discussed in Chapters 1 and 2 of this book. Wilkinson in Chapter 12 looks particularly at the capabilities of sovereign states, and how, after about 5000 years, they finally, in the past 200 years, begin to interact in "the global phase of Central Civilization." In the twenty-first century, however, it would appear that the global system has grown beyond the interaction conceived in COW as military alliances.

In our book, we have a way to deal with these twenty-first-century transformations of the global system. At the conference where our book gestated, the discussion of the global system pivoted around Gottfried Mayer's (2005) paper on "Critical Time Scales in Neural and Global Systems." In the abstract he said, in part:

> When we try to master a complex task like juggling five balls, [or] playing a piano concerto . . . this is only possible [when] . . . complex assemblies of neurons in our brain are active with very precise time scales. We call these time-scales critical when they act as bifurcation parameters and are close to a tipping point.
>
> When global problems are addressed then the simultaneous (in the sense of "within critical time-scales") activation of a large number of individuals with influence on decision makers is essential for triggering successful transitions to improved states. We claim that the Internet plays an increasing role in the emergence of global problem solving structures – sometimes referred to as "Global Brain."

In a race, one group sometimes uses such forces to destroy, while another group rushes to repair. Thus, Mayer (2005) said in the abstract:

> A second domain where time-scales can be critical is related to changes in the environment (e.g., global warming, species extinction rates, pandemics, etc.) and rates of adaptation, learning, and innovation displayed by the system in response.

> We claim that the Internet provides us with a global and fast network tool that can significantly shorten time-scales for pathways to solving global problems.

As founding editor of the online Internet newsletter, *Complexity Digest*, Mayer found information being submitted to him, shortly after 9/11, in which an analyst, Valdis Krebs, had promptly used the Internet to trace the communications among the terrorists who attacked the World Trade Center (see Krebs 2002). Such racing can be seen as a matter of relative time scales.

There was widespread agreement at the conference on the importance of these insights, which lead into the conception of the global system by Paul Williamson (Chapters 14 and 15), in which a key variable is the communication time between pairs of actors. That variable is represented in Williamson's chapters by the distance between pairs of sovereign states in a two-dimensional (or it can be generalized to multidimensional) geometric space, with proximity associated positively with more rapid communication. That space can be thought of in terms of Quincy Wright's field theory, as Williamson explains. Efforts to represent that space are often undertaken by the mathematical technique of principal components analysis and related data-reduction procedures, as discussed across a variety of fields, for example by Rummel (1970) in political science and Gibson et al. (1992) in physics (Gibson's co-author Farmer being the first author of Chapter 5 of our book). Beyond such widespread areas of methodological consensus, however, there are areas of strong disagreement that emerged at our conference. Complex systems people tend to emphasize the evanescent quality of any particular instantiation of reality. Deductive game theorists tend towards a more optimistic view of the possibilities of prediction.

Mayer (2005) pointed out many examples of how, while in physics laws are forever true, in human and social phenomena such competition as just mentioned between groups can subvert a law. For example, it may be a scientific law for a while that students who do well on aptitude tests will do well in future schooling, but then some applicants may sign up for cram courses to score high on the test, and if there are large numbers of them getting high scores, and then doing poorly in school, the prior law is no longer true (or the statistical predictive power of the aptitude test is at least diminished). "And, therefore, we do not have situations where we have time scales that are infinitely long in social systems" (Mayer 2005). Some of the examples Mayer gives, of systems subverted by innovation, were brought up independently by Holland, and are represented in Chapter 10 of our book. In such chaos, with so much noise in the evidence, are there cases in which one nonetheless can make successful predictions about the future? Yes. J. Doyne Farmer reported (in Farmer and Geanakoplos 2005) that his Prediction Company had detected, in the chaos of financial data, a signal (to buy or sell) that had persisted for about 23 years, and that was "extremely tradable" (that is, one could expect to make a profit by acting on it, after taking into account transaction costs). They had found this despite the "rational market" claim that an angle to beat the market should not tend to exist – that is, it should disappear quickly even if it somehow were to materialize. Farmer and Geanakoplos's example illustrates that even in very noisy and complex data, researchers with enough data and analytic skills can find, and in fact have found, ways to make worthwhile predictions.

Where complex systems analysts see the potential for instability and chaos in the world, deductive game theorists such as Bueno de Mesquita (see his Chapter 18) see the potential for predictability, once their methods are employed. As Bueno de Mesquita said at our conference, Illuminating the Shadow of the Future, in a challenge to Mayer, "I have a problem with describing these as complex adaptive systems. I see them as adaptive systems that are very easily explained." There was then a search for common ground to bridge these different understandings. As Williamson put it in notes for this book, "Complexity and ease of explanation might be compatible. A system might be simply explained, yet still be complex in the sense of being entirely unpredictable beyond some future moment (e.g., see the chapter by Karasik [Chapter 11])." Incidentally, Bueno de Mesquita's claim does not depend only on game theory assumptions. The antithesis of Bueno de Mesquita (to the thesis of Mayer), and the synthesis proposed by Williamson, are also found in the work of the Nobel Prize-winning organizational psychologist Herbert Simon (1996). This tension, between thesis and antithesis, between complexity and predictability, can be seen in the two approaches already discussed, the first of Holland (Chapter 10), emphasizing how systems shift in complex ways, and the second of Wilkinson (Chapter 12), who finds predictable and recurrent patterns across thousands of years of the international system.

Williamson also has a chapter on international systems, using a further development of Quincy Wright's field theory to provide a third view. In some respects it is close to the views of Wilkinson and Holland. Williamson's view is that the sorts of transitions discussed by Wilkinson and the adaptive complexity discussed by Holland may be at selected times characteristic of the global system: namely, they may apply when the system is going through disruptions caused by the entry of new parties into the center of the system. The center of the system is the place where the major powers are located. (And a small but highly developed country, like Holland, might sometimes share the center with the majors.) In

Williamson's view, nations are developing politically and economically, and interacting with each other, which allows the weaker peripheral powers to get stronger and move toward the center of the system. This evokes the important work of Organski (1968) on economic development, differential rates of growth, and power transitions. Though not yet as thoroughly developed, this use of field theory may also relate to the systematic evolution in size and relative importance of elites, selectorate, and other functional parts of sovereign political entities (Bueno de Mesquita et al. 2003). Also, methodologically, Williamson explains some of the ways in which uncertainty in prediction in physics (stemming from chaos theory and quantum mechanics) is related to uncertainly in predicting global conditions.

To understand Williamson's contribution (Chapters 14 and 15), it is useful to consider the distinction between a theory and a model; and in fact, there is also a less developed third idea which we could call a framework. All three of these are useful, but in different ways. In their chapters, Holland and Wilkinson basically have frameworks. In frameworks, a set of concepts are defined, and there is usually a discussion of what examples can be given of the different concepts. For example, in Wilkinson's framework, the concentration of power in a civilization is such that the area is either a single empire, or a hegemony (one dominant state that the others follow), or unipolar (one dominant state but the others are not so compliant), bipolar (two dominant states), tripolar, multipolar, or (the least concentrated power of all) non-polar. Wilkinson reports (as seen in his bar graphs) that Egypt, the most unified civilization presented, was most often an empire, and even when not an empire was most often unipolar. Indic civilization was usually unipolar like Egypt, but otherwise bipolar. Far Eastern civilization had two more radically opposed tendencies, one towards unipolarity (basically, dominance by China), the other multipolarity. As the least concentrated of the civilizations studied, Mesopotamia experienced multipolarity most of the time. So a framework like this, when applied to the past, tells us what has happened and, insofar as the future will be similar to the past, what is likely in the future. For example, in Wilkinson's case, if the future is like the past, our civilization will keep the power concentration it now has, or revert to what it had been just before that.

Theories and models differ from such frameworks in having the potential (if they can be shown to be true) of more precise predictions. This stems from what they are by their nature, that is to say, by definition. Alexander, in Chapter 4, has explained this to us for a theory: "A theory is said to be a simple set of propositions that provides a large number of explanations. Einstein noted that 'a theory is the more impressive the greater is the simplicity of its premises, the more different are the kinds of things it relates and the more extended is its range of applicability.'" I would add that the main reason for a theory is to explain why something is likely to happen. A theory, by explaining why something happens, allows us to predict when it will happen. The reason Alexander makes this point is that he and Wilson (Chapter 3) are predicting the future based on the neo-Darwinian theory. This is all a look backwards. Yet in our book, we have not yet dealt as thoroughly with the third kind of organizing scheme, a model. Models can be even more precise predictive tools.

What is a model, as we use the term in this book? A model is a representation of part of the world that encompasses some elements from a theory, or theories, and makes those theories more specific, dynamic, and precise. It does so by the construction of a computer code that tells how events will unfold through time. In other words, we are focusing on dynamic, computational models (as opposed to static models, like a model ship on a mantelpiece; or analog dynamic models, such as an electrified toy model railroad). For instance, the *World Dynamics* model of our biosphere (Forrester 1971) is the computer program that undergirds the ecological theory of the best-selling book, *The Limits to Growth* (Meadows et al. 1972; Meadows et al. 1992). In Chapters 11, 14, and 15, Karasik and Williamson outline the precursors for a dynamic, computational global model that would have nations, sovereign states, societies or civilizations as basic units. This is different than the early global model of Forrester (1971), which focused on worldwide levels of material standard of living, population, and pollution over modern times. Karasik and Williamson are following more in the tradition of Quincy Wright's field theory (see Rummel 1975), in which societies, such as members of the United Nations (UN), or civilizations, are each treated as distinct units, interacting in a global system. In Karasik's theory, the psychological mindsets of the typical members of each society matter, especially their values. Through an "annealing-nucleation process" each society tends to produce a degree of uniformity or conformity within itself, and as the technology develops and people encounter different societies, conflict between these different societies ensues. This is mediated by processes of cognitive dissonance that reinforce conformity within. Hence, if and when these societal units came in contact with each other, the units would interact over time, either enjoying benefits of trade and economic development, or turning to warfare. Karasik's viewpoint is nowadays empirically capable of study in a forecasting model, as there are data over a sufficient number of decades for the central variables. For example, Gurr (1994) showed that armed conflict data (similar to the Correlates of War Project war data discussed in Chapter 13) are associated with the "fault lines" between Huntington's civilizations: where the civilizations meet geographically, there is more warfare. And Inglehart, who has measured values in more than 60 sovereign states over several decades, has teamed up with a series of co-authors to show that global value change, which stems from economic development, moves in a predictable direction, and in turn predicts political and social change, including the spread of stable democracy (see, e.g., Inglehart and Welzel 2005; Inglehart and Baker 2000). When he died, Williamson's organization, Global Vision, had just completed a website with cross-national data, in which individuals around the world (much like in Wikipedia) could contribute or submit hypothesized lists of independent and dependent variables. These individuals (about 100 had been identified as potential contributors) could use very simple codes to indicate roughly how the selected variables might be expected to affect each other. Pieces of programming language code would then be generated at Global Vision (that could be integrated toward the construction of the emerging global model), while running sophisticated tests of the hypothesized relationship between and among the chosen variables. Hopefully, other organizations will take up this work. It would seem that the increasing incorporation of measures from Inglehart into dynamic models such as International Futures (Hughes 1999) would be a good way to continue on the path suggested by Karasik and Williamson at Global Vision.

The remaining chapter to mention in Part V is Wayman's Chapter 13. In it, Wayman discusses, in the context of cooperation and conflict between nations, the difference between explanation and prediction. On the explanatory side, he provides a proof of the conditions under which altruism can emerge; this connects back to the work of Wilson in Chapter 3, insofar as Wilson had said that altruism is "the central theoretical problem of sociobiology" (Wilson 2000 [1975]: 3), a core component of Wilson's life work. (And this is also an important problem that was taken up by Alexander in Chapter 4 in this volume.) On the forecasting side, Wayman provides different predictions of the amount of war in the global system over time. Methodologically, his work represents an innovation on the study of war, in advancing the main theme of this book, that studies should be reoriented where appropriate into models that predict the future and that are tested against empirical evidence.

So we have many views of the global system to consider. To begin these perspectives, we turn to John Holland, one of the leading representatives of the field of complex adaptive systems. From that perspective, Professor Holland presents us with a set of "glimpses of the future."

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10. Glimpses of the future

John Holland

The problems that interest me involve most of the buzzwords you hear in the daily news: innovation, Internet, global trade, equity markets, sustainable human growth, ecosystems, and the immune system (Box 10.1). I would like to take a step back to see if there are common traits in these systems that will aid us in predicting their future impact. Each of these problems involves a system that consists of many interacting individuals or components.

Moreover, in each case, the individuals or components adapt their strategies or actions as they interact; that is, they learn (Figure 10.1). I will use the term "agent" to designate the components, and I will call the system as a whole a complex adaptive system (cas). I will use the term "adaptation" to include both long-term changes, such as the gene modifications involved in speciation, and shorter-term changes, such as learning in the immune system or the central nervous system. The combination of interaction and adaptation makes it difficult to predict the aggregate behavior of a cas.

A theme that Edward Wilson and Richard Alexander both examined earlier in this volume (see Chapters 3 and 4), is common to all cas: the

BOX 10.1 SOME DIFFICULT PROBLEMS

Encouraging innovation in dynamic economies.
Controlling the Internet (e.g. controlling viruses and spam).
Predicting changes in global trade.
Understanding markets.
Providing for sustainable human growth.
Preserving ecosystems.
Strengthening the immune system.

These problems center on systems with many interacting agents (components) that learn or adapt. These systems are called complex adaptive systems (cas).

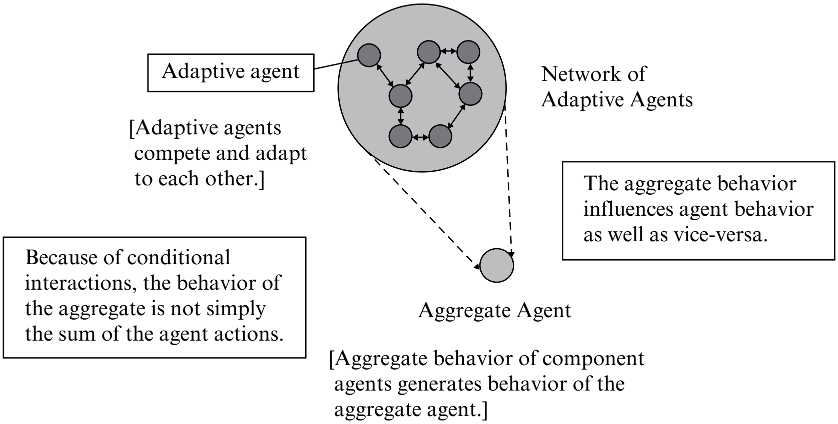


Figure 10.1 A complex adaptive system (cas)

actions of cas agents are conditional on their surroundings, including the actions taken by other agents. That is, we cannot derive the behavior of the cas aggregate by simply summing up the actions of the individual agents. The bottom-up effects that generate the behavior of the aggregate are not additive, so from the mathematical point of view these systems are non-linear (non-additive). There are also top-down effects of the aggregate behavior of the cas on the individual agents. As a simple example, consider the effect of the Dow Jones average on the buying and selling behavior of individual agents in an equities market.

When we look at a cas, there are usually several ways we can decompose it into agents, depending upon the questions we want to ask and the predictions we would like to make. A typical decomposition of an ecosystem is to treat the organisms as agents; a typical decomposition of an economy is to treat firms as agents; a typical decomposition of the immune system is to treat antibodies as agents; and so on (Table 10.1 and Box 10.2). I emphasize that these decompositions are not unique. For

Table 10.1 What is an adaptive agent?

Agent	System
Organism	Ecosystem
Firm	Economy
Antibody	Immune System
Trader	Market
. . .	. . .

BOX 10.2 ADAPTATION

Adaptation occurs when agents learn from each other or change strategies as they gain experience.

> Evolution of ecosystems and economies provides well-studied examples of adaptation.

BOX 10.3 CHARACTERISTICS OF A CAS

A *cas* is an evolving, perpetually novel set of interacting agents where

- There is no universal competitor or global optimum.
- There is great diversity, as in a tropical forest, with many niches occupied by different kinds of agents.
- Innovation is a regular feature – equilibrium is rare and temporary.
- Anticipations change the course of the system.

example, we could decompose an economy into industries or activities, depending upon the question we are asking or the kind of prediction we would like to make.

Some of the characteristics common to all cas are shown in Box 10.3. First of all, there is no superagent. There is no universal competitor that eventually overwhelms all other agents. It is generally not sensible to try to find some "optimal" organization for a cas – who would even try to define an "optimal" rainforest? Because a cas does not devolve into a single kind of agent, it usually exhibits great diversity in its component agents, a diversity that is continually changing. One need only consider a tropical rainforest to see just how great this diversity can be. If we look at a single tree in a tropical rainforest there may be as many as 1000 or more species coexisting on that single tree. Your own human body contains roughly 100 bacteria of many different kinds for every single somatic cell; it is indeed an ecosystem in itself. For the sake of the mobility of our personal ecosystem, it is a good thing the bacteria do not weigh very much.

Even looking at a mammal as an ecosystem supporting a multitude of organisms does not encompass the great complexity of multi-cell

BOX 10.4 DIFFICULTIES (1)

Combinations of conditional interactions (IF/THEN, rule-like interactions), perpetual novelty, and regular innovation occur in all cas.

> [Similar combinations occur in computer programs, and in the play of board games such as chess or Go.]

Traditional mathematics
 [partial differential equations, statistical techniques]
 is of limited help, because the most powerful theorems
 [about formation of attractors, optima, and steady states]
 do not apply.

organisms. Eukaryotes start as a single fertilized cell that develops into a diverse multitude of cells. Development, as Alexander mentioned (Chapter 4), involves innovation (new cell types) in a regular fashion, not as a happenstance or occasional occurrence. Finally, again making a point that Alexander made, anticipation can change the course of the system. Even a prediction that does not come to pass can change the course, as for example prediction in the stock market. These four characteristics acting together – absence of an optimum, diversity, innovation, and anticipation – make prediction of cas behavior an intricate task.

In Box 10.4 we see some additional difficulties. Conditional interactions yield perpetual novelty. This is not an unusual effect. It occurs in board games like chess or Go, or in computer programming. A few rules or instructions define a huge space of possibilities. In chess, defined by less than a dozen rules, you never see the same game twice, unless a game is deliberately replayed. We have studied chess for hundreds of years, and still we come up with new strategies for playing the game. In short, great complexity can arise from a simple set of defining rules.

Because of these non-linearities, cas are difficult to examine with traditional mathematics. The powerful theorems about fixed points, trends, and the like, at best apply only to special periods in cas development. Such theorems can be helpful, but they rarely let us get at the center of the system. It is also true (Box 10.5) that we are not likely to understand these systems without crossing disciplines; we have to synthesize diverse concepts. That, in itself, is difficult because the relevant concepts (say the concept of niche) have already been much studied within the context of a particular discipline (ecology); it takes time to generalize the concept, and

BOX 10.5 DIFFICULTIES (2)

Cas problems typically fall at the intersection of several disciplines, requiring intensive cross-disciplinary study.

Cross-disciplinary research is difficult because:

1) It is necessary to construct a rigorous synthesis of diverse concepts.
2) Established fields want papers with radically new ideas to meet their pre-determined (sometimes obsolete) standards for publication. Moreover, promotion in a department or institute depends upon publication in the standard journals of that field.

Be patient, acquire a patron, and train many students.

its vocabulary, to fit across several disciplines.[1] Beyond this is the usual dislike of abstract theory. This difficulty is nicely captured by an old *New Yorker* cartoon. It shows a typical grammar school classroom, with the teacher teaching the students arithmetic, writing on the chalk board "$2 + 2 = 4$" and further refinements such as "$5 - 2 = 3$." In this case we have one bright guy in the class who is saying, "May I ask where you're going with all this?" All of us working with abstract theory have encountered this difficulty time and time again. People want to know the result, when you are still trying to explore.

Turning, now, to cross-disciplinary synthesis, Table 10.2 shows some of the possibilities. We can start with four fairly standard disciplines, one to each column, which at first sight may look rather different. We have control theory, economics, biological cells, and games. The second row of the table gives the main object of study in each discipline. For instance,

Table 10.2 Possibilities: cross-disciplinary similarities

Control theory	Economics	Biological cells	Games
process variables	activities	phenotypic features	board configurations
operating costs	activity costs	metabolic costs	board evaluation
objective function	profit	fitness	payoff
control policy	plan	reaction net	strategy

in control theory they study process variables. These are the variables that have something to do with the process you are trying to control. In economics, especially in the von Neumann version of economics, the corresponding objects are activities. The corresponding objects of study for biological cells are the cell's phenotypic characteristics. Finally, in games you study sequences of board configurations.

You can go across other rows of the table in the same manner, making further comparisons across the disciplines. Across the bottom row we have the objective that allows predictions; in control theory it is a control policy – how can I control the plant? In economics, it is a plan. In biological cells, it is what I call a reaction net. (This is something on which I am spending a good deal of time. A reaction net is concerned with questions such as: how do proteins within biological cells interact? How do boundaries form? How do signals form? Why?) Finally, strategies are the corresponding objective in games.

It turns out that you can develop a common formalism. You can make even formal comparisons. One way to do this, when the mathematics is difficult, is to build executable computer-based models. The advantage of a computer-based model is that it is as rigorous as any mathematics; in fact, in a way, more rigorous. When we do proofs in mathematics we leave out steps. However, if you leave out a step in a program, it does not work. In either programs or mathematics, we make the assumptions explicit.

Building computer-based models is sort of the modern counterpart of the *gedanken* (thought) experiments of physics. You have some mechanisms in mind and you want to see what they imply. With *gedanken* experiments we were limited to what we could do in our head. With the computer we can, as Gottfried Mayer has said to me, both make our assumptions explicit and follow up the consequences even when the interactions are quite complicated (Mayer, personal communication). A computer-based model does not have the broad generality of a mathematical formulation, but it is rigorous and it does give a feeling for possibilities. A model, like a good theory, tells you where to look when you are collecting data. (These and related points are summarized in Box 10.6.) Of course, our assumptions are important in both the mathematics and the computer model.

There is a common response when you present a model at, say, a conference: there is almost always someone who asks you why you left out some well-known mechanism or variable. It is common for those present to want you to add more "knobs" or "buttons." But the essence of model-making is, in my opinion, getting rid of detail, not adding it. What is detail, of course, depends on the question you are trying to answer. At this level, model-making is an art form depending on scientific taste. There is no easy deductive way to arrive at good models. You have to decide, in an

BOX 10.6 COMPUTER-BASED MODELS OF CAS

Because the interactions in cas are usually conditional and nonlinear, rather than additive, the usual techniques of reduction – studying the parts and then adding the behaviors of the parts – do not work.

The interactions as well as the parts must be studied.

Computer-based models are a crucial tool for exploring the interactions.

A model, like a hypothesis, suggests where to look.

intuitive way, what is central and what can you throw out in order to get at the question. There is a relevant quote from A.S. Eddington (1928): "The contemplation in natural science of a wider domain than the actual leads to a far better understanding of the actual."

My own approach to building models of cas is to look for the "building blocks" of the system (see Figure 10.2 and Box 10.7). Building blocks are, I think, the very essence of human perception and conception, including basic scientific research. It is the way we understand the world; we call something a "tree" because we can pick out certain common building blocks that are present in all trees. Abstraction at that level is critical. In order to see regularities in this perpetually changing world, we must select the building blocks that recur. They provide us with the repetition necessary to learning and prediction.

Building blocks lead, also, to insights concerning the questions about predicting innovations. Though it might seem paradoxical, almost all innovation uses well-known building blocks. The example in Box 10.8 – the internal combustion engine – made one of the biggest societal changes in the first half of the twentieth century. It provided a highly mobile source of power, completely modifying our abilities to get from point to point. All the building blocks for the internal combustion engine – the gears, the pumps, the sparking device that ignites the fuel, the carburetor – had been known for 100 years or more. The innovation was a new combination of these well-known building blocks. (As an aside, I would suggest that recombination of building blocks – genes in this case – is the main driving force in biological evolution. Mutations, often cited as the driving force of evolution in elementary textbooks, are actually quite rare compared to recombination. Recombination takes place in every individual in every generation of sexually reproducing organisms.) In effect, recombination

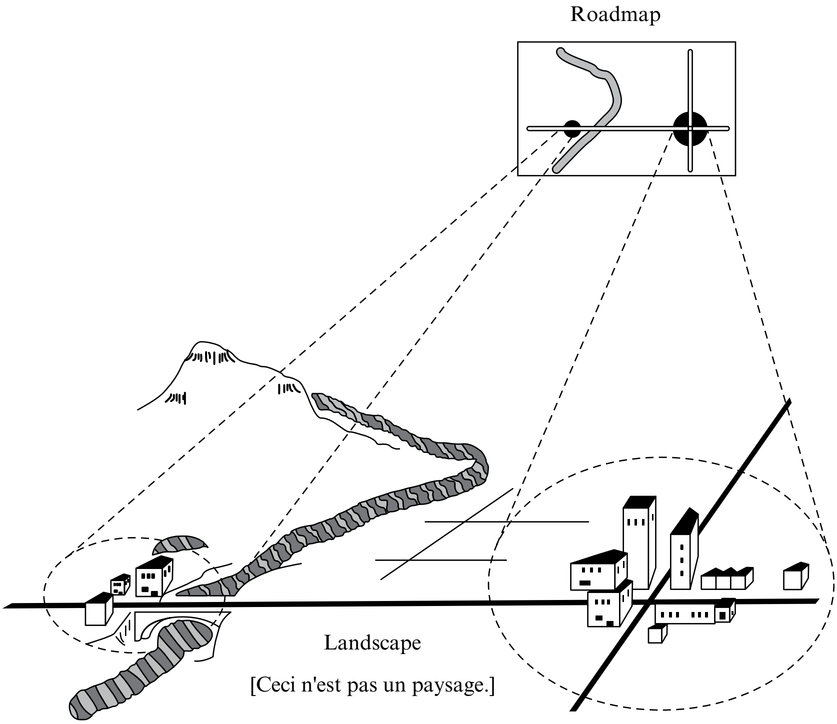


Figure 10.2 A model

BOX 10.7 MODELS USING BUILDING BLOCKS

To understand innovation in cas we must understand the relations between adaptation and building blocks.

"The contemplation in natural science of a wider domain than the actual leads to a far better understanding of the actual"
– A.S. Eddington

uses past experience, in the form of tested building blocks, to yield plausible attempts at innovation.

In Box 10.9 we see some well-known systems of building blocks in science. It emphasizes that building blocks at one level, when put together in particular combinations, often serve as building blocks one

BOX 10.8 BUILDING BLOCKS AND INNOVATION

We understand the world around us – proteins, spacecraft, or languages – by discovering the relevant building blocks.

Most innovation comes from combining well-known building blocks in new ways.

For example, the internal combustion engine combined well-known parts in a new way:
gears for mechanical advantage,
pumps for fuel distribution,
Volta's sparking device for ignition,
Venturi's perfume sprayer for carburetion, and so on.

BOX 10.9 WELL-KNOWN BUILDING BLOCKS (1)

A typical hierarchy of mechanisms (building blocks) in science:

System	Mechanism
nucleon (proton, neutron)	quarks, gluons
atom	protons, neutrons, electrons
gas or fluid	
confined (e.g., a boiler)	PVT equations, flows
free (e.g., weather)	circulation (e.g., fronts), turbulence
molecule	mass action, bonds, active sites
organelle	membranes, transport, enzymes
. . .	. . .
ecosystem	predation, symbiosis, mimicry

level up. My colleague Murray Gell-Mann says, "When you scale up three orders of magnitude in any system, you get a new science" (personal communication). When you go up three orders of magnitude, you have a new set of building blocks, a new set of interactions, and a new

BOX 10.10 WELL-KNOWN BUILDING BLOCKS (2)

Phoneme [elemental sound or gesture]	Letters {a, b, c, . . . }
Morpheme [meaningful combination of phonemes]	Words {ball, cookie, give, . . . }
Sentence [meaningful combination of morphemes]	Sentence {Give the ball to me. }

set of laws. This view does not mean that reduction does not work. To do reduction, when studying a cas, you have to take the interactions into account. Simply dividing the things into the parts and then trying to sum up the behavior of the parts to get the behavior of the whole is not going to get you there.

In Box 10.10 we see that building blocks also play a role in the way we study linguistics. We can also refer to Edward Wilson's discussion of patterns. Humans have subtle pattern recognition, particularly when it comes to the recognition of other human faces. Let us consider a way we might divide a human face into building blocks (see Figure 10.3). Choose, say, ten features, and allow ten alternatives for each feature. For example, allow ten alternative building blocks for eyebrows, ten alternative building blocks for foreheads, for eyes, for noses, for mouths, and so on. That is, we have ten features, with ten alternatives in each feature. Now I ask my graduate students a question about this and they almost always answer the wrong question. How many building blocks do I have? Ten features, ten alternatives for each feature. I have ten sacks with ten blocks in each, so I have 100 building blocks. When I ask this question, my students usually answer a different question: how many faces can be constructed? Well, I can pick one block from each of the ten sacks. So it is ten (one from the first set) times ten (one from the second) times ten . . ., so that we can construct ten to the tenth (10 billion) faces from 100 building blocks. Now I submit that we are good at recognizing different human faces because we have the right building blocks. Along similar lines, we do not distinguish very well between the face of one chimp and another because we do not have the right building blocks. In short, the right building blocks let us make careful distinctions. As the figure shows, building blocks also make it easy to represent a complicated geometric object, like a face, by a string of

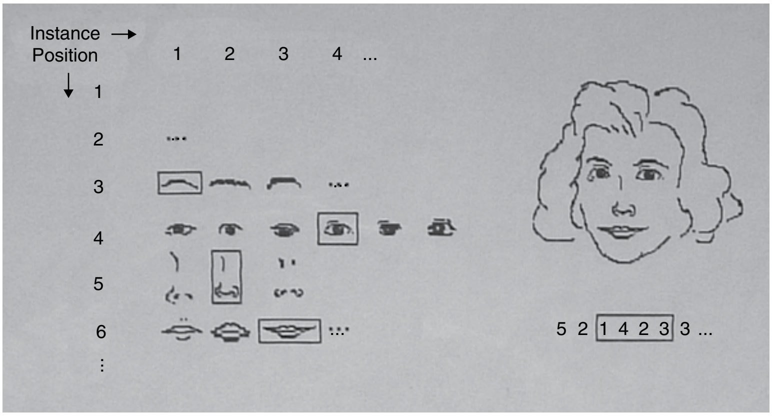
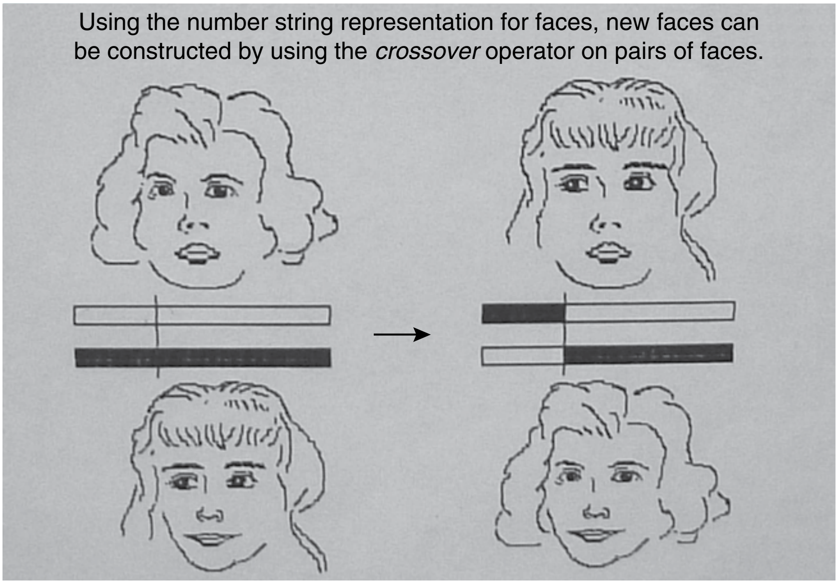


Figure 10.3 Building blocks for a face

numbers – eyebrow one, eye shape four, nose two, mouth three and so on – thus facilitating construction of computer-based models.

We can also use faces constructed of building blocks to point up the value of recombination in producing innovations. Consider the two faces on the left of Figure 10.4. They were both constructed from the given set of 100 building blocks. The bar beneath each face represents the string of ten digits that describes the face. Now let us treat these strings as if they were chromosomes and cross them with a single point of crossover. The result is two new faces (the ones on the right) obtained by recombining the building blocks used in the first two faces.

Now, let us try an experiment: let us randomly generate a set of ten faces from the building blocks. Then let us select someone and ask them to rank the ten faces according to some abstract quality, say honesty. Now, though it is a strange task, most of us would attempt it, even though few of us could write a concise definition of the "face" of honesty. (It seems to be part of human nature to judge people's honesty by their faces.) Next, take the faces ranked highest and cross them to produce a set of ten new faces, just as was done in Figure 10.4. Then, ask the same student to rank these new (crossover) faces as to honesty. I can guarantee you that after five generations of producing new faces by crossover the student will consider almost every face in the fifth generation to be more honest than any face in the first generation. Because of the building block construction, you can even analyze what the differences are between the first generation and the fifth generation. That is, you can see what the student looks for when judging a face as honest. Typically, it is not one single trait or feature; rather it is some combination of features such as a particular nose with



Using the number string representation for faces, new faces can be constructed by using the *crossover* operator on pairs of faces.

Figure 10.4 Innovation by recombination

a particular mouth, or the like. That is what makes it difficult to write an essay on honest faces. It is also the reason that, if you ask different students, you will get different preferred combinations. The human individuality pointed up by this simple illustration contributes to the difficulty of predicting the behavior of cas wherein the agents are human.

When we look to innovation in larger-scale human cas, such as industries and countries, there are some important steps in providing these systems with increasing resilience and sustainability. First of all there is risk-taking. Risk-taking is stage-setting for the future. A former student of mine, John Seely Brown, at the time chief scientist at Xerox Park, says that he did not consider that they were "pressing the envelope" (exploring) enough, unless at least nine out of ten of their research projects failed (personal communication). It is the tenth project, the "home run," that more than pays for all the losses of the other nine. A successful new invention incurs income in an exponential fashion, much as a new species of above-average fitness spreads exponentially. (See the like remark on forward-looking by Richard Alexander, as quoted by Wayman in Chapter 1 in this volume; and the entire passage from which this quotation is taken is in an insightful preliminary version of Alexander's Chapter 4; see Alexander 2005.) How many companies do you know that are taking risks at that level, let alone governments?

BOX 10.11 CAS, EXPLORATORY RESEARCH, AND SUSTAINABILITY

Observing cas that regularly produce innovations, e.g. evolving ecosystems, suggests changes in the way we usually conduct research:

1) Risk-taking. Allow for high failure rates in funding. Because of the exponential growth of the successes and their "spin-offs", the return from "home-runs" greatly exceeds the losses incurred by the failures.
2) Diversity and Parallelism. Follow several paths simultaneously in exploring a given question.
3) Credit assignment. Provide ways of rewarding stage-setting activities.

Cas can explore many options simultaneously (item 2 of Box 10.11). Neither companies nor governments are confined to a single "game plan." It should be a matter of how much effort is to be distributed to each of several promising options. It is as if you can play a game by trying out many moves simultaneously. Clearly, exploration of several options enhances the ability to take risks.

Credit assignment is the process of crediting early actions that set the stage for later successful activities, as in the sacrifice of a piece in chess to gain a more important piece later (Box 10.11, item 3; and Box 10.12). Appropriate credit assignment distinguishes good players from bad players. It is easy enough to make an obvious good move, but it is much harder to credit some much earlier move that made possible the obvious good move. In a contemporary research setting, credit assignment is a question closely related to risk-taking: how do you allocate credit to a research center when most of the projects it generates fail? It is only long after the fact that we learn which of an array of projects were successful, yet the costs of research impact the current "bottom line." There are some recent theoretical advances that go beyond traditional decision theory to do a better job of credit assignment in a risk-taking business setting (see, e.g., Trigeorgis 1996).

Let us look again at these three points in the context of research projects. Risk-taking and exploring multiple options are clearly available to large companies and governments if the credit assignment problem can be handled. The "bottom line" problem looms large. Consider the following

BOX 10.12 CREDIT ASSIGNMENT, STAGE-SETTING, AND SUSTAINABILITY

The most difficult activity in the conduct of science or business is the early, sometimes costly activity that makes possible later, obviously good actions.

Consider the *gambit* in chess.

[Real option theory gives a better approach to these questions than standard decision theory. Trigeorgis (1996)]

fanciful approach to getting future research profits into the current bottom line. What if a company could sell lottery tickets for each of its various research projects? People love to buy lottery tickets. Moreover, a company with a history of successful research could charge a premium for its tickets. The money paid for the tickets goes into the current bottom line, and the chief executive officer (CEO) does not get fired because money allocated to research cut profits. Notice, as an aside, that equity markets greatly undervalue research: a year or two of unprofitable quarters, regardless of the cause, are usually enough to get a CEO replaced. Finally, this lottery system of evaluating research would, in the normal course of events, pay the winning ticket holders with substantially better odds than the typical state lottery.

Let me end with a brief description (Box 10.13) of a computer-based approach that I think will be of substantial help in predicting and controlling the behavior of cas. I will call it a "flight simulator." All airplanes are designed now with the help of a precise computer-based flight simulator. The object is to extend this approach to cas in general. Here, roughly, are the steps in designing such a simulator:

1. Discover the building blocks from which to construct the simulator. You start with the gauges on the control panels that provide the information that enable the pilot to fly the plane. Then look for the components that generate that information. Those components become the building blocks of your model. For cas in general you look for the mechanisms from which the cas is constructed.
2. Next, you design an interface, much as for a video game, which lets an expert in the area, say a pilot (not a programmer) control the system. The expert must see and use the controls with which he is familiar.

BOX 10.13 WHAT IS TO COME

- Flight simulators for organizations
  Gell-Mann's dim flashlight: provides insight into options and possible disasters
  Allows testing and verification by experts who are not programmers

- Exploitation of cas lever points
  Principled discovery of targeted interventions similar to vaccines

- Allocation of credit for exploratory research
  Depreciation-like accounting principles that allow costs of exploratory research to be spread over future income

3. The expert then tests the model by trying out various things that are familiar. The pilot "lands" the plane, for instance. Then he begins to push the envelope: he takes sharp turns; he cuts one engine; he continues with a set of increasingly difficult, and hazardous, maneuvers. It is the expert who determines whether the simulator is good or bad, not the programmer. It is up to the programmer to correct the errors, but it is the expert – the pilot – who determines what the errors are.
4. The object then is to construct for, say, a corporation or a research organization a simulator-like model that lets the CEO or lab director make decisions, and see the effects, in a context provided by a good interface. They do not become programmers; they simply do what they know how to do well.

All cas we have examined carefully exhibit "lever points": conditions under which a small action can have a large directed effect. A simple example is the effect of a vaccine on an immune system. Vaccines are relatively simple and inexpensive, but they change the immune system for life. A relevant "flight simulator," or a good theory, would let us uncover lever points in a principled way, instead of using the trial and error approach now used with all cas. In fact, without a theory, we do it "by God and by guess."

NOTE

1. There is a substantial problem in academia and elsewhere in pursuing cross-disciplinary research. You can rarely advance in a given discipline (read "department") unless you publish papers in the favorite journals of that department. Papers you publish in other journals just do not count. I have seen that over and over again, in several departments, in my time at the University of Michigan. My partial solution – one that I regularly shout at my graduate students – is "find a patron." Find somebody senior in the field who will say to the administration, "Oh, let her/him get on with it." Your ultimate revenge, of course, is to train a lot of PhDs.

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11. Forecasting the evolution of cultural collisions using annealing-nucleation models

Myron S. Karasik

The "anvil" of history lies at intersectional boundaries of cultures. Australia, cut off from the human family for 40 000 years, demonstrates clearly the innate conservatism of successful human traditions. On the other hand, during the same period of time, the permeable boundaries of human cultures, particularly in Eurasia (and most recently, the Americas), have been the wellsprings of our evolutionary history in recent times. They still remain the driving force of future evolution of human socio-political and economic development. Using the concept of annealing-nucleation from the physics of materials, we can predict global evolutionary behaviors over relatively short periods. The macroscopic behavior of materials, representing the sums of many individual components, can be modeled through a relative handful of boundary value measures representing the difference between dissonance experienced by the components, action proclivities, and degree of credibility of communications that are analogous to temperature, field strength, spin orientation, and so on Just as modern weather forecasting has become a more reliable tool through use of similar models and computationally efficient processing of large numbers of instrumented data points through "grouping" techniques, so the ability to forecast major socio-political and economic "storms" could be developed based on a few core principles. These days, i-reporting offers us the multimedia raw data from which observations can be made. Some global modeling features leveraging this approach are described. Note that this work is built upon my earlier work done on conservation laws and the dynamics of economic systems, agent-based modeling, and fuzzy neural networks (Karasik 1984, 1987; Karasik and Williamson 1994).

The quest of science is to develop computational models sufficient to predict the behaviors of a system under various conditions. The accuracy of the prediction serves as a measure of the "correctness" of the model in capturing the essential elements that define the behaviors under study.

Whereas physics has been considered the gold standard for the success of the scientific enterprise, in other areas, such as economics and social behavior, the models are seen as far less reliable.

In the present context I am speaking of carrying out this scientific predictive enterprise with respect to the global (Earth) system, focusing on the dynamics of the behaviors of human populations (economics and social behavior) and more. In physical scientific inquiry, the scope of a system is usually bounded. Thus a scientist studies the behavior of a pendulum by ignoring all other items except the gravitational field of the Earth but excluding the gravity of the Sun and Moon and other sources. In electromagnetic studies, the sides of a conductor or insulator can bound the region of interest and contain the fields. Behavior at a boundary therefore has great import. Einstein's great breakthrough, for which he got the Nobel Prize, was for the photoelectric effect, notably a boundary behavior between photons in the atmosphere and electrons bound to the atoms on the surface of a material. Thus the use has been made of the concepts of "boundary" and "boundary behaviors" in physics. Briefly, the first of these terms has roughly the same meaning as in ordinary conversation – a line enclosing a region; the second term refers to behaviors associated with a boundary, meaning associated with the group possessing that boundary, in a way to which I return later. Analogously, in what follows I consider a proposed use of these concepts in scientific prediction of the global system.

I also need to preface such an undertaking with two issues which, at minimum, shape the predictive undertaking. In what follows next, I consider these two issues; the first one briefly, the second at greater length. Then, in the remainder of this chapter, I consider some possible global system model features that are shaped by or consistent with conclusions drawn, concerning those issues.

TESTING AGAINST "REALITY"

The first issue concerns the requirement of testing a predictive model against realistic referent data; that is, against the reality of known facts. This requirement is essential to scientific practice. Even our religious traditions deal with this issue. Biblically, to determine whether someone is truly a prophet, communicating with the divine, the prophet's predictions must come true (Deuteronomy 18:21). In short, to predict the future, experiential confirmation is key, for which we need data and a yardstick for measuring those data consistently over time.

There is an important refinement, however: we also need what I call models, the ability to properly understand the interrelationships among the observable dimensions, the structures involved in the data. What we measure, empirically, are objective values of variables (that is, values are independent of specific observer), changing over time. What we seek is to establish some correlative relationship that integrates the various values of the variables such that, if we know some of the values, we can anticipate (replicate, to some acceptable degree of accuracy) the others. Thus, the refinement is that measurement should entail some theoretical idea of how the test information is to be used in a predictive modeling program. We cannot have a science without such programmatic measurement – without metrics.

Two further points: first, to successfully anticipate change, there must be a pattern – things that do not change, that is, invariance – from which to infer the changes that do happen. For example, in physics, invariance takes the form of conserved quantities such as mass–energy–momentum, electronic charge, and so on. Corresponding things (not necessarily yet fully known) will be required of global system prediction. In addition, there are key principles, such as the Principle of Least Action in physics, which defines the transformative norms of a physical system. I will postulate, with good reason, that the key invariants for human systems will be the conservation of economic wealth in exchange transactions, increase in social and technical complexity over time, and the Principle of Least Dissonance that drives an entity's behavioral repertoire.

Second, tests against reality, of necessity, are always made against the evidence of the past, for the future has not yet occurred and the present is (at least conventionally) but a moment standing between past and future. In sum, there must be reality checks to our models; and these checks must be against our record of the past. The model must therefore be adaptive and self-correcting, using new data points to refine the modeled relationships and linkage weights.

LIMITS TO PREDICTION

The second issue (suggested by the first) is that our models are meant to be predictive of the human condition; that is, the replication mentioned above must hold for some (at least relatively short) period of time into the future. However, the possibilities of future prediction are subject to inherent limits, which we consider here at some length.

Issues relating to predictability can be sharpened by reference to the idea of the "state space" of a system. Such a space may be defined as one having "orthogonal coordinate directions representing each of the variables needed to specify the instantaneous state of the system" (Baker and Gollub 1991: 7). Such variables are then known as “state variables.” In combination, these state variable coordinates define the location, in the space, of a point – corresponding to a particular definite state of the system (Arrowsmith and Place 1990: 1; Baker and Gollub 1991: 7; Penrose 2005: 220).

We are each members of at least one such system: the social system with which we most closely identify. In turn each such social system exists in the domain of the global (planetary) system. The state of this system (as in most) is time-dependent, that is, it changes (continuously, at least in some dimensions, let us assume) over time. The corresponding series of points forms a trajectory, a state space curve if you will, in a vast number of different dimensions comprising the global system. An accurate future prediction is equivalent to knowing the future path of the trajectory given that you know the historically measured points. The issue however is that we cannot do it, at least precisely, for the following reasons:

- Random perturbations occur (for example climatic and other geologic catastrophes, also biologic events like disease and blight).
- Population growth and demographic changes (including population movements): in larger social systems, individuals might be members of multiple groups, each with their own value set, the combinations of which might not be simply additive.
- Technological discoveries and changes impact the scope of human action.
- Behaviors are not deterministic, but depend on the degree of dissonance that can be tolerated based on socially held core values and the technologic and economic resources available.
- Core values can mutate over time.

The result of these characteristics is that the physics of such a system must inherently be non-linear and chaotic in a very specific sense (also discussed in a separate section, below). Such systems are characterized by trajectories that never quite repeat, that never come to a stop as would a single pendulum (when subject to friction). Instead we get imprecise and partially repetitive patterns that can on occasion flip between multiple temporary rest states or equilibria. The equilibria form around attractors. This conception is illustrated as follows (see also Abraham and Shaw 1984: 131): imagine a colonial three-cornered hat, but having only one side like a Moebius band (take a strip of paper and give it a half twist and stick its ends together, now draw a line, you will find you can make a full circle and come back to where you began). Now instead of a single thin strip, we have a full surface which is thick but there is sort of a drain at the crown of the hat that draws in, say, raindrops if we were to hold the hat upside down in the rain. Now imagine a small circle from which we go drawing lines and as we do the lines diverge throughout the hat. This is a three-dimensional representation of a Rössler diagram and the dynamic system (described by just three dimensions or three independent variables) is called the Rössler cycle. The "cycle" never returns to the starting point, but keeps passing close by, sort of an endless tickertape as the system goes from location to location over time.

An example of this in real life is an electroencephalograph-generated phase portrait of a small set of cells (neurons) while recognizing a particular scent. In remembering something that you smelled a long time ago, you are recruiting small populations of cells to retrace that pattern (Freeman 1991). The spatial dimensions correspond to various electrochemical state variables describing the system of neurons. The aroma need not be exactly the same as that which laid down the original memory. The activation of the memory will require only a degree of similarity in the new pattern and thus can invoke associated memories of dimensions other than smell, including happy or sad feelings associated with the original memory. (One can analogize that the corresponding interactions among the brain cells – the synapses – are not unlike interactions among human agents in a society whose members interact in accordance with degree of proximity and relevance.)

In general, the possible trajectories of future states, pictured as a line sequentially connecting a set of points corresponding to time, can be modeled by complex dynamics (having multiple possible time series of future state values) that typically inhabit a constrained set of values. These sets may or may not incorporate "attractors" (that is, a compact subset of semi-stable equilibrium values, toward which nearby state space points are drawn should the trajectory be closer). Think of a single attractor as like a drain in a sink: as parts of the liquid come closer they spiral into the drain and never escape. The more complex the model in terms of numbers of interacting populations of atomic entities, such as neurons or people, the more alternative attractors there are. (As discussed below, this will have implications for the predictability of human groups as a function of their population.) Further, the existence of multiple attractors leads to bifurcations of possibilities (crises in political discourse) when a particular trajectory comes near enough to the boundary between two such sets of values. The set of possible trajectories includes the potential responses to singularities in complex space; these points of discontinuity, called poles or singularities, may still exhibit well-defined behavior. (See Arrowsmith and Place 1990: 64–89; Ott 1993: 158–166; Zaslavsky et al. 1991.)

In mathematical parlance, the possible trajectories in the state space constitute a set of distributions or spectra supported by a manifold.

(Manifolds are the mathematical term for the abstract geometric concept of space which in this case have as many dimensions as are related to the distinct, independent variables that describe the behavior we are seeking to model.) This notion of a set of values and its affiliated spatial concepts is used throughout the texts cited. For further technical discussion regarding hyperbolic (diverging) and non-hyperbolic linear flows, singularities, and heightened response patterns of trajectories (resonances) see citations in Arrowsmith and Place (1990) and Zaslavsky et al. (1991). In regard to the Hamiltonian formulation, see the latter source. For illustration of the use of Hamiltonians for modeling of conserved economic relationships, see Karasik (1984).

It should be noted that unpredictability of future states due to bifurcations and associated chaotic trajectories does not necessarily imply loss of all behavioral structure or regularity. In a more general sense, it applies to behavior that is unpredictable in the long term, yet found in well-defined regions in the short term, since the orbits are partly constrained. Though my interest in forecasting naturally leads to greater emphasis, below, on the conventional definition of predictive accuracy, the more general sense of (partial) predictability also should be kept in mind. (Indeed, some measure of unpredictability seems unavoidably present even when we encounter the ordinary concepts of statistical uncertainty and measurement or sampling error.)

In a state space view of things, the collection of possible future states can be constrained by the “shape” (that is, location of the state point) of the space at the present; that is, the transition to a next state is completely determined by the current state. Another way of expressing it is that the system exhibits feedback (from present state to next state). This process is recursive or iterative; that is, the current state was determined by the immediately preceding state, which was determined by the state before that one, and so on. (Thus, iterative because the values are found by iterating or computing from one period to the next.) Thus, every future possible state is determined by the shape of the present. Moreover, this process can be probabilistic: each transition from one state to another can be mapped by a transition function which computes the likelihood of the transition of state $x(t - 1) \rightarrow xi(t)$ as $Pi\{x |T\}$; where the sum of Pi’s $= 1$, $T \equiv x(t - 1)$ is a shorthand way of referring to the prior state $x(t - 1)$ that held at time $t - 1$, and the form $Pi\{...|T\}$ denotes a conditional probability. The series of transitions therefore obeys the rules of what are known as Markov transformations. Again, the complexity shows up further in that the probabilities change over time and the number of alternative states changes since the number of entities can change and the possible actions can change.

The most general expression of the state space approach is to view the state as being described by a vector of attributes (a list if you will, like a menu) of those features that completely describe the state. Things like wealth, education, health, gender, religious affiliation, political affiliation, and so on, would describe an individual human. Now to capture the transformation of a state at time $= t - 1$ (unit) to time $= t$, we define a matrix of values, where each row of the matrix contains attributes that act on each of the vector's elements in an additive way (or not, if the row value for that element is zero). In mathematical terms we are 'moving' a vector in a space and this tells us where we are. Our interplanetary satellites are programmed to navigate in the same way.

Today, at time t, we all stand in a world that is in a certain state because of a series of phase points corresponding to the states which the world has previously occupied at all prior values $t_0 < t$. Thus the current state is indirectly a function of all prior ones; in a sense, the present time subsumes the past, is a compression of all prior time periods. The present state has the compressed memory of the system, if you will, of everything that has happened in the past, even if you could not recapitulate it just from knowing the present state. (However, in expressions such as those that will be discussed below, to calculate the future estimate one need only know explicitly the most recent state, which subsumes all the prior ones.)

For example, as individuals we have embedded within us the history of our family, species, and planet. The history of humankind is a portfolio of histories of various subgroups and their interactions. Our genetic endowment can be traced back through the generations (physical traits, personality traits, and so on). We breathe oxygen because billions of years ago single-celled plants "terra-formed" our planet. We have bilateral symmetry because it enabled complex organisms to survive the great catastrophes that punctuated our evolutionary history better than those who did not have it (that is, selection favored creatures with bilateral symmetry after the first great die-off of life forms). Further, the large-scale structure of the universe is defined by the early fluctuations in the energy densities of the early stage as captured by the Wilkinson Microwave Anisotropy Probe (WMAP) map, a snapshot of the universe at age 380 000 years. We respond to events occurring today through the prism of our values and culture. We have been shaped by salient events of the past as incorporated into the consciousness of a society through its narratives, taboos, and norms.

Drawing on the above, we can see various predictive limits. First is the inherent complexity of future possibilities, corresponding to the complications, just mentioned, of possible phase space trajectories, each of whose points represent the state at a specific time. Second, interactions of assemblages of entities are extremely large dimensions. That is, their vectors and matrices are large. The global system has a very large number of possible states, corresponding to the Cartesian product among the various possible values, on each of the separate dimensions in the state space.[1]

A third predictive limitation is that the values of many of the variables describing the current system state are unknown or at best approximately known. We think we are "here," but where is that, really? This is true of that system comprising the entire Earth in its human, other living, and non-living aspects; and it is true of many of the subsystems of the above and, certainly, of any subsystem that includes humans.

As an example, consider again the Rössler cycle trajectory described earlier. The key point is that each trajectory diverges from an exact cycle, in that it returns at time t only to approximately the same location it occupied previously at, let us say, $t - 1$. Further, the uncertainty of phase point location grows with the return cycle, as time progresses. Thus the attempt to predict the return location from the previous one will have a slight error. Over the course of time (in the absence of any subsequent updating information) at each successive near-cycle, the previous error is compounded by a further like error, so there will be successively increasing divergence between predicted and actual locations, as we attempt to predict further into the future.[2]

Fourth, the actual identities of some of the relevant variables may be unknown. In addition to uncertainty in the current values of state variables, there may be ignorance of their very existence. It may very well be the case that we could predict tomorrow, but not two years from now, or ten years, or 100 years, without substantially expanding the number of possible reachable states. Essentially this means that the number of dimensions needed to describe the possible set of future states is not fully known. Two examples can be cited to illustrate this point. First, technological development – electronic, computational, nuclear, biological, materials-structural, and so on – is increasing the known number of variables, namely those describing the previously non-existing inventions that are the embodiments of new technology. Second, societal development enables new organizational forms and options; for example Special Forces in the twenty-first century have (we imagine) a greater range of options than British Redcoats in the eighteenth century. (As discussed below, the contribution of technological growth to complexity has a corresponding contribution to system chaotic instability.)

NON-LINEARITY AND CHAOS

A fifth predictive limitation (also touched upon briefly above) is system non-linearity and its possible expression in the phenomenon of chaos.

Non-linearity means that the responses of the system to any particular stimuli, exogenous shocks, or perturbations, are not necessarily proportional to the strength or significance of the stimuli. In the case of the global system or its subsystems, such stimuli could (and in the second and third examples, they already have) come from sources such as rapid climate change, microbial pandemic, or contact with alien human groups.

Chaos refers to a situation in which, from the phase points comprising any region, no matter how small, surrounding the present phase point, the corresponding phase point trajectories diverge to nearly all locations in the space after a finite period of time. Under that assumption, any uncertainty whatsoever in the present system state implies complete loss of system predictability within that same finite period.

Simple idealized models of species populations and inter-species competition such as the predator–prey and logistic maps illustrate that even very simple non-linear, iterative systems may display chaotic behaviors over time (Arrowsmith and Place 1990: 119–179, 302–378; Baker and Gollub 1991). The term "map" here is simply another name for a function, usually defined on integers such as, in the following, the moments in time corresponding to the beginning of a period $n + 1$ and the beginning of its predecessor period, n. Turning to the second example, suppose (one speculative possibility) that the value of some attribute of interest, say group population, describing a human group at period n be designated by p_n. Then the corresponding logistic map is given (Baker and Gollub 1991: 77) by:

$$p_{n+1} = \mathbf{a}\cdot p_n\cdot(1 - p_n), \text{ where } 0 \le p_n \le 1 \text{ and } \mathbf{a} > 0. \qquad (11.1)$$

If an original variable, call it p^*_n, has values which are bounded between any finite minimum and maximum denoted by $p^*_{n,\,\max}$ and $p^*_{n,\,\min}$, respectively, then the equivalent variable p_n defined by $p_n \equiv (p^*_n - p^*_{n,\,\min})/(p^*_{n',\,\max} - p^*_{n',\,\min})$ will satisfy the constraint appearing to the right of the equation. In addition, one could generalize this expression by writing the coefficient $\mathbf{a} = a(t)$, in essence saying the relationship between the variables has the corresponding additional source of variation.

Equation (11.1) expresses the idea that system state, in the form of the state variable p_{n+1} in period $n + 1$, is dependent on its prior state p_n in period n (the recursive or iterative aspect just mentioned). Note that p_{n+1} depends, also, on the amount by which p_n falls short of its maximum value of 1; that is, p_n appears twice. This leads to a second-order polynomial (non-linear) relationship; and to the fact that as you iterate this particular function you get a very complicated trajectory over time. In consequence, for certain values of the parameter **a** the variable p_n will exhibit chaotic trajectories, meaning that it will bounce from each iteration to the next across the entire available range of values. In this latter case two points with initial values, say p_n and p'_n, no matter how close together they are, can be arbitrarily far apart after a finite number of iterations; so any degree of uncertainty, no matter how small, in the current value of a given p_n will lead, after a finite period of time, to complete uncertainty in its future values. To describe the situation somewhat differently, the ability to predict future states drops exponentially over time (because the number of accessible states – in the example, the range of possible values of p reached in a finite number of steps starting at p_n – grows exponentially; Baker and Gollub 1991: 76–87, 120–128). A function that, like the logistic map (a map which captures population changes over time), exhibits the possibility of chaotic behavior presents the situation in which there is a variable for the growth rate over time, called the Lyapunov exponent, λ, constrained by $\lambda > 0$ (Baker and Gollub 1991: 85ff; Çambel 1993: 82–112), which I return to below. In the models (Karasik, 1987) this value called 'a' shows up in the state space matrix exponent and captures the changes in numbers of columns and rows which define the system's member groups and their capabilities to act. Combined with other realistic limitations (above, previous section), the drop may be more than exponential.

Empirically, chaos is found even in simple systems such as mixtures of two or three species in chemical kinetics. Chaos also is found in realistic models of populations of predator–prey ecologies. Even for something as well understood as the motions of the planets in our solar system, we can only predict with accuracy where the planets will be for the next hundreds of thousands of years; our planetary system is sufficiently chaotic to render prediction of the locations of planets over periods greater than, say 100 million years, virtually impossible (Casti 2000: 80–82).

Concerning the Earth as a whole, the situation is far more complex than simple chemical kinetics or solar system orbits. The global system is undoubtedly (or, absent other information, should be presumed) chaotic. That system may include non-linear elements such as predator–prey subsystems. In the human domain, given different social groups – business firms or industries, for instance (auto industry, energy industry, and so on) – competing in some way for common resources, sharing some common domain or a certain space then has the same fundamental possibility for chaotic behavior. (Perhaps even the same or similar equations as, for example, those of predator–prey subsystems, characterize parts of these other systems.) Moreover, the complicating features of the contemporary world include increased proximity between human groups, in the form of greater interaction facilitated by improved communication, and multiple group memberships, both of which may increase the potential for non-linearities and chaos.

It can plausibly be argued that population and technology changes are the main contributors to the instability of human social systems. For example, technological change allowed humans a greater range of actions to impact their environment and each other. However there is also a consideration more specific to non-linear dynamical systems (Casti 1992: 288–292; Chen 1988; Karasik 1987). In our 100 000-year journey across the planet, certain environments proved to be quite salutary and human populations grew quickly; however, each such environment was subject to resource constraints (even though those constraints received various upward revisions due to technology changes). Accordingly, a model containing such constraints would seem to be more appropriate than a simple exponential growth model. In particular, the logistic map given as equation (11.1), above, exhibits approximately exponential growth in some circumstances (for example, sufficiently small values of p, relative to the carrying capacity of the environment). Thus the logistic map appears to be exponential in character in those same circumstances while, at the same time, containing the latent possibility of chaos in others. Note that equation (11.1) is not precisely the same as the continuous logistic function, though they are closely related in that each is connected to an exponential growth model. Given the above circumstances, the positive coefficient **a** corresponds to a positive rate of growth and, simultaneously, to a positive Lyapunov exponent which, as mentioned earlier, signals the possibility of chaotic behavior in the system under consideration. In situations where the growth process can be regarded as the result of investment, the above positive values also correspond to a return in excess of resource value invested (Karasik 1987). In that regard, the classic criticisms of Malthus and Marx correctly identified the culprit variables defining the crisis of the industrial age (Karasik 1984). In this particular model (that is, the logistic map model) the appearance of chaos in manifest form corresponds to a sufficiently large value of **a**. Another way of viewing the transition is that, as **a** grows in size, the number of bifurcation points (see above) that are reachable increases, thus there is greater uncertainty as to the evolution of the trajectories over time; the state in which essentially all points in state space are reachable corresponds to chaos. The foregoing considerations are in addition to the population and technology contributions to state space high-dimensionality which, as mentioned earlier, increase the size of the state matrix and vectors as time evolves.

In sum, if a model exhibiting chaos (in the manner illustrated above for the logistic map) is realistic – and such models have proven successful on many occasions; for example mapping population growth under predation – then the above is saying that attributes such as population, and so on, are capable of chaotic behavior, therefore unpredictable at times sufficiently far in the future. Note that none of the above precludes the possibility of prediction at times in the (yet to be determined) sufficiently near future.

Thus, while models may demonstrate qualitative correctness, specifying that a particular future state will be somewhere within the set of possibilities computed, the ability to predict the specific state occurring at a specific time is not available (somewhat like the Heisenberg principle, though not with the idea of complementary pairs). Furthermore, the model itself is constrained by the limitations of the number of variables incorporated. Exogenous or novel events, other processes impacting adaptability of a population, as well as overall time frames can make these models even more difficult to use, even virtually useless. (This uncertainty is the underlying reason for the discount function discussed by Farmer and Geanakoplos, Chapter 5 in this book.) So I would suggest that we can predict, perhaps, on the human condition five years from now, ten years from now, but not 100 years from now, not 1000 years from now.[3]

SOCIAL ANNEALING-NUCLEATION PROCESS

To summarize what has been said so far: a reality check has to take the form of testing a model against a record (observations) of the past and such a model has to say something plausible about the future, notwithstanding the huge and growing range of future possibilities. Then what can we say regarding the global system future? Can we harness the tools of science in service of predicting our short-term evolutionary paths? How? All the above provides a very strong indication that long-term prediction is precluded; that whatever predictability there is to the Earth and its subsystems will be limited to some time horizon, be it near in the future or far. Not precluded, however, is the possibility of suitably short-term predictability. In the remainder of this chapter I consider how some aspects of a model allowing such prediction might look.

Granted, our socio–technological–economic–political behaviors are quite complex, particularly when we are factoring in the size of populations and the number of possible interactions; however, as just suggested, complexity in itself does not foreclose short-term predictability (however brief that period may be). We can see this by going back to some basic physics concerning how different elements of a population interact. For example, thermodynamics deals with enormous populations of interacting particles, yet it can encapsulate behaviors in a few variables. Similarly the annealing-nucleation (also aggregation or clustering) process, where once established in a few system members, a pattern is replicated by all other members based on proximity and receptiveness. In physics this receptiveness is a function of interaction strengths, say of a magnetic moment of an entity with the magnetic field within which it finds itself. For human groups, as for collections of atoms, short-term predictability may come from viewing this as an annealing-nucleation process where proximity again plays a factor, as well as receptiveness in the form of credulousness in response to the communications of others.

My first thesis is that the dynamics of human history indeed are analogous to the annealing properties of magnetic materials (such as ferromagnetic spin glasses). When we heat such a material, it becomes amorphous and displays no regular properties, but as it cools, domains form, each showing a uniform preferred orientation of magnetic fields of the atoms, within, but a random orientation of this uniform field relative to other domains. Each such domain forms around a nucleation point, consisting of the collection of a few atoms, initially aligned in a certain common orientation that sets the "tone" (determines the direction of orientation) for the rest nearby. This process is local: atoms participating in a particular orientation will tend to be near the nucleation point. The direction of this alignment may occur by chance or, if the annealing occurs in the presence of a strong external magnetic field, all the domains will align in accordance with it; that is, there will be a single domain for the whole system. (In the latter atomic case, the material will exhibit macroscopic magnetic properties.) In addition to the above, there is a secondary effect that different domains of similar common orientation will tend to cluster together.

Equivalent to the above or in amplification, all atoms within a domain behave as a unit; they all behave alike (show common alignment) because they are linked to each other through a stronger energy bond relative to atoms in other domains (for example, see Arthur 1990: 95, left-hand side of figure). It is the uniform orientation that contributes to this greater bond strength. (This greater strength corresponds to the energy state being lower when the atomic fields are aligned.) The domains are characterized by the strength of nearest-neighbor relationships and solidarity of behavior in face of external forces (those originating from outside of the domain – those forces appearing at the domain boundaries, where, in the atomic case, the latter term expresses a spatial-geometric sense). A further point, of significance below, is that because of the uniformity within a domain, it is interaction at the domain boundaries, where the interacting elements are different, that gives the whole material its characteristic properties. Indeed, the domain boundary itself is the product of internal uniformity of pattern; it comes about as the place of transition from one pattern to another.

Annealing-nucleation is not confined to atomic scales. For instance, at the macroscopic scale, there used to be different types of track gauges in

Europe as people first started to put together the railroad systems. But over the course of time integration was necessary in order for the trains to be able to cross borders, and a certain track gauge became dominant. So again, as nucleation to form a domain occurs, so also does the amount of variability within the domain become less (Stauffer and Aharonov 1992: 70–85). The mathematical tool used to condense the representation of a group of atoms into a single bloc is called "renormalization." Thus I liken the above to the formation of groups, comprised of human beings as the "atomic" entities showing the uniformities.[4]

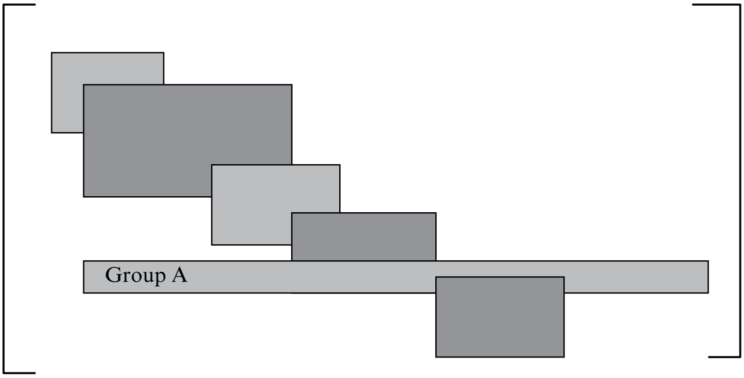
In each human group, the arbiters of a culture are the primary actors (leadership elites) who are able to mobilize the group population one way or another. Continuing with the spin glass analog (see above, in this section) these human arbiters are the nucleation points, so to speak, of the human domains. Each cultural entity posits a first individual arbiter (or founding leader, or elite member) who (together with a small group of followers) supplied the original point of nucleation around which a social group formed.

Within a group, its human members each show a profile of behaviors and beliefs that is tightly correlated with the other members. While individuals will show differing levels of satiation, risk-taking, and emotional rapport, the group members will cluster around certain averages. (In statistical terms, within-group variation is relatively low, compared with between-group. Where there might be individual variances in terms of one's personal experience, if you will, those differences are relatively small.) Thus, the behavioral possibilities and predispositions are encapsulated into group-specific cultural traditions and norms: a group constitutes a collection of individuals who on the whole see the world in the same way, have a common view, a common set of behaviors, a common set of values that they are measuring against, and a common body of knowledge; there are common kinship relations, rituals, taboos, hierarchies, and judicial methods; and characteristic means for achieving goals, technologies they can deploy, resources they can bring to bear. Again, the within-group common profile is the analog of the within-domain common alignment in the spin glass analog. (If the profile is represented as a vector of characteristics, then the analogy to parallel alignment is exact.)[5]

One mechanism of within-group correlation is that the group arbiters both symbolize the group ability to meet the spectrum of individual needs ("group needs"; and see the section below on "Dissonance and Fundamental Needs") and serve as the embodiment of the group's cultural identity. Furthermore, the actions of the group are mediated by the messages of the arbiters in response to environmental stresses and cultural/personal dissonance (between what the culture – and its individual members – finds acceptable, and the way the world is). This is because arbiters constitute those persons of highest credibility (see below) within a group. If the state of the world is "unacceptable" it will lead to strong efforts as a group to ameliorate the situation to become tolerable. Another mechanism is that human societies under duress will respond as a single unit and bear the stamp of the stressful experience, be it the Exodus from Egypt, the Long March, or September 11, 2001.

In sum, the group has, therefore, as part of its cultural repertoire, a series of behavioral predispositions that say that when a certain kind of event happens, then there are allowable recommended behaviors. This fact of relative uniformity, including group-specificity of behavior, simplifies the global state space and, thus, the task of short-term behavioral prediction. We can regard and evaluate norms and other attributes as characteristics of the group around which the clustering occurs, without needing to evaluate each individual member. Rather than contributing N·P -many dimensions to the state space, for N-many attributes and group population P, instead the group contributes the smaller number N or b·N, where 'b' is a small integer.

In the above (see the section on "Limits to Prediction"), a state space was defined in geometric terms. An alternative representation is by means of a state space model, the matrix appearing in Figure 11.1. In this matrix, rows correspond to individual human agents and columns to specific state variable contributions; alternatively – a collapsed version – (some or all of) the rows can be regarded as the groups to which the agents belong. It is the fact of relative uniformity within individual groups of human agents



Source: By Permission of Global Vision Inc.

Figure 11.1 State space model

which allows us to represent the groups as the shaded rectangles (blocs) in the figure. Each such rectangle represents the agent membership and state variable contribution of a specific group. The rectangle includes the portion of system attributes which the group controls or affects. (That is, the individual human agents belonging to the group correspond to the rows occupied by the group rectangle; the contribution to the state variables describing the group – and its members – corresponds to the columns so occupied.) For instance, the region for Group A is vertically thin and horizontally wide; that is, this group has a larger number of behavioral attributes and affects, or is otherwise associated with, a great many (or all) system-wide state variables but has relatively few members. In essence the row values in each column represent the proportion of the total vote that this group has to the total system's next state. Thus this group would be one that has a lot of power or impact on the total system. Through overlapping regions, Figure 11.1 also illustrates that individual human agents may have multiple group memberships, with the possible behavioral consequences which I discuss below (in the section on "Groups in Mutual Contact").

Groups can be tightly interrelated, loosely related, antagonistic, or indifferent to each other (Karasik 1987). In particular, distinct groups having similar culture or other characteristics – that is, common orientation – may (for some characteristics) tend to cluster together, meaning that there would be some degree of uniformity in their behavior. (Again, the above corresponds to the secondary effect in the annealing process of atoms. Though not pursued here, further, mathematical, exploration of these analogies might be productive.) This clustering process can be repeated at higher levels. The varying degrees of commonality among different subgroups allows one to build up larger and larger elements, each composed of sub-elements formed in the previous clustering iteration.

GROUP MEMBERSHIP, BOUNDARIES, AND MUTUAL PROXIMITY

By "boundary" I mean a delineation of one set of elements from another. As in the above, this can be expressed in spatial geometric or geographic terms, as a line drawn between the spatial points belonging to one region versus another. More abstractly, a boundary can be regarded as any way of characterizing circumstances under which elements from two distinct sets (domains) come into mutual contact. In this chapter I started (above) with boundary in the geometric sense but I shall progress to the more abstract sense.

In the following, the question of what constitutes boundaries will largely remain implicit in the major human group memberships. Such memberships should be measured, I propose, by a couple of factors, called proximity and credibility, describing the relationship between pairs of human individuals. By "credibility," I mean the extent of trust between individuals and the degree to which messages received are acted upon in a normative fashion (Yates 1984). By "proximity" I mean the relative ease or difficulty for the pair to interact with each other. Expressed as a quantity, mutual proximity means the same as the reciprocal of mutual distance between the pair. In primitive times this would mean geographical proximity; as we move forward to the present, geography gradually becomes less important relative to other factors – political, economic, sociological – as determinants of proximity. Ideological and sectarian belief systems, coupled with linguistic divisions, are core determining elements; you cannot communicate if you cannot understand each other or if a communication's meaning does not "gel." In addition, increasing fractionalization of knowledge through use of specialty jargon and new variations of beliefs create new elements which may contribute to decreasing proximity, even as older distancing elements are submerged. (Determining factors would continue to include mutual geographical proximity; one imagines that, even today, Bolivia usually pays more attention to what is happening in Peru than in Sri Lanka.)

More abstractly, proximity may be represented by interaction coupling strengths between the parties, meaning the strength with which each reacts to characteristics or events in the other. Consider the game of Go where one places white or black markers at the intersections of the horizontal and vertical lines that define the game board. Control over a section of the board is accomplished through placing a series of markers (in a series of moves) in such a way as to surround an area and convert it to white or black. This leads to a series of territories defined by their boundary color. See, as an example, Bak and Chen (1991: 49), where the relationship among the ideas of a boundary, coupling strengths, and proximity are exemplified in the case of an earthquake model. As with spatial proximity in the atomic and seismic exemplars, human-grouping affects (for example the tendency of individuals to form a group) are further mediated by mutual proximity/distance and receptiveness.

In the proposed approach, individual human system members would be regarded as cross-linked with each other via a series of "coupling strengths" which constitute the means by which aggregation occurs. The corresponding and mediating aggregation parameters – such as language, belief system, economic class, nationality, education level, locality, kinship, internet access, cell phone access, wealth – basically define the degree of mutual proximity and credibility or receptiveness between groups and their individual members. (For example, coupling strengths might take the form of weights appearing in a neural network scheme for modeling the interactions between the parties.) Implicitly these linkages then define the major system groups: members of a group are typically proximate to each other and have a great deal of credibility as evidenced by high volume and data richness of routine communications between them. We gossip only with our close circle of friends and family. Boundaries between groups then correspond to encounters between individuals lacking mutual proximity and/or credibility. Returning to the earlier idea, domain boundaries between social groups are where alignment vector orientations shift (social annealing-nucleation process); this puts a constraint on the choice of the orientation variables. They should be such that mutually proximate, credible pairs tend to have relatively parallel alignment, whereas other pairs do not.

DISSONANCE AND FUNDAMENTAL NEEDS

In addition to group formation (social annealing-nucleation), a second consideration is how group characteristics translate into behavior. A key normative and scientific concern is with the social, political, and economic "storms" that impact all of us on this Earth, directly or indirectly; that is to say, the concern is with conflict and its potential. Moreover, the above analysis suggests that predictable regularities are likely to be found in relationships between groups. Thus, in the present discussion I focus on conflict between groups.

There are two aspects. The first is a proposed role for fundamental human needs. Structurally, we try to assert that certain variables are independent and therefore cause changes in the values of other variables that are deemed to be dependent. My second thesis is that, in the case of human social systems, the fundamental independent variables take the form of four drivers – propensities, by different social groups, to exhibit, in a given set of conditions, certain characteristic behaviors in response to four fundamental needs (attributes that are of concern to them). These needs are for:

- sustenance;
- safety;
- acceptance;
- fulfillment.

Clearly the need for sustenance is basic, without which there is no individual survival. Safety follows closely, otherwise we are some other's meal.

Acceptance in terms of emotional sustenance via group membership is again basic to the primates and many other species. Our long, dependent childhood reinforces all the primal needs (the first three on the list).

The last need is an emergent one among humans, though studies now show that other species have altruistic behaviors that are not always motivated by primal needs (consider cross-species adoptions). In human terms, it is the need to understand one's place in the universe and how the universe functions. I would venture to say it is the need for self-acceptance. It can take the form of an individual's method of expression in the form of artistic, intellectual, or other personal behaviors.

Because they affect the level of comfort of the individual with the state of the world, with the state of the group, and with their own personal state, these core (independent) variables define the potentials to drive action in human populations. (Note that I do not propose these drivers work their effect via utility maximization, a point to which I return, momentarily.) Moreover, the presence and functioning of these four basic drivers is stable over the time scales of interest (thousands of years) in studying the current global system.

Group uniformity and individual basic needs are connected: the commonalities, to which reference was made above, comprise the action set that allows the group to impact the environment to achieve its ideal state, including survival and other basic needs of the human members. The upshot is that each tightly correlated group generates behaviors impacting the environment in a manner (conventionally) deemed advantageous to the group. Each group has desired end states for the environment, the comfort zone of the group. These end state considerations correspond to the drivers just mentioned. ("Conventionally" is used because this idea is not the same as utility maximizing; again, I turn to that issue in a moment.)

The second aspect connecting group characteristics to conflict potential, and of great behavioral interest, is the state of dissonance, meaning the condition in which the environment is too different from the group ideal (from where the group feels it ought to be) for comfort. Such ideals are defined with respect to the drivers.

Depending on the capacity of the group and regardless of its cause, every effort will be expended to bring a dissonant environment back into the comfort zone (that is, to its normal – meaning previous and lower – energy state). One result of dissonance is the societal disruption entailed by this effort.

A second result is the increased potential for overt conflict. In particular, when groups encounter each other, if the alien group is impacting the dissonant environmental state of the referent group, and if the degree of dissonance is great enough, there will be potential for conflict at some level until the dissonance is reduced. The extreme form of this is the idea of war arising from the circumstance in which the referent group feels its survival is threatened by the alien group. One merely has to go to the Middle East to see this at play.

Within-group dissonance is also possible; however the relatively greater variation between groups is likely to prompt much greater dissonance, compared to that within them. When within-group dissonance does take place, it would act as an internal stress on the integrity of the group subsystem. One form this might take is the demand, mentioned earlier, for internal change in response to external stress; another is when multiple nucleation points lead to ambiguity in the identity of the "proper" group arbiters; for example as in Sunni versus Shiite in Iraq after the 2003 invasion. As the example makes clear, such internal stress is not to be regarded as unimportant; however, for simplicity I focus primarily on between-group effects in this discussion.

Stated in a general form, the predictive issue is to capture the "critical points" where group behavior changes, including in particular when violence against members of another group occurs. While we have yet to achieve such prediction, I suggest that one promising indicator of it is a combination of dissonance between the differing group value systems, and proximity between members of the groups (or their individual members) along a common boundary or in a shared environment. This suggests that the potential for between-group conflict may vary with a dissonance–distance gradient, a ratio (between-group differences) / (between-group distance), given in squared form as:

$$(|x - x^*|/\mathbf{r})^2 = (D/\mathbf{r})^2 \tag{11.2}$$

where:
x = actual position of alien group;
x^* = ideal alien group position as judged by referent group from its own norms;
$\mathbf{r}$ = mutual distance (reciprocal of mutual proximity) between the two groups;
$D = |x - x^*|$ = dissonance of referent group with respect to alien group.

In the most common physical usage a "gradient" is the vector of partial derivatives of a potential function with respect to spatial dimensions. In this case the potential function is the "ideal state" characteristics from the point of view of a particular group. The dissonance gradient exists because reality deviates from that ideal through the actions of one or more other groups having different ideals.

By this analysis, therefore, from a mathematical or scientific perspective we are interested in measuring and studying such gradients experienced by different groups of human populations. Empirically, the ideal states – the values of the x* – and the condition or degree of dissonance could be determined by highly structured or standardized opinion surveys (in those instances where it is feasible to conduct them), in which the focus would be on the likely drivers. Informal e-chatter and i-reporting would also allow us to tune in to the social state of mind of the group in question. With some track record we could likely extrapolate behavioral predilections.

The preceding can be contrasted with choice theory. In the above I am saying that actions always seek to reduce dissonance, but minimizing dissonance does not mean maximizing utility, expressed in a different vocabulary. The distinction is that increasing dissonance leads to primal behavior; there is too much pain to think. In neurological terms, the responses to dissonance involve a shutting down of higher cortical functions; thus, in the above-mentioned proposed scheme, the contrast with choice theory is that choices are not taking place. Putting the point another way, there is no strategic thinking here; just activation of a very complex repertoire of responses, albeit one in which memory plays a key role. In utility formulations, the individual party might make a choice based on reason; in contrast, dissonance and the urge to reduce it are biological givens not subject to reasoned choice beyond a very primitive level. Another way to make the point is that the four basic needs are biologically given and dissonance occurs when they are frustrated to an intolerable degree. If we were truly rational players, we would never see behavior that was self-destructive, such as the economic disruptions caused by the Palestinian Intifada, the recent Balkan wars, and so on that impoverished the perpetrators.

Dissonance and its effects hold the prospect of becoming empirical. First, we can measure it; it is physiological, and every human being is constantly measuring their own. Second, the basic needs giving rise to it are themselves fairly concrete and empirical. We can measure macroscopic levels of economic health, safety, physical health, and social cohesiveness. Further, a point to which I return below, one can readily track behavioral changes due to dissonance because they are sudden and discontinuous.

CHARACTER OF ISOLATED GROUPS

Next I consider the affect of group interactions, starting with the simple case of their absence, then turning to the case where interaction is present. This progression is also in approximate chronological order, from distant past to present.

Initially, our ancestors lived as individual players or formed small, very cohesive entities. In the course of human experience, when we came out of Africa we spread over the Earth in very small groups of hunter-gatherer populations; 20, 30, 50 people at a shot. And as the entities spread further, subentities split off and fragmented.

Gradually, these fragments coalesced to form groupings sharing a common geographic and ecological domain. This constituted the case of complex but isolated social groups; that is, those not undergoing relevant external interactions or perturbations. If we take (as an idealization of any one such group) a single society of humans having no contact with any other, then its behaviors will be shaped by its environment (in terms of capacity to provide basic needs of food, shelter and the other essentials named above), by its technology and culture, and by the behaviors enforced by its dominant members (the arbiters). In this regard we are little different from our primate ancestors. That is, for such groups in isolation, the primary stimulus to which the members respond is the feedback from their previous actions. The resulting innate conservatism (as well as successful adaptation) of the pre-European Australian society shows how isolated human societies probably behaved as they spread far and wide across the planet in small groups, budding off as soon as resource scarcity demanded. The evolution of cultural norms, language, and so on represents the increasing variations explored over generations.

It is important to note that the rate of change in such groups is slow and the degree of social discontinuity is small, compared to groups in mutual contact. Even in isolation, however, all groups must inevitably change. Moreover, the situation of initially slow, continuous growth was also one of accelerating growth in variables such as population and technology. These factors would eventually enable the separate groups to connect with one another, with implications which we consider below.

This inevitability of group change is a constant, even at present. With respect to some particular group aspect, it might be argued that stability can be arranged by intentional control; say, of group population – for example, in contemporary Western Europe – through regulating births. However, there are two complications. First, change can take various forms corresponding to the many variables describing groups. Stability in numbers of persons (or any other particular variable) is only one kind of stability; there are other possible changes such as in information, technology, societal organization, and in composition of persons through the birth and death of individuals; though one variable may be static, others can be changing. For example, again considering population, since nation states typically are composed of many different demographic subgroups, there can be changes in their relative population. Individual humans in the group are being born, growing older, and dying. The mix changes over time. Moreover, in connection with prediction limits recall that population and technological growth may decrease future predictability (see the section above on "Non-Linearity and Chaos"); true even of an isolated group. The second complication, to which I now turn, is that internal stability can be defeated by interaction with outside groups.

GROUPS IN MUTUAL CONTACT

The above discussion of isolated groups addresses, if you will, the interior state of a group. Now I look at their exterior interactions. Over the course of time (in contrast to the initial dispersion effect), groups encounter each other with increasing frequency. In part this increase is due to technologically driven improvements in communication and travel. Also, the increasing number of groups (as some branch from others) raises the probability of chance encounters, as the finite land surface of the Earth becomes more crowded. In addition, as early growth societies adapt to more complex social structures, and solve crises regarding food production and distribution, they become attractive to other nearby populations which were previously isolated and self-sufficient. Corresponding to these changes, the dynamics of the interactions between groups begin to predominate over the dynamics internal to any one of them. In part, this is because, as noted above, between-group dissonance is much greater (compared to within groups), thus change – dissonance-driven – is more rapid and discontinuity of change is greater. (Note that the capacity for dissonance lies in between-group differences which, in turn, arise from the slow internal evolution, in differing directions, of the previously isolated groups.)

To make the next point, let us once again consider isolated human groups. Another way to view them is that, in the absence of the exogenous shocks or perturbations of contact with others, they really do not have history as we think of it. They have "dream time," if you will, as Australian native populations had, prior to European contact; meaning that changes in them over time were comparatively evolutionary rather than revolutionary or discontinuous. Australia is a very good case in point, showing how conservative isolated human institutions and behaviors are, viewed over very long periods of time: many generations, tens of thousands of years.

Conversely, I would maintain (this is the point) that the effects we recognize as comprising human societal evolution – history, as we understand the term – came about because of the breakdown of isolation, via contact between groups. These effects were the discontinuous changes forged when a group was confronted with exogenous shocks, such as the shock of contact with an alien group, or the shock of radical and/or rapid (rather than incremental and slow) technological or population change. (These could act in combination; for example the printing press, a technological change, to mass-produce death certificates, occasioned by European depopulation due to plague, in turn arising from long-distance commerce with Asia, thus indirectly a mutual contact effect.) Speaking either of a geographic boundary (as typically occurred at earlier times) or, abstractly, of a boundary as any place of mutual contact, we can say that history is forged at the boundaries of human groups. The earlier remark, concerning interaction at domain boundaries, applies here: the characteristics of the group, as a group, become relevant when it encounters other groups.

With mutual contact, the interactions among the various groups are multifaceted. One aspect is the between-group dissonance phenomenon already discussed; this may take the form of variations between the group behavioral sets impacting on the respective members, who otherwise would view their way as the only way. Another aspect is the potential for cooperation; in some cases the alien group has assets of value: technological, geological, or biological. This actually can be regarded as similar to dissonance, but functional rather than dysfunctional. The similarity is that an interest in alien assets may correspond to perception of differences in the form of economic comparative advantage.

Then three responses are possible:

1. Trade among peoples for excess food production or other vital resources is a common behavior. When this happens and if relationships became routine, then sharing of technologies, knowledge, and cultural traditions also occurs. A further and reinforcing consideration is that groups have variable limits; some are more tolerant than others in terms of how much dissonance they will put up with. These limits may be issue-specific; that probably is the basis for potentially integrating multiple groups, because some groups can say, “Oh, I can let that go; it’s important to you, it’s not that important to me.” Thus, blocs of groups may coalesce (the previously mentioned secondary effect of clustering, in social annealing-nucleation) around major stressors, where the dissonance among the groups within a bloc is far lower than the dissonance experienced with groups outside the bloc.
2. Unfortunately, another common response is the use or threat of physical violence to take the resources desired or needed. As I suggested above, the great stressor, the group-on-group behavior of war, is a response to severe dissonance driving a group to feel that its survival or set of fundamental values is threatened.[6] This response is basically

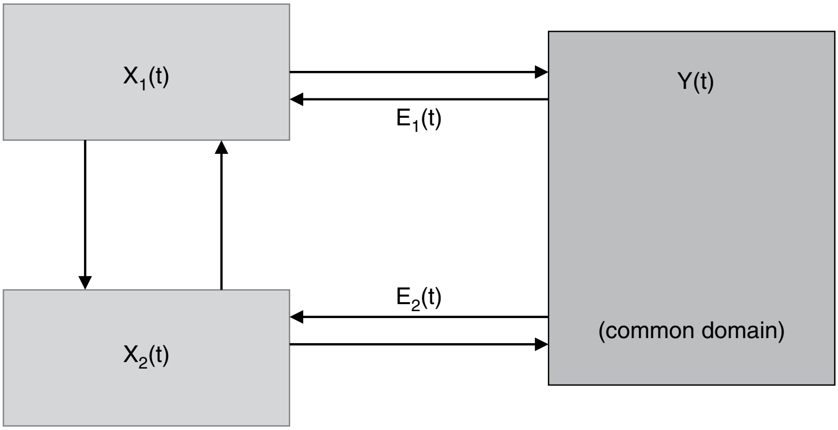
a behavior derived from hunting (a predisposition of human predatory history, reinforced even in modern times by societies that enshrine the warrior-hunter as a role model and ultimate experience). However the proximate cause is the dissonance experienced by the interacting groups; if this is too great, the need for fulfillment or safety will be violated and there will be a clash either between the groups or within one of them.

The latter alternative points to a variant: the creation or increase of instability in the referent group as an internal response to dissonance (perhaps more likely within the weaker group), leading to the overthrow or modification of the cultural traditions as the means of removing the source of dissonance. (Alternatively or concurrently, internal change can be viewed as an aspect of declining predictability due to changes in population, and so on; see the above discussion of prediction limits. Thus, returning to an earlier example, the native European populations may not be growing, but their countries are importing populations. In France, for instance, the growing segment of the population is the North African and Middle Eastern; in Germany it is the Turkish population.)

3. One last response, now almost entirely ineffective, is to maintain (or restore) isolation through the use of technology or force or both. China and Japan for instance, at various points in the past, chose to cut themselves off from the rest of humanity, seeing no value in having commerce or cultural interchange, and developed harsh policies as a means of enforcement until these became no longer viable.

In the terms employed, these three response patterns are the only ones available (Karasik 1984). A somewhat different way of viewing the possibilities of mutual encounter is shown in Figure 11.2 (see also Karasik 1987: 234–239): a group can make a change in the state of the world through physical manipulation of it. Such manipulation can be used, further, by one group to try to control another one. The other thing the group can do is communicate with the other populations or individuals to try to change their behavior, to achieve the end result. And so the politics of persuasion come in that particular factor. (Of course, any communication requires a physical mode of transmission. In that respect, all forms of action involve physical manipulation; but one can further distinguish "communication" as manipulation having a relatively high information content.)

In the figure the situation is illustrated for the case of two groups. The state of the environment in which one of the groups, say X_1, finds itself, is based on its internal state, plus what it is doing to act on other groups such as X_2 and on the environment or "common domain" Y. The latter



Source: By Permission of Global Vision Inc.

Figure 11.2 Two interacting populations

comprises elements or conditions not specific to any one agent or group but common to them all, such as variables describing the non-human ("natural") environment, for example climate and, possibly, other groups momentarily considered as passive elements. The actions taken by X_1 – its various behavioral modalities, if you will – are subsumed in the variable (actually a vector quantity) E_1 in the figure. This latter is the control variable, so-called because it is whatever will impact to change the state of the system to bring it into closer alignment to where the group wants to be (that is, to reduce dissonance). These elements I consider further in the computational model, sketched below (in the section, "Outline of a Possible Dynamic Global Model").

Turning to the present, it is in recent times, particularly with the growth of the agricultural revolution, and now, of course, with the industrial and the post-industrial revolutions, that everything is collapsing back in. Today, in our ever-shrinking, interconnected world, all human groups are touched by many other groups, more than in the past and in greater diversity. More groups are interacting with each other because they are able to communicate across the world. Time and distance do not mean anything any more (or mean little); we can communicate instantaneously; we can travel around the globe within a day. It is almost like the big bang coming back. We are now feeling the crunch. We are now all in each other's face. There is nothing that happens anywhere in the world that does not affect all of us.[7] Correspondingly, there are a great many dissonances with which groups (and individuals, also) must deal, for which the conflict potential is great.

Thus, by the time we arrive at the present epoch, even if one could somehow imagine that a particular group were completely stable in isolation, no group now can be completely isolated, so all of them are made unstable by flows from others across boundaries (for example, migration). Multiple interacting groups may never, in fact, achieve a stable equilibrium, due to the fact that a new condition in one group potentiates changes in all the others, so that change perpetually bounces through the system, from group to group.

If one group has little dissonance when the other has a lot, and vice versa, so that what is good for one is bad for the other, then conflict is further potentiated by viewing things narrowly in the behavioral norms as a zero-sum game: if you win, I lose. Perhaps these differences can be partly or wholly reconciled, however: by enlarging the number of behavioral states one can generate a positive contribution to each group, reducing dissonance experienced and get away from zero-sum and move to a win–win. In essence one is diluting the dissonance by providing countervailing positive attributes. In cases of bloc formation as in trade (the alternative response labeled 1 (see p. 284), the overlap of value systems and degree of consilience regarding appropriate individual and group behaviors may lead to long-term symbiosis – that is, a stable cooperative state – between groups. (On a small scale one gets Switzerland; on a large scale we have yet to find out – perhaps the United States? On the latter, see also the next section.) In Europe we still see the fracturing of multinational states such as Yugoslavia and Czechoslovakia, yet the larger Community of Europe is incorporating all of these now more homogeneous entities.

HUMAN GROUPS FROM AN EMPIRICAL, HISTORICAL PERSPECTIVE

We also can characterize groups, more concretely, in empirical, historical terms. The earliest Neolithic societies of the Middle East, Southern Europe, Egypt, Indus Valley, and China were the first and foremost civilizations and they remain even today the foci of cultural change and conflict. Other nomadic populations and cultures, representing hunting or herding societies, would periodically come into contact with the larger agrarian societies. The nomads were typically more successful at conducting war when circumstances gave them an edge, but typically fell under the sway of the more advanced cultures over the longer term even when they became the ruling class. The salient characteristics of our time have been shaped by the advancing edge of the core civilizations as they have encountered each other and accreted other cultural traditions. (Again, compare with Chapter 12 by Wilkinson in this book.)

Look at the boundaries today between the European descendants of the Greco-Roman core (with a substratum of pre-Islamic Middle Eastern and Egyptian cultural interactions sustained over the course of centuries; so more accurately the Mediterranean littoral "core"), the Muslim (Middle Eastern), the Indian/Hindu and Chinese. The Europeans exported large segments of their populations to the originally isolated Western Hemisphere and Australia. Europeans had technological superiority from the sixteenth century till the present. They were therefore able briefly to exert some physical control and cultural influence on all other parts of the world, c.1750–1950. Muslims conquered and proselytized for much of their history, 632–*c*. 1700, consistent with the Middle Eastern historical model first established by Sargon the Great. The European and Middle Eastern "cores" are mirror-images of one another, for they incorporate a number of common elements informing the evolution of both. Each has a strong "crusader" ideology, each claims divine approbation and revelatory exclusiveness. These cultural traditions have always been in conflict except for a brief respite at the twilight of the Ottoman and Mughal periods. The Indian and Chinese core cultural traditions are not of this type. These cultures have historically accepted input from outside and integrated it into their traditions. For instance Buddhism, originally strong in India, came to China and was integrated with Chinese traditions and back in India became subsumed in Hinduism. The experience with European culture over the past couple of centuries has led to India adopting English as its common language, and democracy, while China has adopted technology and economic organization while still keeping its "mandarin" socio-political structure.

There are many fault lines, even within the core cultural traditions. Europeans as well as Muslims follow several variant religious and linguistic traditions. There are a number of "undigested" subgroups. In the case of Europeans this is particularly true in Central and South America, whose pre-European cultural traditions have been maintained, even after European immigration. In some cases such cultural groups are significant or potentially dominant. Africa remains both the motherland of *Homo sapiens*, and a battleground between tribal groups artificially confederated (by Europeans) with one another into nations having no history except as artifices of a short-term European exploitative relationship. Continued turmoil, the lack of a model providing a basis for making the transition to a stable and economically viable state, apparently makes this area a potential hotbed of conflict for many years to come. There does not seem to be any obvious attractor among the other core traditions around which Africans can coalesce. One anomalous situation, perhaps harbinger of things to come, is the relative success of the United States in creating an environment whereby the cultural traditions of many groups are tolerated and a common social, political, and economic infrastructure is maintained and shared. This did not happen without some conflict and persecution in many cases, but peoples who in other parts of the world are warring seem to be able to come together in the United States without the same level of rancor and hostility. But as happened with Cordovan Spain, such periods of multicultural peace can be destroyed by fanaticism (Menocal 2002: 189ff.) driven by cognitive dissonance and directed by arbiters who sought to purify their traditions (early al-Qaida).

This brief empirical, historical sketch illustrates the previous contention that "history" has occurred at the boundaries between various groups. In addition, one can see the major patterns of group formation and secondary effects that have emerged, the relics of which characterize human civilization at the present time. The long duration of the various effects suggests that these relics are important sources of dissonance today; thus their relevance to short-run forecasting.

ENERGY IN THE GLOBAL SYSTEM

A quantitative-empirical formulation of the idea of history as cultural collisions between groups largely remains to be developed. In this and the next section, I carry the discussion a bit further in that direction by considering additional such elements.

The concept of energy is central to the modeling approach described here. In human societies quantities that have energy-like behavior are wealth (Karasik 1984), price levels, life expectancy, core beliefs. First is the role of such energy-like quantities in a form of system invariance. As suggested above (in the section on "Testing Against 'Reality'"), one of the things for which we should look, in terms of the behavior of any system, is invariance; that is, for things that are unchanging (or changing at a negligible rate, relative to the time interval or horizon of forecasting), on which to base estimates of that which does change. One such unchanging thing is that every time there is a perturbation of the system, it then tends to try to return to its normal state – its lowest energy state, in terms of the way physicists think of things. Or, as we need to think of things, the system tends toward the lowest state of dissonance. Thus, stress and dissonance are equated; they correspond to the application of a force that is counterbalanced up to a point, then followed by a catastrophic break.

A simple physical example is the earthquake model mentioned above (Bak and Chen 1991: 49). Qualitatively we know what one such corresponding break is in this group model: it is the shock of encounter with an alien group, not unlike the slippage in a fault. As a further example, in an economic system, price levels are equivalent to temperature and extreme shifts create stresses and dissonance – think of 1920s Germany, 1980s Argentina and, possibly, present-day Zimbabwe. A predictive application might be that one could recognize the shocks when they have occurred, then anticipate the likely short-run responses to them.

A second aspect of this social system energy is that it is quantized. At several places I have noted the role of discontinuities of behavior, in the form of the change resulting from dissonance of between-group contact (and in contrast with smooth internal change of isolated groups). Having just now identified dissonance reduction with energy minimization, behavioral discontinuity thus corresponds to discrete rather than continuous reduction in energy.

Returning to the contrast between dissonance and utility, another comparison is the permitted character of change over time. Utility functions may involve change that is nice and smooth. Dissonance does not; rather, it involves step functions. One suddenly shifts into another phase. Remember the old movie *Network*? Albert Finney starts ranting and raving, “I can’t take it any more,” because he has reached his tolerance limit. And all of us have that limit. Somewhere along the line that is where we lose our temper. When this break is reached, we have the essence of a catastrophe type of situation. Put another way, discontinuity of behavior is characteristic because either dissonance is adequately minimized or it is not; there is no in-between. Rather than refer to maximizing utility, I would instead refer to satisfaction of primal needs.

Changes in behaviors of an entire group are tied to individual dissonance. You will not get people rioting in the street, nor will people go to war, unless things are bad enough; or if the latter condition is not met but war is still chosen, support for war will be so weak as to threaten its continuance or, even, the continued dominant institutional, or career – even personal – survival of the group arbiters.

The connection between individual and group behavior change is that one gets group behavioral change when the collection of people that first breaks into new behavior turns out to be an important subgroup; that is, if they turn out collectively to constitute a nucleation point. Put another way, an important subgroup is one that is capable of infecting the rest of the group with the behavioral change. In that event, suddenly they can recruit the rest of the larger group who may not have reached their critical dissonance point yet (“critical” in the sense that behavioral norms will switch to "emergency" – by nature a more aggressive response). The smaller subgroup will take everybody else along with it. (This is a further illustration of the significant role played by multiple group memberships; in this instance membership in both the new behavior subgroup and the larger group affects the behavioral propensity of the latter; namely its propensity to shift behavior.) Then, suddenly, one has a mass movement that says "We've all had it." That is where you can get a sudden discontinuous change in the political environment or landscape. That is the way I think we will be able to model discontinuous change (Karasik 1984).[8] In any economic system there are three major strategies to cope with competition: eliminate the competitor (war), cooperate (share the wealth), or mutate (find another niche of one's own). These days from a social point of view the third option is not viable, so we are left with either war or peace. We need to make war the less attractive option even if it means the enemy remains and we cannot have our ideal world. Unfortunately our skills in making war have more than kept pace, while our skills in engineering symbiotic environments and desensitizing core belief systems that are inflexible and intolerant has not kept pace.

So we need to know who is at or beyond their limits of tolerance. And we need to know their predispositions and their capacity to act on the dissonance. Again returning to the previous correspondence, this situation amounts to the quantization of energy levels in the global societal system; and the contrast with utility maximizing is, formally, between quantized versus continuous societal energy change. In part, there remains to translate the above into quantitative terms, such that energy minimization is formally identified with dissonance reduction and, further, that observable effects (such as between-group interactions) follow.

OUTLINE OF A POSSIBLE DYNAMIC GLOBAL MODEL

There are indefinitely many possible and (at this juncture equally) plausible specific dynamic global modeling approaches for representing the group-specific scheme presented above. In this section I consider one such possibility (or a class of them). This approach does not by itself constitute an operative model and it embodies some but not all of the features described above. For instance, it does not incorporate the possibility of multiple group memberships by the same individual. Thus it is incomplete, a work in progress. It comes in two variants, linear and non-linear, of which the former receives greater attention.

For this purpose, consider an augmented form of the state space matrix.

The augmentation, first, is a set of quantities comprising the common domain (see the section on "Groups in Mutual Contact" and Figure 11.2, above) of the global system. In the augmented matrix they appear as a row vector but one which does not intersect any of the group-specific rectangles. A second augmentation is the set of available tools, meaning the state of technology at a given moment in time. (These entries could be very subtle, or as simple as 0 or 1, signifying that the particular tool technology is/is not available at the referent time.) The tool set is somewhat but not entirely conceptually distinct from the common domain, but structurally identical. That is, technological knowledge also is common to all parties; and tool variables and common domain variables occupy the same row vector. In addition, distinct groups may be distinguished in the degree to which they are able to access a given tool; this can be represented by separate entries in the same column but in the appropriate group rows. These arrangements are reflected in the following notation:

- time
  t = referent time, current entries
  t_0 = previous time from which changes are to be evaluated

- matrix elements
  G = previous state matrix, containing the group rectangles
  H = new row vector
  Y = region of H containing common domain variable entries
  T = region of H containing tool variable entries
  S = G,H, new augmented state space matrix.

- cell entries and coefficients
  x_{kj} = j^{th} state variable (attribute, etc.) contribution for k^{th} agent or (in collapsed form) group
  c_{ij} = attributes cross-impact coefficient
  f_{kn} = pairing (groups cross-impact) coefficient between x_{kj}, x_{nj}
  u_l = status of l^{th} tool (e.g. = 0 or 1)
  b_{il} = impact coefficient of l^{th} tool status on change in i^{th} common domain entry
  y_m = m^{th} common domain entry
  a_{im} = impact coefficient of y_m on change in y_i (i^{th} common domain entry)

where the subscript syntax for x_{kj} is row, column (as shown above, k^{th} row, j^{th} column). The reference to "collapsed form" means the case when many rows, each describing a distinct human agent, are replaced with a single row describing the group to which the agent belongs. (This possibility reflects the previously discussed tendency for a high degree of uniformity among the members of a group.)

Then the (linear version) estimated change Δy_i in y_i is determined by:

$$dy_i/dt = \Sigma_j c_{ij} \cdot (\Sigma_{k,n} f_{kn} x_{kj} \cdot x_{nj}) + \Sigma_l b_{il} \cdot u_l + \Sigma_m a_{im} \cdot y_m. \tag{11.3}$$

In general, all the above quantities may be regarded as functions of time t; or (as seems likely) it may be expedient to regard some of them, for example some or all coefficients, as fixed. The value Δy_i, of change in y_i over a finite increment of time $t - t_0$ is found by integrating the expression on the right from t_0 to t. Alternatively, Δy_i can be approximated by inserting right-hand values as previously they appeared at t_0. Either way, the estimated new value of y is given by:

$$y_i(t) = y_i(t_0) + \Delta y_i. \tag{11.4}$$

Returning to equation (11.3), several further comments are appropriate. First, various generalizations are possible. An instance is the generalization $y_i \rightarrow z_i$, where the latter is any element of S. For another, if the allowed domain of the coefficients is the complex numbers, then the equation can incorporate cyclical elements. The solution of $dx/dt = a \cdot [\surd(-1)] \cdot x$ is a sinusoidal function of t.

Second, with the aid of equation (11.3) something more can be said about the role of dissonance. The effect of the pairing coefficient in equation (11.3) is to make quadratic, the contributions from each column of the G region of the matrix S. *Inter alia*, this allows representation of the squared dissonance gradient (equation 11.2, above) as a contributor to dy_i/dt. For suppose $x = x_{11}$ (in the above notation) is an actual state, let us call it state 1, of say group 1 with respect to the corresponding ideal state of group 2, let us call it $x^* = x_{21}$. (That is, group 2 regards this state as an issue of "correct" behavior by group 1. Note that, in effect, the G part of the matrix S now has column 1 reserved for the actual state of group 1 plus, in the remaining rows, what all other groups – minding group 1's business as it were – regard as their respective ideals for group 1. To switch roles between the two groups, not shown here, new variables x_{21} and x_{22} would be introduced, respectively denoting the group 1 ideal concerning the group 2 actual state.) Now let r denote the previously introduced mutual distance (see the section on "Dissonance and Fundamental Needs," and equation 11.2, above) between groups 1 and 2, and assign coefficient values:

$$c_{11} = 1$$

$$f_{11} = f_{22} = 1/\mathbf{r}^2$$
$$f_{12} = f_{21} = -1/\mathbf{r}^2$$

Then:

$$c_{11}\, f_{11}\, x_{11}\cdot x_{11} + c_{11}\, f_{12}\, x_{11}\, x_{21} + c_{11}\, f_{21}\, x_{21}\, x_{11} + c_{11}\, f_{22}\, x_{21}\cdot x_{21}$$

$$= (1/\mathbf{r}^2)x^2 - (2/\mathbf{r}^2)x\cdot x^* + (1/\mathbf{r}^2)(x^*)^2 = (\cdot x - x^*\cdot/\,\mathbf{r})^2 = (D/\mathbf{r})^2,$$

the latter being the square of the dissonance–distance gradient (equation 11.2) which, thus, is contained in the first summation of the right-hand side of equation (11.3). This shows that the supposed dissonance effects can be represented (using the more general $y_i \rightarrow z_i$, above) in estimating change rates dz_i/dt.

A third comment is that equations like (11.3) allow the derivative on the left to assume any real value and to be continuous functions of the weighted variables on the right. But one also would like it to be able to represent discrete system state variables; that is, values that change in jumps, from one state to another, rather than smoothly – for example, as discussed earlier, when the energy levels implicit in dissonance undergo a transition. On the other hand, one certainly imagines that such discrete variables are partly determined by continuous, smoothly changing ones. How can such discreteness coming from continuity be represented? One possibility is that the model first computes the probability of change. Letting z_i represent such a probability in an equation like (11.3) would put the probability change rate as dz_i/dt on the left-hand side, together with a set including continuous variables on the right. A pseudo random number generator would then determine occurrence, or not, of the corresponding discrete event, in computer simulations.[9]

Fourth, though limited in ways outlined above, a linear version may be a valuable intermediate step, by facilitating consideration, in simplified form, of many of the issues just articulated. Further, granted that system complexity may defeat a linear approach to modeling and forecasting, still there is value in seeing where, and how quickly, the latter approach fails. (Scientific progress may happen when one starts by attempting linear approximation; as noted earlier, that has worked pretty well for predicting the future of the non-linear solar system.)

However, finally, and again of key importance, are possible non-linear generalizations. Neural networks (Haykin 1994: Chapter 1 and pp. 201–205) are one non-linear modeling approach that provides, *inter alia*, a possible means of capturing the linkages, the weights of interconnection, between individuals and the groups they form. Such an approach might be to insert all of the x_{jk}, u_l, and y_m as inputs to a feed-forward artificial neural network. Weights of the network (corresponding in function to the coefficients) would then be found via training of the network. (The latter process could assign weights to all input combinations, or some combinations could be set to zero or other fixed value.) Such a scheme would allow incorporation of chaotic behavior via the previously mentioned logistic (equation 11.1), Rössler, and like functions (see the sections on "Limits to Prediction" and "Non-Linearity and Chaos," above) which a linear model does not contain.

CONCLUSION

The above is a scientific message. Underlying it is a normative one: if all human populations shared at least one language and a set of core values then perhaps the human species could evolve without major internecine strife. But war represents the energy-efficient way of permanent dissonance reduction, requiring no change in culture. Peace requires a change among all groups concerned. Ultimately, if we are to create an environment that gets past conflict, we need to develop some common core values and methods to measure and reduce overall dissonance that is felt by all the different populations that are sharing our common planet, our spaceship Earth.

Until we reach that state of affairs, we need to evaluate the intergroup dissonance gradients and channel our efforts to mitigating them. It should be done so as to maximize the ability of our species to fulfill all the needs of its members as much as possible without destroying the planetary resources needed to sustain us indefinitely (Karasik and Williamson 1994). To this end, a program of global computational modeling and forecasting may be indispensable.

By the preceding discussion, such a program entails a proper definition of human population groupings, with sufficient fineness of granularity to capture major value-system variations. The value systems define the group response patterns under stress (severe dissonance). These responses, sources of potential actions for changing the shared environment, need to be catalogued and assigned valuations. Propensities for violence in particular are most important in modeling the possible outbreaks of violence under the duress of extreme dissonance. This chapter has mostly omitted, and I must defer until a later occasion, the obviously crucial empirical aspect of development and testing, and the data on which it would need to be based. Much of the data can be developed from information that now exists in various forms. An additional key element would be based on observers within the various groups reporting on changing memberships, arbiters, available sanctioned actions, and experienced dissonance. As suggested above, reliance would be placed on standardized surveys. Nor have I addressed the issue raised by the need, not necessarily forthcoming in all instances, for government and other authorities to allow the necessary information development activities to take place. This issue, too, will need to be addressed. The above scientific program and its practical application would include a monitoring system capable of tracking environmental states, group membership evolution trends, possible group actions, and group dissonances. Such a program of scientific and applied research would provide at least a crude navigational system to help our species avoid major debacles. Finally, I wish to note that contributing to this program is the mission of Global Vision, Inc. of Ann Arbor, Michigan, www.globechange.org.

NOTES

1. Editorial remark by Paul R. Williamson: Indeed, the latter number, that is, the dimensionality, is itself quite large, as can be seen by referring to Chapters 2 and 15 in this volume. In Table 2.2 of the former, each of the 25 or so rows (and corresponding columns) – that is, each variable or problem group heading – itself labels a bundle of whatever variables are needed to describe the particular group. This is a 25-dimensional space with $25 \times 25 = 625$ possible matrix elements. To multiply that already impressive number by the number of separate persons, physical regions, social groupings, nations, and other relevant entities, each capable of distinct description in terms of those variables, is to suggest a state space dimension number perhaps in the thousands or millions. (Moreover, group populations have, themselves, increased; this contribution to complexity has a matching contribution to chaotic instability, mentioned below.) The product of the number of possible values on each such dimension, across all of them, is the number of possible system states. (If any of the dimensions are regarded, conceptually, as continua, then the number of states is infinite; if the dimensional states are all discrete, then the number is finite but still very large.) Plainly, such a numerous set of states does not appear capable of precise delineation, or fully controllable in an engineering sense.
2. Editorial remark by Paul R. Williamson: This issue works backwards in time as well. We think we are in a certain place at the present moment but we cannot be sure from where we started to get here, and that uncertainty increases as we go further into the past. This past uncertainty reflects that we do not know where "here" is, exactly, so we must work backwards from a range of current locations.
3. Editorial remark by Paul R. Williamson: There may also be hierarchies of predictability, with differing prediction horizons, as in the distinction between weather and climate.
4. Editorial remark by Paul R. Williamson: Compare with the idea of "atomism" in Soodak and Iberall (1978).
5. Editorial remark by Paul R. Williamson: The idea, discussed here, that group members are characterized by a definite common orientation of their attribute vectors might be compared with the idea that parties linked together are characterized by similar orientations of force and velocity vectors. The latter appears in the section on "Linkages in the Global System" in Chapter 14, particularly Table 14.1.
6. Editorial remark by Paul R. Williamson: "Survival" might be translated or generalized as "vital interest," which then may be defined by the group arbiter(s).
7. Editorial remark by Paul R. Williamson: The idea of isolated groups in early times, put

forth by Karasik in the above, might be compared with ideas of pre-convergent civilizations and of a geometric representation of early times, put forth elsewhere in this book (Wilkinson, Chapter 12, and Williamson, Chapter 14). Similarly, the idea of "collapsing back in" at this point in Karasik's discussion might be compared with Wilkinson's "convergence of civilizations" and with Williamson's "social-spatial in-falling," in those same chapters.

8. Editorial remark by Paul R. Williamson: Compare also with the societal discontinuity in the change model proposed by Rashevsky (1968).
9. Editorial remark by Paul R. Williamson: Another idea with similar consequence, thus bearing further exploration, would emulate the situation in quantum mechanics, whereby the discreteness of energy comes from continuous variables via spatial confinement (Feynman et al. 1965).

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12. Power structure fluctuations in the "*longue durée*" of the world system: the shadow of the past upon the future

David Wilkinson

The subject of my research enterprise is fluctuations in the political consolidation of world systems, in the remote to recent past, say 3500 BC to yesterday. What can this study offer to those who wish to illuminate the shadow of the future? It can offer a hypothesis about what they will find there. Based on what I find for the world systems of the past, I would propose that we would be wise to assume that the contemporary global system has, and will continue more or less indefinitely to have, two biases: a "stickiness," a tendency to remain for some while in whatever power configuration it inhabits at any given moment; and in the longer run, an inclination, a tendency to prefer some fairly distinct subset of all its possible power structures (as will be elaborated in this chapter), which I think we can discern by examining its long past.

This approach is different from, but complementary to, an approach which would seek to predict the near-future state of the system from the present distribution of capabilities within it, and present trends in those capabilities. It also differs from, without excluding as a supplement, the attempt to anticipate the direction of change in the system by a trans-historical, trans-systemic examination of all moments at which any world system has been in the same state as the current system now occupies, all transitions which have occurred from such a state, and the causation of all such transitions, leading to an appraisal of the likely next state of the current system based upon the presence or absence within it of the various factors which have in the past driven change in this direction or that. The basis for this quasi-forecast is a comparative study of the long-term sequences of power structures in several world systems.

At this point, it would be wise to pause for some clarification of terminology. What is meant by "world systems"? Politico-military networks of cities and citified polities. For the more remote past, the world systems are the various historically separate systems of states and empires more generally known and studied as civilizations, namely: in Afro-Eurasia, a Sinocentric system in the Far East, another system on the South Asian subcontinent, two neighboring systems centered on Mesopotamia and the Nile Valley which eventually meet, join, and spread throughout the west of the Old World, plus several other smaller systems; and in the New World, two larger systems centered respectively on Mesoamerica and the Andes, plus some number of smaller systems. However, for the present and recent past, there is a single, solitary, all-engulfing global system, the product of the growth, collision, and fusion of the formerly isolated and autonomous historical civilizations.

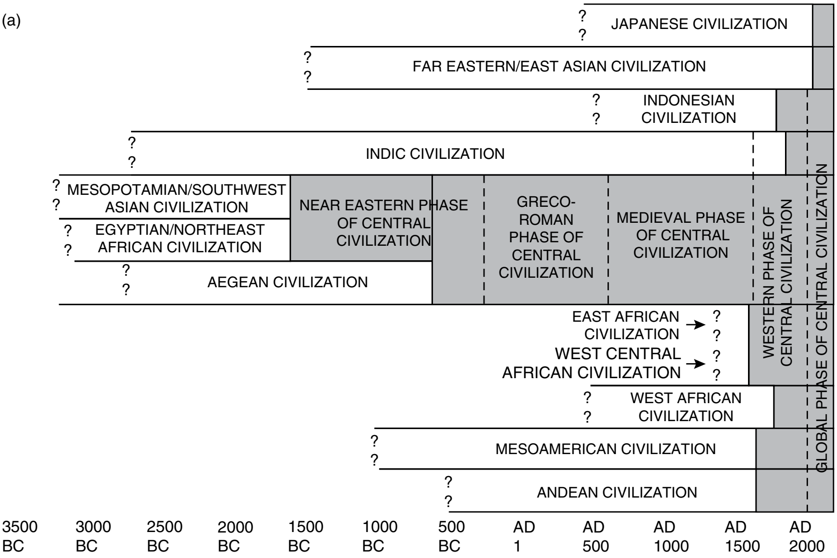
It is important to note that these systems need not be characterized by any legal, moral, political, or cultural unity. For me, following Lewis Coser, conflict, at least habitual and persistent conflict, is, like cooperation, a bond that implies membership of the same world system to the same degree as does alliance, hierarchy, or diplomatic intercourse. (Trade alone does not: Rome and China traded, indirectly, but could neither fight nor ally; India traded with Mesopotamia in the third millennium BC, but lacked the politico-military bond.) It is also worth remarking that I would not consider interactions, diplomatic or military, that forge no lasting politico-military bonds – as those of Alexander with India, of the Mongol Khans with the Popes, with the Hojo regents in Japan, and with Indonesian Singosari and Madjapahit, or of the Ming with Indonesia, East Africa, and Mecca – sufficient reason to declare that the separate world systems which interacted were thereby fused.

The chronogram in Figures 12.1a and 12.1b provides a somewhat more precise listing of the larger and more eventful world systems, and a display of the moments proposed as their historic debouchments into the larger "Central" system, which all sooner or later joined.

This chronogram, as Figure 12.1a, would agree with most civilizationists' rosters of the civilizations of the remotest past; but as time goes on, and as Figure 12.1b illustrates, it breaks with their tradition by viewing the product of the collision of civilizations as a new fused system, or in a more dynamic sense as a confluence of all the streams of civilizational history, beginning in the Middle East with the collision or confluence of Egyptian (or Northeast African) and Mesopotamian (or Southwest Asian) civilizations, which creates a successor stream that I call "Central Civilization" or the "Central World System," which eventually grows to global scope by engulfing each of its companion systems in turn.

The various civilizations each have, for some period, their own systemic political–military history; but because they grow, collide, flow together, and fuse, their political–military histories and structures also fuse, finally,

(a)



Note: This figure illustrates the successive incorporation of autonomous civilizations into a larger, composite "Central civilization" (in grey). ? = transitions to civilization took place no later than this date for this case.

Figure 12.1a The incorporation of 12 civilizations into one "Central" civilization which expanded to global scope

into today's global system, into which all the previously separate histories and structure have been recruited, so that its own history contains all theirs in their many pasts. But some of the autonomous lifetimes of the ultimately united civilizations have been very long; long enough to produce very intriguing power structure time series.

Now civilizationists have certainly been interested in systemwide power structures, which they have often seen as binary, unified as a world empire, or diversified as a system of independent states.

And some while ago I tried to create a binary sequence of systemic power structures – states systems or empires – for the various world systems (see Figure 12.2). There seems to be a strong tendency to oscillate between the two states, except that what I call the Central system seems to have a strong inclination to resist unification.

Now political scientists have an interest in finer structures of power than do most civilizationists. To try to satisfy that interest, I worked out a seven-value variable (Box 12.1), which I have used in Phase II of my ongoing inquiry.

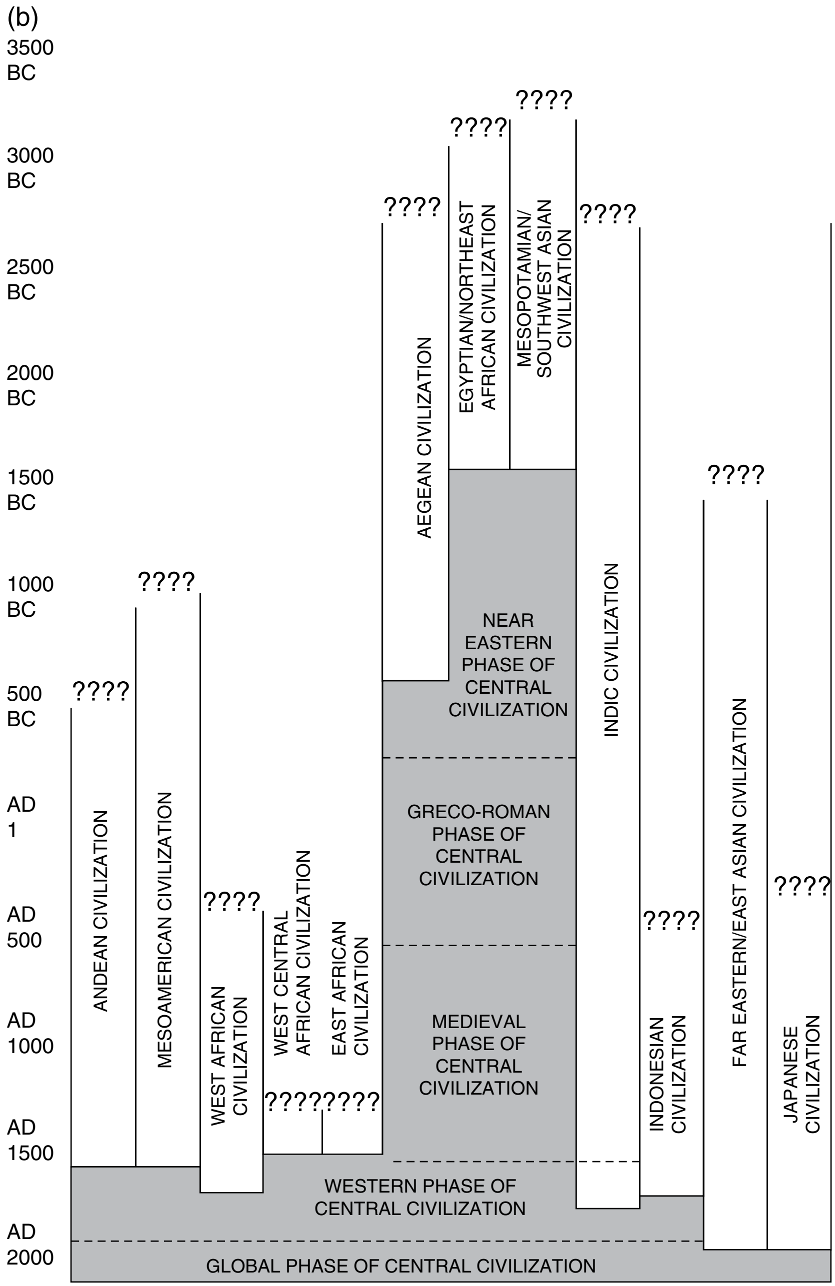
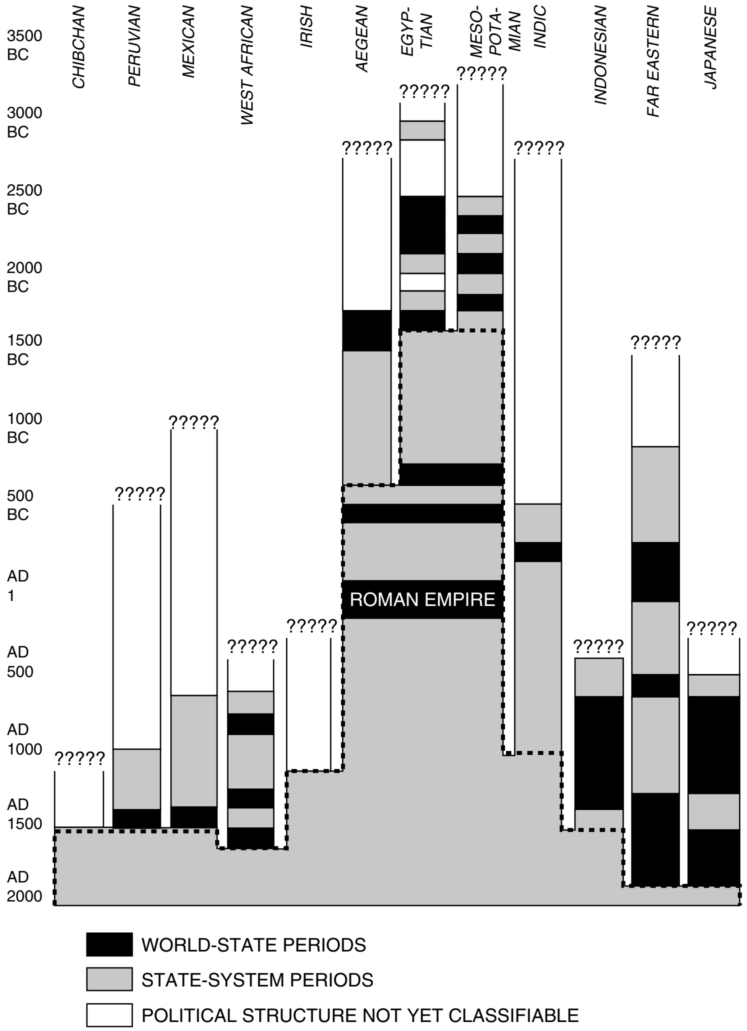


Figure 12.1b *The confluence of civilizations showing the growth of central civilization through time*



Note: Each vertical bar in this figure represents a civilization: see Figure 12.1. Central civilization is set off by a dashed line.

Figure 12.2 Alternations between states systems and universal empires

Unipolarity, bipolarity, and multipolarity I have already instanced: structures respectively having one, two, or many members of a great-power oligarchy. Tripolarity evidently implies three great powers; non-polarity the absence of great powers among a collection of small states.

BOX 12.1 CIVILIZATION/WORLD SYSTEM POWER CONFIGURATIONS

PHASE I: TOW CONFIGURATIONS

1. STATES SYSTEM
2. UNIVERSAL EMPIRE

PHASE II: SEVEN CONFIGURATIONS

0. NONPOLARITY
1. MULTIPOLARITY
2. TRIPOLARITY
3. BIPOLARITY
4. UNIPOLARITY (non-hegemonic)
5. HEGEMONY
6. EMPIRE

Hegemony (a term meant to be applied systemwide, so that a world system with several regional hegemons is not thereby a hegemonic system) adds effective influence to unipolar capability; empire (again a systemwide term: a world system that contains several regional empires is not thereby an imperial system) removes the internal as well as the external autonomy of the system's components, as when tributary allies become provinces.

The United States, for an obvious instance, may stand in an imperial relation to some areas, and in a hegemonic relation to many states; this is not enough to classify the current world system as either imperial or hegemonic, and I would classify it, as I have already suggested, as unipolar (with the US as the polar state), and not as hegemonic nor imperial. (Nor, by the way, can I recognize any British hegemony, ever; nor before that a Dutch hegemony – here I differ sharply with the Wallersteinian tradition of world-systems analysis.)

I make no claim that this specific list is definitive. But I think that this is a reasonable compromise between the desire for extreme particularity in description and the desire to be able to produce generalizations of some kind. When I polled the other authors of this book as to which of seven power structures – empire, hegemony, unipolarity without hegemony, bipolarity, tripolarity, multipolarity, non-polarity – they expected to characterize the world system in the next decade, the results were: empire 0;

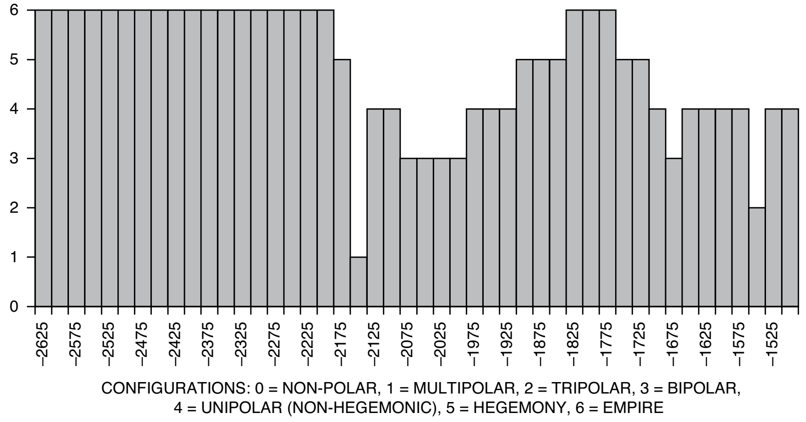


Figure 12.3 Egyptian/Northeast African world system political configurations 2625 BC–1500 BC

hegemony 0; unipolarity 2; bipolarity 1; tripolarity 4; multipolarity 7; nonpolarity 0. I placed my bet on the continuation of the current structure, unipolarity without hegemony.

Using this sevenfold classification, I have been slogging through the interesting labor of coding the political status of several world systems at intervals, sometimes of 50, then of 25, then of 10 years. This produces a string of numbers for each such system, and these strings can be graphed. For instance, here is one such string, for the Egyptian or Northeast African sequence (Figure 12.3).

As the legend indicates, I use the values 0 through 6 to code the seven configurations, in an ordinal sequence from the least consolidated (nonpolarity = 0) to the most centralized (empire = 6). In the Northeast African case the string of numbers evidently began clamped at 6-6-6-6-6. . ., but later became more interestingly diversified.

Now simply by looking at the charts that graph the strings we can see that the various systems have rather different characters. Here, for instance, are the graphs for three other world systems: Southwest Asian/Mesopotamian (Figure 12.4), the early years of the Central System which combines Egypt and Mesopotamia (Figure 12.5); the Far Eastern system, usually Sinocentric, but by no means simply Chinese (Figure 12.6); and the Indic or South Asian system (Figure 12.7).

Now, while I am still working to bring the coding of the Central System up to date, I have also been trying to develop better descriptions of the characters of the various systems, beginning with the Indic system, on which I am working with the help of a Russian statistician, Sergey Tsirel. I

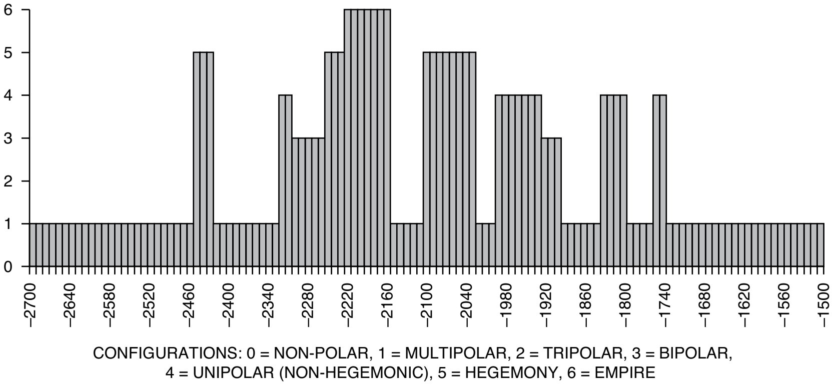


Figure 12.4 Mesopotamian/Southwest Asian world system political configurations 2700 BC–1500 BC

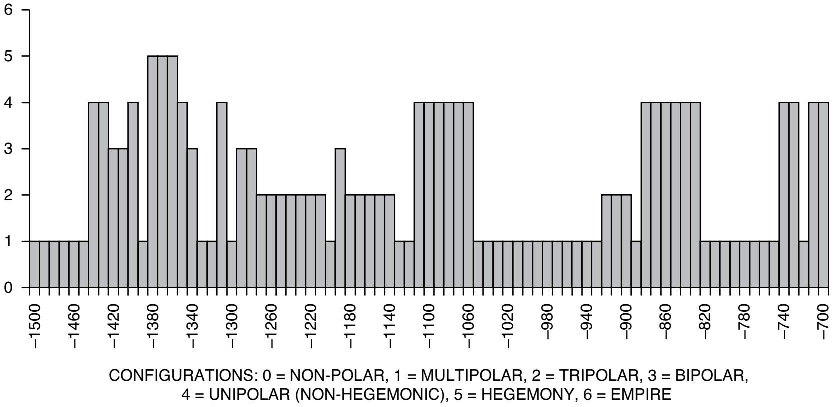


Figure 12.5 Central world system political configurations 1500 BC–700 BC

will not go very far into detail on that subject, except to say that the Indic system seems to display a strong preference for unipolarity and bipolarity (versus all five other available states), as shown in Table 12.1; and a significant degree of conservatism or disinclination to change out of any state it happens to be in (Table 12.2); while preferring, if it does change, to move to unipolarity or to bipolarity (Table 12.3).

Indeed, a brief summary of results to date for five such systems (Far Eastern, Indic, Southwest Asian, Northeast African, and the Central system produced when the last two collided and fused about 1500 BC)

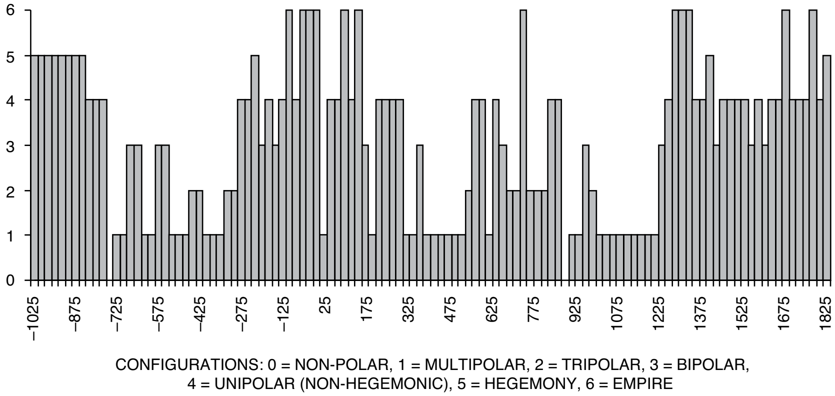


Figure 12.6 Far Eastern world system political configurations 1025 BC–AD 1850

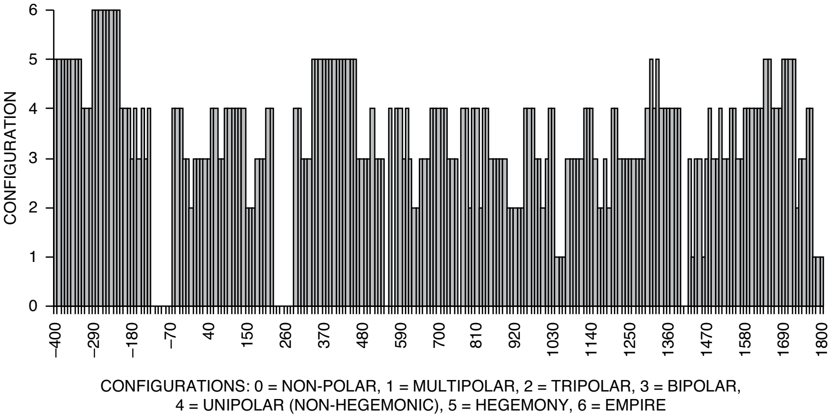


Figure 12.7 Indic world system political configurations 400 BC–AD 1800

is that each world system seems to show a bias toward certain power structures. The Northeast African system seems to have had two phases, perhaps three, in its behavior; but it shows a very distinct propensity towards a high degree of centralization throughout, and some inclination to empire. Southwest Asia shows another pattern: a set of sharp oscillations between a relatively normal state of multipolarity and some strong degree of centralization. The Far Eastern pattern is more difficult to work out, and will likely require a good deal of statistical analysis before it can be pinned down; there may be several phases, phases within phases, or phases overlaid upon other phases.

Table 12.1 Distribution of the index of configuration

Index of configuration	Characteristic of power configuration	Number of observations
0	Non-polarity	17
1	Multipolarity	8
2	Tripolarity	17
3	Bipolarity	72
4	Unipolarity	71
5	Hegemony	28
6	Empire	8
Total		221

Table 12.2 Persistence frequencies of the Indic configurations

Configuration	%
Non-polarity	64.7
Multipolarity	57.1
Tripolarity	47.1
Bipolarity	61.1
Unipolarity	57.7
Hegemony	78.6
Empire	87.5

Table 12.3 Indic world system transition frequency matrix (row percentages)

Old state of system	New state of system						
	Non-polarity (%)	Multi-polarity (%)	Tripolarity (%)	Bipolarity (%)	Unipolarity (%)	Hegemony (%)	Empire (%)
Non-polarity	*64.7*			5.9	29.4		
Multipolarity		*57.1*		42.9			
Tripolarity			*47.1*	35.3	17.6		
Bipolarity	2.8	2.8	8.3	*61.1*	23.6	1.4	
Unipolarity	5.6	2.8	2.8	23.9	*57.7*	5.6	1.4
Hegemony			3.6	3.6	14.3	*78.6*	
Empire					12.5		*87.5*

Note: Rows may not add to 100%, as percentages are rounded.

In short, different world systems show different biases, so that no system's character is very useful in predicting any other system's character. It would seem reasonable to expect that the same will hold true of the current world system.

Furthermore, like the Indic system, all five systems exhibit a strong tendency toward short-term "stickiness," in that the best predictor of the state of the system at the time ($t + 1a$) where a is an interval of 10 years (in some systems) or of 25 years (in others) is the state of the system at time t. In this sense, we are justified in saying that the (subjectively) most likely state for the current world system at ($t + 1a$) = [either AD 2015 or AD 2030], where t = AD 2005 and a = [10 years or 25 years, respectively], is its state at t, that is, non-hegemonic unipolarity. And we are similarly justified in proposing that the system will most likely be found in that subset of its available states in which it has most frequently been found in the past.

Therefore, rather than tamely concur with the expectations of, say, the leaders of France and China that some alleged universal multipolar norm will eventually reassert itself, we would be more prudent to explore the basis for the different and changing systemic norms, and to wonder what structures will be preferred by the current system, rather than to assume that what was true for the West European epoch of say 1648–1945 will again become true in the twenty-first century. It will likely be a subset of the whole set of seven possible states.

I would propose that this subset would include, but not be limited to, the current structure, which I have called "unipolarity without hegemony"; that the subset would also include the just-prior power structure of bipolarity, though probably not with the US and Russia as polar states; and that the subset would, finally, contain the multipolar power structure which preceded bipolarity, though not with the same roster of great powers as before. More definitely: I believe there is an empirical-theoretical basis for predicting, contrary to the views of the great majority of researchers queried for my informal poll, that in 2015–30 the world system will most likely still have a single polar state (not necessarily the United States of America) which however does not "manage" the system; and that if this prediction fails, the next-best bets for the state of the system are bipolarity and multipolarity.

This chapter has looked only at the possible effect of the past of the power structure upon its present and its future: it suggests the presence of endogenous causation that must be accounted for, and taken into account, in looking at presents from their pasts, and futures from the present. A dynamic global model of power structures where "power structure" is the y variable must see y at $t + 1$ as a part-function of y at t, and likely y at $t - 1, t - 2, \ldots. t - n$, where n may be the entire number of observations of y. The power configuration variable does not appear to be "well behaved" in Claudio Cioffi-Revilla's sense: linear, exponential or asymptotic, or regular-oscillatory extrapolation is insufficient for forecasting; nor is there a low-energy state (as with those systems studied by Myron Karasik) to which world systems return after perturbations; nor does y apparently vary in a reliably stable manner – and yet y shows pattern in each world system, but different patterns in different systems.

Should a global model incorporate the power structure variable? That the particular shape of the global power structure has some bearing on such elements of the human condition as the material standard of living, human freedom, political democracy, the structure and intensity of warfare, and the size of population seems quite likely, though the precise connections remain to be examined, as Frank Wayman (1984; updated in Wayman forthcoming) is doing with the effects of different world system power structures upon the patterns of warfare in those systems.

ACKNOWLEDGMENTS

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13. From altruism to the future frequency of war: how consilient explanation differs from prediction

Frank Whelon Wayman

Prediction of the future of armed conflict can be done using methods of extrapolation of long-term and short-term trends, as demonstrated at the outset of this chapter with data on inter-state and intra-state wars (from the Correlates of War Project). The use of Project data over all the years since 1816 allows more accurate forecast of global inter-state war trends than when only data from the past decade are used, so the amount of inter-state war has been more likely to regress to the centuries-long mean than to be correlated with the immediate-past decade.

Such forecasting of a variable using prior data on the same variable is an example of emphasis on prediction and de-emphasis on explanation. Explanation and prediction are often said to be two sides of the same coin, yet the image on the explanatory side is often the more mysterious. Explanation may involve either a predictor variable at the same level of analysis as the outcome variable or predictor variables at a lower level of analysis. Bueno de Mesquita, for example, began his work on armed conflict by explaining war levels in the international system as an outcome of the systemic polarization (with systems becoming more war-prone immediately after the military alliances become more polarized). Wilkinson (2005) continues to refine the understanding of such conditions of systemic polarity and polarization, as in Chapter 12 in this volume. Later, however, Bueno de Mesquita moved to a game-theoretical approach, explaining inter-state war as a function of the rational choice of individual human beings who lead states, and also as a by-product of a variable from a level of analysis in-between individuals and the inter-state system: the characteristics of the regimes that govern individual states. Axelrod drove this quest for explanation to the still lower genetic level by asking if individuals prone to conflict or cooperation would evolve in a computer simulation that was analogous to biological evolution. Later in the present chapter, I examine Axelrod's (1984) *Evolution of Cooperation* on the prisoner's dilemma, by considering conditions in which individuals who find utility in altruistic behavior will be able to do better than others in acquiring the material means to sustain their own survival. Using deduction in a game-theoretical context, I show a condition in which cooperation emerges as a solution to a kind of prisoner's dilemma game. The chapter concludes with a discussion of how this quest for explanation takes us far from the data we were originally motivated to forecast (namely, global war trends), so that there are tensions between explanation and prediction or forecasting. Also, the chapter raises the question of when an approach grounded in evolutionary biology (such as in Axelrod or in Wilson's (1999) *Consilience*) is more appropriate (or less so) than an approach that goes no lower than the individual rational choice (such as in Bueno de Mesquita et al. 2003).

PREDICTING FUTURE LEVELS OF INTER-STATE WAR FROM DATA ON PAST WARS

Defining war as sustained combat involving substantial casualties (Small and Singer 1982), and measuring that as armed conflicts in which at least 1000 people per year are killed in battle, the Correlates of War (COW) project has built a dataset listing all modern wars. The COW project distinguishes types of war based on its list of sovereign states. Wars can be: (1) inter-state, between sovereign states; (2) intra-state, within a sovereign state; (3) extra-state, between a sovereign state and an external entity (these are usually imperial and colonial wars); or (4) non-state, between entities that are not sovereign states (such as the war between the Hashemites and Saudis for control of Mecca and Medina). There have been 95 inter-state, 335 intra-state, 163 extra-state, and 62 non-state wars during the period 1816–2007 (Sarkees et al. 2003; Wayman et al. 2005; Sarkees and Wayman 2010). Some have argued that inter-state war is becoming less of a problem since World War II (Lacina et al. 2005), either in the sense that intra-state war is growing more frequent relative to inter-state war, or that inter-state war is simply becoming less common in absolute terms. It has been argued that inter-state war will die out, like slavery did in the past. In this first section, I take up the question of whether we can predict the future amount of inter-state war.

Two central questions to consider, with regard to this forecasting effort, are whether inter-state war is becoming less common, and whether any trends or patterns in the amount of inter-state war are predictable. A third question would be: if the amount of war that will break out is predictable, is it useful to have very long-term time-series, such as in the COW dataset, or is prediction with shorter-term data sufficient?

To explore these questions, I examine whether the amount of inter-state war in time period t is most likely what it was during period t – 1 (which would be true if there was a long-term, gradual trend to less war because of the spread of trade, prosperity, democracy, education, and international organization) or if the amount of inter-state war in time period t is approximately what it was on average over the known past (which would be true if war was not slowly being replaced by more civilized behavior).[1] A comparison of the two prediction techniques is presented in Table 13.1, based on inter-state war data 1816–1999.

The number of inter-state war onsets is predicted, in Table 13.1, 19 times. The first of these is the prediction of the number of war onsets from 1820 to 1829, the next prediction is the number of war onsets from 1830 to 1839, and so on for each decade, until the last prediction, which is the number of war onsets anticipated for the 2000 to 2009 decade. For each of these 19 decades, two predictions are reported in the table. The simpler prediction, that the number of war onsets in each decade will be the same as in the previous decade, will be off by an amount called delta-war (Δ war), which is the change in the number of war onsets from one decade to the next. Delta-war is summed in the sixth column of Table 13.1, and this sum gives us a total of the errors in our predictions: through the entire 18 predicted intervals for which we have observed data (that is, 1820–29, 1830–39, 1840–49, and so on through 1990–99), this method will result in an error, or inaccuracy, of 49 wars, or an average error of 2.72 per decade over 18 decades.

The other method of prediction is to anticipate that the next decade (called the "present" in the heading of Table 13.1) will be similar to the typical, or average, decade (that is, similar to the average war onsets per decade from 1816 to one decade before the "present"). These predicted values are provided in the third column of Table 13.1. For instance, there were 11 inter-state wars in the first five decades (through 1859), or an average of 2.20 per decade to 1859, so the prediction is that there will be 2.20 inter-state wars in 1860–69. (In fact, there were eight such onsets in 1860–69, so the prediction was 5.80 too low, an error reported in the fourth column of Table 13.1, in the 1860s row.)

The far right column of Table 13.1 compares the accumulating accuracy of the two methods of prediction, summed over all the decades predicted so far. Should the prediction based on only the immediately prior decade be more accurate, then the number in the right-hand column of Table 13.1 would be negative. If, to take the opposite possibility, the prediction based on the prior mean wars per decade is the superior predictor, then the number in the right-hand column of Table 13.1 will be positive. And the exact numerical value indicates the gap in predictive accuracy of the two

Table 13.1 *Two methods of predicting amount of inter-state war per decade*

Decade	Observed wars	Prediction, based on 1816 to “present”			Prediction, based on immediate past decade only		Cumulative error comparison
		Avg. # of previous wars	| Observed − Avg. |	Avg. inaccuracy	Σ Δ in # of wars	Avg. inaccuracy	
1810s	0						
1820s	2	0.00	2.00	2.00	2	2.00	0.00
1830s	0	1.00	1.00	1.50	4	2.00	0.50
1840s	4	0.67	3.33	2.11	8	2.67	0.56
1850s	5	1.50	3.50	2.46	9	2.25	−0.21
1860s	8	2.20	5.80	3.13	12	2.40	−0.73
1870s	4	3.17	0.83	2.74	16	2.67	−0.08
1880s	3	3.29	0.29	2.39	17	2.43	0.04
1890s	4	3.25	0.75	2.19	18	2.25	0.06
1900s	6	3.33	2.67	2.24	20	2.22	−0.02
1910s	8	3.60	4.40	2.46	22	2.20	−0.26
1920s	2	4.00	2.00	2.42	28	2.55	0.13
1930s	9	3.83	5.17	2.65	35	2.92	0.27
1940s	3	4.23	1.23	2.54	41	3.15	0.62
1950s	3	4.14	1.14	2.44	41	2.93	0.49
1960s	6	4.07	1.93	2.40	44	2.93	0.53
1970s	7	4.19	2.81	2.43	45	2.81	0.38
1980s	4	4.35	0.35	2.31	48	2.82	0.52
1990s	5	4.33	0.67	2.22	49	2.72	0.51
2000s		4.37					
Total			39.87				

methods. In the first ten decades being predicted (1820s to 1910s), the two methods run neck and neck, with each leading in accuracy half the time. (For instance, in the 1830s and 1840s, the better bet is to predict the war onsets based on all previous decades. But in the 1850s, the number of wars is very close to the number in the 1840s, and much higher than the previous average, so by the 1850s, with four decades now predicted, the immediate prior decade is the better method.)

But, over a very long period of time, as the amount of prior information available to the mean method exceeds a century, the mean method wins. Its assumption of a stable amount of inter-state war begins to consistently yield superior predictions. By the time we reach the last eight predicted decades (the 1920s to the present), predicting based on the long-term mean remains superior to prediction based only on the immediate past decade. For example, the prediction by the mean led to a prediction of 4.35 inter-state wars in the 1980s. This was the highest number ever predicted historically (that is, for any of the past decades). The actual number of inter-state wars was four in the 1980s, so the predicted value was very close to what happened. For the 1990s, the predicted number of inter-state wars was 4.33; the actual number of inter-state wars was five. The method of using the prior mean allows prediction of the number of wars in the 2000s, and the predicted number is 4.37, a slightly higher number than even the highest of the historical predictions (that is "post-dictions").

The other method, of predicting that the number of inter-state wars will be the number in the immediately previous decade, is a method that is off (as noted above) by a cumulative total of 49 wars in the 18 decades, or about 2.72 mistakes per decade. The superior method, predicting that the number of inter-state wars in a decade will be the average of all observed past decades, produces a cumulative error of 39.87 wars, which is an average of 2.22 mistakes per decade. The improved accuracy rate (39.87/49) represents a 19 percent greater accuracy.

These findings suggest that the amount of inter-state war has been only weakly predictable. The average number of wars per decade is about 4.4, and the error in prediction (even using the superior of the two methods, with which the predictions are off by 2.22 wars) is about half of that. One might say the typical prediction is 4.4 wars plus or minus 2.2. However, it is interesting that the method that assumes the rate of war onsets is stationary over centuries produces superior results to the method that assumes the rate of war onsets is like the immediate past. While we hope war will disappear, or at least be substantially reduced in frequency and destructiveness, these results show that the number of inter-state war onsets per decade does seem to be unpleasantly persistent. Of course, things are slightly more encouraging when one takes into account the growing number of nation-states and the growing world population, so that war's damage is down somewhat on a per capita or per state basis, so there are some signs of progress, even as the number of inter-state wars per decade proves resistant, till now, to change (Sarkees et al. 2003). To look at such broader perspectives, I turn in the next section to predicting inter-state, intra-state, and extra-state war, as well as the totality of war, taking into account both war onsets and battle deaths, both in raw (unadjusted) war numbers and then with war numbers adjusted to system size.

PREDICTING WAR ONSETS AND WAR DEATHS: IS THERE A LONG-TERM TREND, OR A BREAK POINT IMMEDIATELY AFTER WORLD WAR II?

When we move beyond just the onset of inter-state war, and consider all the patterns in war from Sarkees et al. (2003), a good start is a look at the graphs of war over time in that article. Fatalities are dominated with spikes associated with World Wars I and II. In contrast to that, most of the other decades seem fairly similar to each other, though with some signs of trends (the raw number of onsets of intra-state wars seems up over time, extra-state war down). With this in mind, I decided to test for trends in the data using the technique of Poisson regression, which is appropriate for data that are limited on the down side to zero, but fluctuate up from there from time to time (an example of the use of this technique, with militarized inter-state disputes and economic sanctions, is Pollins 1994). I tested 32 models (Tables 13.2 and Table 13.3), by looking at inter-state wars, intra-state wars, extra-state wars, plus the sum of all three of these types of war, and examining for each of those four groups both war onsets and battle deaths, making eight (4×2) dependent variables. That number of dependent variables was further doubled by looking first at raw figures, and then at figures adjusted for system size. These adjustments were to divide the number of war onsets by the number of system members, and to divide battle deaths by system population (all based on data from Sarkees et al. 2003). In each case, a model was run with decade as the independent variable (value of one for the first decade, two for the second decade, and so on), which provides a test of the effect of trend on the war variable. Then, a second model was run with a post-World War II intervention variable brought into a two-independent variable model, along with decade. This second model tests the effect of trend while controlling for a post-World War II one-time drop in the dependent variable, and tests the effect of that one-time drop while controlling for the effect of trend.

In Tables 13.2 and 13.3, I report these 32 predictions of the amount of

Table 13.2 Poisson regression analysis of the totality of war, 1816–1997, unadjusted

Inter-state war

Predictor variables:		Secular trend prediction		Trend (decades) plus break point	
	Variable	Coefficient	% change in war per unit of time	Coefficient	% change in war per unit of time
Onsets	Decade	0.034	3.420	0.097	4.400 *
	Post-1945			−0.867	−42.010
Battle deaths	Decade	0.090	9.400	0.558	75.000 ***
	Post-1945			−5.081	−99.000 ***

Extra-state war

Predictor variables:		Secular trend prediction		Trend (decades) plus break point	
	Variable	Coefficient	% change in war per unit of time	Coefficient	% change in war per unit of time
Onsets	Decade	−0.0051	−5.400	−0.005	−0.460
	Post-1945			−0.910	−60.000
Battle deaths	Decade	−0.0236	−2.300	−0.084	−8.100
	Post-1945			0.913	149.000

Table 13.2 (continued)

Intra-state war

Predictor variables:		Secular trend prediction		Trend (decades) plus break point	
	Variable	Coefficient	% change in war per unit of time	Coefficient	% change in war per unit of time
Onsets	Decade	0.069	7.110***	0.053	5.500
	Post-1945			0.197	21.800
Battle deaths	Decade	0.131	14.000**	0.074	7.700
	Post-1945			0.676	96.000

All War

Predictor variables:		Secular trend prediction		Trend (decades) plus break point	
	Variable	Coefficient	% change in war per unit of time	Coefficient	% change in war per unit of time
Onsets	Decade	0.034	3.430**	0.044	4.400*
	Post-1945			−0.133	−12.400
Battle Deaths	Decade	0.100	10.500	0.327	38.600***
	Post-1945			−2.538	−92.100**

Note: Statistically significant at 0.05 level (*), 0.01 level (**), or 0.001 level (***).

Table 13.3 Poisson regression analysis of the totality of war, 1816–1997, adjusted for system size

Inter-state war

Predictor variables:		Secular trend prediction		Trend (decades) plus break point	
	Variable	Coefficient	% change in war per unit of time	Coefficient	% change in war per unit of time
Onsets	Decade	−0.078	−7.51**	0.0137	1.37
	Post-1945			−1.276	−72.1*
Battle Deaths	Decade	−0.0858	−8.2	0.442	56**
	Post-1945			−5.62	−99.4***

Extra-state war

Predictor variables:		Secular trend prediction		Trend (decades) plus break point	
	Variable	Coefficient	% change in war per unit of time	Coefficient	% change in war per unit of time
Onsets	Decade	−0.1572	−14.5***	−0.0806	−7.7
	Post-1945			−1.3436	−74
Battle Deaths	Decade	0.1993	−18.1***	−0.2717	−23.8
	Post-1945			1.0675	191

Table 13.3 (continued)

Intra-state war

Predictor variables:		Secular trend prediction		Trend (decades) plus break point	
	Variable	Coefficient	% change in war per unit of time	Coefficient	% change in war per unit of time
Onsets	Decade	−0.0470	−4.6***	−0.0383	−3.8
	Post-1945			−0.1137	−10.8
Battle Deaths	Decade	−0.0454	−4.4	−0.1089	−10.3
	Post-1945			0.7426	110

All war

Predictor variables:		Secular trend prediction		trend (decades) plus break point	
	Variable	Coefficient	% change in war per unit of time	Coefficient	% change in war per unit of time
Onsets	Decade	−0.0778	−7.5***	−.042	−4.1*
	Post-1945			−.496	−39*
Battle Deaths	Decade	−0.076	−7.3	0.1837	20.2
	Post-1945			−2.856	−94.3**

Note: Statistically significant at 0.05 level (*), 0.01 level (**), or 0.001 level (***).

war, with coefficients, significance levels, and percentage changes in the dependent variable due to the independent variables. A word on interpreting the tables: the output from Poisson regression is a coefficient that can be converted to a percentage change in war by doing a logarithmic transformation. The analyses were done in the SAS statistical package, which did not present the percentages, so these we computed from the coefficients using a statistical calculator. The percentages in the left side of Tables 13.2 and 13.3 show the percentage change from one decade to the next in the dependent variable. The percentages on the right side show the percentage one-time drop after the World War II spike, controlling for the decade-to-decade trend, and the percentage change from one decade to the next, controlling for the post-World War II drop.

Some may describe the distribution of war over time as an inverted U, but we do not see an inverted U (block or rounded), nor an inverted V, so we are not testing for patterns in the form of those letters, but rather, as I have said, looking for something similar: a possible trend, and a possible post-World War II drop. This tests (and challenges) the "realist" idea that warfare is ubiquitous and a constant part of human nature and international interaction. An early major finding of the COW project was that "more than one-half of all nations now in the international system have never participated in large-scale [international] war under their own governments" (Deutsch 1980: 290). Among even older, well-established nations, for instance, "Sweden and Switzerland have never been at war during the entire 150-year period since 1816" (Deutsch 1980: 290, citing Singer and Small 1972: 275–280, Table 11.2). These successful patterns may spread: "It may not be an act of childlike naivete to believe that the global village may yet return to a long, and perhaps even permanent, period of peace. It is this faith that prompts us to prepare the volume at hand" (Small and Singer 1989: v). There has been no inter-state war between major powers since the end of the Korean War in 1953 – an interval reaching 52 years. Singer (1991: 76–78) developed 45 specific hypothetical reasons for this record-long period of peace among the major powers. These hypotheticals included the effect of United Nations (UN) institutions (hypothesis 10f), "destruction from, and memories of, the two World Wars" (hypothesis 3c), and the way "more nations are becoming democratic and/or capitalist, and these societies are not only less war-like, but rarely fight one another" (hypothesis 3b). I am also sympathetic to the democratic peace hypothesis. Wayman (2002), for instance, found that liberal dyads not only avoid war with each other, but also almost always avoid battle deaths in militarized inter-state disputes (MIDs) with each other. However, the spread of democracy may not always be irenic. Henderson (2002) points to the problem that (although in a multivariate analysis democracy reduces extra-state war) some liberal states such as Belgium were guilty of African genocide and extra-state (that is, imperial) wars. Wayman and Tago (2010) found that democracy does reduce the likelihood of democide (Rummel's 1994, 1997 concept), but in a comparison of the cases of geno-politicide that parallel Rummel's work, democracy does not reduce geno-politicide (Harff's 2003 concept). Hence, the total dead in mass political killings has a mixed relationship to the spread of democracy, just as the international war battle dead have a complex relationship, depending on whether one is considering extra-state wars (Henderson 2002: 80, 93) or inter-state wars. In short, I have faith that efforts – academic, democratic, and activist – toward citizenship in the global village can enhance world peace, but I believe the evidentiary record so far is more complex than a half-century-long march away from fascism and toward democratic peace. This is a story that benefits from a dialog. I welcome good research supporting the Kantian peace (Oneal and Russett 1997), and I also find helpful studies showing how this dyadic pattern could lead to global effects (Gleditsch and Ward 1997). But I now turn to my own data analyses to show that the good news champagne glass does not always look so full.

Of the 48 possible statistically significant coefficients in my Poisson regressions, eight are significant in the positive direction, indicating an increase in war over time. Twelve are significant in a negative direction, indicating a decline in war over time. So there is a slight edge for the optimists, who think things are getting better, over the pessimists, who think things are getting worse, but it is only a 3:2 ratio of optimistic to pessimistic findings, so it reinforces the point of Sarkees et al. (2003) that it really does depend, Rashomon style, on what you choose to emphasize in the evidence.

The significant effects showing increase in war are mostly (seven out of eight) in the table (13.2) of onsets and battle dead, whereas the significant effects showing decline are mostly (ten out of 12) in the table (13.3) that adjusts those figures for system size. Clearly, if one focuses on raw numbers, there are some signs of war increasing, whereas if one focuses on adjusting for growing number of states and growing population, the signs point to a decrease in war. As for war unadjusted for system size, in the raw figures (Table 13.2), it is intra-state war whose significant coefficients are always positive (both for onsets and battle deaths, per decade). Inter-state and total wars also both show a significant upward trend. But when one focuses just on battle deaths in inter-state and total wars, the picture is more complex: the significant upward trend per decade is counterbalanced by a significant decline immediately following World War II. As for war adjusted for system size, in the models adjusted for system size (Table 13.3), there are many hopeful signs. Extra-state war onsets and battle deaths are significantly down per decade. Intra-state war onsets are significantly down per decade. Inter-state wars are significantly down per decade (though controlling for a significant post-World War II one-time drop makes the decade-to-decade result disappear). In battle deaths, inter-state war is significantly up per decade, but this is counterbalanced by a significant one-time post-World War II drop. As for all war, onsets drop significantly both decade to decade and one-time post-World War II; and battle deaths are down significantly post-World War II.

Straight-Line Trend versus Kink

On the right-hand side of the tables, one has a head-to-head test of the straight-line trend versus kink models. There are six significant coefficients indicating a "kink," by which I mean a one-time (*c*. 1945) drop in the amount of war. There are also six significant coefficients indicating a significant straight-line trend of decade-over-decade change. (Five out of six of these are increases.) So the evidence seems evenly balanced: there are signs of a purely straight-line trend, usually in extra-state and intra-state wars. There are also signs of a mix of straight-line trend plus kink, usually in inter-state war and the totality of war. If there is a kink due to such factors as the advent of the UN, revulsion from World War II, or simply regression towards the mean, the kink is focused in inter-state war and cascades from there into the totality of war.

HOW MUCH OPTIMISM IS WARRANTED, GIVEN THESE TRENDS IN WAR?

Looking at the very long term, from the Renaissance to the present, some have seen a growing variance – a heteroskedasticity – in the destructiveness of war. Levy (1983) sees less frequent but more destructive wars. Cioffi-Revilla (2004) sees a growing variance in the deadliness of war, with a prediction that the next record-setting death toll is overdue and will dwarf World War II. On the more encouraging side, looking from 1816 to the present, Lacina et al. (2005), following in the tradition of Deutsch (1980), see signs of a formerly rising but now declining risk of death from war. My own view is optimistic yet guarded. There are certainly encouraging indicators of an unprecedented cessation of inter-state war among the richest nations, a possible Kantian peace (Oneal and Russett 1997), but is any one of us so sure of routing the Hobbesian fear of violent death that they are confident there are no surprises like September 11, 2001 in store? We may be, with regard to war, in the same position as the US in the mid-nineteenth century with regard to slavery: about to see it go away. But we do not know what the future holds, and the recent trends, while encouraging those of us in the peace research community, do not support complacency.

SEEKING EXPLANATION OF WAR AT THE GLOBAL SYSTEMIC LEVEL OF ANALYSIS

The analyses of patterns of modern war in the above were directed toward describing the amount of war, and then examining the degree to which the amount of war varies, and whether that variation can be "explained" by the one independent variable, time. Of course, to the degree that there is a pattern through time, this raises the question of what accounts for that change. For instance, if international war is becoming less common, is that because of the spread of nuclear weapons, or the spread of democracy, or something else?

As data on war first became available from the COW project in the 1960s, the first major research focus was on using characteristics of the entire global system to explain the variation in the total amount of warfare in the global system. This work originated in the debate between Kenneth Waltz (1964), on the one side, and Karl Deutsch and J. David Singer (1964), on the other side, over the role of systemic polarity. Waltz argued that a bipolar international system was more peaceful than a multipolar one, while Deutsch and Singer argued the opposite. Both sides agreed, however, in attending to the systemic level of analysis, and this idea in turn was related to the pioneering work of Singer and of Waltz in emphasizing the levels of analysis in international relations. These were the individual, involving the role of human beings (such as world leaders) and their beliefs and preferences; the state, involving the role of national characteristics such as the military expenditures, economic strength, and population base of each sovereign state; and the global systemic, including such characteristics of the system as whether it was dominated by two large superpowers with most of the material capabilities (military, economic, and demographic). The COW project gathered data on the two higher levels of analysis (global systemic and national) for the period 1816 to the present. The individual level of analysis was less effectively attended to by those gathering data, because the task was more daunting (involving the choice of characterizing all relevant individuals or itemizing a population from which to sample). Again, research tended to focus on the debate about bipolarity and multipolarity. Bruce Bueno de Mesquita (1975) and Wayman (1984) both reported, for example, that when alliances became more tightly bipolarized into opposing camps, war was then likely to become more common. Wayman argued that this alliance pattern affirmed what Deutsch and Singer had predicted, namely, that intermediaries and cross-cutting cleavages reduce the amount of violence in a social system. Further, Waltz's supposition about bipolarity was confirmed by Wayman's finding that most large wars (most dramatically World Wars I and II) were associated with a multipolar distribution of power, whereas wars occurring during bipolarity tended to be small (Vasquez 1993: 249–251). One could summarize this by saying that bipolarization of alliances increased the risk of war breaking out, but a distribution of power that was multipolar increased the risk that existing wars would become very large.

A problem with these analyses was that systemic conditions varied slowly, and there were not many distinct cases to study over a period of time of 200 years. Levy (1983) extended a list of wars back an additional three centuries, to 1495, and Cioffi-Revilla began a long-term project to extend this back to antiquity. Wilkinson (2005) undertook a similar long-term analysis of systemic polarity back to the start of large city-states. Their work makes possible a more comprehensive analysis of the explanation of war over the history of civilization. Some of Wilkinson's work has been presented in Chapter 12 in this volume. In contrast, I want to consider, in the next section, whether explanation can be found in lower levels of analysis.

SEEKING EXPLANATION AT THE INDIVIDUAL LEVEL OF ANALYSIS

All these studies (from the previous section) when put together give us the ability to explain the amount of war in a system from the degree of polarity of the system. Actually, however, the explanation was always reasoned in terms of the interests and passions of sovereign states and their individual leaders. As time went by, this reasoning was made more explicit by the expected utility and game-theoretic calculations of Bueno de Mesquita and his colleagues (among others), culminating in the *Logic of Political Survival* (Bueno de Mesquita et al. 2003), which attempts to explain patterns of international interaction among and by states in terms of the motive of political survival of the ruler and their calculations of how to reward the ruling coalition (whose effect on the calculations depends critically on its size relative to the population base of the country).

While there remain no good data on the individual level of analysis, it is possible for expected utility and game-theoretic calculations to assume that certain conditions of the international system and the form of government of the country (which are all measured) would be strongly correlated with and would induce personal choices based on personal self-interest in such circumstances.

These studies of rational choice (expected utility and game-theoretic), have reached a level of analysis called the individual level. In the full hierarchy now used in international relations, this is the lowest level. The higher levels are the role individuals play in small groups, the more impersonal large organizations such as the Pentagon that are still larger, the governments that are made up of sets of such organizations, the societies in which these governments rule, the dyads (pairs of sovereign states) that may both be democratic (yielding the democratic peace), and the international system as a whole (Russett et al. 2004). Sociobiology and genetics lie outside this canonical set of levels of analysis.

The argument against going to a still lower level of analysis below the individual, and investigating sociobiology and genes, is that the genetic heritage of the human race is in effect a constant over short spans such as years or decades, whereas, as we have seen, warfare varies greatly from year to year or decade to decade. Hence, normal science is concerned with finding the "correlates" of war, or co-variation between war and other measured variables (systemic polarity, joint democracy, nuclear deterrence, and so on). One of the promising efforts to reach out from this normal science towards topics with a sociobiological basis is the theoretical and empirical work of Vasquez (1993: 123–152) on the nature of war, and specifically on territory and war.

There is no inherent logical contradiction between current political science and sociobiology. Rational choice presumably is useful as an approximation for the action of states' leaders because rational calculation has been a survival advantage for humans in the several tens of thousands of years or more of evolution. Those who reject rational choice often invoke psychological arguments (cognitive dissonance, love of the in-group, hatred or fear of the out-group, errors in rational cognition such as in the work of Kahneman and Tversky) that are even more closely grounded in psychological science, and hence potentially readily linked to human biochemistry, genetics, and natural selection.

In fact, significant pioneering efforts were made to unify the sciences, through the general systems movement in the 1960s (von Bertalanffy 1965). General systems theory was in practice sometimes most successful in linking social psychology to world politics (Singer 1965), though even that effort waned as the availability of data on the correlates of war at the national, dyadic, and systemic levels of analysis led scholars to concentrate on such matters as the democratic peace (Vasquez 2000). Today, the somewhat utopian goal of the general systems movement remains to be attained.

However, considerable intellectual obstacles remain in the quest for explanation at these lower levels of the sociobiology of macro-social behavior. In the next section, I take one further step on an already well-trodden path that might link macro-social behaviors to natural selection. The puzzle I focus on is whether altruistic cooperation in the prisoner's dilemma can evolve, which is to say whether altruistic cooperation can lead to enough material rewards for the individual that the individual is likely to survive and have enough material goods to produce and sustain offspring. The path I take, surprisingly, leads to a mathematics that is the same as has been used in an even lower level of analysis below biology, namely, the level of physics, and in particular the special theory of relativity.

SEEKING A DEEPER EXPLANATION FROM EVOLUTION

Most of the severe threats to the future well-being of the human species seem to stem from human behavior itself, and in particular the balance of cooperation and conflict between humans. For those living in the period from the dropping of the Hiroshima bomb to the fall of the Berlin Wall, nuclear annihilation was the most imminent threat, and this risk of nuclear war seems connected to whether we can cooperate broadly in arms control or whether conflict between smaller groups of cooperators will predominate. A growing risk is spoiling our own nest through human-induced climate change and pollution. In the face of that risk there is a need for broad cooperation of the sort described by Hardin in the "tragedy of the commons" theory. Even the threat from mutated disease organisms, such as tropical diseases and HIV/AIDS, is mediated by our ability to cooperate at a higher level (for example, eliminating disease from those at risk in breeding grounds among distant people, such as prison populations or those in regions geographically remote from us).

In the social sciences with which I am familiar, the most useful general way I have found to think about these problems, and to explain our cooperation and conflict mechanisms, is the avenue pursued by the political scientist Robert Axelrod, in *The Evolution of Cooperation* (1984). For this book, to try to meet Edward O. Wilson halfway down that avenue, I have attempted to adapt Axelrod's models from *The Evolution of Cooperation* just a bit, to make them a bit more deductively connected to survival questions that might be on the mind of Edward Wilson the sociobiologist.

Looking from the side of the biological sciences, Wilson in *Sociobiology* (1975: 4) wrote:

> Sociology and the other social sciences, as well as the humanities, are the last branches of biology waiting to be included in the Modern Synthesis. One of the functions of sociobiology, then, is to reformulate the foundations of the social sciences in a way that draws these subjects into the Modern Synthesis. Whether the social sciences can be truly biologicized in this fashion remains to be seen.

On the first page of *Sociobiology*, Wilson said: “the central theoretical problem of sociobiology [is] how can altruism, which by definition reduces personal fitness, possibly evolve by natural selection?” (Wilson 1975: 3; see also Wilson 1975: 106–129). A perspective on this central problem, albeit from the point of view of a political scientist lacking a proper understanding of genes and of non-human species, follows below in this chapter.

In it, the degree of altruism (concern for the well-being of the other player) needed to make cooperation the dominant strategy in the prisoner’s dilemma is established as a function of the outcomes (t, r, p, and s). A tournament is conducted (analogous to Axelrod’s *Evolution of Cooperation*), in which the pay-offs to self-centered players are compared to the pay-offs to altruistic players; and in certain conditions tit-for-tat altruists, who cooperate unless attacked in the prior round, have superior material returns to their own selves.

The problem of factionalism and conflict – that is to say, division of the political system into parts pursuing separate interests – is an enduring one in political science. It dates back to the dawn of political philosophy, where in Book V of the *Republic*, Socrates takes up the problem of conflicts of interest among the members of a republic (Bloom 1968: V, 457a–464e; Bloom 1968: 384–389). Presupposing a shared interest among kin, and a shared interest within social classes, Socrates argues for communal living arrangements to replace the natural family, and communal property to replace private property. Having “nothing in private but the body, while the rest is in common,” the people of this republic will be “free from faction, to the extent at any rate that human beings divide into factions over the possession of money, children, and relatives” (V, 464d). This solution being perhaps necessary, but too drastic to be implemented, faction remained the central problem troubling the founders of the first modern republic (Madison 1961 [1787–1788], *Federalist* 10). The founders assumed the sources of faction could not be removed, so that the regulation of faction became the most important responsibility of constitutional designers. Today, the problems of factionalism and of conflict in the global community remain, but the tools of game theory provide a new way of examining the costs, benefits, and overall feasibility of possible solutions.

Evolutionary theory of natural selection, and the “selfish gene” model of behavior, suggest that cooperation can evolve between independent actors in apparent conflict (Axelrod 1984), especially in cases of close kinship such as parental concern for children (Dawkins 1989). If cooperation can emerge despite selfishness in at least some kinship groups, is Plato right in thinking that cooperation can spread from natural kin to larger community? I model one aspect of this problem of community cooperation as a prisoner's dilemma and iterated prisoner's dilemma game, and examine cooperation as a function of altruism. While some have thought of altruism as a solution to the prisoner's dilemma problem, and others have examined how this might affect play against close relatives such as cousins, a unique element I introduce is a switch that turns off altruism when an altruist is attacked. This altruism that can be switched on or off generates iterated prisoner's dilemma play like Axelrod's tit-for-tat. The difference is that my altruism switch allows the *Evolution of Cooperation* patterns to emerge deductively, as the long-term consequences of the solutions of the one-round game. Further, this occurs between players calculating myopically only what is the best move for the current round. In contrast, in Axelrod (1984) the tit-for-tat strategy was devised intuitively by Anatol Rapoport as an ad hoc solution to the problem of how to come out ahead at the end of a many-round tournament. Also, I treat the prisoner's dilemma geometrically, which differs from the usual algebraic presentation, and this geometric approach helps as I develop an analogy to the Lorentz transformation in Einstein's special theory of relativity.

Prisoner's dilemma is a game in which two players simultaneously decide whether to cooperate with or "defect" on each other (see illustration, Table 13.4). The two players are designated "row" and "column" in Table 13.4. I will consider symmetric games; these are games in which there is no benefit from being row rather than column, or vice versa. There are four possible outcomes of the game, depending on whether both players defect (DD), both players cooperate (CC), or one or the other defects while the other player does the opposite (CD or DC). The respective pay-offs in my example (Table 13.4) are five points each if both defect, 15 points each if both cooperate, and 20 points to the defector and 0 to the cooperator if one defects and the other cooperates. These pay-offs are labelled p (five points in the example) for joint defection, r (15 points in the example) for joint cooperation, s (for example, 0) for being the sucker and cooperating when the other defects, and t (for example, 20) for being the traitor in that situation. Players can only cooperate or defect, and neither side knows the other side's move when it must decide its own move. Generally, a prisoner's dilemma game is any two-person game such as described in which the pay-offs are characterized by the inequalities $s < p < r < t$, and $r > (s + t)/2$.

What is the best strategy for a player trying to maximize his score in the prisoner's dilemma? Row, choosing to cooperate or defect, can deduce that he will score more points by defecting. This is because (as in Table 13.4), if

Table 13.4 Prisoner's dilemma pay-offs

		Column	
		Cooperation	Defection
		r, r	s, t
R	Cooperation	(15, 15)	(0, 20)
o		t, s	p, p
w	Defection	(20, 0)	(5, 5)

column cooperates, row gains 20 points by defecting, but only 15 by cooperating, and so is five points better off by defecting; and if column defects, row gains five points by defecting, and no points by cooperating, so again row is five points better off by defecting. Being five points better off by defecting whether column cooperates or defects, row reasons that his best move is to defect. Column, engaging in the same logic, comes to the same conclusion, and so defects, too. Both players having defected, they are left with only five points each, rather than the 15 points they could each have gained if they had cooperated with each other. Pursuing their self-interest, of seeking a five-point gain each, has led them to a 10-point loss each. This is a total loss of welfare of 20 points to their little community.

If there was some way to induce row and column to cooperate, their community (and each of them) would be better off. This can be viewed in an evolutionary sense (Axelrod 1984: 88–108) as continuing in an iterated game of prisoner's dilemma, in which the game is played repeatedly, gains and losses accumulate, and winning traits (that is, those players who share strategies that gain more points than others) proliferate while losing traits grow extinct. If the added community welfare benefit of 20 points in one round (that is, ten points per capita) of such an evolutionary process conveyed an overall evolutionary advantage, and if some cooperation mechanism arose in both players by some evolutionary mutation, players with that cooperative trait would, *ceteris paribus*, gradually tend to replace more selfish players who lacked this advantage. Of course, one would have to be careful not to evolve an excessive cooperation, because ongoing cooperation when the other player is defecting drags one to an extreme loss of welfare, leading to possible extinction (Axelrod 1984: 48–54, 88–108).

While there is no mathematical proof of what is the best strategy in iterated prisoner's dilemma, Axelrod identifies successful strategies by holding tournaments in which strategies are submitted and play against other strategies. He found that a strategy called "tit-for-tat" did particularly well in his tournaments. Its three main characteristics were that it was nice (that is, cooperated unless previously the target of defection), it was responsive (that is, it retaliated by defecting on its opponent if its opponent had defected on it in the previous round), and it was forgiving (that is, it then returned to cooperation if its opponent had also returned to cooperation). Axelrod's study of tournaments led him to the discovery that tit-for-tat, which was very cooperative, gradually evolved into a proliferating strategy, in an evolutionary process that eventually led to the extinction of strategies that were not nice. Social Darwinism had been turned on its head by these results.

The decision to cooperate or defect was made in these Axelrod tournaments by strategists whose intuition led them to guess what strategy might bear the most fruit in the long run. The strategy is selected before the first round of the game, and specifies what will be done throughout the game. Any cooperation that emerges is the result of the selfish desire of the individual decision-maker to maximize their score by the end of the tournament.

MAKING A PLAYER'S UTILITIES A FUNCTION OF THE OUTCOMES FOR BOTH PLAYERS

I now explore an alternative. In my alternative approach, I introduce a distinction between the resource outcome of a game, represented by the traditional p, r, s, and t of prisoner's dilemma, and the utility a player attaches to the outcomes. When a player is only concerned with his own score in primary goods, then the outcome a player receives equals his utility; the outcome and utility can both be represented by the pay-off (p, r, s, or t), and we have a traditional prisoner's dilemma game. On the other hand, in the innovation I am introducing, a player's utility is a weighted average of the outcome for themself and the outcome for the other player. The weight attached to the other player's outcome has an absolute value and a sign. The absolute value depends on the degree to which the first player cares about the other player's fate; and the sign (positive or negative) on this weight depends on whether the first player wishes the other player well or ill.

When outcomes differ from utilities in this way, a game that is defined as a prisoner's dilemma by the relation among the outcomes [$s < p < r < t$, and $r > (s + t)/2$] may not have a prisoner's dilemma structure regarding utilities, and may therefore have a cooperative solution in utilities. (Since this is a generalization from the classic prisoner's dilemma game, and since I will concentrate on players who want each other to do well, it may be useful, at least for some readers, to call this modified game "prisoners' dilemma." The placement of the apostrophe after rather than before the plural "s" indicates a slight shift in the nature of the game, and a pair of players who see themselves as, to at least a small extent, concerned about each other as well as themselves.) The outcome of the game can be thought of as the actual material value received by each player, such as a cash payment or a supply of some good such as nutrition or salary or security; outcomes are measures of what Rawls (1971: 62) and Rae (1975: 633) call "primary goods." The utility represents how satisfied the player is with the outcomes received by himself and by the other player.

When the outcome and utility differ from each other but are related in the above way, I call a strategy most "appealing" if it is the strategy that yields the highest utility for the player. A player will choose what is most appealing. Thus, in iterated prisoner's dilemma, the decision-maker selects whether to cooperate or defect in the first round based on which of these two is most appealing. Appeal is based on how the player chooses to balance his outcome against the outcome of the other player. Before future rounds in an iterated prisoner's dilemma, this balancing can be adjusted based on the other player's behavior in earlier rounds. In each round, a new choice to cooperate or defect is based on the new assessment of what is most appealing for that round. Any cooperation that emerges in a round is based on these myopic assessments of what is most appealing for the round, and not any look ahead to what will be best by the end of the game.

Regard for the other player can vary from positive (altruistic) to negative (sadistic). This variance can be measured by the variable α, measuring altruism. When α is zero, the player is indifferent to the fate of the adversary. The common analysis of prisoner's dilemma is with α set to zero. In this chapter I allow α to vary. A negative α would be associated with a desire to harm the other player, either for its own sake (pure sadism), or for consideration of relative gains. These cases of negative α will be ignored for the present because instead of leading to a cooperative solution, which is the subject of this investigation, they will simply reinforce the choice to defect.

If the players are so altruistic that they care about the other as much as themselves (what John Stuart Mill called utilitarianism and Rae 1975: 634 called aggregate maximization), the prisoner's dilemma disappears. When both players act as such pure utilitarians, and value a unit of outcome for the other the same as the same unit to themselves, they will each find the greatest satisfaction when both cooperate. To serve as the utilitarians' overall best outcome, joint cooperation (resulting in 2R units of goods) must produce more satisfaction than the other two possibilities, which are one side cooperating while the other defects (leading to T + S units), and joint defection (leading to 2P units). To show that joint cooperation will be

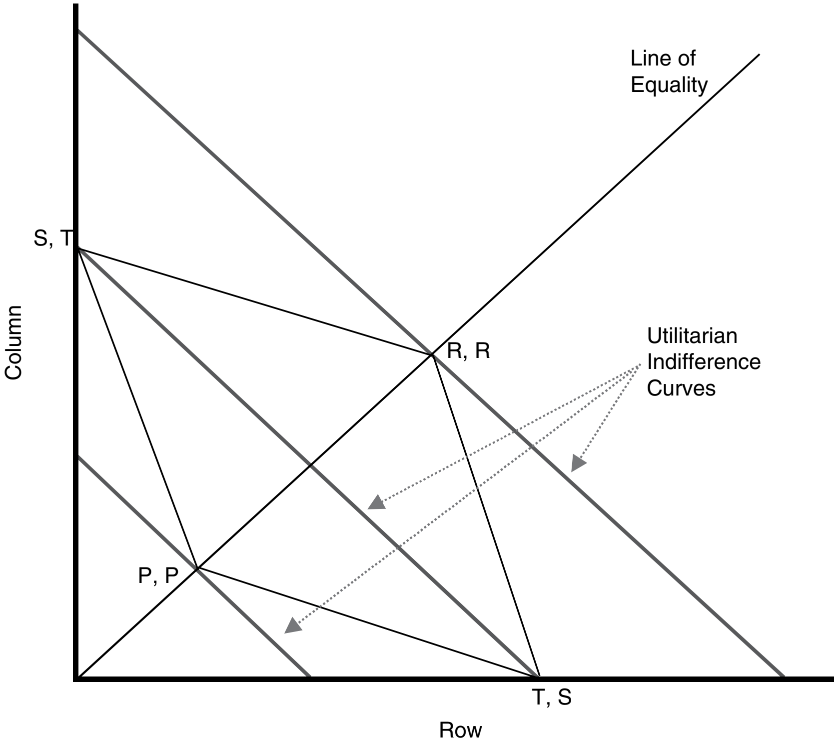


Figure 13.1 Prisoner's dilemma with outcomes for row and column players

the most utilitarian, I turn to the two statements of inequalities that define prisoner's dilemma (see Figure 13.1). The first of these is $t > r > p > s$. In this we see that $r > p$, and it follows that $2R > 2P$. From the other inequality defining prisoner's dilemma, we have $r > (t + s)/2$, and it follows that $2R > T + S$. Hence, joint cooperation, leading to 2R, provides more utility than either alternative.

But will the players, playing independently as utilitarians, both cooperate so that the utilitarian goal can be achieved? Not necessarily. To ensure that they will, we have to add a third stipulation that we restrict ourselves to situations in which $p < (t + s)/2$. This is analogous to the stipulation that $r > (s + t)/2$, which restriction is designed to ensure that joint cooperation gets better long-term results than just taking turns defecting on each other (that is, playing CD and then DC). Likewise, the purpose of making $p < (t + s)/2$ is to ensure that taking turns defecting is not worse than joint defection. If that stipulation is added, then each utilitarian player will prefer to cooperate whether the other player cooperates or defects; this is because, if the other were to cooperate, $2r$ will be greater than $t + s$, and if the other defects, $t + s$ in turn will be greater than $2p$. And hence utilitarian players playing against each other will each have an incentive to cooperate.

With such players playing this game, joint cooperation is the solution of the game, but without the stipulation that $p < (t + s)/2$, the solution is not clear. Without that stipulation, p could be greater or less than $(t + s)/2$. In face of such an unknown, the utilitarian player would prefer cooperation to defection if the opponent cooperated, but would not know whether to prefer cooperation or defection if the opponent defected. If p were greater than $(t + s)/2$, and the opponent defected, the player would prefer defection. So, with a preference for C if the opponent plays C, but D if the opponent plays D, we would have a situation in which a player did not have a dominant strategy. Players would simply prefer to do whatever the opponent did, but unfortunately will not know their opponent's move in time, since the two sides move simultaneously.

What is the effect of the restriction on the range of p? In the aforementioned case of a pure utilitarian, where p is restricted to $p < (t + s)/2$, the effect of the restriction depends on the value of r. R is restrained by the definition of prisoner's dilemma to $r > (t + s)/2$, which means that r must lie above the midpoint (m) of the line segment from s to t. Since by the other part of the definition of prisoner's dilemma p must be less than r, the potential range of p depends on the value of r. If r is asymptotically close to the midpoint of the $t - s$ line segment, then p (needing to be less than r) will already have been restricted to $p \leq m$. At this extreme, all we do by restricting p to $p < (t + s)/2$ is to eliminate the one possible value $p = m$. On the other extreme, if r approaches t, then p would be able to move most of the way toward t, and the restriction $p < (t + s)/2$ eliminates half of the potential range of p. Such eliminated cases are less interesting politically and socially, however, for as p approaches r, the loss of community utility due to prisoner's dilemma problems declines proportionally.

We have seen that pure utilitarianism has as its goal joint cooperation in prisoner's dilemma, and that utilitarianism on the part of the two players leads to joint cooperation (the dominant strategy) in prisoner's dilemma if and only if $p < (t + s)/2$. The next, perhaps more interesting question is at what point, on the move toward that utilitarian ethical ideal of treating all people including oneself as equally important, the prisoner's dilemma in utilities disappears. To determine that, let us define a term, Usum (for sum of utility), which represents the overall appeal of any outcome of the game. Usum is a function of one's own self-regarding condition and the other player's self-regarding condition. These self-regarding conditions, measured as outcomes, and set for ease of presentation to vary from zero to 100, are designated as V_i, for one's own outcome, and V_j, for the other player's outcome. The letter V stands for value, and is used to designate each player's amount of a valued good. The variable α, a measure of degree of altruism, varies from 0 to 1, and measures the impact of the other player's outcome on one's own overall satisfaction with an outcome pair. The remainder of one's satisfaction with an outcome is the impact $(1-\alpha)$ of one's own (self-regarding) outcome.

$$\begin{aligned}\text{Usum} = (1-\alpha)V_i + \alpha V_{j,,}\ & V \text{ go 1 to 100}\\ & \alpha \text{ go 0 to 1}\end{aligned}$$

How big does α need to be to eliminate the dilemma and induce cooperation in the game? To determine this, I examine a subset of prisoner's dilemma games in which $t - r = p - s$. These two differences are the incentives to defect (given $\alpha = 0$) when the other player has cooperated (in which case the incentive to defect is the utility difference $t - r$) or the other player has defected (in which case the incentive to defect is $p - s$). Setting these two numbers equal determines that the incentive to defect (which must be positive for a game to be a prisoner's dilemma) will be the same whichever move the opponent makes.

When α is zero, and there is no regard for the other player, the standard prisoner's dilemma game occurs, and players follow the selfish incentive to defect. When α is 1/2, and so a player is equally concerned with their own welfare and that of the other player, this player will be a pure utilitarian and (subject to the aforementioned restrictions on p, that is, $p < (t + s)/2$), there will be no defection. In my opening example (Table 13.4), the net utility from defection rather than cooperation when $\alpha = 0$ is either:

$$V_i d_i | c_j - V_i c_i | c_j = 20 - 15 = 5$$

or

$$V_i d_i | d_j - V_i c_i | d_j = 5 - 0 = 5,$$

where $V_i d_i | c_j = \text{USUM}d_i | c_j$ is the satisfaction i gains from defection if j cooperates. More generally, since the game is symmetrical, $\text{USUM}d|c$ is the satisfaction from defecting if the other side cooperates.

Since this difference is positive (in fact, +5 in my example) in both cases, it is more appealing to defect that to cooperate.

But that is with completely self-centered $\alpha = 0$. With purely utilitarian $\alpha = 1/2$:

$$\mathrm{USUMd_i|c_j - USUMc_i|c_j} = (20\times0.5 + 0 \times .5) - 15 = 10 - 15 = -5$$

and

$$\mathrm{USUMd_i|d_j - USUMc_i|d_j} = 5 - (0 \times 0.5 + 20\ \mathrm{X}\ .5) = 5 - 10 = -5$$

Since this difference (−5) is negative, it is more appealing to cooperate than defect. Somewhere between $\alpha = 0$ and $\alpha = 0.5$, there will be a critical value of α where α is exactly the size at which one is indifferent between cooperating and defecting. Above that critical number, α is high enough that one is altruistic enough to cooperate, and below it one is selfish enough to defect. We have already determined with the two results immediately above that at this critical value of altruism which makes one indifferent about defection, one will care some about the other player (because $\alpha>0$), but not care as much about the other player as about oneself (because $\alpha < 1/2$).

Let us define the critical value of α, α_c, as the value of α at which, as α rises from zero toward one-half, one switches from being a defector to a cooperator. In the above example of Table 13.4, the dilemma disappears and a player no longer defects when $\alpha \leq 0.25$. At $\alpha > 0.25$ one cooperates, and at $\alpha = 0.25$ one is indifferent between defection and cooperation.

This is because at $\alpha = 0.25$:

$$\mathrm{USUMc|c} = 15,\ \mathrm{USUMd|c} = 0.75 \times 20 + 0.25\ \mathrm{x}\ 0 = 15;$$
$$\text{therefore, } \mathrm{USUMc|c{=}USUMd|c}.$$

$$\mathrm{USUMd|d} = 5,\ \mathrm{USUMc|d} = 0.75 \times 0 + 0.25 \times 0 = 5;$$
$$\text{therefore, } \mathrm{USUMd|d{=}USUMc|d}.$$

These results show that, for the outcomes in Table 13.4, at $\alpha = 0.25$ a player is indifferent between cooperating or defecting whether their opponent cooperates or defects; hence, $\alpha_c = 0.25$.

In the more general case, the outcomes are ranked as in all prisoner's dilemma, $s < p < r < t$. This set of inequalities divides the overall gap, $t - s$, between the best outcome and the worst, into three parts, creating three differences:

1. the incentive to defect if the other side cooperates, $t - r$;
2. the lost welfare to a player from the dilemma, which is difference between what each player gets from joint defection and what each player gets from joint cooperation, $r - p$; and
3. the incentive to defect if the other side defects, $p - s$.

To see how α_c may be derived, consider its value in each of the two mutually exclusive and exhaustive adversarial moves, C or D. If column should cooperate, row may obtain r for each player by cooperating or t for row and s for column by defecting. The point of indifference, α_c, between one's own cooperation and defection is when:

$$\begin{aligned} r &= (1 - \alpha)t + \alpha s \\ &= t - \alpha t + \alpha s \\ t - r &= \alpha(t - s) \\ \alpha &= (t - r)/(t - s) \end{aligned}$$

This particular value of α I call $\alpha_{c|c}$, to designate the critical value of alpha if the other side has cooperated. $\alpha_{c|c}$ is a ratio, with its numerator the incentive to defect if the other side has cooperated, and the denominator the overall distance from best to worst outcome.

If the opponent should defect, the point of indifference, α_c, between one's own cooperation and defection is when:

$$\begin{aligned} p &= \alpha t + (1 - \alpha)s \\ &= s - \alpha s + \alpha t \\ p - s &= \alpha(t - s) \\ \alpha &= (p - s)/(t - s) \end{aligned}$$

This particular value of α I call $\alpha_{c|d}$, to designate the critical value of alpha if the other side has defected. $\alpha_{c|d}$ is a ratio, with its numerator the incentive to defect if the other side has defected, and the denominator the overall distance from best to worst outcome. Setting s to zero to simplify this expression, we have:

$$\alpha = (p - s)/(t - s) \text{ (from } \alpha_{c|d}\text{, as defined above)}$$
$$\alpha = p/t \text{ (from setting } s = 0)$$

Figure 13.2 shows how this $\alpha_{c|d}$ varies with p when t is fixed, and how this establishes a set critical p (p_c) values as a function of the alphas, namely, $p_c = \alpha(t + s)$. In Figure 13.2, the notation $V_i(D_i)|(D_j)$ means the outcome to i of defecting if j has defected.

To recapitulate, in the last couple of pages we have worked toward deriving α_c by establishing its value in each of the two mutually exclusive and exhaustive adversarial moves, C or D. α_c, which we seek, is somewhere in the closed interval between $\alpha_{c|c}$ and $\alpha_{c|d}$. α_c is actually a ratio. Its denominator is $t - s$, the overall range of outcomes (from 20 to zero in my example in Table 13.4). This number is always positive in prisoner's dilemma so the fraction α_c is always defined. Its numerator is the expression:

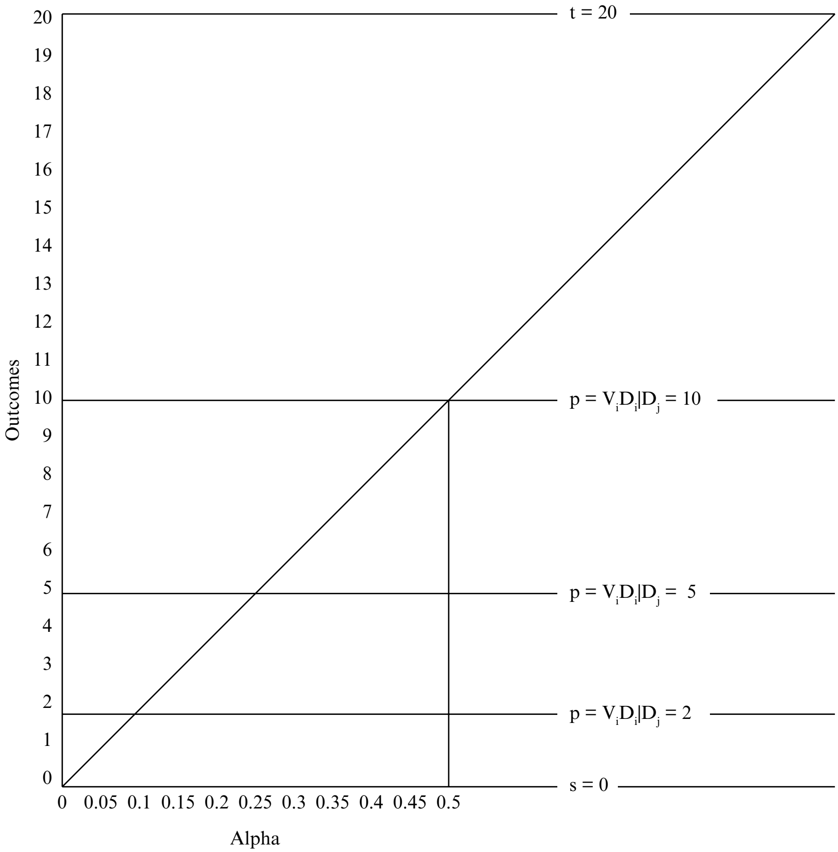


Figure 13.2 Critical values of alpha (α) for p = 2, 5, and 10, with s = 0 and t = 20

$$[q\,(t - r) + (1 - q)\,(p - s)]/2,$$

This numerator is the weighted average of the two incentives to defect, where q is the probability that the other player will cooperate and $1 - q$ is the probability that the other player will defect. In human society, a guess about the value of q might be inferred from knowing the life story of the individuals you encounter. Since it is usually hard to know the probability q, to move ahead it would be helpful if $t - r = p - s$, so that the value of q would not alter the solution of the game. To succeed in calculating a solution, it is necessary to either set q equal to some value like 0.5, or else set $t - r$ equal to $p - s$, so that the fluctuations in the value of q will not alter the value of the numerator, $[q\,(t - r) + (1 - q)(p - s)]$. As mentioned earlier, I will set $t - r = p - s$, to simplify the analysis by removing the need to determine the probability q.

The simpler form of the ratio is now:

$$\alpha_c = [(t - r) + (p - s)/2]/t - s = t - r\,/\,t - s.$$

Recall that by definition the distance $t - s$, which is the entire range of utility variation in prisoner's dilemma, is made up of $t - r$, $r - p$, and $p - s$, all three positive numbers. Let us hold the incentive to defect, $t - r$, constant, and vary the lost welfare from joint defection versus joint cooperation $(r - p)$. With $r - p$ able to vary from just greater than zero to infinity, the possible range of α_c is a function of this domain of $r - p$. The upper limit of α_c, attained as $r - p$ approaches zero (that is, as r approaches p), is:

$$\frac{\{(t - r) + (p - s)\}/2}{(t - r) + (p - s)} = 1/2.$$

This means that as the lost welfare approaches zero, so that the damage done by joint defection becomes almost nil, a player, let's say the row player, must approach being a pure utilitarian (valuing row and its opponent, column, equally) if it is to lose its incentive to defect.

On the other extreme, as that lost welfare from joint defection rather than joint cooperation approaches infinity, let us see what happens to the expression for α_c:

$$\frac{\{(t - r) + (p - s)\}/2}{(t - r) + (r - p) + (p - s)}.$$

With the infinite growth of the $r - p$ portion of the denominator, the denominator itself approaches infinity, and the fraction as a whole therefore approaches zero. This means that as the lost welfare dwarfs the incentive to defect (that is, as the lost welfare approaches infinity), a player's altruism can approach zero and, as long as it remains at least slightly positive, be enough in the limit to remove the player's incentive to defect. We thus see that the term α_c, at which one is indifferent between cooperation and defection, varies over the range $0 < \alpha_c < 1/2$. In ethics, this is the variation between the slightest positive response to the welfare of the other person and a positive response that stops just short of treating other person's welfare as equal to one's own. The mid-point in the range of α_c, $\alpha_c = 1/4$ is reached in examples like that with which I started in Table 13.4, where the lost welfare gap is twice the incentive to defect.

Consider one more simple example, where the gaps between outcomes are all equal, so that the lost welfare from joint defection rather than joint cooperation is exactly equal to the incentives to defect. This example has the four pay-off pairs 10, 10 (for joint cooperation), 5, 5 (for joint defection), and 15, 0 or 0, 15 (for the plays D,C, or C,D); these can be reduced in scale to the pairs 3, 3; 2, 2; 4, 0; and 0, 4 (see Table 13.5). In that case, the value of α_c is 1/3, so a player has to be a bit more altruistic to cooperate than in the Table 13.4 example with which we began. In the news, in histories and biographies, there are cases in which persons of similar age and future prospects to those they are saving, and with no belief in the afterlife and its possible rewards for valor, give their lives to save another; from this we have at least the possibility that in some instances the altruism coefficient α exceeds one-half. So there seems to be some prima facie evidence that for some people, sometimes, the coefficient α reaches a value more than big enough to overcome the prisoner's dilemma welfare problem. This gives enough confidence in the possible or at least occasional real-world relevance to proceed to a simulation of what might happen in iterated prisoner's dilemma if a mix of altruists and non-altruists played each other in a tournament.

In general, these examples and the formula indicate that as the lost welfare from joint defection rather than joint cooperation becomes relatively large – that is, as the prisoner's dilemma becomes more important to the group interest – the alpha grows small. In extreme cases, where the welfare loss is most severe – and the cases therefore become more interesting to social science and philosophy – individuals may cooperate even though they are just barely a little altruistic.

I had shown that p must be less than $(t + s)/2$ for two pure utilitarians to cooperate. The more general formula is that p must be less than $(t + s)\alpha$ and r must be greater than $(t + s)(1 - \alpha)$ for a player to have a dominant strategy of cooperation. As α decreases, then, r must grow and p must shrink (if t and s are constant) for cooperation to occur. That growth of r and reduction of p represents a larger loss in general welfare from joint

Table 13.5 Prisoner's dilemma with equal gaps between pay-offs

		Column	
		Cooperation	Defection
		r, r	s, t
R	Cooperation	(2, 2)	(0, 3)
o		t, s	p, p
w	Defection	(3, 0)	(1, 1)

cooperation (CC) to joint defection (DD). It will take the prospect of such a relatively large loss in general welfare to induce cooperation if the players are only a little altruistic. But even players who have just a little regard for each other will cooperate if the loss of general welfare from not doing so is relatively great.

So I have established times when, if row and column both have altruism levels greater than the critical value α_c, both will cooperate, and each will achieve self-centered outcomes (r) greater than if both had been egoistical (and gotten p). In the example from Table 13.4, the pay-off, r, will be 15, rather than the five if both had been more self-centered. The community as a whole will gain in welfare by double that amount (that is, a community gain of $2x(r - p)$). Again using the example of Table 13.4, the community will get 30 points of primary goods, as opposed to the ten it would have obtained if its members had been more self-centered. And both row and column will achieve total satisfaction (combining the egoistical plus the altruistic components) greater than if they had both defected. In the example from Table 13.4, and assuming say $\alpha = 1/2$, this will be $15 \times 0.5 + 15 \times 0.5 = 15$ rather than $5 \times 0.5 + 5 \times 0.5 = 5$. For these reasons, there are situations in which there are potential benefits for a player who has enough altruism to surpass the critical point and begin cooperation, and for the community in which such players dominate.

However, such a player will not fare as well against a player who defects. In that case, the outcome will be a welfare of s for the row player who cooperates and t for the column player who defects. For instance, in Table 13.4, the egoistical outcome, s, to the cooperating player will be zero. This is important for a number of reasons, notably because even an altruistic player, who gets psychological satisfaction from other players doing well, presumably gets sustenance only from doing well himself. In evolutionary terms, a player getting paid zero may starve or may not produce young who live to reproduce, and hence creatures like him or her may become extinct. In social terms, such a player may lack enough resources to have a long-term beneficial impact on society. Second, the overall benefit to society if row cooperates only to see that the column player defects is suboptimal. And since we are assuming row is a utilitarian this would distress row, if row noticed. When both cooperate, a total of 30 units of primary goods is produced or otherwise attained in my example, whereas if column defects, the total supply of goods drops to 20. One would expect such a large (33 percent) loss usually to be noticed and perhaps even be painfully experienced. Third, the psychological benefit (that is, utility) to row is not as great if column defects. This total satisfaction, again assuming $\alpha = 1/2$, will be $0.5 \times 0 + 0.5 \times 20 = 10$, only twice as high as if both had defected, and lower than the 15 if both had cooperated. Fourth, elements of inequality, unfairness, and exploitation have been introduced. From an initial point in which neither side had gained more than the other, we now have a situation in which column has gained more than row (inequality), has done so even though they are exactly alike except only in the one respect that the one who gained more defected (unfairness), and has gotten ahead by defection and only by defection (exploitation). Related to this, the column player by defecting has indicated that its own altruism coefficient is low, so for the first time row has some information about what specific type of player it is facing.

I have posited that neither the decision to cooperate in a one-shot game nor the initial decision to cooperate in the first round of an iterated game was affected by anticipation of these negative conditions and attendant reasons for desiring to get even. For all these reasons (lack of sustenance, to feeling of being exploited), however, before the next move in an iterated game, row may be motivated to try to get column to cooperate, and perhaps to retaliate against column by defecting next time.

We see from Axelrod (1984) that a strategy of cooperating in the first round of iterated prisoner's dilemma can be very effective, as long as the player is flexible enough to retaliate (if attacked) in later rounds, as in the niceness but provocability of tit-for-tat. I have posited altruism as an alternative to niceness as a basis for first-round cooperation. Is there an alternative to tit-for-tat's provocability trigger?

One possibility is to reset the altruism coefficient, α, based on the move of the other player in the first round. This turns the previous independent variable, α, into an intervening variable. Let us assume that altruism can be turned off for the next round in retaliation for defection against the altruistic player. With $\alpha = 0$ a low enough value to trigger defection, let us set α to zero in the subsequent round after an opponent has defected. If the opponent cooperates in that subsequent round, let us reset α from zero back to its original value, thereby restoring cooperation. This simple on–off switch for α has the effect of turning a first-round cooperator into a tit-for-tat player. In a tournament in which this is all that would change α, all players would be either tit-for-tat or all-D. All D (playing with the payoffs in Table 13.4) would score five sustenance points per round against all D. Tit-for-tat would score 15 sustenance points per round against tit-for-tat. Tit-for-tat against all D would score zero for tit-for-tat, 20 for all D in the first round, and in subsequent rounds both would score five sustenance points each. How many subsequent rounds might there be? Axelrod used 200 rounds and then an approximation of that in his invitational tournaments. He had to expand to 1000 rounds in his ecological tournament, a longer length necessary because of pacifist strategies not relevant in my chapter (Axelrod 1984: 30). A 200-round tournament is the length I will

Table 13.6 Two tit-for-tat players against N all-D players

	A tit-for-tat player's score:	An all-D player's score:	Advantage of playing tit-for-tat:
N of all-D players = 1:	3000 + 995 = 3995	1015 x 2 = 2030	1965
N of all-D players = 2:	3000 + (995 x 2) = 4990	1000 + 2030 = 3030	1960
N of all-D players = 3:	3000 + (995 x 3) = 5985	2000 + 2030 = 4030	1955
N of all-D players = 372:	. . .	. . .	5
N of all-D players = 373:	. . .	. . .	0
N of all-D players = 374:	. . .	. . .	−5

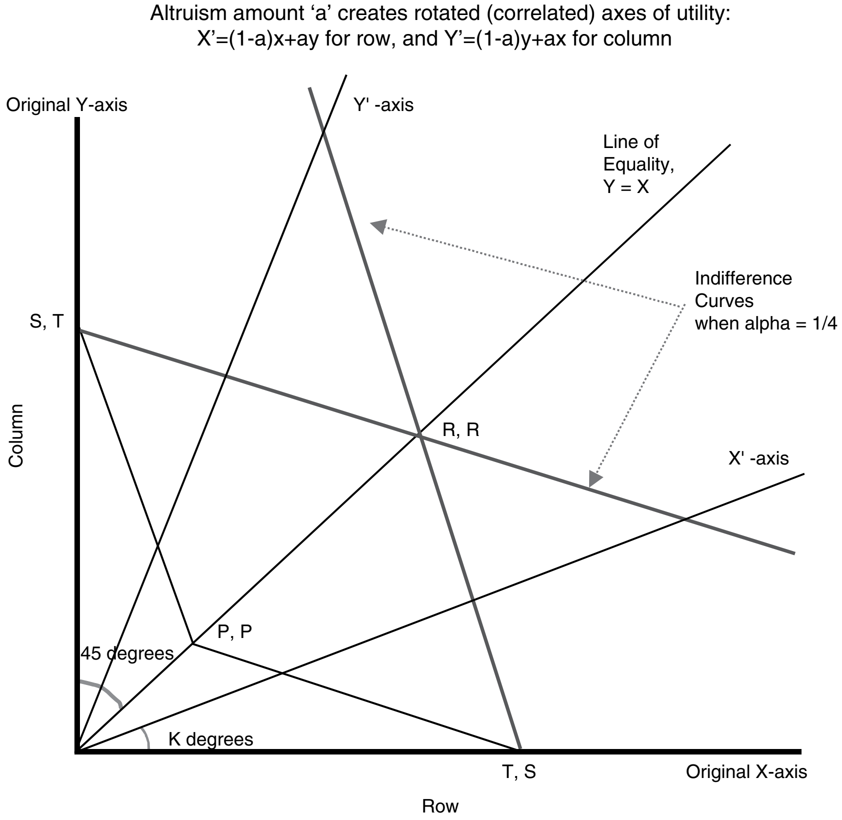
use herein. If there were two tit-for-tat and two all-D players playing a 200-round tournament, tit-for-tat players would get 3000 points playing the 200 rounds against each other. Tit-for-tat against all D, which it would have to play twice, would get 995 points each time. Overall, tit-for-tat teams would get 4990 points. All D players playing against tit-for-tat would get 1015 points. All D players against each other would get 1000 points. Hence, all D, which has to play against tit-for-tat twice, would get 3030 points. Tit-for-tat would win the tournament, with about a 5:3 advantage in points.

The victory of tit-for-tat is not just the result of this situation in which two tit-for-tat players and two all-D players enter the competition. In the example given, as long as two tit-for-tat players enter, and score 3000 points playing each other, they have built up an enormous lead. It is true that when all D plays tit-for-tat, all D comes out 20 points ahead, but all D has only 1015 points for the effort, compared to 995 for tit-for-tat. As seen in Table 13.6, all-D would have to overwhelm tit-for-tat with a 374:2 personnel advantage, which is a ratio of 187:1, to begin to outscore tit-for-tat.

Many physical and psychological traits, such as height and aptitude scores, are distributed normally. Imagine that the altruism factor was distributed normally in the society, with mean zero and standard deviation s. This would yield a bell-shaped curve with average people self-centered but a distribution of partial sadists (who enjoy to a degree the losses of others, and for whom the altruism factor, α, is negative) and partial altruists (who enjoy to a degree the gains of others, and for whom α is positive). If s, the standard deviation of altruism, is some number, say 0.1, then a table of the normal distribution can be used to find what percentage of people have a super-critical altruism level. Playing the game in Table 13.4, this super-critical altruism is a level that must exceed $\alpha_c = 0.25$. With a standard deviation of 0.1, that α_c is 2.5 z-scores out from the mean. A table of cumulative normal probabilities shows that an altruism score greater than 0.25 is in the 99.38 percentile (or higher). Sixty-two people out of 10 000, or one person in 161, would have such a high positive z-score. Thus, people sufficiently altruistic to play cooperatively in the first round of prisoner's dilemma would be slightly more common than the number needed (one person in 186, so that there could be two tit-for-tat players for 372 all-D players) to maintain a higher score in the type of prisoner's dilemma tournament discussed by Axelrod (1984). This will be enough for the tit-for-tat players, that is, those with $\alpha > \alpha_c$, to outscore the all-D players (as illustrated by the calculations in Figure 13.3). In such a scenario, the tit-for-tat players would have an evolutionary advantage in an Axelrod-like tournament with propagation of offspring, and tit-for-tat would be able to expand its share of the population. This indicates that it would be possible for conditions to exist in which a moderate degree of inherited altruism could at least establish an equilibrium value, and even expand its position.

This iterated prisoner's dilemma tournament shows how a result inspired by and analogous to Axelrod (1984) can be motivated by an altruism coefficient which is a mathematical term, instead of by the intuitive strategy of professors submitting computer programs. As such, the later stages of this chapter show that the evolution of cooperation concepts discovered by Axelrod are a syndrome of behavior that can result from more than just which tournament submissions happened to come in the mail. As Axelrod (1984), by running a variety of tournaments, showed the robustness of his results, this chapter shows that his evolution of cooperation results can emerge from a still-broader set of underlying considerations, and are mathematically driven under certain assumptions.

These results establish that individuals do not have to remain isolated in a society under prisoner's dilemma conditions. Instead, at least those predisposed to enjoying joint rewards can cooperate with each other. This possibility could lead to the formation of interest groups; these could be factions, gangs, and cartels, or overall cooperative public interest efforts for the good of the entire community. Which of these will occur, as a function of the altruism factor, α, depends on whether super-critical α values are induced by concern for the community as a whole, in which case cooperative efforts would be directed toward the greater group's greater good, or whether the concern for a smaller group is more compelling. These matters are questions of identity politics, and need to be treated in another paper. Group size questions such as analyzed by Hume (1888)



Altruism amount ‘a’ creates rotated (correlated) axes of utility:
X’=(1-a)x+ay for row, and Y’=(1-a)y+ax for column

Figure 13.3 *Rotated axes with new indifference curves and foreshortened utility scale*

and Olson (1971) would also be relevant to such a study. While methods like the ones utilized herein may be useful in such an analysis, the two-person game methods I have employed would have to be reconceptualized as games of an individual playing another player that is not an individual but a kin group, social class, nation, or other entity. This sort of thing is routinely done in arms-race analyses of nation versus nation, in which neither player is an individual person, so the expansion to larger entities is not without precedent, but it is beyond the scope of this chapter. Perhaps extensions of these remarks will someday show that Socrates was right in seeing that affection does extend beyond a person’s own body to others – especially those closely related, but sometimes, heroically, to broader communities.

THE GEOMETRY OF PRISONERS' DILEMMA, ESPECIALLY CONCERNING LINEAR HOMOGENEOUS TRANSFORMATIONS

The four pairs of pay-offs (for example, one pair is row's pay-off of T and column's pay-off of S if row defects and column does not) in prisoner's dilemma can be plotted as lying in a plane defined by two orthogonal axes, an x axis measuring the row player's outcome and a y axis measuring the column player's outcome (Figure 13.1). Each pair of pay-offs, then, defines a unique point in the plane. The four possible ordered pairs of pay-offs form a quadrilateral in that plane. In the symmetric prisoner's dilemma, two of the corners (r, r and p, p) of the quadrilateral will lie on the line y = x. By the definition of prisoner's dilemma, the quadrilateral is shorter along the axis y = x than along its other axis, namely, the axis connecting the other two corners (t, s and s, t).

The sorts of prisoner's dilemma games for which I derived the critical alpha are games in which the distances along the sides of the quadrilateral are equal in length. This means the quadrilateral is a rhombus. The rhombus has four angles, one at each vertex. Consider the vertices at the corners with uneven pay-offs (t, s and s, t). In Figure 13.1 these two points lie on the x axis and the y axis, respectively. The angles at these two corners will be acute angles, while the angles at the other two corners will be oblique angles. Let us call the angles at the two acute corners (which will be equal to each other since it is a rhombus) the angle theta-rhombus. As long as theta-rhombus is less than 90 degrees, the pattern of pay-offs will describe a prisoner's dilemma game. But if the points on the four corners are moved, so that theta-rhombus is no longer less than 90 degrees, the pay-offs will no longer describe a prisoner's dilemma game.

In this chapter, the calculation of altruistic utilities has the effect of taking a rhombus in outcomes and shifting the points so that it became a different rhombus in utilities. Under certain conditions, I showed that this could transfer a game that had been prisoner's dilemma in outcomes into one that was not prisoner's dilemma in utilities. This had the effect of making it possible to move away from the non-Pareto outcome p, p to the Pareto outcome r, r.

Geometrically, the reason for this is that the outcome t, s, which would have yielded a utility pairing of 20, 0 and 0, 20 for self-centered players, yields a utility pairing of 15, 5 and 5, 15 for players who care about each other exactly one-third as much as they care about themselves. Notice that the points 20, 0 and 0, 20 are further apart from each other than the points 15, 5 and 5, 15 are apart from each other. What I have called altruism in this chapter has the effect of moving the utilities for such uneven pairs of pay-offs closer and closer together as alpha increases. Eventually, the utilities will converge on the line y = x. For instance, in the classic prisoner's dilemma, in which the players' self-regarding outcomes equal their utilities, as in the start of the chapter, the pay-offs were 20, 0 or 0, 20. But if the players' alphas change from zero to 0.25, the 20, 0 outcome will convert to a utility of 15, 5, and the 0, 20 will convert to a utility of 5, 15. As this altruism increases, the angle theta will become less acute, and as alpha grows theta will eventually reach 90 degrees and then progress to an oblique angle, ending the prisoner's dilemma in utilities.

Sadism can now be brought in. To do so, let me slightly modify the example at the beginning of the chapter. Imagine that t and s remain as before, at 20 and 0, but r and p are moved an equal amount so that r is very large and p is very small. The p and r can be set so that r is greater than t and p is less than s, and the game will no longer be a prisoner's dilemma. For example, t remains 20, s remains 0, but r is 21 and p is –1. Now, the rhombus has an oblique angle at t, s (and at s, t), and the game is not prisoner's dilemma. The game can be made prisoner's dilemma in utilities. This will happen when the utilities create a rhombus whose angles at the uneven pairs of utilities are acute.

It is possible to imagine a negative alpha, or sadism towards the other player, that will transform the outcomes into utilities such that the game does become prisoner's dilemma in utilities. As alpha moves from zero and becomes increasingly negative, the utilities from s, t and t, s shift from 20, 0 and 0, 20. They shift away from each other, along a line orthogonal to y = x. As they do so, if r is not too big and p is not too small, the angle theta at their vertices becomes less oblique, eventually equals 90 degrees, and then becomes acute, creating a prisoner's dilemma in utilities.

All these displacements of the s, t and t, s vertices can be thought of as linear, homogeneous transformations (Einstein 1961: 30–34) about the line y = x:

$$X' = (1 - \alpha)\, x + \alpha y$$
$$Y' = (1 - \alpha) y + \alpha x$$

The x' and y' can be thought of as defining new axes. Altruism thus has an effect on classic, self-interested prisoner's dilemma that is analogous (because both effects are linear homogeneous transformations) to effect of velocity near the speed of light on Newtonian space and time in Einstein's special theory of relativity. In the coordinate system of the orthogonal prisoner's dilemma with self-interested individuals, utility for player X, U(x), was measured along one of the axes. For player X (row in my convention), that would be the X axis. The transformation to the new axis X' produces a new measure of utility, perpendicular to the indifference curve, and a foreshortened utility scale on that axis.

Consider Figure 13.1 with which I have been working, which is laid out according to the opening example, with rhombus corners 15, 15; 5, 5; 20, 0; and 0, 20. In that case, the line segment from point 15, 15 to point 20, 0 is part of the line $y = -3x + 60$. It is an indifference curve for player row, whose pay-off can be called pay-off i. The perpendicular to that curve that passes through the origin is the line $y = 1/3\ x$. Along that line, one can measure the utility row gains from any indifference line. The point of intersection of $y = -3x + 60$ and the line $y = 1/3\ x$ is the point 18, 6. Let us call the angle between the X axis and the line $y = 1/3\ x$ the angle kappa. It can be shown by trigonometry and congruent triangles that the scale (along $y = 1/3\ x$) according to which we measure units of utility to the row player is:

$$U' = \sqrt{i^2 + [i(\tan\kappa)]^2} + \sin\kappa[j - i(\tan\kappa)]$$

where i is the pay-off for row and j is the pay-off for column; in the symmetric games I have been discussing, $i = j = r$, the pay-off each receives for joint cooperation.

In the example, with $\kappa = 18.435\ ^{\circ}$:

$$U' = \sqrt{15^2 + [15(6.32/18.197366)]^2} + (6.32/20)[15 - 15(6.32/18.197366)]$$

$$U' = \sqrt{225 + 25} + .316[15 - 5]$$

$$U' = 15.8114 + 3.16 = 18.9714$$

Dividing 18.9714 by 20, we obtain a ratio of 0.9487:1. This ratio is the scale ratio of the altruistic utility, measured along $y = 1/3\ x$, to the self-centered utility, measured along the original X axis, when the altruism measure $\alpha = 1/3$. This scale change is the effect of the linear, homogeneous transformation of the axes from orthogonal to an amount of rotation of each axis toward the other corresponding to angle kappa.

CONCLUSIONS

I had noticed, in Edward O. Wilson's (1999) *Consilience*, the unfinished building project of treating political science (so diverse, in my myopic view, compared to anthropology and economics and the other social sciences) and the related problem of integrating macro-political behavior (war, genocide) into a biologically based explanatory and predictive framework. I am of course a weak reed on which to raise this proposed edifice. Nonetheless, it seems that altruism has a similar (linear homogeneous transformation) distorting effect on the normally "selfish individual" view of the prisoner's dilemma that acceleration to near the speed of light has on Newtonian space and time. Just as Einstein's special relativity makes Newtonian mechanics a special case, so altruism (or sadism) makes self-centered calculations by individual humans a special case. Work through the calculations of this "special relativity of prisoner's dilemma" and one sees that an individual organism can gain sufficient material goods for survival better in many cases by being altruistic. Insofar as the reasoning in this chapter is sound, we have a basis for explaining cooperation that is not just self-centered but may be altruistic. The span from extreme altruism to sadism is a continuum, with self-centered behavior as one point along that line, and this may affect our ability to cooperate politically. But a dilemma is that such deep explanation puts us far from the types of models we examined at the start of the chapter, that focused on prediction. Prediction and explanation are often thought of as two sides of the same coin, yet I am emphasizing the distinction between prediction (which I undertake regarding war early in the chapter) and explanation (which I attempt for human cooperation and conflict later in the chapter). These, assumed to be two sides of the same coin, are so hard to bring together in one view!

NOTE

1. Editorial remarks by Paul Williamson: This approach constitutes a very important start which is perfectly sound in itself for now, and could lead to an important direction: Past experience can be discounted by a negative exponential function, $\exp(-\lambda t)$, with λ greater than zero. Lamda constant is determined empirically to be the value that optimizes the predictive power of future wars, for each past decade based on a weighting of the time since that previous reference decade of war, multiplied by the number of years that have elapsed. This forms an optimal compromise between the two versions explored by Wayman, in which only the last decade is used, or in which all decades count equally. Wayman's use of all prior decades counting equally is implicitly a lamda of zero. A very large value of lamba is an approximation of Wayman's just using the last decade, because that large lamba forces the weights on earlier decades to be very small (though only approaching, not reaching, zero). His finding in the chapter, that earlier decades matter, suggests that an intermediate value of lamba, to be determined by future research, would provide the best fit in predicting the "future" of war.

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14. System change and Richardson processes: application of social field theory

Paul R. Williamson

INTRODUCTION

The key idea of this discussion is an analog, drawn from physics: that societal parties may be regarded as located in an abstract geometric space within which they move about over time and influence each other as a function of their movements. (In this chapter I shall use the term "party" as synonymous with terms such as "actor," "agent," and "societal unit"; all of which I take to be inclusive of, but more general than, expressions such as "nation," "state," and "nation-state.") This idea – location and movement in a space – was discussed by Wright (1961) and further pursued by Rummel (1965). What I will present here began with their work but has diverged from it.

The result is a model into which can be fitted other ideas and work, including the items named in the chapter title. One aspect, the "Richardson process," to be identified below and which is the focus of this chapter, is presented in an informal and, it is hoped, intuitive way. The other elements named in the chapter title are summarized in terms of their relationship to the R-process. (For brevity I will write "R-process" to refer to a Richardson process. Additional discussion is found in the revision of a conference paper and in a mathematical discussion and several figures; Williamson 2008b [2005].)

As it stands, this model is not machine-computable; that is, it does not constitute an operative prediction device. However, that is the ultimate intent; and the work done so far does point in the direction of such a device, by providing many of the relevant ideas in a mathematically exact form.

First, I turn to the key idea to which allusion was made, above: the societal space in question may be regarded as a virtual "space-time" that emulates the physical space-time of special relativity theory, in the manner discussed below.

SIGNALS

To develop the societal space-time concept, I begin by considering time delay in the exchange of physical signals between parties or, equivalently, the finite speed of signal transmission. That is, the finite speed of a signal corresponds to the presence of delay between its emission and its receipt (Williamson 2008b [2005]: 13, 21–22, 25–26, 50–53). In customary usage, one thinks of such "reception" as having occurred when the signal arrives in the physical neighborhood of the recipient. In that sense, communication in current times can be extremely rapid, due to the availability of electronic and computer technology; the time delay in such exchanges may be negligible, indeed often humanly imperceptible, as in local voice telephone communication.

However, the time delay and speed of signal transmission contemplated in this model is not the customary sense just mentioned. In the societal space-time context, what is proposed instead, (first) of the concept of "reception" is that it be regarded to have occurred when the recipient has responded and that the delay should include this response time. For instance, as a human receiver hears something said in conversation by another, the sound enters the receiver's ear; then there is a delay which may be brief – say a few seconds – or not so brief, after which the receiver may respond. The suggested conception of signal delay is over this entire process, however long it takes. Particularly when there is an organizational character to the messages to be processed, this concept of delay may be relatively long and the corresponding signal transmission speed, relatively slow. As stated elsewhere, one may suppose that, realistically, there is some degree of "psychological," "bureaucratic," or other decision-making organizational, or computational process-time constraint, or some combination of them. Every known (or conceived) biological, chemical, or nervous system, and every artificial computing system, would seem to be characterized by greatly varying but non-zero values of such time constraints because recognition or response, or computation, by a physically real decision-making system necessarily entails transmission of signals within it (Williamson 2008b [2005]: 13).

It is further proposed (second) to generalize the idea of emitting a message so that it includes the sender exhibiting a condition, at a particular moment, to which the receiver later responds. Combining the two proposals just made and given plausible corresponding process time constraints

– particularly some kind of organizational change or response – the resulting delay might be very long; maybe years.

Candidates for signal transmission then include receiver responses to sender conditions such as level of armaments, technology, or economic, social, and political development. I will come to the first of these when considering the arms-race model of Richardson (1960); later, though the Richardson mathematical framework will be retained and elaborated, the working assumption is that the second and third types of response may be more appropriate, as the empirical basis on which to define signal transmission. (For example, someone sets up mechanized production of cloth in England; later, someone else in the United States copies the invention. Another possible example is the kind of internal political evolution that is discussed by Bueno de Mesquita et al. 2003.) However, the issue of empirical content is omitted from this chapter; indeed, it remains to be determined. Note also that the distinction between senders and receivers is for the purpose of focusing on those two distinct roles; all parties, at all times, are imagined to be both sending signals and receiving signals to and from all others.

Concerning speed of signal transmission, there is another aspect; one which connects the above to concepts to be drawn from physics. Before turning to it, however, one further point needs to be made about signal delay as an empirical phenomenon. This concerns model falsification. As has just been argued, on physical grounds one can be quite sure of the reality of some amount of delay in processing and responding to signals; the empirically falsifiable novel content of the model must lie elsewhere. This content is that response delays – that is, the signal transmission times – must be consistent with motions, in societal space, that are established by independent considerations. Parties that are “nearby” versus “distant from” each other must have short versus long mutual signal transmission times, respectively; as parties move “away from” versus “toward” each other, their mutual transmission times must become longer versus shorter, respectively. Assuming the suggested interpretation, that signals correspond to technological or economic, social, and political changes, the relative spatial positions and motions in question must be consistent (to some approximation) with such changes. If they are not, then the model should fail, empirically. The model presented here would be empirically disconfirmable to the extent that it implements that consistency requirement; but how, operationally, to do so is an unsolved problem at this juncture. This current presentation is warranted, in part, because it motivates the further task of rendering this model empirically operational. Many of the relevant elements are already in place.

GEOMETRIC SPACE-TIME

I come now to a step necessary to what follows, which is to consider the geometric-physically inspired mathematical picture of space-time. This step is the other aspect of signal transmission to which allusion was made above.

In the theory of special relativity, the speed of light signals plays a key role. In the proposed societal space-time model, the analog of light signal transmission is the transmission of signals from one party to another, in the sense discussed in the previous section. In both the physical original and its proposed societal transcription, here, this speed is not only finite but also it is constant and possesses the same numeric value, denoted by c, relative to all observers regardless of their motions.

Upon one's first understanding it, the literal truth of what was just stated may be startling. Physically, that truth is that if you are passed by a stream of light signals, each moving at speed c and, resolving to pursue them, you take after them in your spaceship at, say, speed $(3/4) \cdot c$, when you then "look out of your window," the light signals will still be moving, relative to you, at speed c. Contrast this with being passed by an automobile moving at speed v and, upon chasing after it at, say, speed $(3/4) \cdot v$, looking out through the windscreen; you expect to see the object of pursuit moving, relative to yourself, at speed $(1/4) \cdot v$; and you will (for $v < \; < c$). But not for light signals. In other words, motions relative to light motions do not subtract (or add) in the way we conventionally think; the speed of light is the same relative to both ground-stationary and moving observers; one cannot alter that relative speed by any possible motion on the part of the observer. In brief, the Newtonian concept of velocity vectors does not apply. However, see equations (14.8) and the discussion following them, below.

To accommodate this physical fact about signal speed, a new definition of "distance" was introduced in physics. The physical fact itself has no directly measurable societal analog (corresponding to the Michelson–Morley experiment), so far as is presently known. Rather, it is this new distance definition and other mathematical facts resulting from or consistent with that definition, which are of present interest; thus I adopt this new definition of distance, as follows.

The new distance definition is based on coordinate differences in both space and time. To aid the conceptual shift in reference from a space to a space-time, an object normally called a point in space becomes an object called an event in space-time; and the new idea of distance between two points in space is called an interval between two events in space-time.

Imagine that events in the space-time are referred to a reference

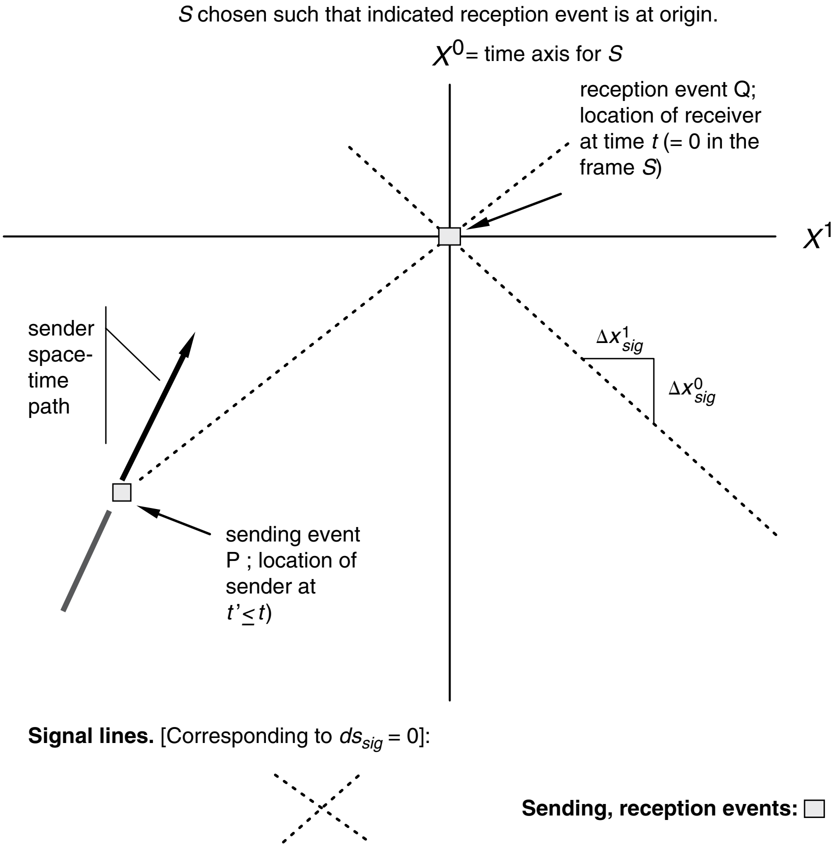


Figure 14.1 Space-time diagram showing X^0, X^1 coordinate axes, a frame S

(coordinate) frame that is orthogonal (that is, composed of axes formed from mutually perpendicular real- or imaginary-valued unit-magnitude basis vectors) but otherwise arbitrarily chosen (one of infinitely many possible such frames). (Figure 14.1: two of the three space dimensions are suppressed; two instances of signal transmission are shown, the two 45 degree angled dashed lines.)

For each event, such a frame supports a composite of several independent coordinates for the event position in a subspace of the space-time which, in that frame, is seen as ordinary space; that is, where the event occurred, relative to that frame, is indicated. In addition there is one coordinate for the event position in what is seen, again in that frame, as ordinary time; that is, when the event occurred, relative to that frame, is also indicated. Let such a frame be called S. Let x_P^k and x_Q^k denote the space coordinates, respectively, of two events P and Q referred to the k^{th} spatial coordinate axis of S; and let t_P and t_Q denote the time coordinates, respectively, of the same two events. Suppose, further, that P is the earlier event, as seen in S. As in the above, let c denote the speed of a signal; in our case, a signal sent by a societal party. Here and below, let the symbol $\equiv$ denote "equal by definition." Then define finite coordinate differences, also called displacements, by:

$$\begin{aligned} \Delta x^k &\equiv x_Q^k - x_P^k \text{ and} \\ \Delta x^0 &\equiv c \cdot (t_Q - t_P), \end{aligned} \tag{14.1}$$

which we will assume form the components of vectors in the space-time. In the second definition, the effect of multiplying by c on the right is to convert units of time into units of space. (For instance, multiplying meters/second by seconds gives a net unit of meters.) One can further replace the left-hand symbols by their differential forms:

$$\begin{aligned} \Delta x^k &\to dx^k \text{ and} \\ \Delta x^0 &\to dx^0, \end{aligned} \tag{14.2}$$

in which case P and Q can be regarded as mutually nearby events (each of the corresponding displacements arbitrarily small). Let a second arbitrary orthogonal reference frame be denoted by S'; then let the above information about the location and relative location of P and Q in this second frame be denoted by symbols corresponding to the above but with the prime mark appearing at the upper right, for example $x_P'^k$ in place of x_P^k. In each expression above, the superscript denotes the coordinate number; it is not a power exponent. (In general the time order of two given events in S' might be reversed, relative to their order in S, in which case the corresponding $\Delta x'^0$ would be negative; however that possibility will not arise given the intended use of displacements to describe the paths of individual parties in the space-time.)

With the above definitions in place, one can define an interval ds between two nearby events in space-time by:

$$\begin{aligned} ds^2 &\equiv \sum_{k=1}^{3} (dx^k)^2 - (dx^0)^2 \text{ (in } S) \\ &= \sum_{k=1}^{3} (dx'^k)^2 - (dx'^0)^2 \text{ (in } S'), \end{aligned} \tag{14.3}$$

where the unprimed and primed quantities refer to any two orthogonal reference frames. Here, the superscripts "2" do denote power exponents, so the expressions are of squared differentials. (Often, the term "interval" is used somewhat differently to name the quantity $d\tau \equiv (1/c)ds$, which expresses the same idea as here but in units of time.)

In expression (14.3), the second (non-definitional) equality establishes the quantity ds as an invariant, meaning that the interval has the same value in any two orthogonal reference frames. This property of invariance is intrinsic to the idea of an interval (just as the ordinary idea of "distance between two points" has the same value regardless of the coordinates used to describe the points). Imagine that, for any object in the space-time, an invariant path length s, starting at some referent moment a, is constructed by adding together the separate elements of interval:

$$s = \int_a^P ds,\ P \text{ marking the present (referent) moment.} \qquad (14.4)$$

The above interval formulae apply to any two nearby events in the space-time; however, suppose P and Q are not just any two nearby events but are events both located on the path of a particular signal. In that case let the interval between them be denoted by ds_{sig}. Now we make the following assumption:

$$ds_{sig} = 0. \qquad (14.5)$$

The combination of equation (14.3) applied to such a signal path, together with (14.5) and the second of (14.1) and of (14.2) implies $c^2 = \sum_{k=1}^{3}(dx^k_{sig}/dt_{sig})^2 = \sum_{k=1}^{3}(dx'^k_{sig}/dt'_{sig})^2$which is the squared speed of a signal in S and S', respectively. This result is the required constant signal speed, irrespective of relative observer motion (that is, in any arbitrary S, S', and so on) – the peculiarity of signal speed noted above. Everything else in space-time modeling and its applications is designed around this result and its contributing equations, (14.1), (14.2), (14.3), and (14.5).

In addition to signals, there are objects that exchange the signals. In the classical physical exemplar, these objects are material bodies having non-zero mass and other properties; as already intimated, in the societal analog, these signal-exchanging objects will be the parties (nation-states, and so on). Let ds_{obj} denote the interval of such an object along any tiny differential piece of its path in the space-time. Then we further introduce the following assumption:

$$ds^2_{obj} < 0, \tag{14.6}$$

which implies that the interval, itself, is an imaginary number. Such intervals are called "timelike." (In an alternative approach, though still called timelike, one requires that the intervals traversed by objects must be real valued. The two approaches are entirely equivalent, however; and both are in wide use.) Below, any displacement vector in the space having a negative squared length will be called a timelike vector; any displacement vector having zero length (namely, along a path traceable by a signal), will be called a null vector; and any displacement vector having a positive squared length will be called a spacelike vector. (They are so-called because, for any timelike vector, there exists a class of reference frames in which the space components would vanish and, for any spacelike vector, there exists a class of reference frames in which the time component would vanish. Note that, in the alternative just mentioned but not followed here, of timelike displacements real valued, the spacelike vectors would then have negative squared lengths.)

Another handy notational convention is to allow Greek indices to denote any of the space components and the time component, without distinguishing between them:

$$dx^\alpha \equiv dx^k, dx^0, k = 1, 2, 3. \tag{14.7}$$

Latin indices are then reserved to denote space components, alone; and 0 to denote the time component. Using the ordinary time differential *dt* and the invariant interval *ds*, additional elements of space-time – Newtonian velocity, covariant velocity, acceleration, and spacelike force – then can be defined:

Newtonian velocity: $u^i \equiv dx^i/dt$,
covariant velocity:$v^\alpha \equiv dx^\alpha/ds \equiv \hat{x}^\alpha$,
acceleration: $a^\alpha \equiv dv^\alpha/ds \equiv \hat{v}^\alpha$,
spacelike force: $f_\alpha(k) \equiv m(k) \cdot a_\alpha(k), m(k) > 0,$ (14.8)

respectively, where $\alpha = 0, 1, 2, 3$, and $a_0 = -a^0$, $a_i = a^i$, $i = 1, 2, 3$.

Concerning the first of equations (14.8), though no longer transforming like a vector, Newtonian velocity is still a convenient quantity because it fits our human intuition concerning rate of change; and one can transform the spacelike part of a covariant velocity vector into its Newtonian counterpart by multiplying by the factor *ds*/*dt*. Unlike Newtonian velocity, the covariant velocity defined above (position differentiated with respect to the invariant path length *s*, rather than with respect to *t*) does act like a vector in the space-time; thus the modifier "covariant," above. That covariant actually describes all the quantities but the first one defined in (14.8) since those quantities act like vectors in the space-time. In the definition of spacelike force, the negative sign serves to build into the involved expressions the negative sign appearing in equations (14.3). The quantity $m(k)$ denotes a constant specific to the k^{th} party; it will play the role of the societal mass of a particle (party). This mass is invariant; that is, has the same value in all frames. The spacelike force then embodies a relativistic version of Newton's force law. It is the force due to all other parties. Note also the further identification of a "party" with the physical notion of a "particle." If, for a given reference frame *S*, the covariant velocity of a given party is constrained (at least momentarily) by $v^k = 0$, then *S* will be called a "rest frame" of the party.

Here we can also see the original idea that Wright proposed, namely that in analogy with the physical force of particles acting on other particles, one can regard that the societal forces take the form of parties acting on other parties (Wright 1961). But, in a further emulation of electrodynamics, one can postulate that this force originates from information previously emitted by the other parties and transmitted to the receiving party at the invariant speed *c*; indeed, in the "empty spaces" between the parties, I will postulate that all information is transmitted with that same invariant signal velocity.

The idea of a force is that of an agent that is correlated with ("causes") changes in the velocity of objects. For the force equation to be empirically falsifiable, as is customary in the physical application, some independent properties would need to be associated with the above definition of force (Feynman et al. 1963: 12-1–12-3). Since the empirical content in this societal model initially lies elsewhere (as I will come to, presently), it is not clear, at this juncture, in what way such independent force properties are relevant, although in equation (14.24) and surrounding discussion I supply one element partly specifying those properties. (The result of force applications, namely changes in velocity, will in turn result in changes of position that will need to correlate with changes in signal transmission times, the yet-to-be-solved problem described above.) Use of the phrase "spacelike force" (present author's coinage) is to distinguish this from two different types, the "incident radiation field force" and the "radiation reaction force" (Rohrlich 1965: 106–112, 192), Rohrlich's equation (7-12). These latter two together with his equation (7-15) are key to the dynamic numerical simulation that is ultimately contemplated; but their role in the present discussion is minimal. Except where otherwise indicated, references below are to the spacelike force of equation (14.8), above.

SOCIETAL SPACE-TIME

The above geometric discussion applies equally to the physical and societal images. Now I turn to geometric aspects that are particular to the proposed societal application. The first such aspect concerns the dimensions. So far as the physical exemplar is concerned, the definitions (14.1), above, refer to displacements in physical space and time. In contrast, the corresponding societal analogs do not, in general, refer to physical displacements. However there is one important exception: we assume that there exists a class of reference frames in which the societal time axis with its corresponding time displacements and differentials actually is the physical time by which we measure events on Earth. Call a typical such frame $\bar{S}$ ("S – bar"); then the corresponding $\bar{t}$ is ordinary physical time. The idea is that we, the human observers of the global societal system, are at rest relative to any such $\bar{S}$. The members of that class of frames will have a common time axis and will differ among themselves only in the choice of space axes. (Corresponding diagrams appear in Williamson, 2008b: 73 and his Figure 14.2.) (Note that physical clocks in relative motion, such as one on board an airplane in flight versus one on the ground, run at slightly different rates; nor does the Earth precisely qualify as a special relativistic reference frame ([--]); but these discrepancies are negligibly tiny.)

Below, any frame of the type $\bar{S}$ will be called a clock reference frame. From the definitions (14.1), above, $\Delta\bar{x}^k = \bar{x}^k_Q - \bar{x}^k_P$ and $\Delta\bar{x}^0 = c \cdot (\bar{t}_Q - \bar{t}_P)$ in a frame $\bar{S}$, from which we get $\Delta\bar{x}^k/c = (\bar{x}^k_Q - \bar{x}^k_P)/c$ and $\Delta\bar{x}^0/c = \bar{t}_Q - \bar{t}_P$. One additional thing we come to here is that division by c in the second set of equations makes the units to be of time rather than of space. For the societal analog this is convenient because, while we do not know what the space unit is, we do know (the idea behind the $\bar{S}$-type frames) that the time unit is ordinary physical time – let us say the unit is years. Following the physical idea of "light years," we can then think of the space displacements of (14.1) and the interval formula of (14.3) as measured in signal-years. So-denominated, the speed of a signal becomes $c = 1$ [signal-year]/[year]. Further, the limiting process expressed in (14.2) can be applied to $\bar{S}$. Combining the above:

$$ds^2 = \sum_{k=1}^{3} (d\bar{x}^k)^2 - (d\bar{x}^0)^2 = \sum_{k=1}^{3} (d\bar{x}^k)^2 - (d\bar{t})^2\,[\text{years}]^2 \qquad (14.9)$$

in $\bar{S}$, where division by $c^2 = 1$ is implicit in the appearance of the years (squared) unit. The definitions of (14.8) can also be applied in $\bar{S}$, using the barred symbols $\bar{v}^\alpha$, $\bar{a}^\alpha$, and $\bar{f}^\alpha$. (Thus, from $\Delta\bar{x}^0/c = \bar{t}_Q - \bar{t}_P$ and $c = 1$ in the above, we know $\Delta\bar{x}^0 = \Delta\bar{t}$; what remains still to be defined, at present, is the direction of travel; that is, the values of the individual space difference components $\Delta\bar{x}^i$, $i = 1, 2, 3$, relative to some common frame $\bar{S}$.)

Now some further notational conventions: for visual simplicity and where the reference to $\bar{S}$-type frames is clear from the context – which is in most of this chapter – I will omit the over-score (bar) mark from coordinate differences and other frame-specific objects. In particular, henceforth references to "time" will mean the physical time in years, as described above; thus in place of $\bar{t}$ I will use the symbol t, with over-score omitted.

Another geometric aspect particular to the proposed societal application is the substantive nature of the signals. Imagine that these signals contain information concerning a quantity that can be called the "provocation" level of the sending party, so named because the quantity will be seen, below, to correspond to what is regarded, in Richardson's equations, as a provocation level of one party by another. Quotation marks are used because, as previously mentioned, Richardson's model is to be reinterpreted as an interaction in terms of a variable marking the rate of national development. The latter may be less "provocative"; however the mathematics will be the same, thus the terminology will be kept the same. (Empirically, as indicated above, this development variable remains invisible in this chapter; its presence is manifest only indirectly, via the nodal pattern introduced in the section on "Linkages in the Global System," below.)

Now a question might be posed of the above. Of the physical ideas on which the space-time conception is based, the motivating consideration in special relativity is that there is no special ("privileged") reference frame, meaning that the laws of the system in question should look the same in each frame. Given that the following discussion is to be formulated in terms of the clock frames $\bar{S}$, are not the $\bar{S}$ thereby such a special class? Here a distinction can be made between the formulation of "laws" and the character of the "measuring instruments" with which the putative law-like system is observed. It is the former that is to be indifferent among reference frames; the latter may be as particular as circumstances dictate. For instance, in physics, some observations on Earth may use different devices from those used in astronomical observations; but such differences do not constitute special frames for Earth versus outer space. The assumption concerning the frames $\bar{S}$ is, that they furnish observations that happen to be accessible to human observation, in the form of R-process or whatever phenomena (see below) are claimed to describe the global societal system; that is, they are a class of measuring instruments. Whatever is seen there could, in principle, be transcribed to any general orthogonal reference frame S (with or without the "bar"). (The method of transcription that would be used is known as the general Lorentz transformation.)

One further preliminary warrants attention: from equations (14.9), evidently we are assuming a 3 + 1 ("three plus one") dimensional space-time continuum; that is, three societal space dimensions and one societal time dimension. Why assume three space dimensions, as opposed to some other number? First, parts of the mathematical physical exemplar are specific to the 3 + 1 constraint. On this account, there are many results worked out in standard expositions, of which one may make use. (Particular use is made of Rohrlich 1965.) The availability of such results is, in fact, the main consideration at this juncture. A second reason: there is indirect empirical evidence that it really should be three space dimensions (Williamson 1985). However, the 3 + 1 choice must be regarded as inconclusive, for while one good reason is welcome, three are an embarrassment. What is truly needed but unavailable at this juncture is a general criterion of appropriate dimensionality, plus a demonstration that the 3 + 1 choice is a good approximation if, indeed, that is the case. As with other omissions, this matter must be deferred till later. Concerning the single time dimension, one may be more definite: it corresponds to the assumption that, in each frame *S*, the order in which events are perceived to occur is one-dimensional; that is certainly how it appears, both in our ordinary experience and in physics.

RICHARDSON PROCESSES AND UTILITIES OF THE PARTIES

Now I turn to the first idea to be fitted into the space-time model and the one to receive emphasis in this chapter, the "classical" arms-race model proposed by Richardson (1960). There is an important qualification, namely that the "races" in the present discussion have stable equilibria (Richardson 1960: 22ff.). Following Boulding, anticipating the shift away from armaments in the discussion to follow, and for brevity, I will refer to the logical structure of this model as an "R-process." Mathematically, there are at least three ways of picturing this classical model: the first is the system of linear differential equations that Richardson, himself, proposed; the second is a view of convergence to partial equilibrium proposed by Boulding (1963: 28); the third is an idea, put forth by Abelson (1963), of arms-racing as the net cumulative result of each party receiving, responding to, and forgetting past provocations by other parties. These three nominally distinct alternative pictures can, via appropriate generalization, be seen to be mathematically equivalent (Williamson 2008b [2005]: 2–19, especially Table 7.1). Though most discussions of R-processes focus on two parties only, the particular form of interest here is a combination of Richardson's multiparty and logarithmic versions (1960: 95–97, 163–183, respectively). However, the approach taken does start with pairwise interactions across all pairs, on which the N-party description is then built.

It is productive to elaborate Boulding's picture. Given a pair of interacting parties: (1) each of them has a partial equilibrium – a "preferred response" – that depends on the provocation level presented by the other party; and (2) each party has a certain rate of convergence to its own partial equilibrium (namely, each party approaches its partial equilibrium at a rate that is proportional to its distance from that equilibrium). Boulding showed that the combination of factors (1) and (2) implies dynamics identical to Richardson's differential equations. A further connection is that the partial equilibrium of item (1) is, itself, equivalent to utility maximizing by each of the parties. This equivalence is formally identical to an analysis leading to a duopoly solution in economics (McGuire 1965). Thereby, rational choice and its corresponding program of inquiry is implicated.

Note that this framework includes utility maximizing and it includes a dynamic – that is, change over time – principle. This dynamic principle actually appears in two different guises. First is the rate of convergence to the respective equilibria of the parties. In effect, this aspect of the R-process model is producing the changes, over time, resulting from a fixed schedule of utilities for each party. In addition, the utilities themselves may change over time. It is this second aspect that connects most critically to the space-time geometry of the model and, for that reason, is the more fundamental aspect. Such change is expressed via the variation over time in the R-process reaction and fatigue coefficients and grievance term. The particular form of their variability over time is an innovation provided by the space-time model. In effect, the spacelike forces at work on the parties will translate back into changes in partial equilibria thus, implicitly via that indirect route, to changes in utility schedules. This may seem like putting the cart before the horse; yet reasoning that derives behavior from presumed preferences would seem implicitly to assume (absent any discussion to the contrary) that such preferences are frozen in time; perhaps a realistic assumption in the short run but not necessarily in the long run. Perhaps for the latter, the opposite direction – inferring utilities from behavior – is productive. That is the point of view taken here. The strongest qualitative argument for this is that the empirically observed pattern of global interactions among parties does distinctly appear to match the indicated dynamics, as will be discussed below. (The quantitative argument must come within the context of a numerical simulation, yet to be supplied.) The appropriate governing suggestion would seem to be, use each of horse–cart and cart–horse sequences according to which is more helpful in any particular circumstance. (This advice comes from Feynman 1967: 46–58, under the contrast of "Babylonian" as opposed to "Greek" mathematics.)

All the above-named views can be combined and folded into a more general form (Williamson 2008b: 2–19, 41–44), for which:

1. Richardson's original form, with constant reaction coefficients, fatigue coefficient, and grievance term, appears as a limiting case;
2. there is a time delay between emission and receipt (in the sense discussed in the sections on "Signals" and "Geometric Space-Time," above) of signals conveying information about the "provocation" level of the sender;
3. all the above quantities are, in general, variable functions of time.

This general function is given by:

$$\dot{z}_k = \left[\sum\nolimits_{j=1}^{N} a_{kj}(u_{kj}) \cdot z_j(u_{kj}) \right] - b_k z_k + g_k,\ j \neq k, \qquad (14.10)$$

where:

$z_k \equiv$ provocation level of receiver k at time t, and $\dot{z}_k$ denotes dz_k/dt

$z_j \equiv$ provocation level of sender j at signal emission time $u_{kj} < t$

$N \equiv$ number of parties in the system

$a_{kj} \equiv$ specific reaction of k to provocation z_j of j

$b_k \equiv$ specific fatigue of k at time t

$g_k \equiv$ grievance of k at time t

$u_{kj} \equiv$ retarded time of sender j signal emission.

In the above, except for N, all named quantities are functions of time t (Williamson 2008b: 41, equation 12.13); and each of the arguments u_{kj} is the earlier time ($< t$) at which the j-th sender emitted its provocative signal seen by the receiver k at time t. (The purpose in using them, rather than t, is to emphasize that the sender values are regarded to be descriptive at the moments of their respective retarded times. However using either one, here, is equivalent to using the other, since there is a one-to-one functional relationship between t and each of the u_{kj}. See the discussion following equation 7.4 appearing in Williamson 2008b.)

Also in the above, the z_j are what Richardson originally interpreted as armament levels to which nation k responds by displaying the rate of increase $\dot{z}_k$ in its own level z_k; in turn, the latter constitutes a provocation level that is conveyed, via emission of signals, to the other nations (or other parties, more generally). All the above variable quantities change by arbitrarily small amounts over sufficiently short time intervals; in this way the original Richardson conception is recovered as a special (temporary) case.

For completeness, I need to mention one additional consideration: the effect of physical geographical distances between the parties and the corresponding loss of strength gradient (Boulding 1963), which the discussion to follow treats only in simplified form. It seems plausible that as one contemplates increasingly earlier epochs, interaction at a distance becomes progressively more difficult so that, in centuries past, intercontinental and even shorter distances acted to attenuate the sort of interactions described above in equation (14.10). Thus, at some sufficiently early moment, Africa, America, Asia, Europe, and Oceana did not know of, or were technologically incapable of reaching, each other in such a way as to sustain R-process, or linkage (see the section on "Linkages in the Global System," below) types of interaction. By contrast, let us assume of current times that the surface of the Earth is effectively located at a single point insofar as capacity for mutual interaction is concerned; thus, there is essentially no penalty for acting at a distance. For example, the United States can interact as readily with China as with Canada. The simplification to follow is that the present epoch is assumed. A proposed treatment including a non-negligible geographic effect is given in Williamson (2008b: 44–46). I return to this issue at the end of the section on "Linkages in the Global System."

RICHARDSON PROCESSES IN SOCIETAL SPACE-TIME

Now I want to connect the quantities named in (14.10), cast in terms of R-process concepts, with corresponding quantities in the space-time representation of the global system of parties. The following is based on previous work that provides, in greater detail, the derivation of the results appearing in summary form below (Williamson 2008b [2005]: 34 – 44); mainly, the focus here is on defining new notation and using it to express the resulting R-process–geometric connections. The ideas used to construct the latter (space-time) quantities are the geometric concepts discussed above. (The reasoning expressed below is pictured in Figures 14.2 and 14.3. The first shows the time dimension and one of the space dimensions; the second shows two of the space dimensions. In these and the following figures and tables, except where noted the term "velocity" refers to covariant velocity, as defined in the second of the equations 14.8.)

The rough idea is this. As mentioned before (just preceding equation 14.1), any given reference frame sees one dimension that looks like time and three that look like space. Using just the space dimensions one can form a three-dimensional sub-continuum into which one can project images of vectors defined in the full 3 + 1-dimensional space-time; in particular, one can project images of the covariant velocity and spacelike

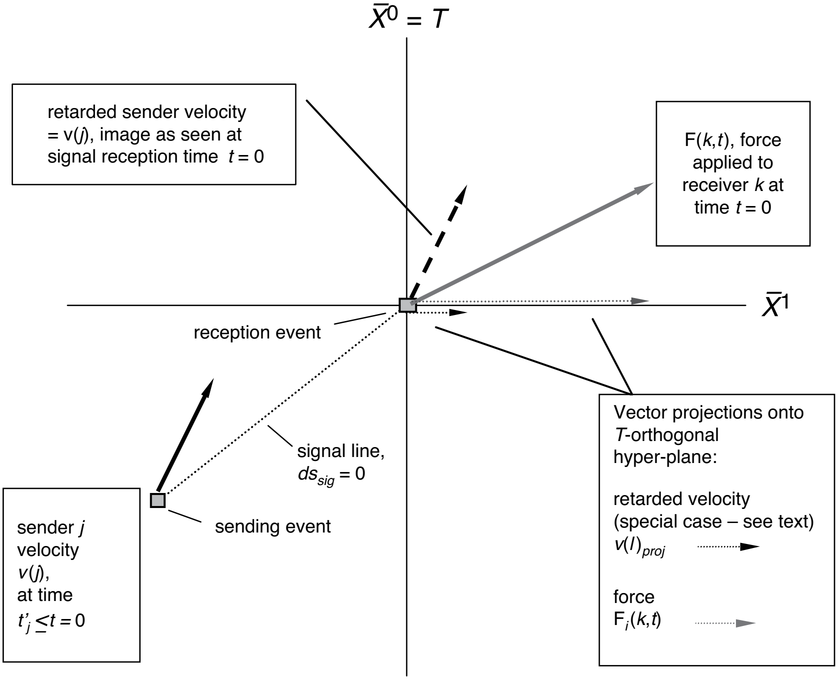


Figure 14.2 Space-time diagram showing generalized R-process expressed in clock frame $\overline{S}_k$

force vectors applying to various parties at various times. (For these projections, the time component = 0.) These projections will, themselves, be vectors that have length (magnitude) and pairs of such projected vectors will form mutual angles (proportional to inner products). The R-process reaction, fatigue, and grievance quantities are to be constructed from such lengths and mutual angles, as applied to the interacting parties. Further, the projected magnitudes of velocities will furnish the various provocation levels of senders and receiver; the projected magnitude of receiver force will furnish the provocation rate-of-change of the receiver.

I proceed with that construction entirely in terms of the values of quantities as seen in clock reference frames $\overline{S}$; that is, it is relative to such frames that the vector projections are to be defined. (These quantities are well defined in any orthogonal frame, $\overline{S}$-type or not, but I do not use that fact in this discussion.) Let us regard party *k* in its role as a receiver of signals (provocations) from other parties (that is, from parties in their role as senders), the typical one of which I denote by *j*. When discussing all parties

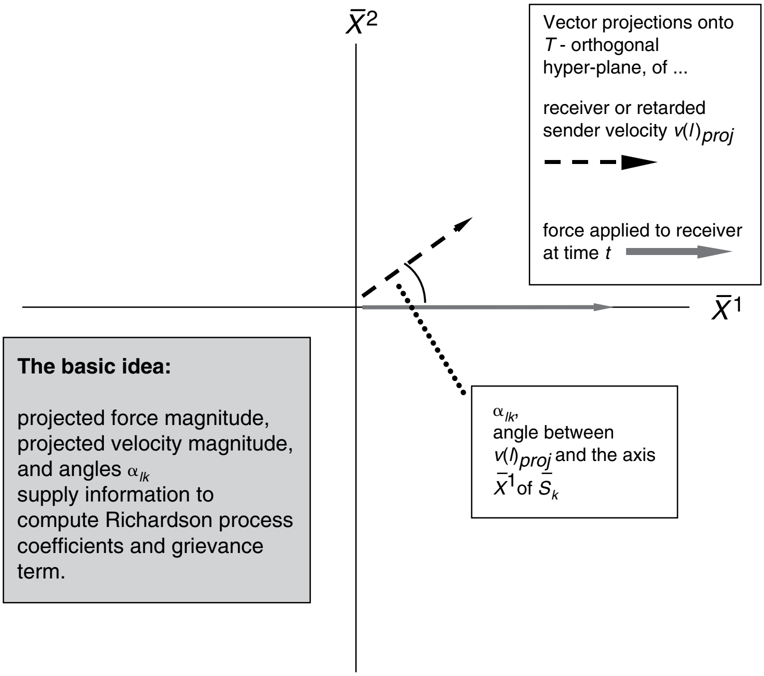


Figure 14.3 *Space sub-continuum of* $\overline{X}^1$, $\overline{X}^2$ *coordinate axes, expressed in clock frame* $\overline{S}_k$

without distinguishing receiver from senders, let us use the index ℓ. As in equation (14.10), let N denote the total number of parties.

The space axes of $\overline{S}$ remain to be specified. For each party acting in its role as a receiver, I specify just one of those axes and label the result $\overline{S}_k$ as follows: let $f(k,t)$ denote the spacelike force (defined in 14.8) felt by k at the moment t, where $f_\alpha(k,t)$ are the vector components in $\overline{S}$, of this force. I make the necessary assumption that this force is non-zero, which is equivalent to:

$$f_\alpha(k,t) \neq 0, \tag{14.11}$$

so that what follows, involving the projection of $f(k,t)$, is well defined (Williamson 2008b [2005]: 39, discussion following equation 12.10). To avoid clutter, since the meaning is clear without the over-score marking, I omit it from quantities in the frame $\overline{S}$; similarly, in places I omit the variable t.

Corresponding to any clock reference frame is a time axis that, to retain the notational conventions, might be called $\overline{X}^0$. (To emphasize that this corresponds to actual physical time – see the discussion in the section on "Societal Space-Time," above – one could also denote the axis by $T \equiv \overline{X}^0$; as a reminder of this, in some of the figures at the end of this chapter, both symbols are used.)

Let $f_\perp(k,t)$ be the part of $f(k,t)$ perpendicular to $\overline{X}^0$; and let $f_i(k)$ be the components of $f_\perp(k,t)$. These components form the projection, just mentioned, of the force vector $f(k,t)$ onto the space sub-continuum of the clock frames. From this one can choose space axes such that one of them is parallel to this projection vector. For the receiver k call this axis $\overline{X}_k^1$ and call any one of the resulting class of reference frames $\overline{S}_k$ ("class" of frames, since the other space axes still are unspecified and there are infinitely many possible such specifications). In sum, the force applied to the receiver k "casts a shadow" on the space part of the continuum (as seen in clock frames $\overline{S}$); we are selecting the axis labeled 1, namely $\overline{X}_k^1$, to be aligned with that shadow. (See Figure 14.2: the "shadow" in question is marked with the label "Vector projections onto T – orthogonal hyper-plane.")

Now let $v(\ell,k,t'_\ell)_{proj}$ be a certain projection of the velocity vector of party ℓ as it existed at the current or retarded (earlier) time $t'_\ell \leq t$ when it emitted the signal received at time t: namely, this projection, also, is onto the space sub-continuum of $\overline{S}_k$ (Williamson 2008b [2005]: 24, equation 9.1 and corresponding discussion). The equality part of the condition $\leq$ reflects that one of the projections onto $\overline{S}_k$ comes from receiver k, itself, for which the time retardation vanishes. For the inequality, the time required for the signal to travel from sender to receiver is the delay discussed in the section on "Geometric Space-Time," above. This projection is literally a "shadow of the past," since it is a projection ("shadow") and it is the present image of a past condition; that is, it represents the present delayed recognition, by a receiver, of a past signal sent by a sender. Let $v^i(\ell,k,t'_\ell)_{proj}$ be the space components in $\overline{S}_k$ of this projection. Below, I want to refer to its magnitude. As mentioned in the section on "Societal Space-Time," the clock frames differ only in the choice of space axes; the time axis $\overline{X}^0$ is common to all of them; thus (while the components $v^i(\ell,k,t'_\ell)_{proj}$ will vary, depending on k) the magnitude of $v(\ell,k,t'_\ell)_{proj}$ is independent of the choice of k which thus may be omitted; also, let us omit the time index, provided the reference is clear. This gives expressions:

$$|v(\ell,k,t'_\ell)|_{proj} = |v(\ell)|_{proj},\ \ell = 1,\ldots,N; \tag{14.12}$$

however, I will continue, as well, to use the longer notation (on the left) in places, such as the next equation.

Additional notation is also needed. Let $\alpha_{\ell k}$ be the angle between

$v(\ell,k,t'_\ell)_{proj}$ and the axis $\overline{X}^1_k$; α_k be the angle between $v(\ell,k,t)_{proj}$ (that is, k's own velocity projection) and $\overline{X}^1_k$; $m(k)$ be k's mass, introduced in equation (14.8); and $\dot{\alpha}_k$ be the rate of change of α_k with respect to clock time t. (This latter quantity first appears in equation 14.15.) The restrictions α_k, $\alpha_{jk} \neq \pm \pi/2$ also apply. (Below, starting at equation 14.16, the one on α_{jk} will be removed.) These angles are the ones to which reference was made a moment ago.

(Note that α_k may be non-vanishing since $v(k)_{proj}$ need not be parallel with the spacelike component of the force applied to k. Also, this notation is redundant, since α_k means the same thing as $\alpha_{\ell k}$ when $\ell = k$, but still convenient. The indicated restrictions on α_k and the α_{jk} follow from the trigonometric functions appearing on the left-hand side. They reflect the inability of the spacelike projection in $\overline{S}_k$ of a velocity vector to generate a non-zero component along any candidate $\overline{X}^1$ if the two are mutually perpendicular and, likewise, for the spacelike projections in $\overline{S}_k$ of sender velocities.)

With the aid of the above notation, I define two new quantities:

$$(f,v) \equiv \sum_{i=1}^{3} f_i(k) \cdot v^i(\ell,k,t'_\ell)_{proj},\ t'_\ell \leq t, \tag{14.13}$$

and, subject to the necessary restrictions for a non-vanishing first denominator,

$$\xi(\ell,k) \equiv \left[\frac{(f,v)}{m(k)\,(\cos\alpha_k)\,(\cos\alpha_{\ell k})}\right] \cdot \left[\frac{-i ds_k}{dt}\right]. \tag{14.14}$$

In (14.14), the short form $|v(\ell)|_{proj}$ [including $|v(k)|_{proj}$] of equation (14.12) is used. As before, ds_k is the invariant path interval (equation 14.3); and all instances of k and j refer to receiver and sender, respectively.

All the above, it can be shown, leads to the result:

$$|v(\ell)|_{proj} \cdot \xi(\ell,k) + \dot{\alpha}_k(\tan\alpha_k)|v(k)|_{proj} \cdot |v(\ell)|^2_{proj} = \left[\frac{d}{dt}|v(k)|_{proj}\right] \cdot |v(\ell)|^2_{proj},$$

$$\ell = j \text{ or } k;\ \alpha_k, \alpha_{jk} \neq \pm\pi/2. \tag{14.15}$$

As before, let N be the total number of parties in the system (including the receiving party). Now we can think of an index p as ranging across the receiver k plus exactly the M-many sender parties for which the restriction on α_{jk} holds, $M \leq N-1$, to form a sequence of equations like (14.15) and, on those equations, we can sum across all such values p. Further, we can divide both sides by $\sum_{p=1}^{M+1}|v(p)|^2_{proj}$ and we can define $\xi(j,k) \equiv 0$ for the case $\alpha_{jk} = \pm\pi/2$, where $j \neq k$. (Readers familiar with bivariate regression may recognize that the procedure followed here emulates the solution of a regression weight.) This definition allows the previous restriction $\alpha_{jk} \neq \pm\pi/2$ to be removed. (The restriction $\alpha_k \neq \pm\pi/2$ is retained.)

All the above then gives the result:

$$\sum_{j=1}^{N} |v(j)|_{proj} \cdot \xi(j,k) / \sum_{p=1}^{M+1} |v(p)|_{proj}^{2}$$

$$+ \; |v(k)|_{proj} \cdot \xi(k,k) / \sum_{p=1}^{M+1} |v(p)|_{proj}^{2} + \dot{\alpha}_k |v(k)|_{proj} \tan\alpha_k$$

$$= \frac{d}{dt}|v(k)|_{proj}, \text{ where } j \neq k, \alpha_k \neq \pm\pi/2, \tag{14.16}$$

where the distinction between receiver k and senders j has been reintroduced. (That is, in place of $\xi(\ell,k)$, the term involving $\xi(k,k)$ on the left-hand side has been separated from the terms involving $\xi(j,k)$, $j \neq k$.)

Now I am ready to connect the above to the Richardson process, equation (14.10). I do this, first, by equating the grievances g_k, the provocation values z_l, and the provocation emission times u to certain of the geometric quantities appearing in (14.16). Let these equivalencies be given by:

$$g_k = \pm[\dot{\alpha}_k |v(k)|_{proj} \tan\alpha_k] \text{ (grievance term)}, \tag{14.17}$$

$$\pm\, z_l = |v(l)|_{proj}, \text{ for all parties } l = 1,2,\ldots,N \text{ (provocation level), and} \tag{14.18}$$

$$u_{kj} = t_j' \text{ (signal emission time)}. \tag{14.19}$$

In equation (14.18), if $z_l < 0$ the negative sign is to be chosen; otherwise choose the positive sign. In words, except for a sign, the magnitude of provocation emitted by any party l equals the magnitude of the space component of its velocity as seen in any $\overline{S}_k$. In (14.17), choose the sign to agree with the sign with respect to receiver k in (14.18) for $\ell = k$.

In equation (14.19), the quantity on the left is the provocation emission time appearing in the R-process equation (14.10); the quantity on the right is the retarded time introduced in equation (14.12). The assertion of their equality is simply the assertion that the emission time in the geometric constructions of this section is the same as the retarded time in the R-process construction: as was discussed earlier, how long it takes for a receiver to respond to a sender provocation equals how long it takes a space-time signal from the latter to reach the former.

From the above, one then can draw the following conclusions, concerning the remaining R-process elements. First, concerning the rate of change in receiver k provocation level:

$$\pm\, \dot{z}_k = \frac{d}{dt}|v(k)|_{proj}, \tag{14.20}$$

for receiver k, where the sign choice follows that of z_k. Second, consider two possible cases. Case (a): $z_k \geq 0$. The R-process reaction coefficients then are given by:

$$a_{kj}(u_{k,j}) = \pm\xi(j,k)/\sum_{p=1}^{M+1}|v(p)|^2_{proj}\ j \neq k \text{ (reaction coefficients)}; \tag{14.21a}$$

Case (b): $z_k < 0$. The R-process reaction coefficients now are given by:

$$a_{kj}(u_{kj}) = \mp\xi(j,k)/\sum_{p=1}^{M+1}|v(p)|^2_{proj},\ j \neq k \text{ (reaction coefficients)}; \tag{14.21b}$$

In (14.21a), the sign is to be chosen the same as the sign given by equation (14.18) as applied to the sender j; in (14.21b), the sign is to be chosen opposite to that given by the same criterion, (14.18). Finally, the fatigue coefficients are found to be given by:

$$b_k = -\xi(k,k)/\sum_{p=1}^{M+1}|v(p)|^2_{proj} \text{ (fatigue coefficient)}. \tag{14.22}$$

When the substitutions indicated by equations (14.17) through (14.22) are made, equation (14.16) becomes equation (14.10).

To summarize the picture at this juncture: (1) the above equates the R-process to a geometric conception defined in a fictitious societal space-time; (2) variations over time in the grievances, and in the reaction and fatigue coefficients, are driven by the motions of the parties in this space-time. We can also revisit the "composition" feature by which the separate provocations by senders combine, as the summation appearing in equation 14.10. This feature corresponds exactly to the physical counterpart of sender–receiver relationships: what a charged "reference" particle "sees" at a given moment t and place x^i is the sum of all the separate signals, each generated by a "source" particle (physics term $\equiv$ "sender party" j) at earlier times $t_j' < t$.

In addition, certain restrictions are needed to achieve an exact emulation of Richardson's original conception; for instance, the fatigue coefficient is constrained to positive values $b_k > 0$, so that "fatigue" acts as a restraint via the term $-b_k z_k$ in equation (14.10). (See Williamson 2008b [2005]: 43–44, for a more complete discussion.) However, such restrictions are subordinated to a more general picture in which they may or may not hold, depending on other considerations, to which we turn next.

LINKAGES IN THE GLOBAL SYSTEM

So far I have discussed a connection between R-processes and a geometric conception, "societal space-time." Of the (no doubt many) issues left hanging, one is the question of assigning an independent empirical meaning, either directly or indirectly, to the definition of spacelike force introduced by the fourth of equations (14.8). A second question might be to ask how strongly is warranted the notion of a time delay between emission and reception of a signal (provocation), of the systematic, geometrically specific, character assumed in the above. Of course, this latter issue clearly is to be adjudicated by empirical evidence (albeit of a character that must still be determined); however there is reason for thinking that such delays "ought" to work. By bringing in the other two aspects named in the chapter title, we will be able, to some degree, to characterize the empirical meaning of "force."

Let us start with a concept of dichotomous linkage, the term denoting a measure of the extent to which the interaction involving a referent party preferentially also involves some other named party; and let us refer to a pair of parties in such a relationship as a dyad. Such a preference can be seen by dividing the quantity of interaction involving a named dyad by the total quantity of the referent party to all other parties, then using some inequality criterion value – such as $\geq$ 20 percent – of the total to assign to each dyad a dichotomous variable: "linked" if satisfying the inequality, versus "not linked" otherwise. For example, by the above percentage criterion most nations (in those few years so far observed) focus their exports, as determined by monetary value, on just a handful of other parties. In what follows, let us call these other parties, on which interaction is focused, "nodal parties," or simply "nodes." (Though the model remains an abstraction about "parties," the discussion beginning here will cite nations as examples. "Linkage" and "nodal structure," to be introduced below, originated with the idea of "structural imperialism" (Galtung 1971).)

In the handful of data years so far examined, the nodal parties appear to be the same few in each case. For example, such dichotomous data based on total trade, on exports, on military personnel deployments, and on arms transfers, all taken from the 1970s or early 1980s, reveal that most nations were linked (in the above sense) primarily to one or more of the United States, the United Kingdom (hereafter: Britain), France and Russia – those four accounted for most of the interaction measured by percentage of other party totals. This is illustrated for total directed trade in Figure 14.4 and Table 14.1. Let us call the resulting global picture a nodal pattern (Williamson 2008b [2005]: 46–47). Russia, a very poor fourth in trade, is more prominent, based on arms transfer monetary values and

BOX 14.1 THE NODAL PATTERN REQUIRES A FINITE SIGNAL TRANSMISSION SPEED

The nodal pattern is built into the space-time model. In the following, numbered equations refer to the chapter, lettered equations to this discussion; j and k denote receiving and sending parties, respectively; and I use the abbreviation $dx^2 \equiv \sum_{k=1}^{3} (dx^k)^2$.

Then, relative to any frame S, concerning the space-time path of any party, using equations (14.3), the second of (14.1), and (14.2), we have $ds^2 = dx^2 - (dx^0)^2$ from which:

$$1/ds = 1/\sqrt{dx^2 - (dx^0)^2} = 1/\sqrt{dx^2 - c^2dt^2} = -i/\sqrt{c^2dt^2 - dx^2}.$$

From this and the second of equations (14.8), we have:

$$v^i = dx^i/ds = -i \cdot dx^i/\sqrt{c^2dt^2 - dx^2}. \qquad (14.a)$$

From the third of (14.8):

$$\begin{aligned} a^i \equiv dv^i/ds &= dv^i/\sqrt{dx^2 - c^2dt^2} \\ &= d^2x^i/(\sqrt{dx^2 - c^2dt^2} \cdot \sqrt{dx^2 - c^2dt^2}) \\ &= d^2x^i/(dx^2 - c^2dt^2) \\ &= -d^2x^i/(c^2dt^2 - dx^2), \qquad (14.b) \end{aligned}$$

applying to any path in the space-time.

Next, for any party, from (14.25) and the fourth of (14.8), we have

$$f_i^R = m \cdot a_i^R = m \cdot a_R^i$$

which from equation (14.b) above, shows:

$$f_i^R = -m \cdot d^2x_R^i/(c^2dt_R^2 - dx_R^2), \qquad (14.c)$$

where x_R^i denotes the space coordinates of the path that would be followed by the party, in the absence of the mutually attractive force.

Thus, if f_i^R denotes the repulsive force felt by sender k and j denotes the receiver, from equations (14.a) and (14.c) we have:

$$\sum_{i=1}^{3} f_i^R \cdot v_j^i = m \cdot i \sum_{i=1}^{3} (d^2 x_R^i)(dx_j^i) / \\ [(c^2 dt_R^2 - dx_R^2)(c^2 dt_j^2 - dx_j^2)^{1/2}]. \qquad (14.\mathrm{d})$$

From equations (14.3) and (14.6), a party (the analog of a physically material object) is constrained by:

$$0 > ds^2 = dx^2 - (dx^0)^2 = dx^2 - c^2 dt^2$$

which shows that the two factors in the denominator of equation (14.d) are both positive for all values of c and become increasingly so with increasing values of c. Thus the expressions on the right and the left of (14.d) $\rightarrow 0$ as $c \rightarrow \infty$ and, from (14.26) and (14.d), above, for any frame $\bar{S}$, the linkages $\theta(j,k,t_j') \rightarrow 0$ as $c \rightarrow \infty$.

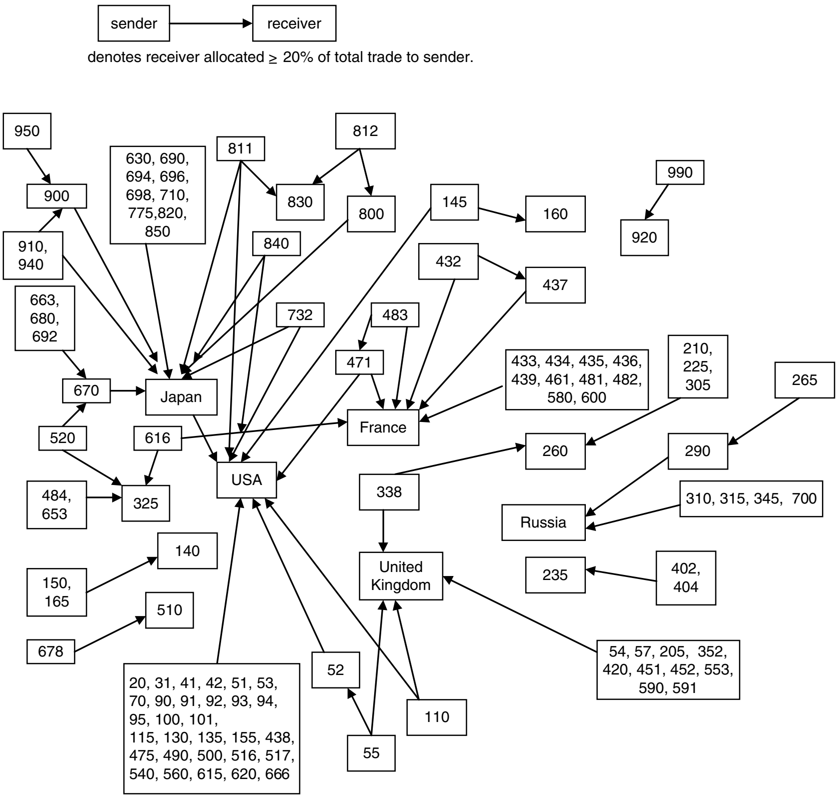
In words, within this model the empirical fact of the nodal pattern requires that c be finite; i.e. that there be systematic delays in response of parties to signals (in the sense of the section on "Signals" in this chapter) emitted by other parties in the global system. Further, the time lag that rationalizes the nodal pattern also rationalizes the R-process, as applied to a modernization process within (national) parties.

military personnel deployments. (See the sociograms in Williamson 1985; 2008a: 17; 1989: 110–112, Table 1. These procedures use a $\geq$ 25 percent connection criterion.) That the data are a couple of decades old and go forward and backward no further in time is a limitation that, of course, needs to be fixed. One other weakly supportive piece of evidence appears in Figure 14.9 later in this chapter. I return to this piece below.

More useful than the dichotomous, for what follows, is a continuous, logarithmic form given by:

$$\theta(j,k) \equiv \ln(w_{jk}/\langle x_j \rangle) = \ln(w_{jk}) - \ln\langle x_j \rangle, \qquad (14.23)$$

where w_{jk} denotes the amount of interaction involving j and k, corresponding to the "referent party" and "other named party," respectively, in the previous paragraph, and $\langle x_j \rangle$ is the geometric mean of non-zero interactions between j and all other parties (Williamson 2008b [2005]: 48, equation 14.2). This representation can assume positive, negative, or zero



Notes:
Data year: 1980.
Numbers in boxes are Correlates of War project nation numbers. See Table 14.1.

Source: Barbieri (1998).

Figure 14.4 Dichotomous linkages based on directed total trade, current epoch

values. With this form, let any positive value be called a state of continuous linkage from k to j (so here I am dropping the percentage threshold); and let the case of a negative value be called a state of alienation of k from j. For convenience, in the following the term "linkage" will refer to this continuous form; "dichotomous linkage" will continue to refer to the first form. In the following, I want $\theta(j,k)$ to carry the information that certain parties, such as Britain, France, Russia, and the United States, in the above, are the nodes of the global system and that other parties are

Table 14.1 *Correlates of War project nation numbers appearing in Figure 14.4*

COW number	Nation
20	Canada
31	Bahamas
41	Haiti
42	Dominican Republic
51	Jamaica
52	Trinidad
53	Barbados
54	Dominica
55	Grenada
57	St Vincent & Grenadines
70	Mexico
90	Guatemala
91	Honduras
92	El Salvador
93	Nicaragua
94	Costa Rica
95	Panama
100	Colombia
101	Venezuela
110	Guyana
115	Suriname
130	Ecuador
135	Peru
140	Brazil
145	Bolivia
150	Paraguay
155	Chile
160	Argentina
165	Uruguay
205	Ireland
210	Netherlands
225	Switzerland
235	Portugal
260	German Federal Republic
265	German Democratic Republic
290	Poland
305	Austria
310	Hungary
315	Czechoslovakia
325	Italy/Sardinia
338	Malta
345	Yugoslavia/Serbia
352	Cyprus
402	Cape Verde
420	Gambia

Table 14.1 (continued)

COW number	Nation
432	Mali
433	Senegal
434	Benin/Dahomey
435	Mauritania
436	Niger
437	Ivory Coast
438	Guinea
439	Burkina Faso (Upper Volta)
451	Sierra Leone
452	Ghana
461	Togo
471	Cameroon
475	Nigeria
481	Gabon
482	Central African Republic
483	Chad
484	Congo
490	Zaire (Congo, Kinshasa)
500	Uganda
510	Tanzania/Tanganyika
516	Burundi
517	Rwanda
520	Somalia
540	Angola
553	Malawi
560	South Africa
580	Malagasy
590	Mauritius
591	Seychelles
600	Morocco
615	Algeria
616	Tunisia
620	Libya
630	Iran (Persia)
652	Syria
663	Jordan
666	Israel
670	Saudi Arabia
678	Yemen Arab Republic
680	Yemen People's Republic
690	Kuwait
692	Bahrain
694	Qatar
698	Oman
700	Afghanistan
710	China

Table 14.1 (continued)

COW number	Nation
732	Korea, Republic of
775	Myanmar (Burma)
800	Thailand
811	Cambodia (Kampuchea)
812	Laos
820	Malaysia
830	Singapore
840	Philippines
850	Indonesia
900	Australia
910	Papua New Guinea
920	New Zealand
940	Solomon Islands
950	Fiji
990	Western Samoa

not. If the model can produce non-zero $\theta(j,k)$ values for combinations involving k-indices corresponding to just (or even primarily) such putative nodal parties and j indices corresponding to all other (putatively non-nodal) parties, but small or zero values for all other combinations, then the model will approximately reflect that linkage property. I proceed as follows.

Returning to the spacelike forces, I further assume (Williamson 2008b [2005]: 49–50) that all pairs of parties are subject to a mutually attractive force f_α^A and to a mutually repulsive force f_α^R, such that the spacelike force, previously given in the fourth of equation (14.8), is also described by:

$$f_\alpha = f_\alpha^A + f_\alpha^R. \tag{14.24}$$

In the above, the two right-hand terms are assumed to be spacelike. Also, they correspond to an empirically independent definition of force (which, as noted earlier, is absent from the equations 14.8). Without specifying those terms exactly, I will assume that each contributes linearly to acceleration with a coefficient of weight $1/m(k)$, so that:

$$a_\alpha^R(k) = f_\alpha^R(k)\,[1/m(k)] \tag{14.25}$$

is the repulsive acceleration term, with a like equation for the attractive term a_α^A. (Another way to state this assumption is that each force terms acts as though the other one was absent. The intended physical models are derivations based on the repulsive electrodynamic vector potential and the attractive Yukawa scalar potential – Feynman et al. 1964: 21-4–21-5, 28-12–28-14 – respectively, but altered to make the former attractive and the latter repulsive.)

Two other remarks are appropriate, concerning both the attractive and repulsive forces: First (again emulating electrodynamics), let us assume that each party possesses the societal analog of electronic charge, such that the capacity of a party, both to exert forces on others and to respond to forces from others, is proportional to its quantity of "charge"; let us denote this quantity by q_k, the subscript identifying the party. This property of charge can be regarded as the geometric analog of the "intrinsic political power" of a nation or other party. Second, let us assume that, like their physical exemplars, parties experiencing acceleration radiate energy in proportion to $(q_k)^2$. (In the physics, this is not an independent property but follows from other considerations. At some point the same must be done in the societal model; but not yet. This phenomenon corresponds to the radiation reaction force mentioned at the end of the section on "Geometric Space-Time," above.) The significance of radiated energy for the present discussion is that the parties lose energy as they experience acceleration, due to the forces they exert on each other; thus, as parties come together in the space, it becomes increasingly difficult for them then to move apart, for they lose the energy easily to do so. This gives an increasing stability (or "decreasing flexibility") to the global system as it evolves through time; one might say the system "cools." (Perhaps it undergoes the process of "annealing"? This might occur when incoming parties impact the system center.)

Now I adopt the same point of view about continuous linkage as I did, above, concerning the Richardson process: linkage is to be regarded as resulting from a function of velocity and force vectors in the societal space-time (Williamson 2008b [2005]: 47–51; and Figure 14.5). Accordingly, to the linkage I equate an expression similar to the right-hand side of equation (14.13):

$$\theta(j,k,t_j') = \sum_{i=1}^{3} f_i^R(k,t) \cdot v^i(j,t_j'),\ t_j' > t, \text{ any } \overline{S}; \tag{14.26}$$

but with certain important differences. As before, velocity and force components are referred specifically to the clock reference frames $\overline{S}$, but now the referent time is t_j'. Note two important further differences, compared with equation (14.13): (1) the reversal of time order between force and velocity vectors, so that the force input is the delayed image of a force that originated at a time preceding rather than following the velocity; and (2)

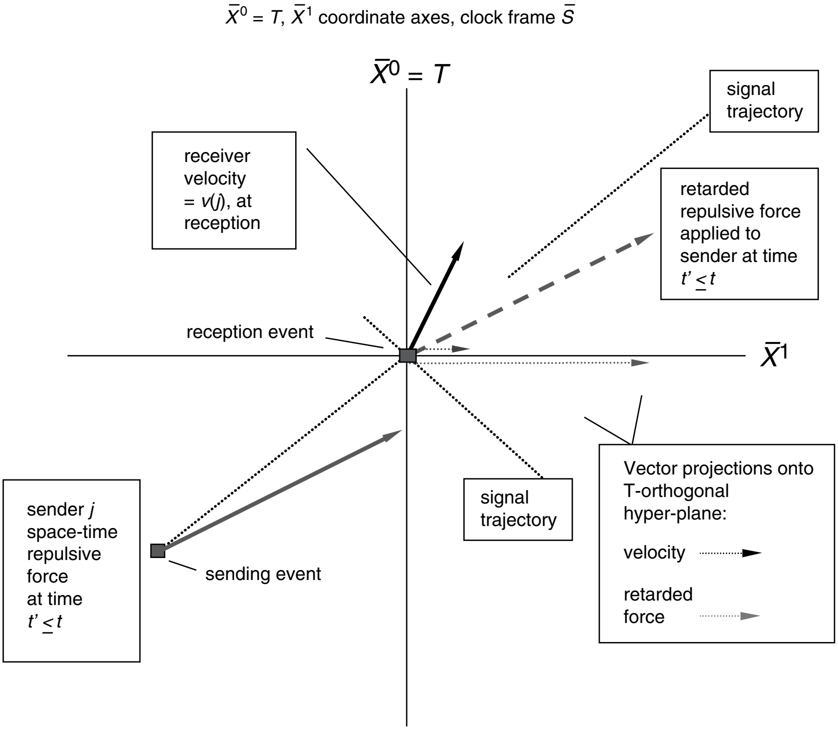


Figure 14.5 Space-time diagram showing linkage aspect (retarded repulsive force)

this force is only the repulsive part f^R_α. The reasons for these differences I will come to in a moment. Note, in equations (14.23) and (14.26) the previous convention regarding equation (14.13) is retained so that, in $\theta(j,k)$, I identify the first position within parentheses, *j*, again as attributing the velocity information to its corresponding party but now concerning the receiver of a signal emission; and I identify the second position, *k*, as attributing the force information but now concerning the emitter of a signal. For visual simplicity the tag $\_{proj}$ is removed from velocity; however the reference remains the projected velocity components of *j* in the space sub-continuum of any $\bar{S}$.

Just as before, concerning information about velocity, I assume that information about force in its various parts applied to a party is subject to the same signal transmission delay. (This and R-process views are compatible; each party is considered to be emitting at all times signals conveying both its velocity and the forces felt by it.) Let us further assume that both f_α^A and f_α^R decline with decreasing mutual societal (not necessarily geographic) distance but that, of the two, f_α^R declines more rapidly, to such a degree that it is negligible across most mutual distances, whereas f_α^A is non-negligible at all mutual distances. This set of assumptions implies that net spacelike force f_α is mutually attractive for all dyads except for those relative few that are "close" to each other in the space.

Now consider further what equation (14.26) says: linkage $\theta(j,k)$ is non-zero only if the space components of receiver velocity and of the (retarded) repulsive term of sender force are both non-zero, for at least one of the terms, $f_1^R v^1$, $f_2^R v^2$, or $f_3^R v^3$. Let us imagine that exactly (or primarily) the nodal parties cluster together in sufficient mutual proximity that they feel the force f_α^R; and suppose these same parties are at rest, or of negligibly small spacelike velocity components, relative to any of the frames $\overline{S}$. Let us further imagine that most other parties are each too remote from all others to feel the force part f_α^R and that their velocities contain a non-negligible net "inward" component toward the nodals. To simplify the discussion, for the k-th sender, let us assume a clock frame $\overline{S}_k^R$ in which one of the space axes, call it $\overline{X}_1^R$, is parallel to the projection of the repulsive term f_α^R (rather than, as before, the entire spacelike force f_α) onto the space subcontinuum. These results will be entirely equivalent in any $\overline{S}$-type frame. (As with any such force, its spacelike character assures that, if f_α^R is non-zero, then its space projection will be, also.) Then, in $\overline{S}_k^R$, we have $f_i^A = 0$, $i > 1$, and the only relevant force and velocity components in equation (14.26) are $\overline{f}_1^R$ and (let us call it) $\overline{v}_R^1$, respectively. The corresponding results are those given in Table 14.2, where the only non-vanishing linkage values are in the lower right-hand cell, corresponding to a nodal sender and a non-nodal receiver.

Empirically, the nodal pattern, appearing in dichotomous form in the references cited in the section on "Linkages in the Global System," is the corresponding image.[1]

One further consideration concerns the effect of geographic distance (the "loss of strength gradient") mentioned above. As noted, this effect may be disregarded for the present epoch, but not so, for earlier times; thus, here, it must be included. Let the left-hand side of equation (14.26) be changed so that the expression now reads:

$$\theta(j,k,t_j') \cdot D_{jk}(t)^w = \sum_{i=1}^{3} f_i^R(k,t) \cdot v^i(j,t_j'),\ t_j' > t, \text{ any } \overline{S} \text{ (revised linkage, including geographic distance effect)}, \qquad (14.27)$$

Table 14.2 Global linkage function values in $\overline{\mathrm{S}}^{R}_{\mathrm{k}}$ under various idealized circumstances

	Spacelike velocity components:	
Spacelike force components:	$\bar{v}^{1}_{R}(j, t'_j) = 0$	$\bar{v}^{1}_{R}(j, t'_j) \neq 0$
$\bar{f}^{R}_{1}(j, t_j) = 0$	$\theta(j, k, t') = 0$	$\theta(j, k, t') = 0$
$\bar{f}^{R}_{1}(j, t_j) \neq 0$	$\theta(j, k, t') = 0$	$\theta(j, k, t') \neq 0$

where $D_{jk}(t) \geq 0$ and $w(t) > 0$ (Williamson 2008b [2005]: 44–46, 52). Likewise, for the R-process the left-hand side of (14.13) is to be replaced by $(f, v) \cdot D_{jk}(t)^{w}$. For a fixed value on the right-hand side of (14.27), as the new term becomes increasingly large at earlier times in the past, the linkage factor will become increasingly small.

PROPOSED FIELD-THEORETIC HISTORY OF THE WORLD

Addressing, now, the theme of system change, I am ready to tell a story that gets the global system from prehistoric times to the present epoch, focusing on the emergence of conditions which, according to the section on "Linkages in the Global System," imply the nodal pattern. (Aspects of this history are pictured and described in Box 14.2 and Figures 14.6 and 14.7.) In the "primitive era" (early times, say c.10 000 YBP) small bands of humans occasionally interacted with each other at very local mutual distances. In model terms, these parties were at random spatial locations, moving with random velocities, each feeling the attractive force from all others, of a magnitude approaching zero as $t \to -\infty$. Typically, dyads were too remote to feel the mutually repulsive force.

Under the attractive force, the parties gradually drifted toward each other in the space; the global system contracted. By chance, some dyads became sufficiently proximate to feel the repulsive force; this proximity corresponds to non-negligible values on the right-hand side of (14.27) but the factor $D_{jk}(t)^{w}$ is so large as to restrict the observed effect – namely $\theta(j,k,t')$ – to geographically proximate dyads. This corresponds to the various regional civilizations of pre-modern times. Loss of energy via acceleration gives stability to these local configurations. Let us further imagine that, by chance, at a relatively early moment in time a cluster of particularly powerful – that is, large q-valued – parties (see the comment

BOX 14.2 POSTULATES OF GLOBAL SYSTEM DYNAMIC CHARACTERISTICS

I. All epochs; each party . . .

1. . . . exerts attractive force f_{α}^{A} on each of the others.
2. . . . exerts repulsive force f_{α}^{R} on others at sufficiently small distances, only.
3. . . . possesses a charge q (analog of electronic charge); exerts / experiences forces f_{α}^{A}, f_{α}^{R} on / from other parties in proportion to magnitude of q.
4. . . . is characterized by linkage as modified by geographic distance (Williamson 2008b [2005], equations 12.24–12.27 and 15.6).
5. . . . otherwise, emulates dynamics of electrically charged particles.

II. “Current” epoch (year 2000)

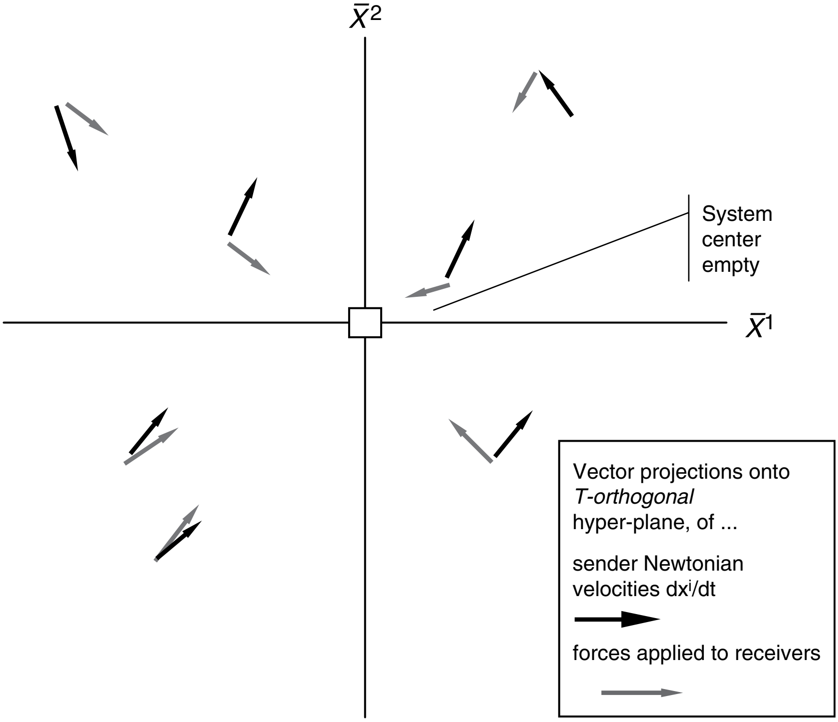
Group L (“local”) nations:

6. Relatively few in number.
7. Mutual space distances sufficiently small to feel mutual f_{α}^{R} forces (from each other).
8. Typical Newtonian velocity space components small $(< \; < 1)$ in clock frames $\overline{S}$.
9. Clustered about system center-of-mass $\overline{cm}$.

Other (non-L) nations:

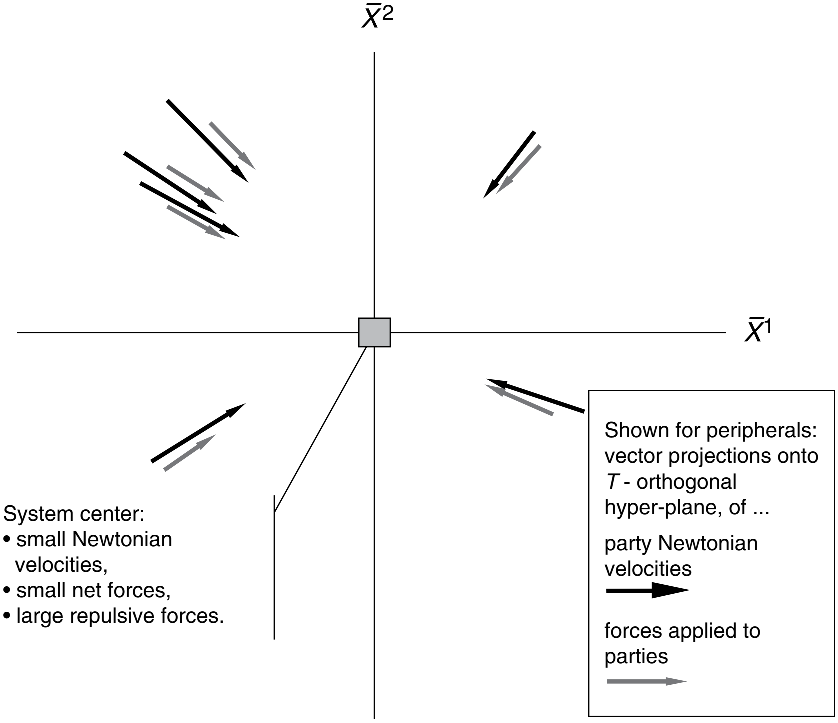
10. Relatively numerous.
11. Mutually remote (space distances from all others too large to feel f_{α}^{R} forces).
12. Typical Newtonian velocity space components large (non-negligible fraction of 1) in clock frames $\overline{S}$.
13. Typical $\overline{v}^{i}$ shows large component toward or away from system center of mass $\overline{cm}$.

III.	“Primitive” epoch (c.5000 to 10 000 years before present)
14.	Group L (“local”) nations non-existent.
15.	Non-Group L nations characterized by points 8 and 11, above.
Source: By permission Global Vision, Inc.	



Note: Black arrows represent Newtonian velocities (see p. 359) and the grey arrows, spacelike forces. Pre-history thus is characterized as like a gas consisting of random motions of local societal “particles,” except that the parties feel a mutual attraction as shown by the light gray arrows, all of them pointing toward the system center (but with force magnitudes $\to 0$ as $t \to -\infty$). The mutual repulsive force is negligible.

Figure 14.6 Social space configuration, primitive epoch (c.10 000 YBP): space sub-continuum diagram showing $\bar{X}^1$, $\bar{X}^2$ coordinate axes, $\bar{X}^0 = T$ – orthogonal hyper-plane of $\bar{S}$



Note: The square at the origin denotes the place occupied by the nodal parties. Newtonian velocity arrows describe the migration toward the center of the peripherals (which in global political terms are the “minor powers”). At the large distances involving peripherals the attractive force remains dominant as before; however, the nodal parties are mutually proximate, thus their mutual repulsive forces are non-negligible (thus implying the capacity to act as centrals/”major powers”).

Figure 14.7 Social space configuration, current epoch (c. year 2000), space sub-continuum diagram showing $\overline{X}^1$, $\overline{X}^2$ *coordinate axes,* $\overline{X}^0 = T$ *– orthogonal hyper-plane of* $\overline{S}$

following equation 14.25) came together. From the consequent acceleration (due to mutual repulsion) they lost energy, which stabilized their mutual configuration.

The above roughly emulates the observed emergence of central civilization and the convergence of 12 civilizations into one (Wilkinson 1987; and his Chapter 12 in the present book, especially his world system chronograms, Figures 12.1a, 12.1b, and 12.2). In time, this process of progressive mutual attraction and loss of energy leads to the present “current epoch” (circa year 2000), in which a single nodal pattern prevails, the effects of which are no longer restricted by geographic distance (Williamson 2008a).

By "system center" let us mean the social spatial region surrounding the nodal parties, within which, referring to their force magnitudes, $|f^R_\alpha| > |f^A_\alpha|$; and let the remainder of the space be called the "system periphery." Clearly the identities of nodal parties have changed over time. Such changes might happen if, occasionally, a party previously in the periphery reached the system center with sufficient momentum as to greatly alter the relative nodal–peripheral alignments and, possibly, to knock one or more established nodal parties into the periphery, via transfer of kinetic energy. (Compare with the concept of power transition: Organski 1968; Organski and Kugler 1980; Wayman 1983, 1989; Williamson 2008b [2005]: 54, 63.)

The period from 1945 to the collapse of the Soviet Union also invites a simplification in which, roughly, there is a single pair of opposing central parties – the United States versus the Soviet Union (disregarding all other nodal parties). Let us suppose that, in space-time geometric terms, these two nodal parties have assumed positions of negligible acceleration. (This would correspond to loss of energy plus equality of mutually attractive and repulsive force terms.) Then each would feel a powerful net repulsive force from the other and these forces would be equal and opposite (depicted in Figure 14.8). Let us call this the "bipolar approximation" to the global system. That circumstance implies a negative correlation between the linkages of third parties to the United States versus to the Soviet Union during the indicated period. This expectation is modestly sustained by a scatter plot of corresponding data (Figure 14.9), based on combined trade data (Barbieri 1998). (Further discussion is at Williamson 2008b [2005]: 48, 51–52, 54.)

Another aspect of the current epoch concerns the other two prominent nodes of the mid- to late twentieth century: Britain and France. At that time several other nations (West Germany, Japan, perhaps China or India) possessed equal or greater amounts of the material resources widely regarded as conferring global influence; nevertheless, it is the first two and not the latter three that then occupied the nodal role. Note also the tardy (post-1940) entrance of the United States into a central global role, well after the time at which it had reached the first rank of materially endowed nations. It is as if the responses of the various parties lag the present situation and respond to the past reality. These historical delays at least roughly fit the premise of a finite rate of signal transmission of a relativistic space-time model; and the condition $t'_j > t$ in equation (14.26) fits the identities of the actual nodal parties, Britain and France. (This, of course, is a very loose fit; for instance, do the established central parties respond to each other promptly, as they should,

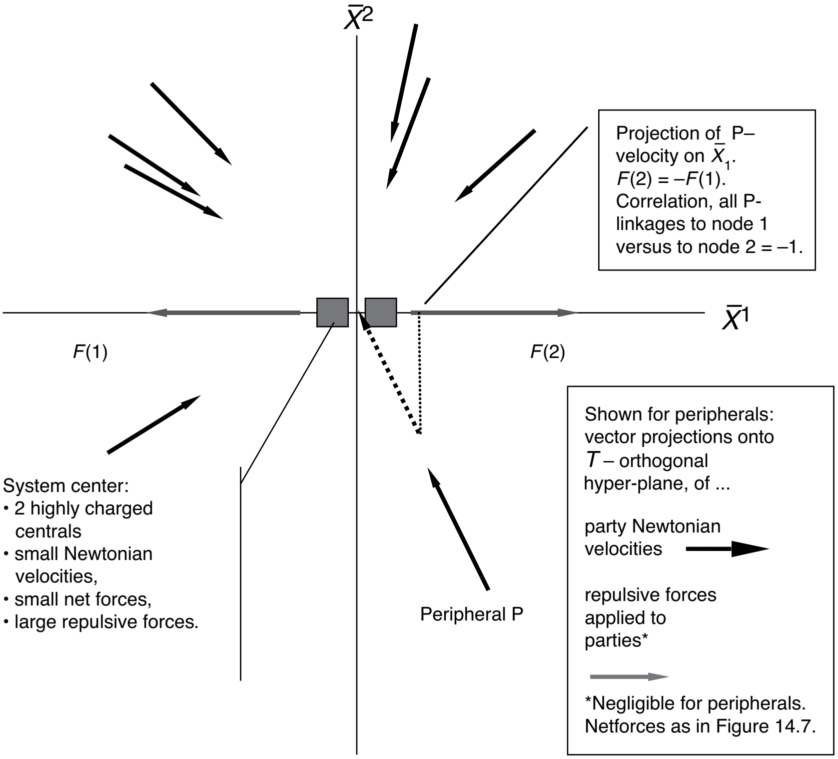
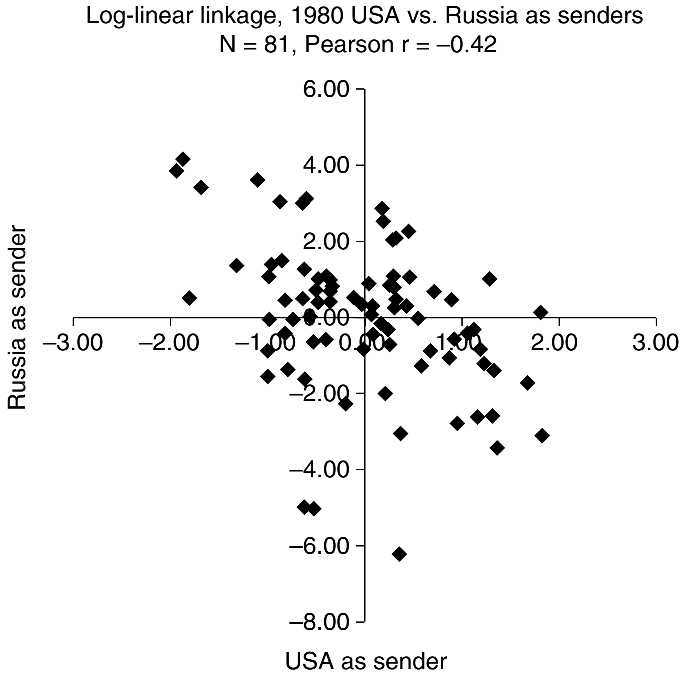


Figure 14.8 Current epoch, bipolar approximation, space sub-continuum diagram showing $\bar{X}^1$, $\bar{X}^2$ *coordinate axes,* $\bar{X}^0 = T$ *– orthogonal hyper-plane of* $\bar{S}$

given their mutual proximity in this picture? Tests of such questions need to be devised and carried out.)

In sum, when the present-day conditions described above are input to equation (14.26) (or 14.27), we see the results described in Table 14.2, above. These results agree modestly with the various pieces of evidence (nodal pattern, bipolar approximation, time delays in nodal positions) already cited. In addition, the dynamics from primitive to current epochs qualitatively emulate the historically observed convergence of civilizations.



Source: By permission of Global Vision, Inc.

Figure 14.9 Evidence bearing on Figure 14.8

WHAT MIGHT BE PREDICTED FROM THIS MODEL?

As was made clear at the outset, the present development of the proposed societal space-time model still lacks a machine-computable basis; which is to say that, at a mathematical, computational, and empirical level of detail, the proposed model remains incomplete. Until that level is reached, one cannot reliably begin to say what is, or is not, predictable. Interesting conjectures can be made, however, concerning various predictions that might be possible, as follows:

1. Predict response times of all pairs of parties (dyads) to each other; that is, of dyads according to how distant they are imagined to be from each other in the social space. From the above, an example is the delay of peripherals, in responding to the decline of Britain and France and to the rise of the United States. (The latter would need to include the

effect of US domestic reluctance to assume a global leadership role, as this is usually regarded as a significant substantive consideration.) The critical question is, for all dyads in the system: can such modal response times be established in a consistent way from the perspective of various indicators?

2. Predict short-run rates of change in central–peripheral linkages, in terms of various correlates (exports, armaments received, troop deployments hosted, and so on) of linkage. In the above-proposed picture of the system center, the central parties are wiggling around over time (see point 3, below); that is, their mutual spatial orientations are changing. This means that (in model terms) linkages are fed by two factors confounding each other: peripheral trajectories and central motions. "Short run" is here defined as periods over which the changes due to those central motions are small enough to be ignored. Putting the matter in empirical terms, the short run means: before central parties have had time to appreciably and significantly change their relationships to one another or, in coordination, to the peripherals.
3. Predict the probability distribution, over time, of radical realignments of peripheral–central linkages, of which there are several possibilities:
   a. The central system has angular momentum, relative to the peripherals (and relative to an "inertial" system; Einstein and Infeld, 1938). This momentum implies coordinated shifts in all central–peripheral linkages.
   b. The central parties chaotically rearrange their relative positions in response to their residual momenta; this implies uncoordinated shifts in central-peripheral linkages.
   c. A party formerly in the periphery collides with the center, resulting in chaotic disruption of central and central–peripheral relationships ("power transition"; Organski 1968; Organski and Kugler 1980).
   d. In a special case of point c, a peripheral party previously ejected from the center via prior collision or power transition (itself or other party as entrant) re-enters the system center. Given many subsequent re-entries of a given party, they should be progressively less energetic, that is, less disruptive. (Formally this progressive effect is due to repeated radiation of energy which corresponds, empirically, to gradual achievement of full equality-reciprocity relative to other centrals.)

   The important idea is that which of the above changes happen, and exactly when, may not be predictable because those aspects depend on exact knowledge that may not be available, namely (in model terms) of relative position of centrals, and of position and trajectory of any peripheral that is to collide with the center. Nor necessarily will it be possible, empirically, to disentangle the effects. Exact knowledge is required because of extreme sensitivity to initial conditions. In brief, the future of the central system may be chaotic; however, it may still be possible to form an idea of the approximate timing, i.e. the hazard rates, of such events. (Years away? Decades? Centuries?)

4. Distribution in time of major war risk and probability of opposing alliance formations (a secondary effect of point 3, above). The model presented here talks about changes in a geometric picture that omits wars and alliances; however empirical phenomena corresponding to points 3a through 3d above are often conjectured to relate to alliances and wars (for example by Organski and Kugler in the previous citations; compare their "challenger" with the idea, here, of a central system entrant). Further work on such connections might imply corresponding ideas about the timing of future wars and of alliance relationships.
5. Predict rough timing of emergence of new centrals and their identities: China? India? Brazil? . . .? These are the parties discussed in point 3c. Ability to predict such timing entails greater information about specific parties, than is presumed in point 3.
6. Time horizon defining limit of forecasting of short-run changes described in point 2. How soon the next central disruption occurs, points 3b through 3d, may also be the limit or "time horizon" of predictability in point 2.
7. Estimate the time required for the historic structural (central–peripheral) epoch to end, corresponding to loss of kinetic-potential energy, after which all parties remain permanently near the center of mass of the system. This would correspond to the end-state of Wilkinson's evolution (1987; and Chapter 12 in this volume) evolution of separate historically distinct civilizations into one global civilization.
8. Estimate error bounds for each of the various quantities – times, linkages, other interactions – predicted in the above.

In the above note, first, that the primary effects capable of observation are patterns of linkage in the system, including the nodal structure; that is, they are to be found in changes, over time, in data like that presented in Figures 14.4 and 14.9 of this chapter.

Second, the effects described assume the existence of a central system having reached "stability" in the limited sense that the centrals of the moment will remain clustered together until disrupted by a new entrant (from the periphery). However, the effects in points 3a and 3b depend on the central system not having reached stability in the different sense that they have not shed some measure of residual linear or angular momentum. (One might visualize the centrals roughly as a collection of billiard balls attached to each other by springs: push them close together and the repulsive force prevails, put them far apart and the attractive force prevails; the balls cannot escape but they keep wiggling around and the whole configuration may be rotating, relative to any inertial reference frame.)

CONCLUSIONS

Linkage, and R-process in the form of one party emulating the internal development of another, fit together: each concept is based on the inner product of force on one party and velocity of another; equations (14.13) (R-process) and (14.26) (linkage). (As discussed in the section on "Linkages in the Global System," the differences are in timing and in which parts of the spacelike force are to be involved.) Substantively, also, one can think of the linkages involving a specific party as the external manifestation of that process which, internally, is manifest as the political-economic-societal development of that party; in geometric terms, the process resulting from mutually attractive and repulsive forces at respectively large and small mutual distances.

Returning to the other conceptual element, linkage and societal space-time fit together because the nodal pattern is built into the space-time model: the pattern requires, it can be shown, that c be finite; that is, that there be systematic delays in response of parties to signals (in the sense of the earlier section on "Signals") emitted by other parties in the global system (Box 14.1). The space-time signal lags that characterize the nodal pattern also rationalize the R-process: developmental response delays are plausible. Further, the velocities and accelerations coming from the space-time picture define time-varying R-processes, via equations (14.17), (14.21a), (14.21b), and (14.22). In turn, the latter imply changes over time in the utilities appearing in the McGuire (1965) picture of the equivalent duopoly situation, cited on p. 364 (suggesting dynamic over-time treatment of time-varying utilities as a future topic).

An interesting question was raised by another participant in the forum where this chapter was first presented: in moving from macroscopic classically sized phenomena to the more microscopic (for example, atomic level), physicists encountered new types of phenomena requiring a new conception, namely, quantum physics. The "old" macro- and the "new" micro-level then needed to be reconciled into a more general picture containing both; which was successfully done. (Yet to be done is a satisfactory synthesis of the latter, special relativistic quantum theory, with gravitational phenomena and general relativity.) Will a similar macro–micro tension – involving perhaps the individual human decision-maker as the analog of the atomic level – arise, requiring its own reconciliation? Is the fact of strategic thinking by humans part of that tension? To such questions the utility contours mentioned in the above are meant as one contribution; however such issues remain mostly to be explored.

Because of the various logical connections explored in this chapter, the modest empirical evidence cited in the section on "Proposed Field-Theoretic History of the World," in relation to the linkage concept, actually bears on the whole model. (See also the additional points summarized in Williamson 2008b [2005]: 65–66.) Yet unanswered is whether this model produces an empirically disconfirmable but confirmed picture of the global system, and in what level of detail. Perhaps (paraphrasing still another participant in the seminar where this was presented) there are specific very long-range dynamics that might still be playing themselves out in modern history, that the model might capture. Or, perhaps more plausibly, the model might give only the most very undetailed representations. (Chaos seems always to be working against long-run order.) Again to highlight a point, one way of answering such questions requires, as noted at the start of this chapter, what presently is lacking: a machine-computable (that is, operational) model.

Finally, the possibility and goal of such a machine-computational simulation of global societal evolution is raised, realistically it is hoped, based on further development of the ideas presented above. The possibilities named in the previous section, "What Might be Predicted from This Model?" constitute potential agenda items for the use of such a machine-computational simulation. To explore the great variety of possible alternative global histories, stemming from varying parameter values and starting conditions, and from random (Monte Carlo) variation, such a simulation would employ supercomputation to step through a great many iterations, perhaps millions of them. For example, the quantity of "charge" on the various parties, corresponding to their respective power assessments, might be varied; and, similarly, their mutual distances at the historical moment where one begins to run the model. One might, for example, picture the various local civilizations as clusters randomly occurring in the initial global system configuration of charges and distances. A great many alternative model details would also be explored. One would want that such iterations then turn out definitely to emulate the actual world "well," "moderately," or "poorly," using criteria that remain to be developed.

NOTE

1. The idea, discussed here, that parties linked together are characterized by similar orientations of force and velocity vectors, might be compared with the idea that group members are characterized by a definite common orientation of their attribute vectors. The latter appears in the section on "Social Annealing-Nucleation Process" in Chapter 11 in this volume by Karasik.

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15. Computational dynamic modeling of the global state space

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INTRODUCTION

While nominally distinct, the above two ideas – computational dynamic modeling and state space of a global system – are fundamentally connected. In this introduction I start with the former, global modeling, and briefly identify the idea of state spaces. Then, in subsequent sections I develop a particular global modeling scheme. Finally, drawing on the prior discussion, I use the state space framework to draw several conclusions and suggestions about global modeling and related issues.

As used here, the term "global" refers to a scope that includes the entire Earth, in both human and non-human aspects, contemplated (if not yet realized) as a unified subject of study. The term "dynamic" reflects that time is to be explicitly a variable; the intent is to reflect not only what happens, but when it happens. These calculations, of what and when, are to be done to whatever degree of inferred or presumed accuracy is appropriate, in each individual predictive circumstance. Some global modeling is already dynamic in this time-specific sense, particularly econometric models; and there are a few more general dynamic models (e.g. Hughes 1999; Hughes and Hillebrand 2006; Meadows et al. 1972). The further idea being expressed here is that dynamic modeling be inclusive of more variables to the maximally feasible extent, and that it utilize a full repertoire of methods, including some discussed below.

Further, although the focus in global models of the sort I am considering is typically on politically sovereign nations as the behavioral units (agents), alternative regional, subnational, and transnational, and other types of defined units, such as geophysical, are also to be contemplated. The rationale is that such a broad scope is necessary because of the likelihood of important couplings (functional relationships or causal connections) among diverse human and non-human phenomena. For speculative examples of such couplings, see the matrix in Chapter 2 of this book and its discussion there and in this chapter, below. In what follows, I refer to this figure as the Couplings Matrix. (To consider a specific example in regard to the choosing of agents, one would probably not regard the nation as a suitable unit on which to model weather or climate.)

As the above may suggest, an important criterion is that global modeling development follow an extremely general scheme, capable of synthesizing, competitively evaluating, and otherwise accommodating a diverse assortment of factors and candidate methods, partial models, and model fragments. The modeling scheme presented below fits that requirement. Thus, the discussions in the various chapters of this book can be so accommodated, including the examples of empirical predictive work (by Bueno de Mesquita, cited in his Chapter 18; by Tago and Singer, Chapter 8; and by Wayman, Chapter 13). Further, the above remarks apply to a development effort currently under way, a "demonstration global model" (Global Vision, Inc. 2008), in which effort the author of this chapter is a participant. To make the discussion somewhat less hypothetical, some comments refer to this specific project.

Concerning, now, state space, in sum this idea is that, at any one moment in time, the world can be described by a collection of "state variables," as explained below. State space is a multidimensional space spanned by coordinate axes, each of which corresponds to one of those state variables. The world is then described at any one moment as a single point having coordinates, each of which is the momentary value of the corresponding state variable. As those values change over time, the point moves about, tracing a trajectory through the space. Let the collectivity of coordinates be called the system state and let the point itself be called the phase point. (For further elaboration see Arrowsmith and Place 1990: 1; see also the expressions "phase space" and "configuration space," Baker and Gollub 1990: 7 and *passim*, and Penrose 2004: 220, which specialize and overlap the concept of state space.)

GENERAL DYNAMIC MODELING SCHEME

In this and several sections following, I turn to specifying a particular model scheme. This is not a complete specification of a model; rather it is a list of constraints on how that specification should appear. It should at once be acknowledged that this scheme is certainly not the only one that could be chosen (and it reflects the belief that explicit numerical modeling is the appropriate route to prediction); however the present choice does have great generality and power, and it leads directly and easily to the state space concept; thus the reasons for choosing it.

As mentioned, at any specified time, t, each of the state variables has a definite value, thus the phase point has a definite location. The model regards that, though it may be unavailable to an observer, precise information on this location does exist; that is, its probability distribution is the Dirac delta function (Byron and Fuller 1992), which can be thought of as the limit of a normal distribution as the standard deviation approaches zero. Such definiteness excludes any fundamentally indeterminate probability distribution (that is, one with non-zero standard deviation), so this model scheme might be called a "classical" as opposed to "quantum" version. Note that this does not exclude uncertainty due to information that exists but is unavailable to an observer or is available but imprecise.

Imagine each variable has a definite rate of change at *t*, which the model is to represent in a particular way, equation (15.1) below. Call the quantity on the left-hand side of this representation an output of the model. For example, in the demonstration model, national gross domestic product (GDP) will be the variable of primary interest (though see the section below on the "change order" or variables) and, for each of several nations or other agents, its estimated rate of change will be an output. We may take as a definition that a state variable is a variable having its change rate represented in the manner of equation (15.1) and its constraints. (See also the section, "Earth Global System State Space," below.)

To further sharpen the above notions, in what follows let x^k denote a variable corresponding to the *k*-th output. "Dynamic" then means: given a picture of the state of the world at some referent ("present") moment in time – that is, given the present coordinates of the phase point (the state of the world), there exists a computational program for constructing immediately past and future states of the world. That is, given at time *t* a current world description in the form of a sequence of N-many quantities $x^1(t)$, $x^2(t), \ldots x^k(t), \ldots x^N(t)$ and, possibly, L-many quantities $E^l(t)$, for each such quantity $x^k(t)$, its rate of change $\mathrm{d}x^k(t) / dt$ is given as a function f_k of some or all of them:

$$dx^k(t) / dt = f_k \, [x^1(t), x^2(t), \ldots x^k(t), \ldots x^N(t), E^l(t)], \quad l = 1, \ldots L \tag{15.1}$$

where the k^{th} variable $x^k(t)$ is, itself, among the possible contributors to its own rate of change and the superscripts are indices (not powers). (Note that any predictive equation not explicitly showing a change rate can be rewritten so that it does: subtract the "old" output value from both sides of the equation that shows the "new" output value on the left, then divide both sides by the time difference, Δt. The result will be a finite approximation to equation 15.1.)

While the $x^k(t)$ vary continuously, the $E^l(t)$ do not; it is sufficient that they be allowed to equal either 0 or 1, only. (Weights applied to them can assume any value, however.) As reflected in the notation of the equation and with an important exception, namely the $E^l(t)$ discussed in the next section, every variable on the right is also named, on the left, as the subject of a change rate calculation (namely the k^{th} variable $x^k(t)$ is so named in the k^{th} instance of equation 15.1) and every variable named by its change rate on the left also appears as an argument on the right, in the expressions f_k. (The contribution of any $x^j(t), j = 1, \ldots N$, in any particular f_k can be made zero, if desired. Note also that one of the input variables, say the T^{th}, could be time itself, $x^T(t) = t$, for which the function corresponding to $dx^T(t)/dt$ is the constant $f_T = 1$.)

Combining all the above, a state variable is one that fits the description just articulated by (15.1) and a model is dynamic when just such a description applies. (Compare equation 15.1 with the differential equations found in Rashevsky 1968 and Richardson 1960a: roughly the same core idea as here.)

Further, while the input variables $x^k(t)$ and $E^l(t)$ on the right-hand side of (15.1) nominally refer to the argument t, this is not meant necessarily to preclude use of information from previous times $t', t'', t''' \ldots < t$. The rationale would be that the state of the system at the present moment includes a memory of conditions or events having occurred at the indicated prior times. (For example, see Abelson 1963; Williamson 2008: 11–12.) Corresponding notation might then be elaborated as $x^{k,n}(t) \equiv$ input factor k, from period $t - n\Delta t, n = 0, 1, 2, \ldots$; similarly for $E^{l,n}(t)$.

In essence, a dynamic model means the ability to bootstrap from a referent moment to an immediately past or future moment; for given a value of the left-hand expression in equation (15.1), one can approximate the value of x^k at an earlier or later time $t + \Delta t$ as:

$$x^k(t + \Delta t) = x^k(t) + \Delta x^k(t, \Delta t) \tag{15.2}$$

where:

$$\Delta x^k(t, \Delta t) \equiv \Delta t \cdot [\mathrm{d}x^k(t) \,/\, dt]. \tag{15.3}$$

The qualifier "immediately" is meant to reflect the idea that the smaller the value of Δt, the more accurate the approximation. For an earlier time, Δt would be a negative quantity. In words, equation (15.2) expresses the value of x^k as equal to its value at the "present" moment plus the product of the elapsed time with the time rate at which x^k is changing.

(The above, called Euler's method of approximation, entails potential distortions that are addressed by other similar but more elaborate numerical approximation methods; however the basic idea, estimating instantaneous change rates from finite differences, is the same. See Edwards and Penney 2008: Chapter 6, pp. 430–476.)

Note that the dependent variable in equation (15.1) is expressed as a rate of change, while (15.2) and (15.3) together refer to a difference from one time period to another. This points to a distinction between the abstract reasoning, expressed in equation (15.1), and what is actually to be numerically estimated or inferred by empirical data and calculations. The quantity to be addressed by empirical means is $\Delta x^k(t)$ (rather than the analytic abstraction $\mathrm{d}x^k(t) / dt$); empirical change data come in the form of finite differences, not differentials. Thus, the empirically functional form to be estimated is the finite increment $\Delta t \cdot f_k\,[x^1(t), x^2(t), \ldots x^k(t), \ldots x^N(t), E^l(t)]$, (rather than the right-hand side of equation 15.1, which, however, can then be estimated by dividing the finite increment by Δt).

In addition, numeric estimates will have residual error, which can be denoted by:

$$r^k(t,\Delta t) \equiv \Delta x^k(t,\Delta t) - \langle \Delta x^k(t,\Delta t) \rangle, \tag{15.4}$$

where $\langle \Delta x^k(t,\Delta t) \rangle$ is a model estimate of $\Delta x^k(t,\Delta t)$.

DISCONTINUITIES

Now to the important exception, the $E^l(t)$ –type arguments of equation (15.1), of which there are two aspects. Addressing the first of these, it is implicit in the left-hand side of (15.1) that the x^k are differentiable and therefore continuous functions of time (otherwise the usual idea of differentiation is undefined). Thereby, discrete variables – those defined only for nominal or integer values – are excluded; it is these latter types, if they are present, which are represented by the arguments $E^l(t)$. This second type of argument thus represents the possibility that discrete events or factors might, themselves, affect rates of change of continuous variables, such effect to be represented by flipping one or more $E^l(t)$ between values of 1 and 0 (corresponding, respectively, to occurrence/presence or non-occurrence/absence/resolution of the discrete event or factor) whenever the change of status occurs. Such variables might include events such as onsets and terminations of militarized interstate disputes and wars; also, the proliferation events discussed by Tago and Singer, Chapter 8 in this book, as well as many other kinds of event. For example, in the contemplated demonstration model, the inputs $E^l(t)$ are to take the form:

$$E^{\mathrm{l}=j,n}(t) = y^{j,n}(t, \Delta t) \equiv 1 \text{ if conflict factor of type } j, j = 1, 2, \ldots, \text{ occurred}$$
$$\text{during time period } t - n\Delta t, n = 0, 1, 2, \ldots;$$
$$\equiv 0 \text{ otherwise;} \tag{15.5}$$

upon occurrence of the indicated conflict event, the value jumps immediately from *0* to *1* (or vice versa in the event of a termination). This quantity is then multiplied by a weight which quantifies the rate-of-change impact of the event value.

Thus, in the above, rather than by a continuous function, discrete events are assessed by a pseudo random number table or generating function, exogenous to equation (15.1), of what the model regards to be transpiring, underneath – namely, the presence and, possibly, continuous variation of event risks, quantified in the form of hazard rates. Though not explicitly represented in equation (15.1), one can imagine that, to each discrete event, there is a corresponding such hazard rate, which can (but need not) be regarded as one of the continuously varying arguments x^k of equation (15.1). (One should also acknowledge that a nominally continuous variable may be only approximately so. Total number of humans in a population may be treated as continuous, though humans cannot, we suppose, meaningfully be subdivided into fractions of a human. Or this might be addressed, for example for households, by saying that 3.2 members – or like number – is the "expectation" of household size.)

Turning to a second aspect of discrete events: what cannot happen in the above procedure is that the change in value of $E^l(t)$ at the moment $t_{0,}$ corresponding to the discrete event, takes a form such as to induce a discontinuity in the derivative of $x^k(t)$ on the left-hand side of (15.1). For example, if $E^l(t)$ jumps between 0 and 1, the impact cannot be simply a multiplication of some input, $w \cdot [E^l(t)][x^j(t)]$, w a weight, which then additively contributes to the function f_k, for then the jump in $E^l(t_0)$ would translate directly to a jump in the corresponding $dx^k(t) \,/\, dt$, leaving the latter undefined at t_0.

Though the above may seem to require a choice between continuity and discrete change, there are two approaches whereby one might possibly have one's cake and eat it, too. The first, which I mention only in passing, is to seek to adapt methods (for example, Byron and Fuller 1992; Rohrlich 2007) appearing, *inter alia*, in treatments of the physics of electrically charged particles. These methods combine continuous and discrete phenomena (via the Dirac delta function) in a fully consistent manner. This approach is well beyond the present scope and, in any case, remains to be developed. (It will be a demanding undertaking.)

A second, much simpler approach is to imagine that the change in the event function value is not discrete but, instead, approximates a continuous function; say, for definiteness, a logistic curve, which executes a very rapid smooth transition to a new value when the event occurs. Suppose the time interval has some fixed value, say $\Delta t = 1\ year$, relative to which the functional transition period is much shorter; one can then imagine that a transition occurring at t is mostly complete well before $t + \Delta t$. The discontinuous transition is then an acceptable approximation, that is, a logistic curve with increasingly rapid transition looks progressively more like a step function; and this is assumed in the present discussion.

AN IMPLICATION OF LIMITED INFORMATION

A further implication follows from the character of discrete events as probabilistic; for then their timing is indeterminate thus, also, is the timing of their impact on the evolution of the system. Thus the model must act as though we do not know whether, for a given event in a given time period, the event tag *0* or *1* should be input. Note that the above holds even if the underlying probability is continuous; and even for a classical (objectively deterministic) system, such as posited in this discussion. Complete information is regarded to exist but to be unavailable.

A similar situation holds concerning continuous variables (including probabilities); for them, the limitation is in their precision. Any such numerical value used as an input is subject to some degree of uncertainty concerning its true value; that is, it may be in error. This possibility, in turn, raises the question how sensitive is the evolution of the system to such errors.

I return, later, to some implications of the above kinds of uncertainty. One immediate consequence, however, is that results from individual runs of a simulation mean less than do average results assessed over many individual runs, since the latter give some representation of the probability distribution of results, when indeterminate factors are at work. In other words, a “best” guess as to what “actually” happens, in the simulated world, is to be determined by running the simulation many times with starting conditions that are fixed except for new random number inputs and/or for incremental variations in continuous input values, then viewing the distribution of output values.

CHANGE ORDER OF REFERENT VARIABLES IN A MODEL SCHEME

A further consideration distinguishes between what might be called first-order change, versus second-order and higher-order change. “First order” refers to the change in an initially introduced or referent quantity over some time period. If $x(t)$ is the quantity at time t, then its first-order change is given by $\Delta x^k(t, \Delta t)$ in equation (15.2). With error term included, the first-order change model is:

$$x^k(t + \Delta t) = x^k(t) + \langle \Delta x^k(t,\Delta t)\rangle + r^k(t,\Delta t) \tag{15.6}$$

In words, the value of x^k in the year $t + \Delta t$ will equal the sum of three terms: the value of x^k in the referent year t, the model estimate of the change in x^k from t to year $t + \Delta t$, and the error in that estimate. The second term (the model estimate) is what the computer program will calculate; the first term will come from an input table or have been calculated in a previous step. The third term is uncontrolled and constitutes the part (namely error) that one seeks to minimize.

“Second order” refers to the following. Let us define a new variable:

$$\Delta^2 x^k(t,\Delta t) \equiv \Delta x^k(t,\Delta t) - \Delta x^k(t - 1,\Delta t), \tag{15.7}$$

where the second term on the right denotes the change that occurred from the next previous period to the previous one; so we can think of the quantity on the left-hand side as the “change in the change” of the referent variable. Using similar notation as before, let us define residual error by:

$$r^{2,k}(t,\Delta t) \equiv \Delta^2 x^k(t,\Delta t) - \langle \Delta^2 x^k(t,\Delta t)\rangle, \tag{15.8}$$

where $\langle \Delta^2 x^k(t,\Delta t)\rangle$ is a model estimate of $\Delta^2 x^k(t,\Delta t)$. The second-order change model is then:

$$x^k(t + \Delta t) = x^k(t) + \Delta x^k(t - 1, \Delta t) + \langle \Delta^2 x^k(t,\Delta t)\rangle + r^{2,k}(t,\Delta t). \tag{15.9}$$

In words, one uses the estimated second order (“change-of-change”) values to estimate the first-order changes themselves, by adding the former to the latter, previously observed [*period t*] − [*period t* − Δt] change values. The change in $x^k(t)$, in going from the referent time t to $t + \Delta t$ then is given as its value at the referent time, plus the change in going from the previous t

$- \Delta t$ to the referent time, plus the estimated change in the change, in going from the referent time to time $t + \Delta t$.

Third- and higher-order changes would be defined in a similar recursive manner. However, consistent with the above, the indicated shift is not just a shift in the dependent variable (the left-hand side of equation 15.1) at time $t + 1$. Rather, as previously indicated, x_t (that is, the variable referred to its value at referent, "present," time t) is, itself, one of the independent variables possibly appearing in the first-order change expression; that is, it is one of the input variables on the right-hand side of (15.1). Then, in the second-order expression, it is replaced also on the right-hand side by $\Delta x_t \equiv x_t - x_{t-1}$; similarly, to maintain the structure of (15.1) the other continuous inputs are to be replaced by their corresponding changes. Higher-order change expressions would likewise have the next-lower change order of the same variable for the preceding time period on the right-hand side. The significance is that, given the above conventions, regularity may be observed at a higher order, even though none might be found at the lower order. (An example is in Williamson 2002.) In the demonstration model, the initially introduced quantity is GDP, so that first-order change is in that variable, itself, and the second-order is change-in-the-change of GDP, and with the corresponding substitution to prior period change in GDP on the right-hand side.

CHOOSING AMONG ALTERNATIVE FUNCTIONAL FORMS

A final model scheme consideration is the form that equation (15.1) will take, upon further elaboration, on its right-hand side. A very simple form is that the latter be a linear combination of inputs. This has the virtue that there are very general analytic tools for solving and otherwise working with linear equations. The defect is that it seems unrealistic to suppose that linear forms can remain accurate for more than comparatively short time periods. Depending on context, "short" times may still be useful; however the limits of computational accuracy will always be at particular issue with such models. More general, non-linear alternatives are also available; these may be more realistic though more difficult to use. An important aid in such use is computer simulation to approximately specify a model, where analytic (closed-form) solutions are unknown or non-existent. One interesting approach is feed-forward artificial neural networks (Haykin 1994). Applications to international conflict behavior include Karasik and Williamson (1994), Tago and Singer (their Chapter 8 in this book), Williamson (1996), and Williamson and Bueno de Mesquita (2000).

More general is the method of genetic programming (Cowan 2007: Cowan and Reynolds 2003). It has the following merit. Normally, one develops a model-like equation (15.1) by picking functions of input data that reflect one's ideas about what mechanisms, causes, processes, and so on are at work to produce the result, then testing the model on empirical data, using the functions chosen. A problem is that global social and other subsystems have large numbers of different human and non-human phenomena, factors, processes, variables, and so on that mutually affect each other in a variety of ways, typically understood poorly or not at all. Consequently, there may be no relatively prominent good ideas about what functions to use in the first place, because there are so many equally plausible ones from which to pick. Also, there may be a great many quite different functions variously appropriate to the various distinct aspects – human, societal, technological, environmental – of the (global) system being modeled. Considering the above possibilities, there is a greatly varied territory to be covered. An "open-ended" approach such as genetic programming is suited to covering that territory in a relatively efficient way. (It does this by belting out, and evaluating the accuracy of, a great many functional possibilities quickly, within whatever constraints of form the user may have specified.) This approach seems sufficiently general that it can include many more specific options, among them linear and feed-forward neural network models, also hybrids that combine various options in various ways in a single computational model. (For example, pieces of a model might be linear combinations of variables – say, several economic indicators or several conflict indicators – with those combinations themselves then further combined in non-linear ways.)

BROADER CONTEXT OF GLOBAL MODELING

Stepping away, now, from the details of a global modeling scheme, let us again consider the (at present, entirely speculative and empirically untested) matrix that appears as the Couplings Matrix in Chapter 2 of this book (Table 2.2). The rows and columns of this matrix are labels for various bundles (sets) of variables. Each bundle corresponds to some nominal underlying theoretical concept or some normatively defined problem or issue area (for example, war, global warming, public health, economic development, and so on). A given column number denotes the column representation of the bundle having the same row number. For example, row 8 is marked for a bundle of factors labeled "demography, population instability"; column 8 represents that same bundle of variables.)

In this table, cell entries identify hypothetical non-negligible ("strong") couplings from row entry to column entry. These couplings are to be defined numerically by various constants, parameters, and variables occupying whatever functional forms would appear in any specific realization of the right-hand side of equation (15.1). The general scheme is: an occupied cell signifies the idea that one or more variables of the corresponding row factor strongly impacts the rate of change of one or more variables of the corresponding column factor. Using language from my earlier discussion, a given row corresponds to its variables in their roles as inputs to a change function. The column of the same name corresponds to computing outputs and estimating the corresponding period changes, then updating each variable by adding its change estimate to the previous value. If this process, done once for all outputs in the model, is regarded as one computational cycle, then the next cycle corresponds to the updated output variables, symbolized by the rows of the figure, being entered as the inputs for computing the next round of changes; and so on, for as many cycles as may have been chosen (or until the computer is stopped). Again, each succeeding cycle occurs at a new time incremented from the time of the previous cycle by the amount Δt.

In the cells of the matrix, the symbol • represents a non-negligible coupling operating in "normal" times. For example, the dot in the cell with row number 8 and column number 1 means that "demography, population instability" (row 8) is considered at all times to affect "general health indicators, symptoms" (column 1). The symbol + supposes a contingent strong coupling, actual coupling only following occurrence of some discrete named event that does not normally happen. The inputs $E^l(t)$ (with tag values *0* or *1*) in equation (15.1) include this contingent couplings type, in addition to more "ordinary" discrete events (conventional war onsets and terminations, and so on). More catastrophic contingencies are shown in the Couplings Matrix. The net effect of all occupied cells in the k-th column, corresponding to output *k*, is expressed by the left-hand side of equation (15.1).

If one imagines the Couplings Matrix of Chapter 2 to be replaced by either a truly gigantic or else highly selective matrix (see below) representing each individual variable with its own row and column, rather than the bundles shown in the Couplings Matrix, then – for the continuous variables – the occupied cells in the k-th column would correspond to those (row) variables $x^i(t)$ in the right-hand side of equation (15.1) for which the partial derivative–ordinary derivative combinations $(\partial f_k / \partial x^i)\cdot(dx^i/dt)$ are non-negligible.

Continuing with what we see in the Couplings Matrix, at top left the caption reading "All factors to be geo-encoded where applicable" means that, in a complete realization of the modeling concept, a geographic information system would be used to code information that is specific to geographic location. For example, information on named cities, in those instances where they are conceived as dimensionless points, would include their geographic coordinates; information on entities conceived as having a non-vanishing geographic extent (for example, sufficiently large cities, nation-states, regions) would include geographic coordinates of the vertices of polygons roughly approximating their boundaries (or equivalent scheme for digitizing regions).

In sum, the Couplings Matrix speculates, in an unsubstantiated but reasonable way, how various problem and factor groups might be connected. To emphasize a point made earlier, the cell entries in this figure show possible, not at this juncture necessarily realistic, couplings and they are not quantified. To quantify and realistically estimate actual couplings is a significant part of the global modeling agenda. To emphasize the connection between the above and earlier discussion: the approach of genetic programming (GP) provides a possible means for finding and evaluating suitable functions for translating row factor antecedents into column consequences; that is, for quantifying and estimating the couplings.

LIKELY EXTREME IMPRACTICALITY OF A FULLY ADEQUATE GLOBAL MODEL, PLUS PARTIAL CORRECTIVES

In this and the remaining sections I enter into a discussion involving modeling requirements that are patently (even astronomically) unrealistic. Recognition of this unrealism is itself an important conclusion; in addition the discussion will help to define a limiting goal and to establish connections to other forecasting and global studies endeavors.

As a corrective to any optimistic tone so far, it is important to keep in mind that the computational dynamic global model concept introduced above (or any other such concept) is, at best, an acceptable approximation to an ideal, pristine form of a model which, itself, is very likely to be a practical impossibility because it would be unmanageably large. As may already be intuitively obvious to the reader, this gap, between ideal and practical, necessarily is huge. How huge can be seen from the following plausible account of the elements that might ideally be involved. Of the approximately 25 factor and issue bundles shown in the Couplings Matrix, suppose on average we choose to pay attention to ten variables per bundle. (Such a number does not seem too large, given the subjects indicated in the Couplings Matrix.) Then we are talking about approximately $25 \times 10 = 2.5 \times 10^2 = 250$ distinct variables; let us call them the substantive variables.

Of these 250 substantive variables, let us suppose that 25 have geographic pair specificity (for example, trade and/or violent conflict between one party and another); that leaves $225 = 2.25 \times 10^2$ other substantive variables. Now, that number is geographically non-specific: it disregards that the same substantive variable may have differing values depending on geographic region. The number of such regions will vary considerably, depending on the degree of spatial resolution – global, regional, local, and so on – of the variable in question. Purely as a further guess, let us suppose that these geographic variations are, on average, defined with respect to, say, $2 \times 10^2 = 200$ geographically specific regions of the Earth. (I have picked this number as the approximate number of nominally sovereign nation-states at present. For some variable types that number would be too small.) Combining the above two numbers by assuming that each substantive variable is also regionally specific gives a combined total of $(2.25 \times 10^2) \times (2 \times 10^2) = 4.5 \times 10^4 = 45\,000$ substantive-geographic specific variables. Let us call this the total of "Group A."

In addition, as just mentioned, some variables are defined with respect to pairs of geographic regions (for example, economic trade and other directed behaviors between them). The number of such geographic pair variations will vary roughly as the square of the number of regions, implying, for the above number of regions, $(2 \times 10^2)^2 = 4 \times 10^4 = 40\,000$ geographic pair values for any one substantive variable. (The above calculation assumes ordered pairs, that is, the relationships, region p → region q and region q → region p, are distinct.) Over all the 250 substantive variables if, say, the 25 mentioned in the previous paragraph are (like trade) geographic-pair-specific, then we are talking about $25 \times 4 \times 10^4 = 10^6 = 1$ million substantive-geographic-pair-specific variables. Let us call this the total of "Group B." Combining Group A and Group B totals gives the (highly conjectural but plausible) number $(4.5 \times 10^4) + (25 \times 4 \times 10^4) = 1.045 \times 10^6 \sim 10^6$ global system variables. Notice that the number of pair-specific variables swamps all the others in this particular estimate, a point to which I will return, below. Finally, suppose each coupling between a pair of global system variables is characterized, conservatively, by one coupling number (coefficient, parameter, and so on), describing the impact of one of the pair on the rate of change of the other, as symbolized by equation (15.1). This gives, for this particular set of guesses, $(10^6)^2 = 10^{12} = 1$ trillion such numbers to be established in a global model. These numbers are further to be multiplied by the several alternative possible modeling approaches outlined in the previous sections of this chapter. (With that many alternatives, the world system may be evolving faster than we can model it; maybe it will end before we finish the first cut!)

Clearly, to be speaking realistically of a functional model version, we must mean something having many orders of magnitude fewer variables than what was just indicated. There are several ways this can happen. First, for many pairs of variables, the model developers will assume, on the basis of intuition alone, that the connections, in one direction or both, can be ignored. Many such assumptions will be by default; there are simply too many pairs of things to explicitly consider all of them. (Also, depending on what sorts of relationship are being considered, the numbers involved may easily be well beyond the possibilities of inference based on empirical data, there being too few cases.)

Second, prediction is temporary; that is, it covers some finite period of time from present to future; thus some variables may be omitted because their impacts occur sufficiently far in the future that they can be ignored in the time frame of the model. (This can lead to difficulty, as the future does, eventually, become the present; spread of nuclear weapons and global warming, perhaps once thought safely in the future, may be examples.) Those variables which the model developers have chosen not to ignore, via one of the above routes, will be subject to the two additional possibilities outlined in the next two paragraphs.

Third, many of the pair-specific variables will have impacts that are negligibly small, or zero, because the entities in question are geographically remote and otherwise lack the capacity to interact with each other. For instance, political entities that do not share a geographic boundary (and that normally are considered to be "minor powers"), Bolivia and Thailand for example, are not at all likely to get into a mutual border dispute. (This idea was developed by Richardson 1960b, who argued that potential for mutual war involvement could be approximated by considering only nation pairs having common geographic boundaries plus the "seagoing nations" – by which he meant roughly the same as "major powers" – paired with all nations.) For reasons other than geographic, other types of pair interaction will have impacts that either are huge or tiny, with very few or no in-between values. For these types it may be acceptable to regard the tiny values as essentially zero. Monetary value of bilateral exports to a named other country, divided by total exports of the exporting country, may be a good example. (At least in some data years, most countries concentrated almost all their exports on one or more of four or five major economic parties such as the United States; Williamson 1985, 1989.) Since, as noted above, pair-specific variables account disproportionately for the data and coupling numeric requirements, substitution of zeros in the above manner will disproportionately reduce those requirements.

Fourth, it may be possible for several variables to be represented by a single variable that is strongly correlated with all of them. One such possibility of representation has two parts. The first part is the point just made in the preceding paragraph, applied to several bilateral indicators. For example, at least some data years reveal that, in addition to export concentrations on a few importers, most countries acquire their armaments from a few weapon suppliers and, if they host foreign military personnel deployments, those foreign personnel come from a few other countries. The second part is, for each of the three indicators, that the list of the few parties is the same. For example, circa 1970 these parties were the United States, Russia, the United Kingdom, and France for all three indicators (Williamson 1985, 1989). This may extend to other sorts of variables also, which suggests that one conceptual variable (I called it "linkage"), can serve in place of the three empirical variables and others. Such possibilities, the above and others, having so far received little attention, would receive considerable attention in the process of devising a practical functioning set of indicators for a global model.

A variation on item four: as one goes to smaller (more overtly "physical") units (see below), the collection of fundamental variables becomes smaller and more simple (tending, in the extreme limit, toward elementary properties such as position, momentum, electric charge, and so on). The complexity then appears in auxiliary conditions. (At rock bottom, the simplicity comes from fundamental conservation of things such as electric charge, and mass, energy, and momentum. At a not nearly so simple level, such conditions would include constraints such as the prevalence of certain minerals and energy sources near the surface of the Earth, and of the fact of a difference in temperature between day and night; at a still more complex level, they would be things like biological inheritance, including language learning abilities.) While still complex, the recurrence of the same fundamental variables in many different contexts may offer some possibilities of simplification. For this to work, the auxiliary conditions must stay fixed, to provide a framework within which the system then evolves. (The complex adaptive systems concept of "emergent phenomena" in effect appears to say that this requirement is not met. Changes such as learning take place – "emerge" – which constitute changed constraints.) This point interacts with the second one, above: the requirement of fixed conditions is more readily met over a shorter time period.

EARTH GLOBAL SYSTEM STATE SPACE

Now let us turn to fitting the various above modeling aspects into an explicit discussion of the global system state space. First, it was argued that the number of global system variables could be quite large; and this could be true even after effecting reductions, using some combination of the four

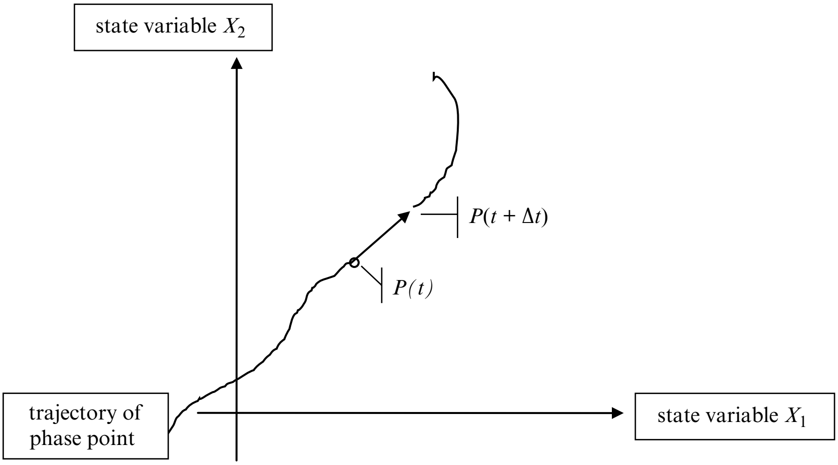

Figure 15.1 Two-dimensional state space

considerations mentioned. Whatever that number may be, except where noted otherwise let us now assume it is small enough to be manageable. Consider a space having N-many coordinate axes, each corresponding to a dimension, each such dimension representing the value, at the common time t, of one of those system variables. Recalling the Introduction, the space thereby formed in that way is referred to as a "state space" (Arrowsmith and Place 1990). In this abstract geometric context, let us again refer to the system variables as "state variables." This arrangement is represented in Figure 15.1, where there are just two dimensions, corresponding to two state variables. (For more than two dimensions, one could think of Figure 15.1 as a "spatial cross-section" parallel to the two dimensions shown and perpendicular to all the others in the space.) Given this arrangement, suppose we imagine assigning a definite numeric value to each system variable (including, if we are dealing with a cross-section, all the variables not shown in the figure). This assignment will correspond to a definite state of the global system. Geometrically, it will correspond to exactly one point in the space; namely, the point having exactly the coordinate values each of which corresponds to, and equals, its respective variable value. Below (again to repeat), I refer to this point as a "phase point." Such a phase point is shown as the point $\mathbf{P}(t)$ in the figure. In sum, the location of the phase point in the state space represents the state of the entire global system.

Now let us suppose that, for each state variable, its own distinctive equation, like equation (15.1) but of constructive form (meaning the actual steps are indicated for computing the function on the right-hand side), has been provided; and let us further suppose that every piece of information, that is, each variable value to which allusion is made on the right-hand side of equation (15.1), has also been provided. According to these suppositions, the rate of change on the left, $dx^k(t)/dt$, can be computed for each system variable; thus the new value $x^k(t + \Delta t)$ can be computed in the manner of equation (15.2) (that is, by adding each computed change to its respective variable value that held at time t), for all values of $k = 1, 2, \ldots, N$. (As mentioned, the operative procedure will be to compute Δx^k directly.) In geometric terms, this means that the new location of the system at the new time $t + \Delta t$ thereby is determined. This is shown as the phase point $\mathbf{P}(t + \Delta t)$ in the figure. The arrow is showing the direction of motion of the phase point in the state space, in moving from one time to the other. In an earlier section ("General Dynamic Modeling Scheme"), it was mentioned that the system variables must be assumed continuous functions of time, for equation (15.1) to be meaningful. Graphically, this is expressed by depicting the movement of the system phase point over time as a smooth curve. (My MS Draw program, however, gives the shakier line shown in the figure.)

There is a very important further assumption implicit in the above. It is that movement over time of the phase point is unique: a definite location of the phase point at time t leads to exactly one and only one new location at time $t + \Delta t$. This means that the left-hand sides of equations like (15.1) are each an exactly precise single number or array of numbers (such as a vector), with no statistical or other uncertainty whatsoever (that is, the above-mentioned "classical" model applies). Moreover, changes from two different points cannot end up at the same point (which already follows from the previous, by considering cases where $\Delta t < 0$). This is not, of course, the realistic situation; rather, it is assumed so as to facilitate exposition. This is a place where the manageable number N, introduced above, equation (15.1), may not – and probably will not – be sufficiently large. I return to that point below. This assumption corresponds to a single trajectory leading from one phase point location to another; for instance, $\mathbf{P}(t)$ leads only to $\mathbf{P}(t + \Delta t)$ at the time $t + \Delta t$ (that is, to none other) at that time. Graphically, it also takes the form that no two trajectories cross each other (for if they did, a phase point at their intersection would lack the unique direction of movement required by the above; Baker and Gollub 1990: 9). This constraint is like laminar flow in hydrodynamics. Another way of stating this assumption is that, with sufficient information, that is, with sufficiently many state variable values, the progress of the system is completely determined; moreover there is a definite collection of variables (the state variables) that will confer this determination. Provided this assumption were to hold, if we actually had that collection of variables, in those idealized circumstances let us then speak of the state space as being "complete" (my terminology, not standard).

In addition, given a complete state space, an ideal model then provides a change function like that of equation (15.1) for every possible combination of the values of the state variables (and one that meets the constraint of laminar-like flow). Geometrically, this means that, for a given value t, every phase point in the space generates its own unique trajectory in both time directions, $\Delta t > 0$ and $\Delta t < 0$. That is, we know where the trajectory goes from an arbitrary starting point. Further, this generality applies to some definite, if finite, period of time.

The following may also be noted. Firstly, two possible special situations constitute partial exceptions to the determinism: points in the state space that constitute "sources" or "sinks." A source is a point $x^k{}_{source}$ from which infinitely many trajectories depart; a sink (also called an "attractor") is a point $x^k{}_{sink}$ to which infinitely many trajectories arrive. On each of these departing or arriving trajectories there are infinitely many points $x^k(t)$, each one different from and converging on the respective $x^k{}_{source}$ or $x^k{}_{sink}$. Provided there are at most finitely many sources and sinks, system determinism is still defined for all these $x^k(t)$ plus all points on any trajectories that do not encounter sources or sinks. Secondly, if one variable was exactly a function of one or more other variables while holding time constant, then that one variable would not be counted as providing a distinct coordinate of the state space; that is, one is looking for independent variables to form the coordinates. (Time is held constant to preclude the possibility that the variables are related only because they are both functions of time.) Given two variables functionally linked, with time controlled, then just one of them can be a state variable; which, however, allows an interest in the other one. From the above, linkage may be regarded as a state variable, while exports, military personnel deployments, and so on are regarded as variables dependent on the linkage. Thirdly, the condition of independence is highly idealized; in practice it will always be ambiguous whether a slight difference between two highly but imperfectly correlated variables reveals mutual independence or mutual dependence obscured by measurement error.

CHOICES AND STATE SPACE ERRORS

I now consider sources or types of error in state space calculations but, as the subheading above suggests, with a particular purpose in mind. Coming to a first type of error: complete exactitude in predicting the global system trajectory from a given point $\mathbf{P}(t)$ in the state space is unrealistic. In addition – a second type – there will be error in knowing exactly where **P**(t) is located, in the space; that is, in knowing the exact values of the state variables at time t (Orrell 2007; who argues that the first type receives insufficient attention). The second type of error is what leads to the phenomenon of "chaos" in system dynamics literature (Baker and Gollub 1990).

The uncertainty in location of **P**(t) presents itself as a collection of candidate points, any one of which could be the true location of the phase point at t. (This differs from the uncertainty concept discussed under the subheading, "General Dynamic Modeling Scheme," above. There, no amount of information can remedy the uncertainty; here, uncertainty can be reduced with additional information.) Each of these candidates comes with its own trajectory through the space. If these distinct trajectories diverge with time, then the uncertainty of prediction grows correspondingly; if the divergence is so great as gradually to fill the entire state space, then the uncertainty increases without limit; the predictions progressively lose all exactitude. (Note the conditional in the above; rate and character of divergence – exactly which state variables actually do diverge – are questions that need to be addressed on the basis of specific information, not just in the abstract.)

An interesting special case arises when, prior to divergence at time t, the trajectories were too close together to be distinguished; for then they appear to be a single trajectory prior to t, after which that one putative trajectory appears to split into two or more. (See Figure 15.2.) This kind of split, sometimes called "bifurcation" (Baker and Gollub 1990: 68–82), would present the appearance of a violation of the unique trajectory assumption.

Coming to the third error source, suppose for sake of argument that the state space consists of just three dimensions, two of which are shown in each of Figures 15.3 and 15.4; and suppose the phase point can assume either one of two possible coordinate values on dimension 3 (or a statistical distribution in x_3 that is strongly bimodal). Presuming we have exact knowledge of the first two coordinates, then the phase point at time t has the possible coordinate values ($x_1, x_2, x_3 \approx x$) and, alternatively, ($x_1, x_2, x_3 \approx x'$) (with x and x' the local maxima of the distribution; ≈ means approximately =). The difference between the two figures is in the third coordinate x_3, not shown in the figure. On account of this difference, the trajectories passing through the two alternative locations of **P**(t) differ; imagine they appear, in this particular instance, as sketched in the two figures. That is, on account of the difference between $x_3 \approx x$ and $x_3 \approx x'$, the two trajectories visibly diverge, starting at time t. Now, what if we do not know which of x or x', or even some third value x'', . . . and so on, is the true value of x_3? Perhaps we do not even know of the existence of state

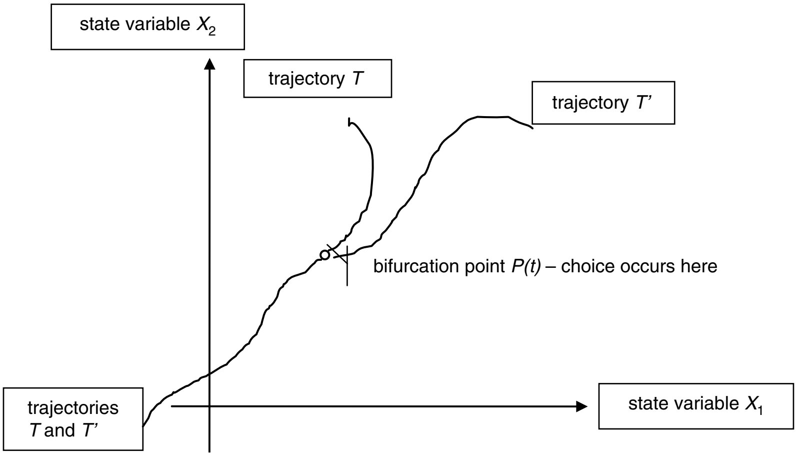

Figure 15.2 *N-dimensional state space; trajectories T and T' projected onto X_1, X_2 cross-section; alternatively, T and T' have common value X_3 but are indistinguishably proximate, prior to time t*

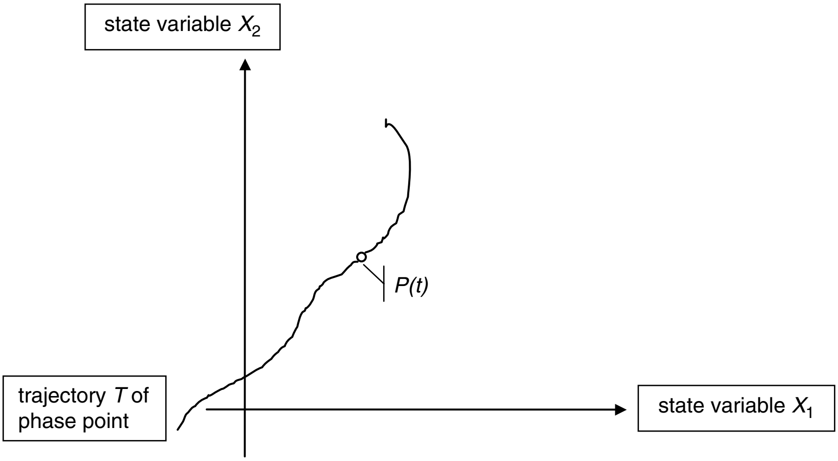

Figure 15.3 *Cross-section of n-dimensional state space; trajectory T passing through X_1, X_2, $X_3 = X$ at time t*

variable 3. We would then be seeking to represent the three-dimensional space on two dimensions; in effect we would be projecting the third dimension onto the other two ("collapsing" the dimensions of the space), with a result like that shown in Figure 15.4, where the two trajectories

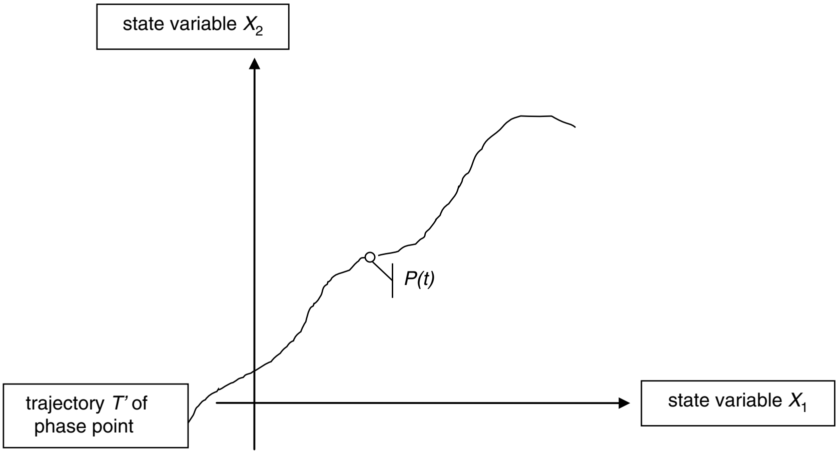

Figure 15.4 Cross-section of n-dimensional state space; trajectory T' passing through X_1, X_2, X_3 = X' at time t

become superimposed and appear to present an indeterminacy (an unpredictability) of the system at the moment *t* in the future of the phase point **P**(*t*). As in the special case of the second error type, this third type again shows that an apparent failure of the deterministic assumption – that is, of the uniqueness of trajectory through a given phase point – can be an artifact of incomplete information concerning the value of a coordinate or even of its existence. That is, an apparent indeterminacy can arise in a state space which actually is entirely deterministic. Restoring all the other state variables, again indeterminacy can result from complete information regarding x_1, x_2, combined with any amount of ignorance or knowledge of x_4, x_5, . . ., x_N and complete ignorance of x_3. To connect with the earlier discussion, perhaps what I have just called x_3 is not actually among the *N*-many state variables that could feasibly be included in a working global model. (One can also think of this third error type as an extreme version of the second type, in which there is no information whatever, concerning the value of x_3.)

There is another way of interpreting the second (special) and third error types (hence the purpose in mentioning them). The forked trajectory in Figure 15.2 can be regarded as a decision or choice, taken at the time *t*; the split at **P**(*t*) (more precisely, the topology of the split) then becomes a piece of a decision tree, as that phrase is used in the study of decisions. Working back to the previous logic, evidently the appearance of choice can be regarded as an artifact of incomplete information regarding the system state variables (number 3 in the fancied example) or due to the undiscernable differences between the two trajectories prior to time *t*.

While the above regards choices as (apparently) indeterminate events, that does not exclude that other events also called "choices" may be predictable, thus not bifurcation events. Such events would be part of the deterministic evolution of the phase point trajectory. From this viewpoint, decision theory aims to move decisions from the indeterminate (bifurcation) event type to the predictable type by adding additional state variables (relating to utilities of agents; see the next section). Chapter 18 by Bueno de Mesquita in this book further compares strategic versus non-strategic behavior in making choices. In the present framework, the distinction might correspond to whether forecasts made by agents, of the future behavior of other agents in the system, have roles as state variables. Granted the above, it would still seem that degree of behavioral predictability must be somewhat imperfect for one to think of the behavior as involving a choice; manifestly robotic behavior is regarded to have less an element of choice than human behavior, precisely to the extent that the latter is less predictable, though both may be determinate.

Examples of choice reasoning abound, this being the standard modality in economic and political analyses, all of which might also be addressed within the state space framework, as just discussed. One interesting example is Bueno de Mesquita et al. (2003), who posit a definite historical progression in the relative size of various politically relevant groups – elites, "selectorate," and so on – and for corresponding changes in the internal character of national polities. Identifying "historical progression" with change over time suggests a fit between their ideas and the approaches of Wilkinson in Chapter 12 and Williamson in Chapter 14 of this book; and all three approaches seem to fit the idea of phase point trajectory within a state space.

PHYSICAL AND SOCIAL INQUIRY COMPARED

The previous discussion leads, further, to consideration of the distinguishing of "physical" from "social" inquiries. Based on its commonly pursued forms, the latter would seem not to have much to do with state spaces or determinism but a lot to do with decision-making or choosing. Perhaps more generally, there is the "science of the artificial" (Simon 1980), which presumably includes the products of decision-making; as opposed to natural inquiry, the science of processes not involving decision-making. In global model terms, such a dichotomy would distinguish factors such as disease transmission and climate change (physical) versus factors such as the behavior of political entities (societal), as differences in kind. However, the above gives several reasons for regarding them as fundamentally alike:

1. The special feature distinguishing societal study would seem to be that many decisions, structured as to who is deciding what, and for whom, are being made by the parties (decision-makers) of a society. As before, in the state space view these many structured choices can be regarded as an appearance brought about by incomplete information (imperfect resolution and/or omission of state variables) available to us, the observers.
2. By its form, equation (15.1) is cast as a deterministic ("physical") recipe; as idealized – given complete information – the trajectories are imagined not to cross each other. Moreover, though "physical" and "societal" input categories may serve as labels, the couplings do not look different according to what they are connecting: social to physical, physical to social, social to social, physical to physical – they are all represented by functions from numbers to numbers. The issue of couplings across types is, further, a suggestion that simplifications of the referent world (the global system) do not necessarily break along conventional subject matter boundaries (politics, economics, climate, other environment, and so on); that which is social may be infiltrated by the physical and conversely. In sum, state space accommodates and partly embodies an approach that is physical in terms of methods and concepts employed, even where nominally physical state variables and reasoning are not invoked. (Societal examples include Rashevsky 1968; Richardson 1960a; Rummel 1965, 1966; Williamson 1985, 1989, 2007 [2005]; Wright 1961.)
3. A particular kind of resemblance lies in the idea of behavior constrained by a maximizing principle. The physical idea is that trajectories of objects subject to conservative (total system energy-momentum preserving) forces maximize or minimize (thus maximize the negative of) a function called the "action." This resembles the utility-maximizing idea in decision-making studies. More specifically, Richardson processes (dynamics resembling arms races) can be derived from a utility-maximizing principle cast within a physics-like representation of political agents (Boulding 1963; McGuire 1965; Williamson 2007 [2005] and Chapter 14 in this book; Wright 1961).
4. In the above, societal inquiry is already implicitly physical except for the use of immensely fewer state variables. If one were to move to progressively smaller units of analysis, the lower extreme of that process would be a state space in which the state variables were positions and momenta of individual particles; and, in carrying out that progression,

one would not be destroying or abandoning the original space but adding dimensions to it. The original global system space would have incrementally morphed into what is conventionally a physical state space. The distinction between "physical" and "societal" is an artifact of this process. (Born 1949 shows how fully deterministic and fully statistical systems morph into each other, becoming more deterministic when moving in the direction of more information about individual components – that is, with more state space dimensions – and more statistical when moving oppositely.)

CONCLUSIONS

Several conclusions follow or can be summarized from the above:

1. The requirements of an appropriately general global modeling scheme are symbolized in the Couplings Matrix and in equation (15.1), including requirements that cannot be fully met. Concerning the latter, with something like $\approx 10^{12}$ state variables, if indeed there are that many then a global model in pristine form is unattainable; but that form can still serve as a limiting ideal against which to compare attainable models (using ideas like the "partial correctives" mentioned above). Additional aspects of these conclusions appear below.
2. If the range of cases, times, or other variables addressed in a study be called "scope," social inquiry tends to show narrowness of scope. Case studies, say a particular country in a particular time or circumstance, exemplify the extreme. A state space contemplates the opposite: dynamic principles that work for all domains (from all locations in the space, that is, with all possible combinations of input values) at all times. Granted this goal is unreachable, it should be approached to the extent feasible.
3. The Earth needs to be grasped as a single system. Models that consider predicting changes in, for instance, global trade in economic goods need also to consider changes in the trading of human migrants, of microbes, of conventional armaments, of nuclear warheads, of ideas and information, of diplomatic representatives, and so on. The Couplings Matrix expresses the relevant point of view as to how quite diverse may be the appropriate collection of problem groups and factor groups to be considered, to effectively do global modeling and to understand global change.
4. System dynamics – the time-rate-of-change concept of equation (15.1) – should be a central concern of social studies (as it already is to

a limited extent, in economic and global modeling). Closely related to this, studies of equilibria should consider their time scales, the rates at which they are approached. Also there is the possibility of equilibria that change over time, thereby the possibility of never reaching them. (The goal posts move faster than one can run.) Comparison between equilibrium time scales and times required for appreciable change in the equilibrium point then become important.

Of course, posing the question of dynamics does not answer it. Finding and considering possible answers should be an intrinsic part of the modeling problem. To this end there is the great variety of candidate dynamic principles that may be considered; and there are search methods such as genetic programming. These candidates and methods can be added to the repertoire of social inquiry.

5. Drawing on point 4 in the comparison of societal and physical inquiry, above, and as exemplified in this book in Chapters 3 and 4 by Wilson and Alexander, respectively, one direction of work is to make social inquiry explicitly physical by addressing the issues of reduction and synthesis: reduction being the analysis of macroscopic entities (societies, living things, weather, and so on) in terms of smaller (more elementary) things; and synthesis being the demonstration of how, given suitable conditions, the smaller things can combine to form the macroscopic ones. (Additional conceptual discussion of reduction and synthesis appears in Chapter 2 of this book.) A recurring task of science has been to get to a sufficiently elementary level to be below where innovation is occurring, then to seek emulation of the higher level via combination of the lower-level rules with special conditions. One form of innovation is adaptive (learned) behavior; and one form of adaptive behavior is strategically reasoned behavior. So one part of this task is to get to small enough behavioral units that the strategic or other adaptive aspects disappear; then to synthesize (reconstruct, derive) the higher level, including adaptive-strategic aspects.

   As one moves to lower levels, the inquiry may look more like physics; at higher levels, it may look more like social inquiry; somewhere in between, like biology. (See Figure 2.1 of Chapter 2.) Also deserving more thorough consideration is the idea of a complex adaptive system (Holland, Chapter 10 in this book). Remove "adaptive" and speak merely of a complex system, then recovering the adaptive aspects at a higher level becomes part of the synthesis agenda. (Going to a very low level, can quantum mechanical effects be expressed at a macroscopic scale of size? Interestingly, genetic transmission of traits is said to be a quantum effect; Schrodinger 1944, 1956. Consider Chapters 3 and 4 by Wilson and Alexander, respectively, from that perspective.)

6. As mentioned, one can imagine some events called "choices" to be entirely predictable, therefore not bifurcations, that is, not entirely "voluntary"; but state space alters such distinctions by making bifurcations (including unpredictable choices – "artifacts") an artifact (in a different sense): the world is not composed of actions that are of just one (voluntary/artificial) or the other (deterministic/natural) type, but both, the distinction depending on degree of information.

   What, then, happens to calculation in this picture? Conventionally one thinks of "choice" as something that has resulted from it. Humans calculate; as a result, they choose. By contrast, weather does not, we imagine, calculate; therefore it does not choose to do whatever (rain, shine, and so on) it may do, though it often bifurcates, as anyone planning a picnic is aware. But there is a greater variety of possibilities: perhaps human action is based on some combination of calculation and uncalculated habit or intuition; or the behavior was entirely habitual or intuitive, then rationalized, *ex post facto*, by suitable assumptions and reasoning, so that the calculations come after the act (or the commitment to act) and rationalize it. (Perhaps, in memory, the order was inverted.) Perhaps the calculations come after some previous similar act while preceding the next instance of that same kind of act. Given also the question of the neurological or other basis of calculation, these questions lead into the reduction–synthesis agenda.

   Still another direction: though choice is associated with humans and other living creatures, perhaps human artifacts also calculate, then choose, as with electronic computers for example. (For one idea about this see Mayer-Kress and Barczys 1995.) More generally, if the global system has regularities of any kind, those regularities might be regarded as a form of calculation.

In sum, concerning social choice issues and their roles in global modeling, human behavior, human artifacts, and "natural" phenomena such as weather are not fundamentally distinct. Putting all deterministic behavior and all bifurcations, of the type shown in Figure 15.2, into the general framework that I have considered here, with due attention also to the role of calculations, points to an enlarged and provocative agenda.

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PART VI

New Approaches

16. Scientific revolutions and the advancement of explanation and prediction

Frank Whelon Wayman

THE SCIENTIFIC REVOLUTION

Our book, *Predicting the Future in Science, Economics, and Politics* (hereafter: *Prediction*), is intended as an example of a needed revolution in scientific thinking. This requires not only a fundamental alteration in the social sciences, since human behavior and relationships affect so much of our path into the future, but also, as we have tried to illustrate, a revolution in the way the various sciences connect themselves to each other.

In this chapter I want to discuss the role of revolutionary change in science, so that we can be instructed on how best to move on from current shortcomings. I think a sound way to find guidance is to start with a view of how science in the sense of the physical sciences (and to an extent the biological sciences) has successfully developed in the past. This can give us a better perspective on how to construct an effective social science, and ideally then step toward even broader integration of the sciences predicting global conditions.

The scientific revolution, which culminated in Newton's ideas of how the planets move around the Sun, was the major intellectual accomplishment of Europeans in the sixteenth and seventeenth centuries, and was something that has long been looked upon as a great turning point in human history. And when social scientists, starting with John Locke and Montesquieu and Adam Smith and others in the eighteenth century, began to construct a science of society, they looked to that for a model on how to operate in the social realm. And even today, people talk about the scientific perspective of the natural sciences as a standard with which to evaluate and sometimes criticize the accomplishments of social science. So let us take a look at the scientific revolution.

To begin this story, it is necessary to set a broad frame for it. What we are looking at is a revolution in which European science leapt ahead with the ideas of inertia and gravity to explain how objects like rocks fall back to earth, or missiles fall back to earth, and the ways in which planets and comets go around the Sun. This general view of gravity and inertia was something that was built in two stages. The first was the destruction of the view that Aristotle had held of the subject, and the second was the construction of a new view which was the modern view that started in the Renaissance and culminated in Newton. The major players involved began with Aristotle and Ptolemy in the classical period, then – after the hiatus of the Middle Ages when not much was accomplished – the Renaissance and early modern thinkers: Copernicus, Galileo, Kepler, and Newton, who brought science into the modern era.

Aristotle's view was that most things were (belonged) at rest, that each thing had a natural resting place; and the motions of things like rocks and planets flying through space was strange and hard to account for; that is, the abnormality demanding explanation. His, the ancient Greek idea, was that everything had its natural place; thus Aristotle explained this strange thing – motion – in terms of the natural place things would be in. A rock would fall to earth because its natural place was in the earth. Air would bubble up out of water because its natural place was above the water. In this view motion was just accounted for by the explanation that everything was trying to get back to where it belonged. When Christian monotheism became the dominant creed, "where it belonged" would mean "where its natural place was in God's great universe." Similarly, the moon moved in a perfect circle around the Earth because that circle – an unchanging endless loop – is the very thing that is geometric perfection, and such perfection is the way a proper body would move.

Now, to understand more chaotic kinds of motion of, say, someone throwing a rock, or a sculptor chiseling something into a beautiful statue, Aristotle developed an idea of how causation occurred, in terms of its four different parts. The first is material cause. If you are thinking about what creates a great sculpture, the first thing is the material cause, which is the thing (that is, the marble itself) that is being used to make the sculpture. Then, the efficient cause is what operates closest to our understanding of cause today: in our example, it is what operates on the marble to create the final product – the sculptor and his chiseling are the efficient cause. Then there were Aristotle's two other ideas of causation: the formal cause, which was the artist's vision of what he wanted to create; and the final cause, which was the goal the artist was attaining, for example to achieve fame, or to make a lot of money. Those four pieces of causation were all important, for Aristotle, to explain something like the chiseling that would produce the final product of the sculpture and the way in which the chisel would be striking the rock, and making the pieces fall, and creating the final product.

We will see that these formal and final causes, dropped in the "paradigm shift" or scientific revolution of Galileo and Newton, need to be brought back in (as in the work of my co-editor Bueno de Mesquita and my colleague Axelrod) to a full science of global change, including changes produced by choice. This is because, within biological organisms created through evolution, there is a final cause, Darwinian survival of species (as discussed in this book by Wilson and Alexander, Chapters 3 and 4, respectively); and, with consciousness and human beings, this is complemented with a formal cause, conscious goal-seeking behavior (Simon 1996).

This Aristotelian view, that there were causes, which operated in a way to produce certain types of motion, dominated Western thinking for a long time. Ptolemy, an Alexandrine Greek of the second century AD – the classical height of Greco-Roman civilization – realized that things were not quite the way Aristotle had envisioned. For if you looked at the motion of Mars around the Earth, you saw that it really did not move exactly in a circle; it would move across the sky, further and further, then it would move back for a while, then move forward again. Ptolemy's idea was that you could still account for the motion of Mars in terms of circles of the Sun, Mars, and the other planets moving around the Earth if you built in little epicycles. The latter consist of circles inscribed on circles: on the rim of a big circle, anchor the center of a smaller circle, then rotate both of them. The net effect will be the interrupted forward motions of planets. For more complex motions, on the rim of the little circle, inscribe the center of one still smaller. By building in dozens of such epicycles, Ptolemy could account for this strange behavior of planets. In this way, Ptolemy managed to salvage Aristotle's perfect circles, thereby retaining perfection in the motion of the heavenly bodies.

As Edward O. Wilson and others have emphasized, this "Ptolemaic" approach to science, this tendency to build "epicycles" rather than take a fresh approach, is one of the great banes of science. In such a system as Ptolemy's, the problem is that the research program has become "degenerative" rather than "progressive" (Lakatos 1970). The cost is that much effort goes into justifying the original mistake (in this example, that heavenly objects must move in perfect circles). Rather than being open-minded and seeking an alternative, great effort is put into showing that (in this example from Ptolemy), if circles are added tangentially to previous circles, the heavenly bodies move in circles. Instead of one circle, maybe it takes 77. If you add enough such epicycles, any back-and-forth linear motion around the Earth can be fit to the pattern. Nobody was asking what explanation there would be for all these epicycles. This basic Aristotelian view – that the Earth was the center of the universe, man was at the center of things, God was out there in the heavens somewhere, and the heavenly bodies were moving in perfect circles – lasted until the Renaissance.

It was with the Renaissance that this view began to change, with a series of thinkers. First was Copernicus, writing around the early 1500s (born in 1473, died in 1543) who came up with the idea that the Sun might be the center of the universe; if true, the Earth and the planets would be moving around the Sun. And one compelling reason to think that might be true was that if you looked at it that way you could get rid of a lot of the epicycles. It turns out that actually, as we know now, the Sun really is the center of the solar system, and so when you make that change you do make a much cleaner picture, and you can get rid of a lot of Ptolemy's epicycles, cut them about in half. You still do not have quite the right answer, but you are getting there. There was an explanatory problem, though, even with Copernicus's view. First of all, as I mentioned, it was not quite accurate. But a deeper problem was that there was no explanation for why the Sun should be the center of the universe. After all, Aristotle had at least some notion that was compelling to him about why: his idea was that the natural place for the Earth was as the center of the universe, then further out, water; further out, air; further out, fire – and so on. So he had an explanation in terms of his four types of causation that made sense to a lot of people, whereas Copernicus could not begin to answer the question of why. He just noted that if you put the Sun in the center, that made things simpler.

Galileo, who came along next, tried to get at a better understanding of why things move. While Aristotle's basic idea was that everything belonged at rest – that stability was the natural order of things, and that motion was the odd thing that had to be explained – Galileo developed a series of experiments which contradicted this Aristotelian idea. Galileo's notion was that if you rolled a ball down a plane onto a flat surface like in a bowl, then across the bottom of the bowl, then up the other side, provided it was a sufficiently round ball so as not to have too much friction, then a very interesting thing happened (Figure 16.1). Always, the result was that the ball would roll up exactly to the height from which it had begun. That suggested a series of experiments (Galileo 1959) in which he changed the slope of that third plane (that is, of the second side of the bowl): if he flattened it out a bit the ball still rolled up to its original height. Then came the radical idea that if he did not have that final upward slope at all (that is, if the third plane was flat) then the ball could never reach the original height; so, if the ball just went on flat forever, the ball might never stop. So now he had a different view of motion. In place of Aristotle's idea, that motion was unnatural and had to be explained, Galileo's different idea is that there is something called inertia: this is the property that the ball has. Once it gets going from rolling down the plane, it could go on forever; that is, the state of motion then is the natural state. So the planets might be able to move around the Sun like that if there was some sort of plane they

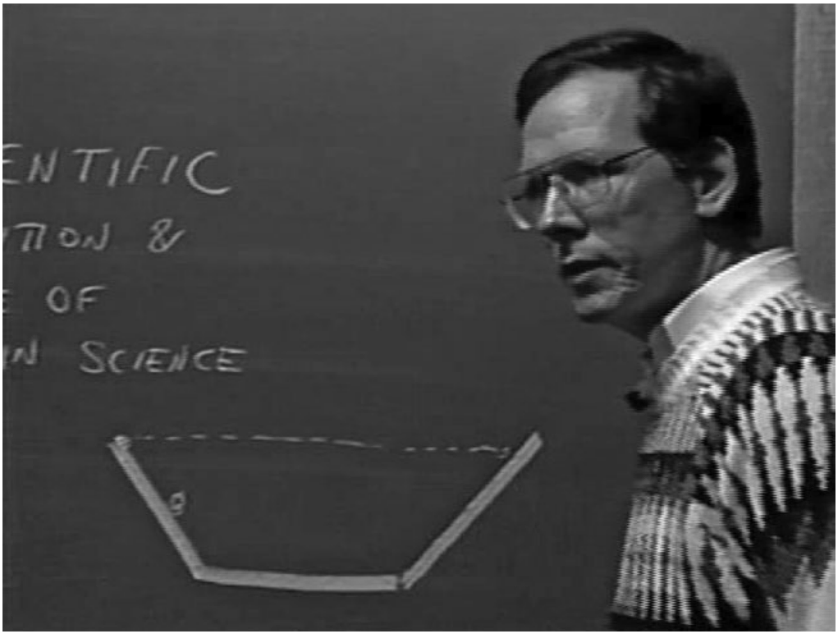

Figure 16.1 Galileo's initial experiments with a ball rolling down the side of a bowl and back up to its original height

could be traveling on, a circular kind of plane that they would just be going around forever. This was different from Aristotle's view, that God was out there somehow pushing the planets around in a circle. Now, God could just be the creator at the very beginning of the universe who started the whole thing moving, and then forever after with inertia the planet would continue around and around. So Galileo began to provide through his experiments a different sense of motion than Aristotle had had, and these experiments pointed to a different possible explanation of why motion occurred.

The next phase in all of this activity was that Tycho Brahe, a Danish astronomer, developed a planetary observatory near Helsingør, after which *Hamlet*'s castle of Elsinore was named. Tycho made much more detailed observations of the planets than ever before. Johannes Kepler, from Germany, then looked at thousands and thousands of Brahe's observations with which Kepler was able to show a new pattern, namely that the planets (and other astronomical bodies of the solar system) are moving not in circles (as both Copernicus and Aristotle had thought) but in ellipses around the Sun; and, for each such ellipse, one of the two focal points is the Sun itself. So we have Kepler's first law: planets move in ellipses.

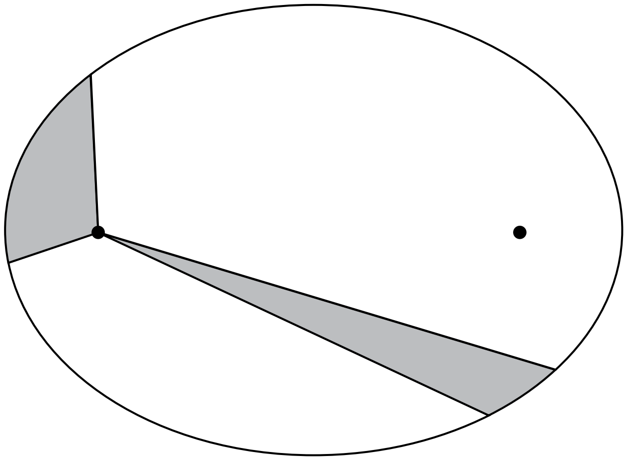

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Figure 16.2 Illustration of Kepler's second law of planetary motion, that planets sweep out equal areas (the two shaded areas) in equal amounts of time

Kepler was able to determine two other laws of planetary motion. The second is the law of equal areas: the straight line – the distance – connecting Sun and planet sweeps out equal areas during equal times. Thus, when it is far from the Sun the planet orbits slowly, so over, say, a month's time it traverses an arc of very small length. This short arc combines with a distance of great length to sweep an area (see the hatched area in Figure 16.2) that is the same as that swept by a shorter distance from the Sun but longer arc, when the planet is close to the Sun and racing fast. So, always, the two variables – arc length and distance to the Sun – co-vary in the above manner to keep constant the area swept during one month. The third law is that the square of the planet's mean radius from the Sun, divided by the cube of its orbiting time, $k = r^2/t^3$, is a constant, and k has the same value for all planets.

Where did these laws come from? Like Ptolemy, Kepler had discovered a group of laws, the origins of which he did not understand. Why should the Sun be one of the focal points of the planetary ellipses? Why ellipses? Why equal areas swept in equal times? As it turned out, answers would be provided by Isaac Newton in the final stage of this scientific revolution.

In pursuit of these answers, Newton innovated a form of mathematical reasoning, the “calculus” (which continues in use today) and he posited laws, including the force law $F = G\ (m_1)\ (m_2)/\ d^2$ (that is, the force F of gravity of one body on another equals a constant G times the mass m_1 of one body, times the mass m_2 of the other over the distance d between them squared). From a framework consisting of the above and other elements, including Galileo’s concept of inertia, Newton was able to logically derive – that is, to “explain” – Kepler’s three laws. In that sense, Newton answered the questions posed above concerning the three laws. Thus, Newton’s framework is more fundamental. It unified heavenly and earthly motion by saying that planets in orbit, and also rocks thrown in the air, all follow paths determined by their initial inertia and the force of gravity.

With Newton’s breakthrough suddenly the Europeans were ahead of where the Greeks had been in ancient times. For the first time the Europeans felt superior to classical civilization and to Greece, because their intellectual accomplishment had finally gone beyond Aristotle. They now had a kind of explanation for planetary motion – in the form of logical derivation as in the above – that in time would become more accurate than what the Greeks had, and was more elegant.

Along the way a number of things, however, were lost. For one, Aristotle’s idea of the final cause, that is to say, the thing that the sculptor had in mind when he was chiseling the marble, was gone. The universe was a much more empty place with no purpose in it, no one knew why the planets were following these laws of gravity; whereas in the Aristotelian universe there was always some underlying purpose for things, the final cause. Also gone was that formal cause, the artist’s goal in creating a sculpture. However, in their place was a science that could allow men to go to the moon by planning, through the gravitational attraction, exactly what kind of rocket forces they would need to make the flight, and that could predict for future times exactly where the planets would be. So, with Newton’s formulas you could, in his time, tell where Mars was going to be in the year 2001 and you would be right. Astronomers also used Newton’s laws to predict where missing planets were, by noticing perturbations in the outer planet’s motions and reasoning, “This must be gravity pulling from some object further out, and it must be located in a certain place to fit Newton’s laws.” Then they would look there with their telescope and, behold, there would be an outer planet; and they could discover, in another solar system, a planet orbiting a wobbling star. And so it was predictive science, one that could tell you where things were that nobody had dreamed would be there. So this was very powerful stuff.

What about social science, the field that many of the chapter authors in this book are from, a field that has remained doggedly outside of what Wilson calls the neo-Darwinian synthesis? Is any of this relevant to concerning our book project of unified scientific prediction of global conditions? Well, there are a few interesting things to consider. One of them is the struggle between induction and deduction in science. Sometimes we wonder whether we should be just inductive or deductive. Should we just gather evidence and look at it before us, and try to say, "Well now, as we look at this evidence is there a pattern here?" That is called induction: you start to see a pattern and you say, "Ah, now I see a pattern." For example, Kepler looked at all those data on where the planets were and perhaps thought, "Oh, I see a pattern. Look, it's so clear. It is that these things were traveling in ellipses, and it's so clear, they're sweeping out equal areas." And he found these three patterns. Well, sometimes science works that way very well. For example, in social science it was discovered that there was a principle of inter-democratic peace, that democratic countries never fight each other in inter-state wars, and it is a principle that is held up as having no exceptions so far in all of our studies (see literature reviews, dissenting views, and evidence in Wayman 2002a, 2002b). It is based on induction: countries that were not fighting each other, people started to notice, were pairs of democracies. Canada does not fight the US, Norway does not fight Denmark, and so on. And it was not deductively arrived at. There was no grand theory of human behavior, certainly no sociobiology, that predicted that democracies would not fight each other. It is an inductive finding. It is universally true. So that is a useful finding. Induction sometimes works very well. As Williamson points out in Chapter 2 in this volume, such findings are extremely useful, even if it would eventually be desirable to link them to more basic science.

Kepler used induction to find his three laws. But induction always leaves you a little bit puzzled about why the pattern should be true, and whether it would hold up in the future, and indeed, whether it even is necessarily a true pattern, and what its full meaning is. For example, with regard to Kepler's laws, why were they true? Well, Newton had an answer: that there is a gravitation force, which is a universal thing in the whole universe. And it explains things like the motions of the planets, and the movement of rocks and of missiles. So it has a general pattern that he found of force equals the constant times the mass of one body, times the mass of the other, over the distance between them squared, that can account for all three laws. It is an elegant answer to why the three laws are true. Well, that is one advantage of going beyond induction to having some sort of deduction.

Another advantage is that sometimes you get an empirical result and you are not quite sure why it is true; it might even be just accidental. For example, it was found in the US South 100 years ago that the places that discriminated most against African-Americans were the places where a lot of cotton was grown. Was that just an accidental connection, or was there some causal pattern there? There is always a need to get to some meaning as to why such a pattern would be true. It was found out later that, indeed, those counties with lots of cotton growing were places where blacks were in the majority, and where the whites were therefore most afraid of the African-Americans and, therefore, most determined to be mean towards them and keep them down so that they would not become a threat. That was explained in V.O. Key's (1949) *Southern Politics in State and Nation*, a classic in political science. The theoretical explanation that Key provided had to do with the idea that discrimination would be the result of this fear and apprehension about the way in which majority rule might lead to black control of the counties where blacks were a majority of the population. So theory can come in and provide an understanding of why a pattern occurred, and whether it is just a chance pattern that would go away; such as it might have with the case of cotton growing where people were being mean-spirited, or it might have been a true causal pattern that had something to it. But you need a theory to detect what that pattern really was, and why it was important. So induction and deduction both have their role, and you can see them in this scientific revolution.

Another big question from this study of the scientific revolution is the question of why it is that you would have any kind of behavior in the social sciences be meaningful. The way in which it was approached by Newton and Kepler leaves a little bit out, I think, because from a social science perspective it leaves out those final causes that we were so interested in, such as why the sculptor was chiseling. Was he trying to make money, or was he trying to be famous? Why exactly was he trying to create that particular type of sculpture? If it was a particularly beautiful sculpture, it might be because he could make more money selling pleasing artworks. If it was a particularly revealing sculpture about human emotion, it might be because he wanted to be famous for revealing the deeper psyche of human beings. In order to understand why he was doing what he was doing it seems as if we would need to understand his motives. And so we would like to have a social science that would be as powerful as what Newton provided, but one that would be able to also bring into account the human motives that got left out in the physical sciences.

So the dilemma for social scientists, which I am going to consider next, is how we could take this scientific revolution and apply some of the good ideas from it to social science, and get a good social science while bringing in some additional ideas; such as something like a final cause that could enrich a social science but would not be needed in physics, because you would not need motivation for rocks and planets, but you would need motivation for people. So I am going to consider that, and also the limits of social science in the next section of this chapter (see also Chapter 18 in this volume by Bueno de Mesquita). Unfortunately, as you can imagine from the example I have just given of Newton, it is not likely that the social scientists are going to be able to come up with something as elegant, as powerful as what Newton found, when you consider that what he found was that one basic force, gravity, was accounting for all of this behavior of all this planetary motion, and that it could be described so elegantly as ellipses going around the Sun. In social science there are many variables. There is a lot of error in our measurement. Newton's ideas are presumably invariant across all time, whereas social patterns alter as their very discovery leads purposive people to change their previous behavior to take advantage of opportunities revealed by the newly minted observation. There is a lot of difficulty therefore in finding elegant, simple solutions like Newton did, and therefore social science is limited in a way that planetary science is not. And of course this point would apply to an integrated, consilient science of global conditions, as the social and biological elements would be affected strongly by such complexities (see Holland's Chapter 10 and Williamson's Chapters 2, 14, and 15 in this volume; and Axelrod 1984).

So I will consider all these things in our next section of this chapter. But I think we will always be coming back, as human beings, to this fundamental scientific revolution of Galileo and Newton that was so compelling to people. And the reason we will is because it is a kind of a model of excellence of really getting somewhere with science, of really revealing how the world works in a powerful way that could be very useful to people. And of course, we would like a globally predictive science that would be very deterministic like Newton's, that would have clear policy applications such as how to send a rocket to the moon, or in the social sciences how to solve basic problems like correcting the ills of the cities, or the international conflicts that lead to so much genocide and war. The ideal would be to find, through social science, simple explanations of human behavior, and then be able to use those to solve problems. But as you can already imagine from some of the tone of my writing, it is a lot more difficult than that, and you know that from your own experience already. Social science is only partially successful, because it has limitations that were not faced by people like Newton studying planetary motion.

And, as for the immediate viability of our favorite life forms on planet Earth, the important menacing variables are all too human. (This point is developed further and refined in Bueno de Mesquita's Chapter 18, on "particles, genes, and couplings"). We are just not going to get very far on prediction of global conditions, then, without turning, as I do now, to the social sciences.

SCIENTIFIC REVOLUTIONS WITH PARTICULAR ATTENTION TO THE MACRO-SOCIAL SCIENCES

So far in considering the role of theory in science and how to construct a proper methodology for science, I have been looking at the scientific revolution that occurred in the sixteenth and seventeenth centuries in science of astronomy and physics, studying planetary motion. And by looking at that, there are a number of questions raised about exactly how to proceed. The science in the natural sciences, for example, has two different alternatives presented by the work of Tycho Brahe on the one hand, who emphasized along with Kepler the role of induction, versus Newton's emphasis on deduction on the other hand. One also has problems in deciding within this kind of a science how big a role mathematics should play in a science of world affairs. Just to recapitulate briefly, starting with Aristotle's approach to the world in which he viewed the earth as the center of all things, and the solar system going around outside of it with planets and the moon moving in circles around the earth, I moved to Copernicus's view that the Sun was actually the center of the universe and the planets, including the Earth, moved in perfect circles around the Sun; and then reviewed the data gathering of Tycho Brahe, which Kepler used to show that actually the planets moved in ellipses around the Sun; and I concluded with Newton's deductive use of calculus to show that actually the force of gravity, acting to alter Galileo's inertia, could explain all this.

In that progression from Aristotle to Newton were two ways of advancing. One was the inductive way, in which Tycho Brahe gathered thousands and thousands of hours of evidence to try to show which was the best way to proceed in constructing a science of astronomy and physics; and by gathering all these detailed observations he allowed Kepler to come along and demonstrate that all these observations of where Mars, Jupiter, and Venus were, could be accounted for by the principle that the planets were all traveling in perfect ellipses around the Sun, with the Sun one of the focal points of the ellipse. This revolution that Kepler brought about was based on induction, on the gathering of enormous amounts of data, which Kepler spent hours looking at, page by page, trying to make sense of them. That is the inductive approach. You would look from the particular and try to get the general idea. So that is a good approach.

But there is an alternative approach in science, which Newton exemplified, which is the deductive approach in science. In the deductive approach you look instead at something like integral calculus, and you come up with an idea that gravity that is pulling the rock back down to earth might also be disturbing the inertial movement of the planet off in space, and the Sun's gravity might be pulling that planet like a big rock in a big arc around the Sun, just like the rock is moving in an arc as you throw it through the air. In both cases gravity is a force that acts on a body in proportion to the mass of that body, the mass of its attracting body and the inverse of the distance between them squared. Further, the acceleration of a body is proportional to the net force upon it, its mass the constant of proportionality. These laws could "explain" – in the sense of deduce – all of Tycho Brahe's observations, all three of Kepler's laws, and with the exception of Mercury, the motions and positions of the planets for centuries into the future, eventually though not at first with unparalleled precision. (Later, Einstein's work corrected the orbit of Mercury and added other important phenomena missed by Newton's work.) So Newton's revolution created the notion that deduction in mathematics might be the key to a great science, that induction was not sufficient in itself to really get to the heart of the matter. So we have a challenge of choosing whether to be inductive or deductive in science, and that is the first choice that we have to consider making if we are going to try to construct a good science of social affairs.

The second choice that we have to make involves the role of mathematics itself in science. Newton's theory is a very powerful theory, and gives the impression that theory and deduction have to be mathematical, because after all, he spent a year developing integral calculus and calculus in general as a way of deducing where all these bodies were going to be. However, there is an alternative, that comes about in the field of biology, and that is Darwin's idea of evolution of the survival of the fittest. This is a simple verbal idea that, once you get it into your head, gives you a sense of how dinosaurs were replaced by mammals, how mammals evolved, how the whole progression of life on Earth took place; and it is a very powerful idea, but entirely a verbal one with no mathematical deduction. So we have a second set of choices, a choice between mathematics, of the Newtonian approach, and of verbal approach to deductive science exemplified by the fine work of Darwin. Which are we going to follow? Now, those are two questions: (1) shall we be inductive or deductive? and (2) shall we be mathematical or verbal? Since each made a contribution, the practical answer would seem to be to use all four approaches by turns.

A third question emerges from our book. Not present in the Newtonian revolution, it is the question of the role of reductionist versus emergent properties. It can be seen in the work of Edward O. Wilson (1975, 1998). When the DNA double helix was discovered, by Watson and Crick, Watson at Harvard believed the future of biology lay at the molecular level. Wilson seemed to Watson old-fashioned, as Wilson continued to study behavior of ants and other social insects. Although from Watson's molecular perspective Wilson was studying emergent properties at higher levels of analysis (the species and its individual members), to social scientists Wilson seemed a reductionist, trying to explain all animal social behavior from evolutionary biological terms. These are complexities that never had to be examined in Newton's study of gravity. There are no simple answers, but in *Sociobiology* (1975), in *Consilience* (1998), and now in *Prediction* (Chapter 3), Wilson argues for a search for cause-and-effect links between levels of aggregation and between fields of human learning. Williamson, in Chapter 2 in this book, emphasizes that the more focused science of a pure biologist or a pure economist can be extremely helpful, as long as we do not lose sight of the value of some higher-level integration of the knowledge such as Wilson can inspire us to attain.

Fourth, there is also a question of determinism versus probabilistic forecasting. Newton's math is continuous and his results deterministic. This can make global forecasts which fail to anticipate the end of the Cold War, or overstate the world's human population (*Limits to Growth*, Meadows et al. 1972), seem unscientific, especially from the mentality of a sophomore physicist or engineer. This quest for certitude has practical utility for careers. If one's job is to design the Golden Gate Bridge, one needs to have some extraordinarily high practical level of confidence that the design will be stable. But it is worth pondering a moment the broader question of inherent uncertainty, as Stephen Hawking does in these words from a web-lecture that he has posted under the title "dice 2":

> It seems Einstein was doubly wrong when he said, God does not play dice. Not only does God definitely play dice, but He sometimes confuses us by throwing them where they can't be seen. Many scientists are like Einstein, in that they have a deep emotional attachment to determinism. Unlike Einstein, they have accepted the reduction in our ability to predict, that quantum theory brought about. But that was far enough. They didn't like the further reduction, which black holes seemed to imply . . . It is just a pious hope that the universe is deterministic, in the way that Laplace thought. I feel these scientists have not learnt the lesson of history. The universe does not behave according to our preconceived ideas. It continues to surprise us. (Hawking 2007)

It might be added in the context of our book that this unpredictability is not just a problem of very small, quantum phenomena, or of black holes, but also of very large, multi-level terrestrial systems, such as weather and the other things discussed in this book. All the contributors, and many of our readers, have been wrestling with this set of problems in their work. This does not make our job hopeless, because there are alternatives in between determinism and complete unpredictability. We may not know whether it will rain in Vienna next January 1, but we still can know, with a degree of probability, that it will be winter weather – though likely milder than before so much carbon dioxide was added to the atmosphere.

A final basic question, left from my consideration of the scientific revolution, involves the idea of the paradigm in science. So far everything I have talked about could be covered in a few basic terms in philosophy of science: concepts, variables, operationalizations, hypotheses, and theories. But now we have a final building block, the term "paradigm." It was used by Thomas Kuhn (1962), who wrote a book, *The Structure of Scientific Revolutions*, to account for this evolution starting with Aristotle. Kuhn pointed out that there are two types of science: normal and revolutionary. Normal science operates within an established paradigm, such as Aristotle's paradigm that the Earth is the center of the universe. Often, as in a paradigm like that, you have enormous emotional attachment to the idea that people are the center of the universe: God created it so that we would be the center of all things. Sometimes that is very hard to challenge. If you did so, as Galileo did by looking up and seeing the movement of the moons around Jupiter, and seeing that there might be a miniature solar system there, and that Jupiter might be the center of it, like the Sun might be the center of our solar system, and you begin to publish ideas like this, you can get into trouble, for example, with a Church that says, "Wait. We already bought into Aristotle's idea that the Earth is the center of the universe. We're feeling uncomfortable." Many people were feeling uncomfortable with this displacement of human beings from the center to the outer part of the universe that was going on as the Aristotelian paradigm was giving way, the newer Newtonian paradigm being the crystallization of this scientific revolution.

Kuhn says that science is normally just careful study, such as, "Well, where is Mars tonight, and where has Mars been for the last three years?" Very important. But the task here is: just add to an existing paradigm and do not challenge it. (Incidentally, I like to define a "paradigm" as a set of agreed-upon questions, with each question associated with some limited range of expected answers.) What is revolutionary in science is an idea that can break out of the old paradigm and replace it with a new one; in the progression of science, probably the major paradigms are the Aristotelian one that the Earth is the center of the universe; the Newtonian one that gravity accounts for how things are going on in the universe; then Einstein's revolution, which created the idea that when things are approaching the speed of light, for example, or nearing a sufficiently intense gravitational field, Newton's laws do not operate the way Newton thought they did, but become a special case which applies to massive objects moving at speeds negligible compared to light speed and at sufficiently great distances from other massive objects. So the above-named are the great paradigm shift people who created a sequence of revolutions in science.

And when we turn to social science we can dwell on these dilemmas: shall we be inductive or deductive? Shall we be mathematical or verbal?

What is the role of paradigms in social science, and what kind of new paradigm is needed? We can use those questions to turn to social science and begin to consider how social science might best operate. We should add two further questions: how do we integrate levels of aggregation, from physics of particles and chemistry of substances up to biological systems, and then to micro- and macro-social systems? And how deterministic do we think these linkages are?

And the way I want to update these questions is to take a look at the revolution in world politics that occurred in the beginning of the 1960s and continued to the present. It is a revolution that shifted from a traditional type of study of international politics (also known as international relations). This traditional approach might be compared to Aristotle's view of the way the solar system operated. The tradition was pre-scientific, if you will, if we take as our point of departure the sense that science has to be very data-oriented and very precise. We moved from that tradition to a more quantitative, precise, up-to-date modern science, through a scientific revolution called the behavioralist revolution. In order to consider how that revolution occurred, what I want to do is take a look at the dominant realist paradigm that existed before the behavioralist revolution, then consider how the behavioralist revolution was able to slightly modify the original realist paradigm.

The reasons for this inquiry are several. First, Chapters 10 through 15 in this volume represent, I believe, an advance over the usual, often realist, thinking about the global system. By discussing the realist paradigm (dubbed "realism" for short or, following German usage, *realpolitik*) we are reviewing the paradigm we wish to supplant. Second, the realists provide a model of the global system that we, too, wish to model for forecasting, and some elements of the realist views can be retained, or can at least be of heuristic value as a step toward our emerging vision. Third, realism represents the dominant view of world politics in many places, and that prominence makes it important to suggest the ways in which realism seems at best a partial answer to our needs. Related to this, fourth, is that many people, especially in physical and biological inquiry, are not aware that there are competing paradigms in social inquiry. There is also an excessive negative tendency of some scientific innovators to see no merit in realism, and, fifth, I want to correct that too, by trying to retrieve some things that, in my view, it does have to offer us, so that we can incorporate them in a proper science of the global system; Diehl and I called this retrieval process "reconstructing *realpolitik*" in our book of that title (Wayman and Diehl 1994). Sixth and finally, realism epitomizes a political view of the global system, and political science still has an architectonic group within it that believes that political science, in one sense of that term, is the science concerned with how everything related to the human community fits together. That makes political science one of the fields worth reviewing for synthetic views like realism that attempt to provide a grand theory about how global affairs work. So for these reasons I want to make realism the starting paradigm of my analysis here, just as the model of Aristotle–Ptolemy was the starting point of the revolution of Galileo and Newton.

So, in a kind of Hegelian dialectic process, I want to examine both realism and the scientific revolution that seems to promise to supplant it. This supplanting revolution came about as part of reaching the historical point, in the 1960s, where high-speed computers could store data on databases, and use them to compare things and study associations in a way that had not been possible in earlier periods because it took too long. Such was the behavioralist revolution.

Well, that 1960s revolution was running up against the realist paradigm, which could be described most briefly as a paradigm that emphasizes "power" and strategy in social relations. Any social science that has realist elements in it is a theory constructed around the relative power of the actors involved and the strategies they have for getting to their goals. Within the field of international politics, the realist approach is one that puts the independent sovereign states at the center of the political universe; states like Germany, Russia, England/United Kingdom, Australia, Canada, the United States, Japan. These are the centers of the realist political universe, just like the Earth was the center of the Aristotelian universe. (I am not talking about non-sovereign entities like Florida and Minnesota.) That is a kind of bias, if you will, towards the government, towards the state, towards authority, towards the central military authorities of a country giving them primacy in international affairs. Within the US, it is giving the Pentagon, the President, and his national security advisor this centerpiece in the American role in international affairs. That is something about which, relatively speaking, conservatives or "hawks" feel a little comfortable, liberals or "doves" feel a little uncomfortable, so there is an ideological split over how important realism is, and whether it really should be the way of thinking about politics as realists claim, or whether there is an appropriate challenge to it. (Often the major challenge is something called idealism or, more recently, neoliberalism, a money-and-politics-oriented updating of idealism.) Realists use the word "idealism" to suggest it is just a head-in-the-clouds utopian kind of thing that has no relevance to reality and is just wishful thinking. But the idealists have some good ideas, too, that I will come to momentarily, as I begin to explore the scientific challenge brought by behavioralism in world politics.

The realist approach is perhaps best initially studied by looking at one book, Hans Morgenthau's *Politics Among Nations*, published in 1948. But realism is a paradigm, not just one man's theory. It is a paradigm that has gone on for thousands of years. Normally the questions guide scientists to look at particular things to observe, then if the observations come back consistent with the paradigm they say, "Oh, sure enough, the paradigm's right." And if the observations are not consistent, often scientists in normal science say, "Well, maybe we made bad observations, or maybe the paradigm needs some minor corrections," but they do not fundamentally change it. For example, in the scientific revolution I was considering, when they found out that the planets were not exactly moving in circles around the Earth they said, "Well, let's tack on some little epicycles, little circles on top of the circles that will be mini circles that will keep everything circular," so that the basic Aristotelian idea that everything is moving in circles in the heavens can be upheld; whereas a revolutionary idea would say, "A pox upon your circles. It's really ellipses, and it's really the Earth is not the center, the Sun is the center, and once we do that we can have planets traveling in ellipses and get rid of all that epicycle junk." But that calls for a revolution in science, which is moving beyond the paradigm.

The realist paradigm is so dominant because it has had both: (1) parsimonious ideas that have a lot of "face validity" – they seem very plausible; and (2) great policy relevance to leaders of states who are making decisions about war and peace. So it has had a compelling interest for thousands of years, and has been the dominant approach to international affairs. It is a paradigm within which many particular theories, like Morgenthau's theory, are contained. Let me begin with Morgenthau and then I will talk about the more general realist paradigm.

Morgenthau was writing in 1948, if you can imagine, when the United States was suddenly thrust upon the stage of world leadership by confrontation, first against Hitler and now Stalin, and he was writing the book as a professor at the University of Chicago addressing primarily an audience of American leaders and future American leaders, namely the students at American universities and graduate schools. And he said that the way to think about international politics is that it is an anarchic system, an anarchy in which countries have great threats to their own security. There is no international police force, no help to be provided by the United Nations (UN). To update this, you can see that in a post-Cold War country like Bosnia & Herzegovina, where they initially hoped the UN might save them from Serbian attack, instead they were being destroyed, because if you do not have an army – cannot protect yourself – you are vulnerable in international affairs. The Kuwaitis, with a tiny army and a big pot of oil, discovered this, too. Consistent with realist principles, Saddam Hussein with a large army right next door and acting, if you will, in Iraqi national interests in the realist paradigm, made Iraq richer by grabbing Kuwait and its oil. In the realist view, these illustrations show the world to be a very dangerous place, where one must have a strong army and be concerned about military security matters quite a bit. Further, potential security threats can come in the form of revisionist states: places like Saddam Hussein's Iraq that might decide to use force to overthrow the status quo. In this case the status quo was the independence of Kuwait. Revision of that status quo by Iraq took the form of making Kuwait the nineteenth province of Iraq, which Saddam did in August of 1990. In sum, the realist idea is: if you do not pay attention to your security problems, you will no longer exist.

If, however, you do pay attention, this has certain implications. You begin, first, by identifying revisionist states who are powerful. Then if, building your own country's strength, you can match the revisionist's strength, you will probably be safe because you will be able to threaten it enough to deter it. If not, you must seek allies, a process called the balance of power. In addition to being strong yourself and having strong allies, a third realist policy prescription from Morgenthau is to be tough in bargaining. Do not cave in, lest you encourage further revisionist demands, as when Hitler, given the Sudetenland, thereby was encouraged to go further and say, "Ah, well, Sudetenland was easy. We'll take Poland next. That will be easy, too, because that wimp, Neville Chamberlain, doesn't have the guts to stand up to me" (though it is often asserted that, actually, Hitler wanted war in 1938). In sum, you create an image of weakness if you bargain too cooperatively with a revisionist threat.

Beyond Morgenthau's ideas, above, and in quick summary, it is possible to generalize to a diverse set of realist writers. I start with Thucydides, who was a general in the Peloponnesian War between Athens and Sparta and who wrote a history about war. This history made manifest that a state is always looking out for its security and is ruthless in pursuit of it. For instance, during that war the Athenians destroyed a city-state (Melos) to demonstrate that they were ruthless. The people of the place said (paraphrasing), "We've never done anything bad to you, so you shouldn't destroy us. We'll cooperate with you if you don't destroy us, and we'll do good things for you." The Athenians replied, "No, if we destroy you then everyone will realize how ruthless we are, and everybody will be afraid of our power, thus we'll be stronger, which will increase our security." So they attacked. That is one of the ways in which Thucydides began this study of political realism thousands of years ago. He also pointed out that countries were "balancing" against threats, which is to say allying with the weaker side in a war, in order to block the victory of the stronger and more dangerous, just as a balance of power theory argues (Thucydides 1954: 30–34).

Later, in the time of the Renaissance, Machiavelli added some ideas of realist thought. One of them was the idea of the national interest, that Italy came first, Italian unification being the most important thing to him (see the conclusion of *The Prince*). So he was transferring realism from the old city-state system to the modern system of nationalism that came about in our post-Renaissance times. Later, at the time of the American Revolution, David Hume discussed how Britain, his country, had pursued a balance-of-power policy in Europe by being the balancer, the country that always acted to block a revisionist state from unifying Europe in an empire. Hume saw how first the Spanish with the Spanish Armada, then the French, for example under Louis XIV, had been blocked from setting up such an empire. He further saw Britain as playing a role in keeping Europe fragmented and diverse, like ancient Greece in the era from Aeschylus to Aristotle. If this system were to continue beyond Hume down to our own time, then it would cover five centuries (1495 to present) rather than the two-and-a-half centuries he would have been able to observe. Would it continue as he had envisioned, so that his model was predictive? Would the United Kingdom continue to balance power and block would-be emperors of all Europe? If so, in future times beyond Hume, you could envision the British also stopping Napoleon in 1815 at Waterloo, Kaiser Wilhelm in World War I, and Hitler in World War II. It seems that many times even after Hume, the British continued to do what he noticed, which was play the role of balancer in Europe. So realism is an old paradigm going back to Thucydides up through Machiavelli, David Hume and many modern writers, including Teddy Roosevelt, Henry Kissinger, and as cited initially, Morgenthau.

For a more systematic idea of this realist paradigm, consider the 11 realist propositions briefly outlined as follows (and drawn, along with the rest of this discussion of realism, from Wayman and Diehl 1994). With these propositions in mind, we can then see how world politics scholars of the scientific-behavioralist revolution were attempting to show weaknesses in realism.

The first proposition – on which all realists tend to agree, "the" central proposition, if you will – is that states, or what we call nation-states today, are the key actors. International organizations like the UN are not important.

The second proposition is that the state system is anarchic: there is no international organization, law, police force, chief executive, or legislature that is going to make good rules, and enforce them, and protect your state if it is threatened. If you are a citizen in the US and you are threatened, the police can come to your aid; but, according to the realists, international affairs is like Dodge City in the classic Hollywood westerns. You (as a country) must be able to defend yourself.

A third realist proposition is that subnational actors are not important.

The sovereign states are unitary and pursue their state interests. That is, they disregard the domestic political forces of people who would be leaning one way or another because they are from an ethnic group that wants special privileges, or protection for distant relatives overseas; economic interest groups, likewise. For example, US military spending is not dominated by industrial corporations that make profits selling things to the military and give campaign contributions to congressmen to make them vote for more defense spending so their companies will get richer. Instead the United States leadership – the President, the Secretary of State, the intelligence directors, the Joint Chiefs of Staff and the Secretary of Defense, and so on – together these people coordinate to define the United States' national interest. Those principles: sovereign states are key, the state system is anarchic, international organizations and subnational actors play minor roles, all unite in the idea that the states define and pursue their own interests in world affairs.

Let us take a look at the fourth principle: states are rational and in being so they are pursuing their interests, what is good for them and not at all what is good for the world as a whole. According to this realist view that we are beginning to see unfold here in these first four principles, nobody in world affairs really takes seriously things like the good of humanity, or what Catholicism, or Christianity, or Islam would call for, or what a good environmentalist would do, or how to achieve peace and security for the good of all mankind. All those things are things that, according to realists, idealists dream about and talk about as important, but when push comes to shove nobody powerful really, really cares about them. Fundamentally states are concerned about their national security, and that is what they will fight for. The United States fought over the Gulf, for example, when Saddam Hussein attacked Kuwait, because it has interests there in making sure that that oil is not lost to the Western world. But the US did not fight so much in Bosnia or Somalia, because fundamentally its interests are not challenged there.

Of course, the US did finally intervene in Bosnia & Herzegovina and Kosovo (though not in Rwanda or Darfur, nor did it bomb the concentration camp rail network in the Holocaust), so there are exceptions. Realists would say the exceptions are few and far between, whereas idealists see them as signs that we are finally moving toward a more civilized world system.

Moving on to the fifth realist principle, it is that in looking out for self-interest, states are looking out for their own survival, maintenance of their own power, and maintenance of their own territorial integrity. I call those principles 5A, 5B, and 5C; the letters highlight that there are three slightly distinct goals. A good place to start is 5C: if you do not have your own territory under control, as the Kuwaitis found out, or the Taliban–al Qaida ("Base") are now finding out, you do not have as good a base from which to operate. But certainly 5A is the minimum requirement of self-interest. Beyond that (Morgenthau's point), you act to enhance and maintain your own power, 5B: power being defined as ability to get others to do what you want them to do, and prevent them from pushing you around. And, of course, the more powerful you are, the more you will be able to survive and maintain your integrity. So those 5A, 5B, and 5C principles or propositions go together into a sense that a nation's self-interest is defined in a particular way. Countries are rationally pursuing survival, improvement of their power position, and maintenance of their territorial integrity, and these three things support each other.

Point number six is that states work hard to enhance their military strength, this being the key to maintenance of territorial integrity and to taking care of power and independence maintenance or enhancement concerns. Economic strength is also important, but fundamentally to enhance military security. A modern economy wins wars.

Next comes the question of who could threaten your territorial integrity? Take it away? Push you around and make you weak instead of powerful? Deprive you of political independence? The answer the realists have to this is, well, a little two-faced. On one hand, the first face, they say it is other power centers, which could be any powerful country. Then the second face, a different point of view slightly, is that threat comes from revisionist states, like those under Saddam Hussein or Hitler, who want to seize other countries by force. Now, there is paradox here. Obviously a very strong revisionist state might indeed be a security threat. But what happens when you have to decide whether to be scared about a powerful state or a slightly weaker state that is also revisionist? Should Americans, for instance, be more worried about the power centers, such as China and Japan, powers roughly equal almost to the US in a national economic capability; or countries such as Iraq (under Saddam), Iran, or North Korea, which are very small but plainly revisionist?

Finally, once the threats are defined, we come to three policies (already briefly discussed), which I call principles eight, nine and ten of the realist paradigm. Principle eight is that the state should strengthen its own material capability to protect against revisionist threats. Principle nine is that if you are not strong enough on your own, find allies who will make you strong. Principle ten is that if you are in a crisis against one of these tough-minded guys like Saddam Hussein, or Khrushchev, or Brezhnev, or Stalin, or Hitler, or Mao Zedong, well, you had better show a lot of resolve, because if you start to show that you are a weakling, they will start pushing you around. There is a famous example. President Kennedy wanted to get along well with Khrushchev when he was first elected US President, so he went to Vienna to meet with Khrushchev, and he said (to give the gist of it in paraphrase), “You know, now that we Democrats are in power, I’m pleased to say, Premier Khrushchev, that we can get along better, your country and ours. You know, the Republicans were the party of big business, but our party is the party of the working man just like your Bolshevik party is the party of the working man in Russia. We even have labor union leaders like Walter Reuther in my party.” And Khrushchev glowered at him and said (again to paraphrase), “In our revolution we hung people like Walter Reuther.” Well, Kennedy was set back on his heels, because Khrushchev was thinking, “This guy’s a wimp, he’s saying that he wants to get along with me. I’ll show him.” And shortly thereafter, Khrushchev snuck missiles into Cuba, almost creating World War III, because – at least in this realist story – he thought he could push Kennedy around, as Kennedy had shown weakness in this negotiating session.

The eleventh, final, proposition is that realism is relevant for all time; it will never be obsolete.

The above propositions lead, now, to the behavioralist revolution against realism. This revolution tried to overturn realism, to show that it has many contradictions, weaknesses, and empirical failings. In the behavioralist view, these could be demonstrated by looking at the evidence. This approach was most fully exemplified by a group started at the University of Michigan, the Correlates of War (COW) Project. Also there were several others, some at other US universities including Hawaii, Maryland, and Southern California, and the self-funded pioneering work by Lewis F. Richardson. Like those of Brahe and Kepler, these were attempts, aimed toward scientific induction, to gather a lot of data; in the case of COW, on all the wars that have occurred in the last 200 years, and all of the factors that might have brought about those wars – what they called the correlates of war – to see whether the realist ideas really held up under the scrutiny of the high-speed computer that could investigate patterns, and see if these 11 propositions are really true. Well, 30 years later a lot of research has been done, and hundreds of interesting scientific articles have been printed that fill up interesting classrooms full of students who can take notes and have to tell about them on exams. And beyond that, synthetic books have been written of charming insight interpreting what has come about through the evidence gathered by this scientific revolution. What has it all led to? What is needed most in this context is a hypothesis from realism that is able to be tested against a contradictory hypothesis from a competing paradigm, so that an empirical test of the predictions from the two paradigms can falsify one or the other.

For example, a leading realist named Kenneth Waltz came up with the theory of neorealism, which was an attempt to make realism relevant to the nuclear age. What had happened was that once nuclear weapons came along in 1945 with Hiroshima and Nagasaki, the superpowers stopped fighting each other. There were no wars between the United States and the Soviet Union after 1945. This was an unprecedented long peace between the two dominant powers in the world. It seemed inconsistent with the realist ideas that the world was an anarchic place where you have to be worried constantly that a war might occur that will destroy you. How can this be, that there is this long peace going on? Well, Waltz said that it all makes sense: realism is really intact. He was adding an epicycle, if you will, to the realist idea. He was defending the realist paradigm by updating it – somewhat successfully, by the way; I am not trying to demean what he had in mind. It was a very ingenious idea, and a very important idea that he came up with. He said that heretofore international affairs had been multipolar, that there had been many important major powers, many important centers of power in the world. But now, with the nuclear age, there were just two superpowers. And because there were just two superpowers, each one dominated half the globe. Each one had a strong interest in maintaining the status quo and not jeopardizing its own position as ruler of half the world. And in that position as a status quo state, a superpower would keep small actors like Saddam Hussein in line. If Saddam Hussein was getting support from the Soviet Union, they would help him and let him get his way in much of Middle Eastern affairs until he started to contemplate something like a big war, such as seizing Kuwait, which might start a conflict between the United States and him. And there was no invasion of Kuwait during the Cold War. It was after the fall of the Soviet Union that Saddam Hussein used his military hardware to conquer Kuwait. So Waltz had a very important idea that bipolarity could create stability, and that the reason that there was a peace in the world was because of the fundamental realist ideas that the way the world works depends on the power structure, and the strategies that countries use to think about power, and how to relate to the power structure in the existing world order. In fact, a disciple of Waltz, John Mearsheimer (1990), wrote a very widely read and cited article, "Why We Will Soon Miss The Cold War," applying these ideas of Waltz about the Cold War to the post-Cold War world.

So Mearsheimer provides one example of how these ideas live on, and that illustrates the good that came from Waltz's neorealism. But when you actually test it scientifically, as was done in the scientific revolution, it was found by people who compared bipolar eras of world history to multipolar eras of world history that what Waltz had predicted was not true all the time. There was a reprinted study of mine that said, for example, that he was basically right, that the bipolar affairs of the superpower age were indeed preventing World War III, in that World War I and World War II had occurred during multipolar times. But there was a greater probability of small wars during bipolar eras (Wayman 1984). So there was no crystal clear pattern, like a Newton would have found. Instead, it was very messy, that bipolarity contributed in some ways to peace (preventing world wars), but in other ways contributed to war (increasing the likelihood of "small," regional wars). So the behavioralist revolution had produced a study that yielded the prediction that Mearsheimer was wrong in forecasting more frequent wars after the Cold War. Unfortunately, realism and neorealism are based partly on ignoring or at least marginalizing such scientific evidence, in a manner that has been explicitly denounced as Ptolemaic and degenerative (Mansbach and Vasquez 1981; Vasquez and Henehan 1999; Vasquez 1993; Vasquez 1997 – and see the forum in that review issue for other points of view, by realists in response).

Then somebody decided to investigate an idealist idea – this could be thought of as a paradigm shift. Centuries ago the philosopher Immanuel Kant had come up with an idealist view of world politics. He said that we would have world peace when all countries became what we would call democratic and freedom-loving countries ruled by their own people, rather than by autocratic rulers. That shift from monarchism to republicanism had not happened in his own time in any country, really, except perhaps the Swiss confederation and the fledgling United States (Doyle 1986). So, this sounded like Utopianism. Someday the world will change and we will have peace. And of course, realists said that that change would never come about. But today we do have many democratic, freedom-loving societies; not just democratic in the sense that everybody has the right to vote (that is, all the adults have the right to vote), but beyond that, that there are constitutional guarantees to minorities of their rights, and also, constitutional limitations on government authority. When you have governments that are truly freedom-oriented governments in that sense – of not just being democratic in terms of majority rule, but also democratic in the broader sense of constitutional guarantees of liberty to create free societies with limited governments – when you have that a very interesting thing was found out by a political scientist named R.J. Rummel (1983) at the University of Hawaii, and then by many, many others who replicated his work. The finding was that there has never been war between two "democratic" states, and as yet there are no exceptions to that. Well, "democratic" is actually the popular word; Rummel (1983) and Doyle (1986), more correctly I think, use terms like "free" or "Liberal." The main point: there has never been such a war. And it is rare in my study of social science to ever find anything that is a deterministic principle like that, which there are no exceptions to.

But Rummel finds hundreds of wars in the last few hundred years, and none between two "democracies." This is called the inter-democratic peace. And that principle then leads us to an outcome – a preliminary outcome – from this scientific revolution, namely that the scientific revolution of the behavioralist revolution, namely that the behavioralist scientists started out focusing mainly on testing the realist paradigm, that there was constant anarchy in the world, constant threats to security, and that war was always going to be with us. But now we have a test that suggests an alternative paradigm, namely, that the idealist paradigm may be right, that the world may actually be entering a peaceful era, that several of those key realist propositions I spoke of may be wrong, namely, that the realists say that their principles are timeless. Maybe we are moving, as the world develops economically, towards more and more democracies (a pattern perhaps first demonstrated with data by Lipset 1960). And it looks as though once you get lots of democracies you get what are called zones of peace: regions of the world, like the US and Canada, where you do not have to worry about international anarchy leading to war, because the US and Canada are not going to go to war with each other, given that they are both democracies.

That should counter a number of the realist propositions. For example, it raises questions about whether states have to worry constantly about military security, which was proposition number six. It raises questions about whether states have to worry about things like building up their military strength and their alliances, and worry about revisionist states (propositions seven, eight, and nine), because if every state is a democracy there may not be any revisionist states out there. Japan, for example, was becoming very powerful vis-à-vis the United States in the 1980s. Would the US then have a war with Japan? Well, if Japan is not revisionist and does not want to use force against the US, and the US does not want to use force against Japan, maybe we are entering a new age where competition is becoming competition of trading states: commercial rivals of each other trying to export to each other and make a good standard of living for their citizens, who want a higher standard of living, rather than have wars that would be supported by their dictators, and paid for by the blood of the citizens who do not have the right to vote in the pre-democratic era. And similar thoughts may go for the decline of realism's relevance for the US–China dyad. For the People's Republic of China is decidedly not a democracy, but seems to believe that harmonious relations and trade with the US is a cornerstone of what the Chinese call an "open door" policy of economic development. This policy, ushered in by Deng Xiaoping, is of course even in name a bedrock policy of the US from 1898 to 1945. And this common nomenclature illustrates a convergence of interests of both twenty-first-century superpowers towards a Liberal model of world politics.

So this is an illustration, I think, of how social science can proceed, that through the Correlates of War Project effort of 30 years of meticulous data gathering, such as exemplified by Tycho Brahe and by Kepler in the scientific revolution of the sixteenth and seventeenth centuries, you can get a database from which you can begin to test ideas. And when you test ideas, if you do it with an eye towards theory, and an eye towards the paradigms behind the theories, you can begin to restructure your entire view of something like how the world as a whole works, how international affairs operates, by using scientific evidence to question which paradigm is the right one to follow, and perhaps, replacing an obsolete Aristotelian or purely realist kind of paradigm with a newer, fresher, better Newtonian kind of paradigm, such as we are beginning to see in the scientific revolution here. Now, that does not mean that realism is completely wrong and idealism is entirely right. These paradigms are very complicated and need detailed scrutiny as to what the good parts of realism still are that are worth retaining. Certainly if China suddenly becomes a revisionist state, or if Zhirinovsky rises to power in reconstituted Russia in the shell of the former Soviet Union and begins to say once again, as he supposedly did when he spoke some years ago, that he wants to take Alaska back for Russia by force, then we might again be in an era where realism would be relevant, and security of affairs would become pre-eminent in our concerns. Today, Putin instantiates these concerns, albeit in the former Soviet backyard. As we publish, Crimea is suddenly his. It remains to be seen how persistently East–West tensions will rise over clashes in eastern Ukraine. But as the world changes, we have to continually reassess it, based on empirical evidence. It is intriguing to think that what I have picked on here is a very difficult area for science to succeed in. It is very easy to have a successful science in something like public opinion, where you have thousands of people to study, and you can investigate their views by data gathering, polling people all over the world, or all over the US, and constantly be updating their views in presidential elections and so on. The study of war is more difficult because there was not a lot of data available when the COW project started in the 1960s, and because even now there are not very many wars to study (compared with, say, the number of voters), so it would be very easy to say, “Oh, we should just be historians and treat each war as unique and not look for general patterns, because we’ll never find any.” Who would have guessed when this project started out that something like the inter-democratic peace proposition would be discovered, and that the skeptics who said, “Each war is unique. You can’t possibly have a science of something like the study of war” would have been so wrong? And yet there is one more piece of the chapter to be written.

BIG PROBLEMS IN NEED OF FUTURE WORK

Such is the state of the behavioral study of global politics, particularly of armed conflict today (within the scope of the pages available for this chapter). It is a remarkable accomplishment compared to the field's status. But it has its limitations; and these limits are amplified when moving to more general global study of which peace and conflict is a vital aspect. One is its degree of acceptance.

The first survey of which I am aware of virtually all the scholars in the field of world politics was recently produced (and has since been updated, with few changes; the original is in Peterson et al. 2005). It shows the continued existence of the competing paradigms I have been examining, with none attaining supremacy. Realism and neo-Liberalism vie for first place: Keohane (a neoliberal) is the number one ranked scholar in terms of influence on the field, followed by Waltz (a neorealist). Morgenthau (the mid-century realist), still at number 19, remains the only figure whose influence has continued as top-ranked after his own death. Mearsheimer, another realist I have mentioned, is number five on the list. The top behavioralist (Russett) is at number nine – showing that empirical evidence has not exactly swept the field – and Singer, the next-most cited behavioralist, is trailing behind that at number 21. Three leaders of the rational choice revolution (Bueno de Mesquita, Fearon, and Axelrod) rank 8, 16, and 23, respectively. What I have called traditionalism (and illustrated mostly with realist examples) has made a comeback as "constructivism." It emphasizes how, in each historical context, people "construct" an ideology that, in turn, creates an intellectual climate affecting the course of events; Wendt at number three illustrates this paradigm. In practice it takes an anti-scientific bent (as "science" is defined in this chapter).

There is nothing inherently wrong with diversity. The theories of Newtonian mechanics, electrodynamics, special relativity (which omits gravitation), and quantum theory are mutually diverse to a great degree, yet all coexist as special cases of quantum theory; and each has its empirical domain of acceptably accurate prediction (for example, space flight and ordinary terrestrial engineering from mechanics, radio and television from electrodynamics, nuclear energy and solid state electronics from quantum theory, and so on).

Similarly, there is considerable diversity in studying global politics (not to mention the even greater diversity in studying the entire global system of which politics is a part). One difference is that there are no Aristotelians or Newtonians today trying to get their students not to read works in relativity and quantum mechanics, but there are such attempts by certain traditionalists in world politics concerning the basic validity (as they judge it) of a scientific method (as defined in this chapter). Outside the US, Canada, and Northern Europe, things are much worse, and in whole major countries such as Japan and China behavioralist work is frowned on as "un-Japanese" or perhaps not what the government and other employers welcome.

A second, more intrinsic limitation with the social science revolution I have been considering is its predictive power. The predictive power of, for example, the inter-democratic peace as a pacifying condition for a dyad is not strong. The percentage of variance explained in the war/no war variable by the democratic dyad/non-democratic dyad variable would generally be on the order of magnitude of between 1 percent and 10 percent, rather than between 10 percent and 100 percent. The reasons are several, including the comparative rarity of democratic dyads and the rarity of inter-state war: fewer than 100, in 1816 to the present (and reflecting that many dyads are also at peace, one or both of which are non-democratic). But, further, the procedure perhaps does not fully exploit present opportunities. War onsets are almost certainly the product, in part, of purposive choices by leaders, yet it is not clear how these choices can be meshed with the findings about the democratic peace. (See Oneal and Russett 1997 for one such study. Note that this process of meshing is a central agenda item in the modern physical inquiry that constitutes the standard of comparison in this discussion.) A related difficulty is that data are not available (or even empirically defined) that directly measure utilities and probabilities of purposive choice, so these must be inferred from less direct measures.

To address such problems, one of the editors of this volume incorporated in his research behavioral (Bueno de Mesquita 1975) and choice-theoretic modes (Bueno de Mesquita and Lalman 1992). This can be seen as the introduction of a rational choice paradigm into the field, hence another scientific revolution. Bueno de Mesquita and his colleagues later also incorporated three levels of analysis: the individual human leader seen as a rational decision-maker; the sovereign state in which the leader operated seen as either having a broad or narrow set of "selectorate" and "winning coalition"; and inter-state relations of war and peace as an outcome between pairs of states (Bueno de Mesquita et al. 2003). This attempts to account for war (at a dyadic level) as a result of lower levels of aggregation (individuals, and their location in a state with a wide or narrow selectorate) as well as a result of conditions in the international system (such as the power balances between pairs of states).

In this book we consider additional levels of analysis, for example in Chapters 3 and 4 by Wilson and Alexander, respectively, so preferences and rationality become outcomes of underlying biological and evolutionary processes. Williamson (the underlying basis outlined in Chapter 2 and in Figure 2.1 there) and I have speculated that, in a still broader global model, it will eventually be shown that economic development, with the spread of education and a middle class (Lipset 1960), are part of the underlying social forces contributing to the growth of these selectorates and winning coalitions.

It remains to be demonstrated the degree to which such new scientific efforts will be successful. Science depends on a certain simplicity of the field of study, so that there can be a sufficient number of similar cases, not in excess of the number of pertinent variables. In fields such as climate change, economic development, and global warming, this should not (relatively speaking) be such a big problem. In fields such as the study of war and peace, or of nuclear proliferation, these difficulties are probably going to be harder to surmount, but we have tried, in this chapter and throughout this book, to point out a few promising avenues of attack. As one prominent example, however, it is heartening that our book is perhaps the beginning of a convergence – as signified by the shared desire to contribute their respective chapters – of efforts by evolutionary theorists such as Wilson and Alexander, by physicists such as Farmer (Chapter 5, with Geanakoplos), and by rational choice theorists such as Bueno de Mesquita. Surely there is an underlying biological, evolutionary, and environmental basis for purposive or rational choice, and undergirding that, a physical basis for all the above, and it is going to be exciting to see continuing efforts to discover these bases. For instance, the basis for group identity feelings that give rise to in-group armed conflict with out-groups is an area that may profit. The nationalistic and religious identities thus forged seem to be at the root of a lot of mass killing in international wars and genocide. Much of the study of nationalism, however, has been left to constructivists (such as Anderson 1991). This work could become better linked to the work of this book if scholars were to heed the words of Alexander (in an early draft of Chapter 4 in this volume), and all of their implications:

> Darwin's hostile forces . . . predators . . . parasites and diseases, food shortages, climate and weather . . . I didn't see how any of those could be used to explain the human brain . . . I wrote, "It looks as though we will have to count that hostile force as members of our own species." And that meant to me that I would have to think about humans evolving to live in groups and groups competing against groups and being hostile to other groups.

NEXT STEPS

In their concluding chapters, my fellow editors join in this effort at synthesis and stock-taking. Already, in his chapters, Williamson has broadened the discussion from social science (which has been my topic in the second part of this chapter) to the integration of all the sciences in a global forecasting model. In Chapter 17, Polachek, our rapporteur, examines the existing standards of forecasting, critiques the contributions of the individual chapters, and suggests some integration and future directions that hold particular promise. Bueno de Mesquita (Chapter 18) then concludes the entire book with his own views on an assessment of current (and anticipated future) forecasting methods, and policy implications (academic research versus policy needs).

To translate from my discussion to those chapters by Williamson, Polachek, and Bueno de Mesquita, let me provide a concluding generalization about the global system they discuss, and how it differs from the inter-state system of realism. In realism, there is an interstate system, composed of territorial entities that satisfy the criteria of system membership or statehood (for example, as defined in Sarkees and Wayman 2010: Chapter 1). These entities are the ones on which "national" economic data tend to be created by the World Bank, UN, and so on. Their interaction is the basis for the discussions of bipolarity, multipolarity, and other power relationships in realism; this may be entirely appropriate for relatively narrow political science studies, such as predicting some features of the onset of interstate war. Slightly more broadly, there is an international system, comprised of all those geopolitical units, plus a plethora of subnational and extra-national groupings, including non-territorial entities (Sarkees and Wayman 2010). Even by getting to the international system, we have gone beyond realism to non-state actors. However, these inter-state and even international systems thus defined, which are the focus of political science, all seem to be purely social or political systems. Some might prefer to speak of the international economic system, plus the international political system, all together in the international system, which is thus broadened to include economics as well as politics. This approach could be called political economy, and would be more interdisciplinary and more inclusive. But it would still be short of what we seek.

Broader, and on our mark: the global biospheric system of Earth, emphasized in our book *Prediction*, is the physical, biological, and social context in which, and only in which, humans have evolved to live. It is affected by physical, biological, and social processes, and can only be understood from an ecological perspective covering, and integrating, the whole range of the sciences. Such a perspective might add empirical content to the term "general systems theory." The limits and possibilities of scientific prediction and explanation of this system's properties are in fact a large part of the content of our book.

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17. Innovations in forecasting the future that one can learn from: predicting the future in science, economics, and politics

Solomon W. Polachek

Forecasting is a standard undergraduate and master's degree course in many economics and statistics departments. This course mostly teaches students econometric packages so they can fit time-series data to predict the future from past information, usually via statistical regression analysis of one kind or another. Unfortunately, the approach employed in these disciplines is often too simple to yield reliable and informative predictions for a host of phenomena that policy-makers find important. *Predicting the Future in Science, Economics, and Politics* (hereafter *Prediction*) is an important breakthrough pushing forecasting well past its current analytical and conceptual frontiers. By taking account of new theory spanning various academic disciplines, what Edward Wilson (Chapter 3 in this volume) calls "consilience," and by utilizing sophisticated mathematics and statistics, the authors of this volume map out techniques that can be used to foretell important issues regarding human well-being that forecasters now do not study because these issues are currently far too complex. The innovations outlined in *Prediction* include a call to expand the topics currently forecast to include predictions on civil and international war severity, environmental catastrophe, and evolutionary biological transformation. *Prediction* also calls for expanding the forecasting techniques now used. These innovations are to incorporate discounting, boundary value behaviors, complex adaptive and neural systems, social field theory, game theory, and computational dynamics. In what follows, I divide my comments into four parts. First, I describe current forecasting techniques. Second, I explain many of the limitations of current forecasting models. Third, I explain what I believe are some of the main advances outlined in *Prediction*. Finally, I reflect on how the forecasting field should change, based on the material discussed in *Prediction*.

CURRENT FORECASTING TECHNIQUES: USING THE PAST TO PREDICT THE FUTURE

Current forecasts are limited. They are bound by conceptual issues, they are bound by measurement issues, and they are bound by statistical functional form issues. To see these limitations, in this section, I review some fundamentals of current forecasting models. Then, in the next section, I describe their limitations.

Generally forecasts are of the following mathematical form:

$$\begin{gathered} y(t)=F[t, t^2, \ldots t^n, y(t-1), y(t-2), \ldots y(t-j), y^2(t-1), \ldots \\ y^2(t-j), y^n(t-1), \ldots y^n(t-j),\ x(t-1), x(t-2), \ldots x(t-j), x^2(t-1), \\ x^2(t-2), \ldots x^n(t-1) \ldots x^n(t-j); \varepsilon(t), \varepsilon(t-1) \ldots e(t-j)] \qquad (17.1) \end{gathered}$$

The dependent variable $y(t)$ is the entity to be forecast. Actual prediction is based on one or all of the following: (1) the time period t in which y is observed; (2) the lagged $y(t-j)$ values which have been observed in the past; (3) other also lagged factors $x(t-j)$ similarly observed in the past; and (d) an error structure $\varepsilon(t)$ denoting imperfections in the process. The mapping F must be a well-behaved function adhering to the usual mathematical properties of functions, namely a continuous differentiable many-to-one mapping that one can estimate with standard statistical programs so that y is explainable by time t, by its own lagged values ($y(t-j)$), and by the other quantifiable variables comprising x. What is to be forecasted must be definable and easy to measure; otherwise there would be no data on which to base one's predictions. The same measurability criteria are true for the predictor variables X.

The simplest adaptation of (17.1) is merely to predict y as a function of t:

$$y(t) = \alpha_0 + \alpha_1 t + \varepsilon \qquad (17.2)$$

The coefficient α_0 is the predicted value of y at the initial time period, and α_1 is the time trend, namely how y changes with each time period (for example, a year, a quarter, or a month). More sophisticated time trend formulations treat t non-linearly, meaning y can increase or decrease at a quicker or slower rate as time passes. Equation (17.1) illustrates this by allowing quadratic, quartic, or higher-order specifications of t. In addition, exponential ($e^{\alpha t}$) or other functional forms are clearly possible, though estimating an n-th degree polynomial in t can be viewed essentially as estimating a Taylor approximation. However, not always does y follow a simple linear or non-linear time trend.

Often y follows a cyclical nature. These cycles can be seasonal, such as when sales skyrocket during the holiday season, or they can follow more complicated cycles adhering to less discernable oscillations that characterize various economic business or financial cycles. The usual approach to get at seasonality is to introduce a seasonal dummy variable D so that:

$$y(t) = \alpha_0 + \alpha_1 t + \sum_{i=j}^{S-1} \gamma_i D(it) + \varepsilon(t) \tag{17.3}$$

Note that to identify γ_i one can only depict seasonal variables for all but one of S seasons. Clearly, also, one can account for other known cyclical phenomena, such as particular holidays, weekends, or (in finance) trading-day variations by including independent variables for these events, as well.

Getting at other cyclical effects more generally is far more complicated. Here one often relies on a number of approaches. Perhaps the simplest is to lag the dependent variable Y so that one estimates:

$$y(t) = \alpha_0 + \alpha_1 y(t-1) + \alpha_2 y(t-2) + \ldots + \alpha_m y(t-m) + \varepsilon(t) \tag{17.4}$$

where m is a finite number indicating the number of lags. A more general approach considers infinite lags. However, based on Herman Wold's representation theorem, one can approximate the dynamic evolution of y by a linear model having a finite number of parameters often adding autoregressive and moving-average terms to the equation:

$$y(t) = \alpha_0 y(t-1) + \ldots \alpha_{t-j} y(t-j) + \varepsilon_t + \gamma_1 \varepsilon(t-1) + \ldots + \lambda_{t-k} \varepsilon(t-k) \tag{17.5}$$

where the error ε is normally distributed with mean 0 and variance σ^2, that is, $\varepsilon_t \sim N(0, \sigma^2)$. Still other possible data variations perceived as cycles can be white noise and completely indiscernible in the data.

LIMITATIONS OF SIMPLY USING THE PAST TO PREDICT THE FUTURE

Forecasts based on (17.1) are usually evaluated using related but more complicated goodness of fit measures such as R^2, the Akaike information criteria (AIC), or the Schwarz information criteria; but in reality it is difficult to establish what constitutes a good or bad fit. Even what we think might comprise a good fit can be weak when predicting out of sample. Further, it is not obvious that simple well-behaved mathematical functions used for F in current statistical packages always do the job well. Nor is it obvious that easily measurable dependent variables such as gross national product (GNP), inflation, and product demand in economics, or storm conditions in meteorology, are the only ones of interest. For example, rather than simply predicting inflation level, one might want to predict the timing of inflation. Instead of simply the number of storms per year in the aggregate, one might want to predict the number of storms to hit a particular location, such as a specific Florida county, next year. Similarly with political variables, one might want to predict where and when coups occur, where and when wars take place, or the intensity of such wars. Alternatively, one might want to predict power transitions or the timing of these transitions, and more. And what about more difficult to define phenomena, such as a population's well-being including its environment? Of course, the latter phenomena are difficult to measure since well-being is hard to define. In short, we now forecast what we can easily measure, and we forecast using tools based on simple mathematical functions, but unfortunately these forecasts are not good enough.

To illustrate some of these pitfalls, Frank Wayman (Chapter 13 in this volume) eloquently presents a set of forecasting models of war onset based on the past. He uses several adaptations of (17.1). First, beginning in 1820 and going through 1999, he predicts the number of wars in each decade based on each past decade's number of wars. Second, he predicts each decade's number of wars based solely on the previous decade. These two models are versions of (17.4).[1] Third, he predicts wars (interstate, intra-state, extra-state, and total wars) accounting for battle deaths and system size. These latter models augment (17.4) by incorporating extra variables $x(t)$ and use a more complicated functional form.

Wayman shows that such simple forecasts can be fraught with error. In his Table 13.1 he illustrates inaccuracies common to these estimation methods. His prediction based on each past decade yields about a 65 percent error rate which is about 20 percent higher that the prediction based on all past decades. So using models akin to (17.1) can yield large errors, thus implying the need to do better. Others in the book who apply statistics to present actual predictions include Atsushi Tago and J. David Singer (Chapter 8). Using data from Singer and Tago (2004), they utilize a hazard model to predict the probability that a state will become nuclear weapon capable. While we have no estimates of the accuracy of these latter forecasts, they are also subject to error.

BEYOND CURRENT FORECASTING MODELS

Prediction indicates why current forecasts are often deficient. It also illustrates what must be done to improve predictive power. Essentially *Prediction* makes three recommendations. First, that the theory underlying current forecasts is too simple. As such, it fails to use all we know, implying that one can do better by incorporating knowledge from numerous academic disciplines in tandem, what Edward Wilson calls "consilience," the underlying theme of the book. Second, whereas Wilson mostly considers the hard sciences, particularly synthesizing knowledge to explain evolutionary biological phenomena, this book emphasizes incorporating material from a wide range of disciplines, namely evolution, environmental science, economics, mathematics, and political science. Assimilating material from these widely disparate disciplines is this book's second theme. Third, the book argues that the mathematical theory underlying current forecasting models does not take into account some of the newer advances made in statistics, mathematics, and computational dynamics.

A Historical Perspective

Perhaps the oldest, most widespread forecasting challenge is to predict the weather. As early as 650 BC Babylonians predicted weather from cloud formations and optical phenomena such as haloes. Several centuries later, though not explicitly dealing with forecasting weather per se, Aristotle's (n.d.) treatise *Meteorologica* devised theories with regard to the formation of clouds, rain, hail, thunder, and other meteorological phenomena. By 300 BC the Chinese created a calendar dividing the year into 24 weather-related festivals. But it was not until Vilhelm Bjerknes (1904 [2009]) and Lewis Frey Richardson (1922) that differential equation models were introduced to predict the weather, and not until the mid-1950s when Jule Charney solved a modified version of the Richardson equations using the ENIAC, one of the early mainframe computers. Whereas back in the early 1900s, Richardson took several months to create an inaccurate six-hour forecast, Charney took a mere 24 hours to compute his forecast, illustrating the tremendous progress 40 years can make.

What is interesting is that Richardson would not have been able to devise his mathematical models if it had not become clear in the fourteenth to sixteenth centuries that Aristotelian and later natural philosophers were off-base in their theories. These erroneous theories led leading scientists to create new instruments. The hygrometer invented by Cardinal Nicholas de Cusa in 1450 measures humidity. The thermometer invented by Galileo in 1592 measures temperature. The barometer invented by Evangelista

Torricelli in 1643 measures atmospheric pressure. And the anemometer invented by Robert Hooke in 1667 measures wind speed. Taken together, all four of these instruments better measure facets of the weather. The new data enabled scientists to deduce a new theory consistent with the data.

I give this concise history of weather forecasting because to a certain extent it illustrates consilience. In order to understand meteorology scientists combined knowledge of philosophy (philosophy of science), devised intuitive tests of predictability, utilized measurement, adopted mathematics, designed high-speed computers based on electromagnetic theory, and synthesized various fields to eventually obtain forecasts of what at one time seemed like an immeasurable entity.

Consilience Expanded: Extending What One Forecasts

But consilience goes further. The science of meteorology took thousands of years to evolve, and indeed is still advancing. The goal of consilience is to gain a better understanding of the fundamental core principles governing human behavior. It seeks not only to widen our knowledge base, but also to speed the process; not just with meteorology or biological processes, but also with regard to gaining a better understanding of all aspects of life on this planet. *Prediction* takes steps in this direction. The book has brought together some of the world's leading scholars to synthesize knowledge from a number of the disciplines to augment current underlying approaches used to predict the future. With that in mind, this book contains chapters by a number of leading scholars in biology, economics, electrical engineering, history, mathematics, physics, and political science.

Along with expanding the underlying theory upon which forecasting is based, *Prediction* advocates that scientists focus on the big picture, what one might call macro-phenomena, namely phenomena that affect large segments of the population, and not simply microcosms. In this vein, Richard Alexander (Chapter 4) examines a wide range of aspects concerning the general well-being of people. He emphasizes evolution and applies these biological evolutionary principles to muse over how we can attain greater human security and goodness. He listed (in his conference presentation) a number of evolutionary traits unique to humans, and concluded by challenging scholars "to identify . . . particular development experiences that promote such traits as conscience, trust, and enthusiasm, and . . . provide . . . equal access to at least the lowest rungs [of the population] on intact and climbable ladders of affluence to be generated within their respective societies." As a subset of this broad question, but perhaps a bit more narrow, Urs Luterbacher et al. (Chapter 7), Detlef Sprinz (Chapter 6), Atsushi Tago and J. David Singer (Chapter 8), Gerald

Schneider (Chapter 9), Frank Wayman (Chapter 13) and Paul Williamson (Chapter 14) all take up issues of war and peace. Clearly war and peace affects our civilization's well-being, particularly human viability. In this regard Lutenbacher et al. (Chapter 7) examine how such collective behavior as environmental degradation leads to scarcities which in turn can lead to fights about natural resource allocation. This in turn results in war and eventually mankind's destruction. Wayman (Chapter 13) describes how engaging in war can lead to involvement in future conflict. Often these conflicts develop into arms races whereby military build-ups are constantly escalating into Richardson arms races. While he may appear to be addressing this issue by working within Richardson's well-known differential arms race equations, Williamson (Chapter 14) is actually proposing to apply those equations to an entirely distinct empirical domain, namely internal national development, which he posits to be driven by Richardson-like interactions among national and other actors. Similarly, arms races can evolve into severe wars with significant destruction and high numbers of fatalities. War severity is exacerbated as weapons systems get more powerful with the advent of nuclear proliferation, which is what Tago and Singer model using a statistical hazard model approach. In this vein David Wilkinson (Chapter 12) concentrates on how world power structures have changed. He develops his analysis by applying a world-systems approach by examining power polarity from about 3500 BC to the present. Then he observes the probability of war based on the number of major powers. So, in short, the second innovation of *Prediction* is to expand the dependent variable $y(t)$ to more complex difficult-to-measure issues to be forecast.

Introducing Mathematically Sophisticated Models

The speed at which environmental degradation, military build-ups and polarities change within the time frames alluded to above is critically important. *Prediction*'s third innovative message is to espouse why prognosticators need to introduce sophisticated mathematically based models in current forecasting techniques. To date simple formulations underlie equation (17.1). For example, equation (17.2) is linear. Equation (17.3) introduces non-linearities via categorical seasonal variables. Equations (17.4) and (17.5) do so via various lag structures. But how one's models change is crucial to getting accurate forecasts. In the sciences, change is well defined. According to Gottfried Mayer (2005), "once the measurement has been made the system will continue to evolve according to Schroedinger's equation," which describes how a quantum state (of a physical system) changes in time. With this in mind, Paul Williamson utilizes sophisticated mathematical formulations to suggest faster change. In

Chapter 14, he further develops Quincy Wright's concept of social field theory based on societal "space-time that emulates the physical space-time of special relativity theory." Not so in the social sciences. Here change is more complicated. People learn at different rates and hence change occurs in a very heterogeneous way.

Sprinz (Chapter 6) generalizes these time-dependent notions concerning long-run phenomena. He classifies long-run problems, describes why they exist, and then talks about institutional aspects in general and the environment as a specific case. Luterbacher et al. (Chapter 7) speak more specifically of how scarcity arising from environmental degradation can yield bad effects such as war. But determining how to weigh current events far in the future is tricky. Comparing the future to the present depends on integrating "discounting" techniques into the analysis. Farmer and Geanakoplos (Chapter 5) provide the mathematical tools used in the finance literature to better evaluate the present impact on society of the future effects via discounting. Discounting is a simple mathematical technique to compare states of being from one time period to another. It can be used to evaluate future well-being now in the present, or to evaluate current well-being at some point in the future, but it says nothing about how to model the current state.

Two Approaches to Systemic Forecasts

There are two approaches to analyze and forecast large-scale civilization-wide issues. One is to take a macro approach and look at the whole system, as espoused above. A second approach is focus on each entity within the system and later aggregate over all entities to build up to the whole. This is what John Holland suggests by his complex adaptive system approach in Chapter 10. As yet, the jury is still out on which approach is best. Accordingly, *Prediction* does not argue in favor of one approach over the other.

There are a number of ways to model each component of a larger system. *Prediction* deals with several. In Chapter 14, Paul Williamson describes social field theory. This theory portrays individual and social group emotional and cognitive behavior as similar to the "inverse square law" used to describe physical masses attracted to each other by gravitational attraction. Here masses pull towards each other more weakly the greater their distance. In the economics literature, such gravitational models have been used to predict trade flows between countries. Here "close" countries trade more than "distant" countries because transportation costs fall with proximity. According to Williamson (Chapter 2), other such approaches include Maxwell's electromagnetic equations which quantify the attraction and repulsion in particle physics. Social scientists such as Sallach (2006) advocate using these theories to model social behavior. Economists advocate using social welfare functions. These are more general because they are not bound by specific functional form restrictions. On the other hand, economics-based social welfare functions tend to assume rationality, which current behavioral economists reject (Kahneman and Tversky 1979).

But as already mentioned, each of the system's components must be linked to the others in order to get back to the whole system. This would be easy if each component were independent of the others. Independence simply implies summing the values of each component to get the whole. As such, the whole equals the sum of its parts. But, should there be externalities, this simple addition does not hold. Externalities imply one component to be dependent on the behavior of another. These externalities can be a by-product, coming about naturally such as when a factory pollutes nearby areas causing local citizens to alter their individual and collective behavior even though citizens and factories do not directly interact with each other. Alternatively, externalities can arise when individual entities actually negotiate each other's behavior. Analyses of this latter case often imply using game theory to ascertain each side's behavior. Game-theoretic models have been introduced by Bruce Bueno de Mesquita (1975, 2003) and eloquently described in Chapter 13 by Frank Wayman. Such interactions make forecasting more difficult, but if done right they lead to more accuracy.

WHERE DO WE GO FROM HERE

Current forecasting models deal with easily measurable estimates and use standard regression analysis. *Prediction* argues that such forecasts are too simple. First, they are based on crude models because they are rooted solely in knowledge from a single discipline. Second, they involve easily measurable phenomena but neglect more socially interesting and important concepts that are more difficult to quantify. Third, the estimation models adopt unsophisticated functional forms, thereby neglecting newer, more complicated mathematical modeling techniques. Finally, *Prediction* gives examples of how to improve prognostication. But can one go further?

Functional Form

A number of chapters in *Prediction* describe mathematical techniques. These techniques are important, but perhaps one cannot willy-nilly adopt complex mathematical models to describe social issues that were invented to explain specific physical science phenomena. More research is needed on whether these models actually apply, and if so, how. Perhaps social scientists should emphasize a whole array of simpler statistical models, not quite as complex as those portrayed in *Prediction* but more complex than the simple forecasting models currently used. The underlying equations surely should not be straightforward linear expressions which are obviously flawed. Instead one can use currently available techniques to modify basic estimation. One possibility entails Box–Cox (1964) and Box–Tidwell (1962) flexible functional form estimation techniques to introduce non-linearities in the estimation process. These models transform independent and dependent variables so that the data themselves determine the appropriate functional form. Other techniques to experiment with functional form include finite difference methods often used in numerical analysis (Rübenkönig 2006). The finite difference approach approximates complex functional forms by n-th order polynomials found by taking a set of successive first-differences within the data. Other approaches to functional form are given in standard numerical analysis and econometrics texts (e.g., Morton and Mayers 2005; Greene 2008).

Multiple-Equation Models

Examining single-equation models might also be too simple. Not all entities are governed by a single equation. For example wars typically involve multiple parties. Yet the models outlined by Tago and Singer (Chapter 8) are single-equation summaries which have some advantages when one concentrates on aggregate behavior. However, Holland (Chapter 10) and others advocate disaggregating by depicting each component of the aggregate structure by a separate equation. Disaggregating as such involves a system of equations. For example, in economics, formulation of large multi-equation scale micro-based rational choice macroeconomic models began in the 1980s. These models specify separate equations depicting households, firms, and governments in one or more countries as economic agents making optimal choices. While complex, these models have still been criticized because they typically assume that all agents of a given type make decisions using identical processes. Nevertheless, such multi-equation models yield relatively accurate economic predictions. Though political phenomena are often deemed more complex, these multi-equation type models might be promising and worthy of further exploration.

Structural Change

Things change over time. Although by their very nature forecasting models deal with change, they usually do not handle structural changes that underlie the very variables forecasters wish to predict. For example, economics macro models often do not predict the technological change that influences each underlying structural equation. Who would have known in 1990 that consumers would now be spending billions of dollars in purchases on the Internet? In this regard, Tago and Singer's hazard model of nuclear proliferation (Chapter 8) assumes that the hazard function itself stays stable over time. But what happens if advances in technology change the very structure of the hazard function? Clearly, structural changes need be incorporated into the analysis.

Structural changes can be deterministic. Deterministic changes imply the ability to model technological change, particularly the timing depicting when technological developments occur. To do so usually implies adopting a simultaneous equations approach: one equation to describe technical transformations, and another to incorporate these changes into the original forecasting model. Also, structural change can take many forms. Whereas I have described technological innovation, instead structural change can involve more broad-based society-wide phenomena such as nuclear proliferation. As an example, take the case of incorporating nuclear proliferation to forecast war. Here war is a function not simply of relative power measured by a country's weapons, but also of deterrence as measured by worldwide nuclear capabilities. In this case modeling how the probability of war changes over time might entail two equations: one predicting nuclear proliferation, and the other including predicted nuclear proliferation in the probability of war. Here worldwide nuclear deterrence might change parameters underlying the mathematical function used to predict how conventional weapons affect a country's probability of entering a war.

Structural change can be stochastic instead of deterministic. In this case, the timing of an event's occurrence cannot easily be modeled. Here one cannot easily predict when a new momentous event will occur. Whereas such events can be positive breakthroughs such as new technology, they can equally be massive catastrophes such as earthquakes. In either case the change arises suddenly. In these cases stochastic models may be more useful than deterministic approaches. But again, more work is needed on how best to model such unexpected change.

Incorporating Financial Markets as An Alternative Forecasting Scheme

Adopting econometric modeling is just one approach. Schneider (Chapter 9) discusses an entirely different and innovative method of making political inferences from financial markets. Based on the Condorcet Jury Theorem, which argues that collectives better judge true states of the world than individual experts, he argues that financial markets can function like collectives and thus be used to predict political phenomena. This makes particular sense because stockholders have money at stake. Accordingly, he shows that information from the Tel Aviv Stock Exchange improves the predictive accuracy in models that largely rely on typical autoregressive processes to predict cooperation levels in the Israel–Palestine unrest. Zussman and Zussman (2006) represent another case in point. They assess the benefits of the Israeli Mossad's counterterrorist targeted killings. Based on the assumption that the Israeli stock market reacts positively to news of effective counterterrorism measures but negatively to news of detrimental ones, they show assassinations of senior political leaders of Palestinians to be harmful, while assassinations of Palestinian military leaders are beneficial. The Iowa Electronic Markets (IEM) is another stock market application used for prediction. Here traders buy and sell futures contracts based on political election results. At any point in time the relative price of one candidate over another candidate yields the relative probability (the odds ratio) of one candidate winning. To date, the political election results have been more accurate than those attained from traditional polling.

Better Measurement

A number of the chapters talk about human well-being, but it is not obvious how to measure well-being. Economists mostly settle on GNP and GNP growth to get at countrywide well-being. They employ personal income and wealth to get at individual well-being, and they use measures such as income variance ($\sigma^2(Y)$) or the Gini coefficient to get at distributional aspects of human welfare. But it is not obvious that these measures capture what social scientists really mean by well-being. In *Prediction*, Wilson (Chapter 3) discusses culture, esthetic judgment, innate neurobiological monitoring, local habitat, and evolution. Alexander (Chapter 4) concentrates on human attributes that affect evolution. Luterbacher et al. (Chapter 7) focuse on resource scarcity. Sprinz (Chapter 6) deals with climate. And Tago and Singer (Chapter 8), Wayman (Chapter 13), Wilkinson (Chapter 12) and Williamson (Chapter 15) deal with world peace. Some of these welfare concepts are measurable, some not. But none of these notions are comprehensive enough to encompass all there is to be concerned with about human well-being. What about other quality-of-life measures? What about indices of human suffering? What about health quality? What about happiness? These and other well-being concepts are not easily quantified by income alone as economists often assume, nor are they measured by evolutionary indices, climatic indices, or war data.

World peace is certainly part of human well-being. As *Prediction* illustrates, political scientists have used measures of war and peace widely. But even here, not all datasets agree on how to measure wars. Do 1000 annual battle deaths really constitute war, or is this definition too stringent? Also, wars constitute a severe type interaction, yet not all interaction is hostile, and much interaction is actually cooperative. The Cooperation and Peace Data Bank and the Virtual Resource Associates data find more cooperation between countries than conflict. Surely such peaceful accommodation between countries increases human welfare, but it is only recently that social scientists have devised measures of interstate cooperation, and few studies incorporate these measures. Clearly scholars still need to identify the societal factors that bring about more cooperation and less hostility. They also need to determine the relationship between cooperative international relations and human well-being.

These same issues plague micro-level research. Individuals cooperate, but they also fight. We observe marriage, but we also observe divorce. Billions of dollars are contributed to charity, but billions of dollars are also squandered on crime. As Alexander (Chapter 4) posits, some of these individual interactions arise for evolutionary reasons, but they probably also in turn evolve because of environmental considerations. Poverty, opportunities, and the availability of education no doubt affect how well people get along. But predicting individual interactions can be important to predicting civil wars if credence is given to Holland's (Chapter 10) complex adoptive system approach in which each individual component must be modeled when attempting to make aggregate predictions.

The Very Long Run

Meteorologists generally predict, at best, weeks ahead. Political scientists (Bueno de Mesquita 2002) and economists are lucky to predict years ahead. Yet, astronomers can accurately predict thousands of years ahead. In all disciplines, accuracy diminishes with the length of the forecast. But the real question is how social sciences can become more like the hard scientists in their predictive power. Without doubt, discounting makes far-off events less valuable, but nonetheless such events are important when the stakes are especially high, and they are high for significant questions. Knowing when technological breakthroughs in energy resources will come about has dramatic implications for world power and world peace. Knowing when catastrophes will occur can save hundreds of thousands of lives. Knowing when man will begin interplanetary exploration in earnest can lead to breakthroughs never before dreamed. And knowing when computers will develop brain power and dexterity far greater than humans will lead to as yet unimaginable change. This *Prediction* book illustrates that the field of prediction is still in its infancy. Nevertheless *Prediction* makes many important suggestions as to how the social sciences can predict far into the future and far more accurately, as do the hard sciences. My own prediction of our predictive prowess is optimistic if scholars follow the prescription outlined in *Predicting the Future in Science, Economics, and Politics*.

NOTE

1. The first is represented as: $y(t) = \frac{1}{j}\sum_{j=1}^{t-1} y(t-j) + \varepsilon(t)$
   The second as: $y(t) = y(t-1) + \varepsilon(t)$

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18. Predicting the future to shape the future

Bruce Bueno de Mesquita

The urge to predict has occupied a prominent place in history since the dawn of humanity. Whether gazing at the stars, untangling sheep entrails, or praying to the gods, the human story entails trying to anticipate the future and maybe even change it. The undertakings in this book are, in that sense, part of a long line of efforts to devise ways to foretell, to anticipate, and to prepare for what is to come. Yet, its contributors tackle the problems of prediction in a manner completely unlike those who sought revelation in omens and portents. While breaking sharply with the fortune-teller, soothsayer approach to prediction, still ours is not an entirely new effort. We can go back at least to some of the important Greek mathematicians, such as Pythagoras or Zeno, and certainly to the founders of the modern scientific method, people such as Galileo, Hobbes,[1] Boyle, Newton, Lavoisier, and Priestley, as well as Fermat and Pascal, and find in them a keen desire to predict, but to predict based on the rigors of logic and evidence rather than divination. That has been the mission here, to investigate what rigorous logic and equally rigorous uses of evidence can do to help uncover the likely paths of the future and the likely mechanisms to redirect those paths.

In this chapter, I hope to elucidate two sets of issues related to using science to predict and to engineer the future. First, I discuss some of the philosophical and epistemological underpinnings to prediction. This discussion examines many of the perspectives set out in this volume, expanding on some, proposing small modifications to others, and casting all in a general context intended to help us understand the feasibility and limitations to a unified science that makes reliable prediction possible. Second, I illustrate the prospects of successful prediction and its applications to enhancing policy decision-making by discussing my own and others' experiences in this arena. Here I focus on prediction within a limited time scale, typically not more than a few years or at the outside, a couple of decades. I emphasize the marriage of the hard science behind prediction and its applied engineering aspects that call for compromise between "pure" science and "practical" science.

THE FOUNDATIONS OF PREDICTION

We have been occupied by several important themes. One theme is physical. Can we integrate predictions about changes in inanimate objects like rocks and rivers with forecasts about physical processes like climate change or geologic upheavals, and animate objects like ourselves? If so, can we also integrate forecasts about long-term physical processes such as geological upheavals, totally dependent on the physical world, with forecasts about events such as climate change that are affected by both physical processes and human behavior? Another important theme concerns time. Can we think of the long term – that is, hundreds, thousands, maybe even millions or billions of years – in the same way that we think about the short term, by which I mean today, the next month, the coming year or two, or even a generation or a lifetime? A third theme draws our attention to whether we can extrapolate from current patterns or whether complexity precludes a continuous view of the future from past patterns or functions.

Taken together, these themes return us to where we started, with Edward Wilson's (Chapter 3) aspiration and maybe even expectation that the sciences can move and are moving toward consilience, toward a fundamental unity. Science, of course, is a method, not a subject, but here we will follow the colloquial usage in asking whether such a unity of subjects can be attained within the constraints of the method of science.

THE BIG PICTURE

Looked at from a high-altitude, big-picture perspective this volume tries to understand what elements need to be integrated to instantiate a science of prediction. Some chapters have examined this question purely within a human framework. Farmer and Geanakoplos (Chapter 5), for instance, examine variable discounting within human time frames. Tago and Singer (Chapter 8) look at something like a nexus between individual human choices and social constructs, such as nation-states, in their discussion of nuclear proliferation. Others, such as Luterbacher, Rohner, Wiegandt, and di Iorio (Chapter 7), or Sprinz (Chapter 6), investigate the nexus between physical processes and human contributions to changing those processes. At a somewhat higher level of abstraction, so do Alexander (Chapter 4) and Holland (Chapter 10), each of whom is concerned with how animate, biological agents, whether human or not, shape the future as a consequence of their interactions.

Well-formulated and tested theories that link physical processes to human endeavors, showing how each changes future states of the other, are, I believe, an essential element if there is to be consilience. The divide between physical sciences and social sciences has largely thus far served as an impediment to this linkage. The methods, theories, and explanations in these two vast bodies of research can, however, be brought together into a unified whole. How we might think about that divide and how to bridge it is the topic to which I now turn.

DO PHYSICAL DIVISIONS MATTER?

Behind the concord hinted at in this volume on what needs to be integrated, lurk important divides over what is essential for understanding how things work in the world. Wilson (Chapter 3) offers an integrative perspective on how things work. He draws out a trinity or a hierarchy that moves from gene to brain to culture. His organizing triad leads to useful syntheses of vast portions of biology and social behavior. But I also believe that we can usefully extend that consilient effort downwards toward physics and upward toward economics and politics by imagining another triad with a still broader base. My corners, defining a bigger and more stable base triangle, are particles, genes, and couplings. In the area circumscribed by such a triangle, one will find the foundations of this book, because this large triad is the necessary basis of comprehensive global forecasting.

The triad of particles, genes, and couplings provides us with a bridge from the physical world to the animate or sentient world. It includes the notion that inanimate objects or physical processes are drivers – albeit not the only drivers – in our capacity to predict. For instance, it provides a place for thinking about human effects on global warming while also leaving room, largely absent in Wilson's triad, for evaluating the extent to which global warming is due to properties of the physical environment that create climate cycles independent of human activity and that, nevertheless, change human interaction. To predict climate change and to sort out how we might alter it, we need to understand both its physical, inanimate sources and its sources that reflect interactions between the animate (us) and the inanimate.

To be sure, in emphasizing a triad of particles, genes, and couplings I do not mean to suggest that animate (or even human) endeavors are wholly separable from physical processes in their explanation. Quite to the contrary. We are long past this false Cartesian dichotomy.[2] Rather, I wish to distinguish between those physical processes that are not so complex as to involve some self-preservation or survival orientation from those that do, recognizing that the interplay across these dimensions is often critical for prediction of human and physical outcomes.

Wilson's hierarchy progresses from a basic unit of life, the gene, to the brain. It moves from there to the presumptively high-order organizing principle of culture. This, it seems to me, leaves too much out and fails to expose what I, at least, believe is the core distinction between the domain of the physical sciences and the domain of the life sciences and social sciences. If the implicit organizing principles behind what drives outcomes are to be useful, they must at a minimum be readily defined and their import explained. Genes certainly meet these criteria. Brains probably do too, at least as bundles of interconnected electro-chemical information storage, retrieval, and transmission mechanisms. But then there is this notion of culture. Perhaps "culture" is clear to others, but I am afraid I have a very limited comprehension of its meaning.

Most people seem to mean by culture something like learned patterns of values and beliefs that are highly correlated within groups and poorly correlated across groups. But then how do we decide the boundaries that define one group from another, and how high must the within-group correlation be compared to the between-group association before we are ready to ascribe it to "culture"? Here studies of culture are silent, tending to assume that the answer lies in the eyes of the beholder rather than in any systematic, well-defined, and implemented set of principles or rules. That leaves us with a rather vague concept at the peak of the hierarchy. Vagueness can, of course, facilitate integration of science by default, but seems to belie the very notion that science seeks to make precise claims leading to the discovery of predictive laws of action.

Perhaps a consilient way around this vagueness is to think of culture as analogous to the inertia of particles. Within that frame of reference, strategic pairings may be a mechanism to shift inertial motion into a more purposive direction. In a society (be it of ants or people), there are elements of inertia, such as culture or shared values, however the boundaries are drawn to distinguish the within-group from outsiders, and there are elements of strategic steering. While brains are finite and cannot constantly and perfectly steer every creature's every action (at any instant, some things remain habit), still Wilson shows that even in the case of the tiny mymarid fly, with a barely visible brain, strong and effective purposive behavior occurs. So biology bequeaths us and even some of the humblest creatures with a mix of purposive, self-interested, perhaps even conscious capacity and inertial tendency, the blending of which may improve efficiency in the face of new conditions. This may help to clarify what we mean by culture but still it leaves us with a concept lacking in the precision of meaning attributable to the other elements in Wilson's hierarchy or in the one I have proposed. That is not to dismiss culture, inertia, or habit, as they (for they are not identical with one another) surely play an important role in organizing action at least at the animate level. Consilience will surely be advanced by others reflecting more deeply on how these forces – strategy and inertia – interact to shape actions, events, and outcomes.[3]

Placing particles rather than genes at the bottom of the organizing hierarchy leaves space for physical properties to act as constraints on future states. The critical distinction between particles and genes is that the latter seem to manifest a survival property not found in particles such as photons, neutrons, electrons, or their constituent quarks. By "survival property" I do not have in mind how long the object or particle lasts, but rather a distinction between things that seem to manifest patterns of interaction that improve survival prospects, and particles that simply persist or decay. Genes, for instance, provide a useful elemental divide between physical properties or occurrences – the coming of an ice age, a massive earthquake, meteors or asteroids striking our planet or some other planet, the half-life of an element – and survival-oriented elements that shape endogenous, strategically driven responses to stimuli, whether those stimuli are themselves the endogenous products of strategic interactions or the product of exogenous shocks beyond the control of sentient or quasi-sentient animate bodies. I place pairings or couplings at the top of the hierarchy to make a further distinction. If we are to succeed in building a reliable science of prediction we need a way to think about the essence of high-level interactions. For me, at least, the central difference between particles at the bottom of my hierarchy, and couplings or pairings at the top, is the distinction facilitated by the mid-level of genes.

The subject of the physical sciences is particles and how they interact. An essential feature of particle interactions is that they do not interact strategically. Subatomic particles, atoms, and molecules do not interact by taking into account in advance what is going to be the reaction of another particle to whatever happens to them. Their interactions are neither purposive, nor can they be readily explained as if they were purposive. Following Alexander's perspective (Chapter 4), I see the shift from particle to gene as an evolutionary process in which, if you will forgive a bit of anthropomorphism, particles are rearranged as if to protect the particular distribution and survival process of their matter. So the gene is, in that "as if" sense, purposive. It is as if the defining characteristic of genes is to seek their own survival. Then we can see the brain or other high-order organic integrations as machines trying to facilitate the survival prospects not only of their individual elements, but of the combination of the genes into some complex system. And for me the next leap in knowledge is from the subject of the life sciences to the subject of the social sciences.

The subject of the social sciences as I see it is largely strategic interaction; that is, how two or more entities, organisms, including human beings, deal with each other knowing (or acting as if they know) that what they do affects what the other(s) will do, and knowing that the other knows that they know that what they do affects what will be done in response and therefore will affect what they must do. That is, they have ceased being simply particles that interact by crashing into things and have become particles that interact strategically in trying to shape what they interact with, and how they interact with it, and what they crash into, and what they do not crash into. This notion of strategic interaction crucially enlarges how we think about prediction. In the world of particles, for example, actions are not anticipatory. This means that things happening earlier in time are candidates as causes for what happens later. In the arena of strategic interaction – that is, in the domain of the social sciences – temporal ordering often is uninformative about causality. This is true simply because, at least at the level of pairings – of interactions – anticipation of consequences often shapes prior action so that the anticipation causes action rather than the action causing the anticipated consequence. Arms races are no more likely, for instance, to cause wars than is decorating a Christmas tree likely to cause Christmas. With these thoughts in mind, let me turn to the ties between prediction and time.

IS THE VERY LONG TERM THE PRODUCT OF THE HERE AND NOW?

One of the puzzles that crops up repeatedly in the contributions to this volume relates change to time. We humans, for instance, try to make predictions about our environment. We investigate questions such as whether the Earth is warming; if so, how fast; whether warming is mostly a product of human activity or part of a climatic earth cycle; and, most importantly, what we can do about it. Of course, what we can do depends strongly on the answer to the earlier questions.

The questions we pose must be cast in time frames. Doing so leads to different answers, different methodologies, and different assumptions about the processes that drive global warming or other questions that are pertinent in both the short and the very long term. Alexander's Chapter 4, for example, ponders facets of evolution over millennia. Over these time spans the hazards – whether Earth-cycle related or the product of human choice – that lead to selection in favor of some genes or even species and against others can be crucial to understanding the prospects of long-term survival in a changing and challenging environment. Farmer and Geanakoplos (Chapter 5) reflect on change more or less over individual lifetimes, a long period relative to many forecasts and yet barely an instant when compared to questions of evolution. Sprinz (Chapter 6) looks over an even shorter time horizon at immediate decisions, although his interest is to make projections about their consequences for decades and maybe even centuries into the future. How, then, to unify these themes and concerns for predicting outcomes, whether regarding global warming or other long-term issues with potential short-term causes?

Time horizons dictate a great deal about the structure of any forecasting tool. As Wayman (Chapters 1 and 16) notes, some variables do not change in a time frame – say years or decades – that constitutes the focus of most research regarding human interaction. Others, of course, move more quickly. Culture, for instance, with all the caveats stated earlier, is generally thought to move slowly, whereas inventiveness and technology seem to change rapidly. Can we say that cultural change is the product of the accumulated impact of changes in faster-moving variables, or is culture more likely to change in response to a sudden, massive shock? If variation in slow-moving variables is best thought of as the accumulated effects of changes in rapidly varying variables, then the problem of time is mitigated because we can think of change as a continuous function. That makes it relatively easy to model it mathematically and to study the data statistically. But not all slow-moving variations are easily seen as the product of smooth functions, even when their changes are the accumulated product of movement in other variables. Consider a game-theoretic perspective to see this.

The central equilibrium concept in game theory defines a set of player actions as forming an equilibrium if none of the players have a unilateral incentive to switch to a different strategy, with a strategy defined as a complete plan of action for all contingencies that could arise in the game. Let me offer an example to show how slow movement can lead to a seemingly sudden, discontinuous change for which standard statistical models are inadequate (although some classes of statistical models, especially Bayesian models, may prove helpful).

In 1122 the Pope, the Holy Roman Emperor, and the kings of France and England agreed to a new policy for appointing bishops. The essence of the deal (the Concordat of Worms between the Pope and the Emperor) was that the Pope nominated prospective bishops and the secular monarch got to accept or reject the nominees. During the interregnum before a bishop was appointed, income from the bishopric went to the monarch. Once a bishop was consecrated, subsequent revenue went to the Church. Elsewhere I have shown that this created an incentive for the Pope to stifle economic growth in the secular (but not in the ecclesiastical) domain (Bueno de Mesquita 2000). By doing so, he increased the odds that the King would prefer to get along with the Pope by accepting his nominees rather than fight with the Pope, rejecting his nominees while earning only a paltry sum. Monarchs, however, acquired the incentive to find ways to stimulate growth in their domain. Besides other income benefits from growth, a higher income meant that the Pope was more likely to nominate a bishop expected to be loyal to the monarch (whether King or Holy Roman Emperor) in order to avoid rejection and loss of revenue. But if the income were high enough, the monarch just would not care about getting along with the Pope and so would reject all nominees. In that environment, the monarch no longer needed the Pope and so the Pope's political power was all but lost. This latter condition is probably a pretty good description of the circumstances leading to the Protestant Reformation more than 400 years after the agreement was reached at Worms.

An interesting thing about the different equilibria in the game is that there is not a gradual shift from one outcome to another with time. Growing incomes do not alter the Pope's discrete choice of a bishop until the income passes a threshold value. Beyond the threshold value, irritating the Pope costs the monarch less than losing the income to avoid getting a bishop sufficiently more likely to be loyal to the Pope than the monarch. The change in equilibrium is abrupt. The same is true for the switch from the monarch caring who the bishop is at a modest income to not caring at all when the income is sufficiently high. Again epsilon less income and the equilibrium favors agreement on a bishop; epsilon more income and it does not. The change in choice is discontinuous.[4]

This phenomenon of seemingly discontinuous breaks with the past preceded by a long period of incremental change in one or more crucial variables is a common characteristic of strategic settings. In such settings, the past pattern of behavior is the best predictor of the future, except – and this is crucial to understanding the role that time and strategic interests play in prediction – when enough time has passed for incremental changes to have reached a tipping point at which the past equilibrium is no longer sustainable. Thus, there are two interesting effects of time when we consider strategic interaction (the domain of what I referred to as pairings or couplings). First, strategic behavior can create discontinuities that are mistakenly viewed as chaotic if not evaluated in their strategic environment.[5] Second, as the Christmas tree example highlights, strategic environments often lead to endogeneity or reverse causality: anticipated future outcomes alter current behavior so that some sense of the future causes the past. In such circumstances, those who do not predict using strategic logic are likely to see either chaos where there is order, or causality where there is only correlation.

Without attending to strategically induced discontinuities or reverse causality produced by endogeneity, efforts at prediction about pairings are likely to go off course, especially when the process of change is not smooth and continuous. Failure to attend to the implications of strategic interaction lie, I believe, at the heart of many wrong predictions in the social sciences. Here the methodology of evolutionary models or game theory models sometimes clash with classical approaches to statistical analysis in which A cannot be a cause of B if A happens after B. Indeed, attentiveness to reverse causality is one of the principal contributions of strategic reasoning to improved prediction, as I will try to illustrate later.

I do not want to be misunderstood here. I am not suggesting that prediction without strategic reasoning is neither possible nor productive. Many processes in human behavior, as in non-human behavior, seem well described as smooth, continuous, and amenable to prediction based on deterministic or statistical, probabilistic patterns of correlation. Broadly speaking, we might divide the domain of predictive orientations into three categories:

1. Present behavior directly affects future behavior.
2. Present behavior is directly affected by the future or, more likely and precisely, by a present image or expectation of the future.
3. Present behavior is affected by memory of the past or, as a special case of the past, by a selection process (such as natural selection) whereby dysfunctional prior modes of response tend to be eliminated in favor of functional modes.

Each of these means of projecting the future is valuable when applied to the appropriate domain of questions. When events or outcomes are thought to follow in a temporally orderly way from past to present, with experiences of the past shaping current actions, then classical statistical approaches should fare well in providing good fits to the future. In situations of strategic interplay, where expectations about alternative actions by others, conditioned on current actions by oneself, are paramount, then expectations-based approaches are more likely to yield productive prediction. Of course, the expectations may be the product of memory of past, similar experiences and in that sense may seem not to differ much from other modes of analysis, but the logic of action is quite different. It is expectations about specific others now in such cases that shape endogenous choice, rather than memories of what they did in similar, but still different, circumstances.

In this regard, the Christmas tree example is not entirely apt in that memory is an equally useful basis for predicting that Christmas is coming from observing tree sales, not to mention the calendar. The two are observationally equivalent. Here the more apt illustration relates to arguments that arms races lead to war. Debates over the role of arms races revolve around views that emphasize reverse causality, or memory or knowledge of past patterns, or selection-driven bases of prediction. Looking forward, from arms build-ups to outcomes the evidence does not support the notion that arms races lead to war. Looking backwards, we see that many wars are preceded by an arms build-up. The classical statistical inference that arms races spiral out of control and produce war seems wrong, since few arms races eventuate in war. Rather, expectational arguments seem to offer an account more consistent with the observed empirical record, explaining when arms races eventuate in war and when they do not. For instance, anticipating a serious risk of war, governments elect to build up arms. Much of the time their build-up succeeds in deterring war rather than provoking it, but in those cases when war occurs we observe an earlier arms race. The arms race was not the cause of war; the anticipation of war was the cause of arms acquisition. That is, the expectation of war creates a selection effect in which arms are acquired, and as a result many prospective wars do not occur, because the cost has been raised too high; and when they do occur, we see that they were preceded by arms purchases. Looking only forward in a classical statistical way we are left with a weak correlation; a positive one if we select on the dependent variable (as in many case studies). Looking strategically, we anticipate a weak correlation and, furthermore, can anticipate which cases are likely to eventuate in fighting and which are not.

Selection, natural or strategic, provides two ways of thinking about temporal causation. The role of natural selection is, *ceteris paribus*, to favor organisms that responded "correctly" (known only *ex post*) in the past and continue to do so in the present. Choice in models of natural selection is likely to be considerably more stochastic than in cases of strategic selection, in that natural selection does not inherently assume a forward-looking agent seeking optimal actions. In strategic selection, past experience plays a crucial role too. Learning, for instance, is grounded in reconciling inconsistencies between beliefs about actions and their consequences, and prior observations that are inconsistent with those beliefs. Thus, in strategic selection, actors are "consciously" choosing to optimize consequences, something they do not do in most accounts of natural selection. Still, the *ceteris paribus* condition cannot be dismissed. It is difficult in practice to separate outcomes that are the product of stochastically correct responses from outcomes that are the product of strategically anticipatory responses. Thus, as long as the future is not too different from the past, this process of learned behavior seems to have the effect of taking the future into account; and in that circumstance, the indicated process confers survival value to the strategically acting particles; indeed, the process confers the strategic property itself (for example via brains that calculate) to the complex "particle" (animal, and so on). Putting this point in a slightly different way, natural selection seems to provide a mechanism by which non-strategic interactions at a simpler level deliver the strategic interactions at the higher level.

This means that the palette for predicting is rich with much opportunity for cross-fertilization (to mix metaphors). The three means of prediction listed above are complements, not mutually exclusive perspectives, and their interplay is not as well understood as it will need to be as we strive to advance consilience and predictive reliability.

DISCONTINUITY AND PREDICTION

As we have seen, reverse causality can, but need not, confound standard thinking about social phenomena. The same, of course, is true for discontinuities. I have already highlighted one problem with discontinuity: its challenges for those who prefer to think about smooth transitions from one state of the world to another. But there is a perhaps more profound form of discontinuity when we operate at the level of pairings; that is, at the level of strategic interactions.

The interplay between quantum mechanics and the general theory of relativity can help us to think about problems in moving from individuals to social aggregates within the human (or more broadly, sentient) domain. This is true in the following sense. Quantum mechanics provides an account of particle interaction at the subatomic level. Its account seems to fit well with observations at that level but is inconsistent with general relativity's predictions and with observations at the macro or large particle level. Thus there is a challenge in building a consilient theory even just at the level of particles, big and small.

Human choice at the individual – decoupled – level is likewise broadly inconsistent with choices made across aggregations of individuals; that is, at the macro, societal level (Arrow 1950; McKelvey 1976; Schofield 1978; McKelvey and Schofield 1986). When we go down to the human equivalent of individual particles, to the individual decision-maker as opposed to the community or nation, the laws governing outcomes differ. This is easily seen and is fundamental to understanding some of the more misguided arguments against the notion that choices can be thought about and predicted as the rational outcomes of individual values and beliefs acted on under constraints, whether they are institutional, informational, or temporal.

Individual choices may be perfectly rational in the sense that choosers can relate actions and outcomes in terms of preferences (I like A better than B, B better than A, or I am indifferent between A and B) and they act on their preferences taking into account constraints over their choices and how those constraints are expected to influence outcomes. Still, even when individuals choose rationally, it does not follow that the outcome of their choices reflects their collective interests. Let us consider a few simple examples from the domain of voting. That is an arena in which it seems reasonable to expect that preferences translate straightforwardly into outcomes, as long as there is no corruption of the fair vote-counting process. We know this is not true.

The 1992 US presidential election included three main candidates: William Clinton, George H.W. Bush, and Ross Perot. Clinton won about 43 percent of the popular vote, Bush about 38 percent, and Perot about 19 percent. Ignoring the complexities of the electoral college, we can see that Clinton won because he had a plurality of the votes. So it would seem that adding up the votes fairly inevitably had to mean that Clinton would be elected; and yet in the French run-off system this might not have been true. Let me stipulate that 13 of the 19 percent of Perot voters preferred Bush over Clinton (as is plausible) and that the remaining 6 percent preferred Clinton over Bush. Then in a run-off election, Perot having been eliminated, Bush would have won 51 percent of the vote to Clinton's 49 percent, making Bush president. Indeed, even Perot could have been elected president without changing any preferences by the simple expedient of adding the votes fairly, but based on different rules. Imagine, for example, that each candidate went head to head with each other. The run-off result tells us that Bush would have beaten Clinton in a two-way race. But if Clinton voters preferred Perot to Bush, as is likely for many of them, then Bush might easily have lost to Perot. Likewise, if Bush voters held Perot as their second choice, then a head-to-head contest between Clinton and Perot would have ended with Perot as the winner. Thus, using different – but equally fair – rules, voter preferences in 1992 could have been added up to make Bush, Clinton, or Perot president. So here we see that individuals acting rationally pursue their own self-interest, and what that interest translates into, depends less on their preferences than on the institutional, vote-aggregating rules they have inherited.

We have, then, a disconnection between micro-level choice and collective, macro-social outcomes. However, the parallel to the difficulties between a quantum-mechanical view of micro-phenomena in physics and a macro view in general relativity, are not so strong and may even help point the way to analytic integration. While the problem of moving from the micro level to the aggregate level is not yet solved for particles, it is largely solved for couplings or pairings. If we know the aggregation rule – and this is easily known when it is a choice that was made earlier, or it might be figured out if it is a strategic, endogenous choice made in the context of the given circumstances – we can predict the outcome. The linkage at the level of non-survival-oriented particles – that is, at the intersection of quantum mechanics and general relativity – is not yet worked out, although string theory may be moving us on a path to its resolution. But the social choice problem's solutions are well understood and focus our attention on strategic behavior.

The principles behind rationality are sufficient to move us far down the path to seeing how to work out what individuals or groups with shared values will do in different circumstances. Of course, there may be practical problems in gaining sufficient information to predict accurately, and there may be multiple equilibria that force us to predict distributions over large numbers of events, but at least we can see through the logic of such problems. Some may be too complicated to have nice analytic solutions, forcing us to rely on computational models, but again, guided by the logic of a situation, we should have a reasonable prospect of predicting outcomes. In the next section, I fortify these claims with evidence from my own experience in trying to predict outcomes of complex negotiations, ranging from national security issues, to mergers and acquisitions, and to large-scale litigation.

PREDICTING POLITICS

Ultimately, the best way we have to evaluate the explanatory power of any model or construct designed to enhance prediction is to assess how well its detailed analysis fits with reality when the analysis is undertaken before the outcome is known. The prediction of uncertain events is demanding exactly because the researcher cannot fit the argument to the known results. This is a fundamental test which too infrequently is applied to models of social phenomena, but is commonly applied in the physical sciences to assess theoretically derived propositions about particle properties or their interactions. Here is another area in which a unified science can be built by adopting common norms for assessing the linkage between logic and evidence.

I have developed some game theory models that have proven useful for predicting political outcomes before they occur. As discussed elsewhere, my forecasting work requires one to specify the actors with an interest in trying to influence the issue's outcome, what their relative clout is, what their negotiating stance is, how salient each issue is to each actor, and how resolved or flexible they are about alternative views. The model then sorts out the strategic interplay among the stakeholders, taking into account as appropriate institutional or other constraints (Bueno de Mesquita 1997, 2002, 2011). Frans Stokman and his colleagues likewise have developed another set of models that have been tested by making predictions ahead of the known outcomes (Bueno de Mesquita and Stokman 1994; Thomson et al. 2006). I briefly discuss the published performance record of these models. I focus on these models because they have amassed a body of published results that are open to the scrutiny of the academic audience, and that involved real-time prediction rather than only post-diction. Most social science results are based on fitting a model to data on known outcomes; these models do not rely on known outcomes.

Before turning to the academic record, however, let me note that these models have also been used to make predictions in commercial settings for businesses and for government. The Central Intelligence Agency (CIA) is one of the users of my modeling and it has published its own, in-house evaluation of its accuracy. In 1989, Dr Stanley Feder of the CIA gave a speech reported on by the *Salt Lake City Tribune* (March 1). He said that "the 'Spatial Theory of Politics' has been gaining increased acceptance at the agency and has resulted in accurate predictions in 90 percent of the situations in which it has been utilized." In response to that article, Professor James Ray contacted Dr Feder to find out more about the claim of predictive accuracy. On October 22, 1991, Dr Feder wrote to Professor Ray, saying that:

> The article correctly reports that I said that political forecasts made with a model based on the "spatial theory of voting" were accurate about 90 percent of the time . . . The forecasting model about which I lectured at the University of Utah was developed by Professor Bruce Bueno de Mesquita, now at Stanford University . . . Since 1982 a colleague and I have used Bruce's models to analyze and identify policy choice scenarios for over 1000 issues in scores of countries around the world . . . At the end of 1985 we did a systematic analysis of the accuracy of forecasts made with the policy choice model. That assessment showed the policy decision model with inputs provided by recognized country or issue experts correctly identified the configurations of political forces that would lead to specific, well defined policy decisions over 90 percent of the time. The model made it possible to identify easy-to-observe differences among alternative political situations and to forecast correctly the policy decision associated with each . . . [The models] provide specific forecasts, something few other methods or pundits can do with more than a moderate degree of accuracy.

A similar view was expressed by Charles Buffalano, Deputy Director of Research at the Defense Advanced Research Projects Agency, in a letter dated June 12, 1984. He said:

> [O]ne of the last (and most successful projects) in the political methodologies program was the expected utility theory work of Professor Bruce Bueno de Mesquita of the University of Rochester. The theory is both exploratory and predictive and has been rigorously evaluated through post-diction and in real time. Of all quantitative political forecasting methodologies of which I am aware, the expected utility work is the most useful to policy makers because it

> has the power to predict *specific* policies, their nuances, and ways in which they might be changed.

Feder referred to a systematic assessment in his letter. That assessment was originally published as an article for a classified government journal (*Studies in Intelligence*) and was later declassified and published in a volume edited by H. Bradford Westerfield (1995). As that article contains many specific, detailed examples, I take the liberty of examining it in depth. What types of issues has the CIA analyzed using these models? A sampler, taken from Table 2 in the declassified article, includes:

- What policy is Egypt likely to adopt toward Israel?
- How fully will France participate in the Strategic Defense Initiative (SDI)?
- What is the Philippines likely to do about US bases?
- What stand will Pakistan take on the Soviet occupation of Afghanistan?
- How much is Mozambique likely to accommodate with the West?
- What policy will Beijing adopt toward Taiwan's role in the Asian Development Bank?
- How much support is South Yemen likely to give to the insurgency in North Yemen?
- What is the South Korean government likely to do about large-scale demonstrations?
- What will Japan's foreign trade policy look like?
- What stand will the Mexican government take on official corruption?
- When will presidential elections be held in Brazil?
- Can the Italian government be brought down over the wage indexing issue?

As is evident from this sampler, the modeling method addresses diverse questions. Analysts have examined economic, social, and political issues. They have dealt with routine policy decisions and with questions threatening the very survival of particular regimes. Issues have spanned a variety of cultural settings, economic systems, and political systems.

Feder's assessment compares the forecasts based on this so-called expected utility model to more conventional approaches used by the intelligence community. Feder notes that the model makes specific, detailed predictions 60 percent of the time. Such specificity is found only 33 percent of the time in "traditional" intelligence analyses (Feder 1995). He goes on to note that while traditional and expected utility analyses both scored well in terms of forecast accuracy, the latter offered greater detail and less vagueness. He notes that the predictions using my applied game-theoretic models hit what he calls the "bullseye" twice as often as standard intelligence analyses. Perhaps more importantly, Feder notes that while the data for the model generally are obtained from area experts, the predictions frequently differ from those made by the very experts who provide the data. He reports that every time the model and the intelligence community made different predictions, the model proved correct, and he offers many detailed examples (Feder 1995, 2002).

Feder's assessment is not the only basis on which to evaluate predictions from this rational actor model. Frans Stokman and I examine five competing models in our book, *European Community Decision Making* (Bueno de Mesquita and Stokman 1994) and Stokman and colleagues look at 162 European Union issues using his models in a more recent publication (Thomson et al. 2006). The various models were tested against a common database of policy decisions taken by the European Community. Statistical tests were used to compare the accuracy of the alternative models relative to the now-known actual outcomes on the issues we examined. The various network analysis and logrolling models of Coleman, Stokman, and others in the 1994 investigation produced predicted values that when compared to the actual outcomes had probabilities of being correct varying from a low of 10 percent to a high of 62 percent. The expected utility model's results had a probability of being the same as the actual outcome on the same issues that slightly outperformed Stokman's best-performing model. In his more recent study using many more cases, his best model outperformed my model, demonstrating the advantages of a cooperative game over my non-cooperative game in the European Union context. Which model did best under which conditions is, of course, of less concern here than that a set of models – each relying on exactly the same input data that evaluates what players want, how focused they are on getting it, and how persuasive they could be if they tried as hard as possible – demonstrated that by focusing on strategic interaction, it was possible to make reliable predictions about future outcomes.[6]

Additional evidence for the predictive reliability of such models can be found by examining the predictions made in articles published before the outcomes being predicted were known. Professors James Ray and Bruce Russett evaluated most of the journal and book publications using my model to ascertain accuracy. Motivated by John Gaddis's claim that international relations theory is a failure at prediction, they note that:

> he does not mention a set of related streams of research and theory that justifies, we believe, a more optimistic evaluation of the field's ability to deliver accurate predictions. The streams of research to which we refer are, specifically: a rational choice approach to political forecasting . . . This 'expected utility' forecasting model has now been tried and tested extensively. [T]he amount of publicly available information and evidence regarding this model and the accuracy of its forecasts is sufficiently substantial, it seems to us, to make it deserving of serious consideration as a 'scientific' enterprise . . . [W]e would argue in a Lakatosian fashion that in terms of the range of issues and political settings to which it has been applied, and the body of available evidence regarding its utility and validity, it may be superior to any alternative approaches designed to offer specific predictions and projections regarding political events. (Ray and Russett 1996)

These authors go on to report that John Gaddis, in private correspondence, has agreed that the model in question "strikes me as an important advance over earlier approaches to predictive modeling because it takes into account the emergent properties of complex adaptive systems . . . [and] there has been a sort of Bueno de Mesquita–John Lewis Gaddis convergence."

Of course it is one thing to make reasonably accurate predictions and quite another to convince policy-makers to listen. It turns out to be much easier to convince people in business environments to change behavior largely, I believe, because they have a profit line to worry about and they and the predictions are evaluated in terms of their contribution to it. A method that helps them is a method they are eager to use. In government there is not quite such a bottom line. Instead, rational actors that they are, government officials tend to emphasize not getting things wrong as distinct from getting them right. This translates into a more risk-averse approach to decision-making than I have experienced on the commercial, private sector side. Especially in the government context, one encounters the problem that if a model provides advice consonant with what the client expects, then they are less likely to take the model seriously, feeling that it is telling them nothing new. If, instead, it challenges them by saying something contrary to their beliefs, they are likely to become protective of their own point of view and contend that the model must be wrong. Such circumstances, however, at least open a dialog that encourages decision-makers to consider how they arrived at their conclusions and how they can support their conclusions against a dispassionate, logical analysis driven by their own data inputs. Engaging them in that discussion from time to time persuades them to reassess situations. When they do, they typically get the result predicted by the model. When they do not, they typically get the result the model predicts in the case where they act contrary to its assessment.

To be sure, some predictions are just plain wrong or inadequate. The model I developed successfully predicted the break of several East European states from the Soviet Union, but failed to anticipate the fall of the Berlin Wall. The model predicted that the August 1991 Soviet coup would fail quickly and that the Soviet Union would unravel during the coming year, but it did not predict the earlier, dramatic policy shifts introduced by Mikhail Gorbachev (*Izvestiya* 1995). To be sure, the model was not applied to that situation, so that such predictions could not have been made. That, of course, is an important difference between prediction and prophecy. The first step to a correct – or incorrect – prediction is to ask for a prediction about the relevant issue. Alas, no one sought from me or my colleagues any predictions about the demise of the Soviet Union before critical events had begun to unfold.

These illustrative examples are intended to highlight the prospects for reliable prediction at least in the domain of politics (with a small p). They draw our attention to the importance that strategic interaction – pairings or couplings in my proposed hierarchy – plays in moving from individual interests to collective outcomes, thereby emphasizing the generic importance of this top element in a hierarchy that is hoped to contribute to consilience. Perhaps by integrating the insights from the physical and social sciences found across the chapters in this volume others will add to the hoped-for progress toward a unity of science.

NOTES

1. I quite intentionally include Hobbes – the anti-experimentalist – in this list to highlight the modern marriage between experimental methods as a cornerstone of science and the Hobbesian emphasis on deductive reasoning as the path to causal explanation. See Shapin (2011).
2. See Dennett (1992) and Shorto (2008).
3. By way of illustration of the interplay between strategic interaction and habit or inertia in shaping important political choices, consider voting. Grofman et al. (2009) provide a synthesis of the view of voters as affective, driven by their party identification which is mostly inherited from their parents, and the view of voters as retrospective assessors of policy outcomes and the compatibility of those outcomes – and the politicians who advocated or opposed them – and the voter's preferences. The latter is voting as a strategic act while the former is voting as an inertial or habitual act. There is substantial evidence in support of each perspective. Grofman et al. show how to integrate them in a manner consistent with the need for linkage proposed here between strategic choice and inherited values or culture. The linkage is even stronger here in that models of strategic interaction are not concerned with how beliefs, constraints, and values are formed so much as they are concerned with the actions implied by their mix, whether that mix was inherited, socially or culturally constructed, or formed in some other way.
4. Here is a place where theories of human behavior, such as game theory, some applications of Thom's theorem, and some aspects of evolutionary models overlap nicely, pointing to a possible source of consilience, with theories of inanimate, physical processes. Discontinuity is commonplace in state-changes for physical properties as it is for state-changes in human interactions.
5. Of course, not all seemingly chaotic behavior is strategic; some is surely genuinely chaotic, even random. But much behavior that is interpreted as chaotic becomes orderly once a theory – often a strategic theory – is articulated for which predicted outcomes fall into place despite such mechanisms as non-linear feedback loops or other factors that seemingly induce chaos. This is an important feature of game-theoretic equilibrium analysis and its attendant comparative static and dynamic analysis.
6. I have since constructed a new forecasting model and tested it against the 162 issues in Thomson et al. (2006). The new model outperforms my old model and the other contenders examined in the 2006 volume under most circumstances. See Bueno de Mesquita (2011).

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