Understanding Complex Systems

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Non-Equilibrium Social Science and Policy

Introduction and Essays on New and Changing Paradigms in Socio-Economic Thinking

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Non-Equilibrium Social Science and Policy

Jeffrey Johnson, Paul Ormerod, Bridget Rosewell, Andrzej Nowak, and Yi-Cheng Zhang

Abstract Between 2011 and 2014 the European Non-Equilibrium Social Science Project (NESS) investigated the place of equilibrium in the social sciences and policy. Orthodox economics is based on an equilibrium view of how the economy functions and does not offer a complete description of how the world operates. However, mainstream economics is not an empty box. Its fundamental insight, that people respond to incentives, may be the only universal law of behaviour in the social sciences. Only economics has used equilibrium as a primary driver of system behaviour, but economics has become much more empirical at the microlevel over the past two decades. This is due to two factors: advances in statistical theory enabling better estimates of policy consequences at the microlevel, and the rise of behavioural economics which looks at how people, firms and governments really do behave in practice. In this context, this chapter briefly reviews the contributions of this book across the social sciences and ends with a discussion of the research themes that act as a roadmap for further research. These include: realistic models of agent behaviour; multilevel systems; policy informatics; narratives and decision making under uncertainty; and validation of agent-based complex systems models.

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1 Introduction

The European Non-Equilibrium Social Science (NESS) project that ran between 2011 and 2014 investigated the place of equilibrium in the social sciences and policy. NESS had its origins a year earlier in a late night discussion on economics and policy during a conference on complex systems in Shanghai. We were interested in the conundrum that, although orthodox economics had some questionable premises, it was widely used in policy. The purpose of the resulting project was not to reject existing economics, but to learn from and build upon it

We find that mainstream economics is not an empty box. Its fundamental insight, that people react to changes in incentives, is perhaps the only universal law of behaviour in the whole of the social sciences. It may often be difficult in advance to predict exactly what the effects of a change in incentives in any given situation might be. People can be very creative and innovative in how they adapt to change.

For example, do higher taxes on cigarettes improve human health? Higher taxes on products are usually passed on, in whole or in part, to the consumer in the form of higher prices. And higher prices reduce consumption, which in the case of cigarettes must lead to better health outcomes. The first part of the previous statement is very well established empirically in the economics literature. It is the second which is more problematic to establish, precisely because of the inventive ways in which smokers might react to higher prices.

A sophisticated statistical analysis by Adda and Cornaglia of US data across the states, published in the American Economic Review in 2013 [1], indicated two further ways in which smokers reacted to higher taxes, in addition to the obvious one of buying fewer cigarettes. First, there was a switch to higher tar brands. Second, making use of detailed data, the researchers showed an increased propensity amongst some groups to smoke further down towards the butt of the cigarette, where the concentration of potentially dangerous substances is higher. So, in essence, some smokers reacted to higher prices by increasing the intensity of their smoking, raising doubts about the positive impact on health which is the intended outcome of higher taxes.

This potential uncertainty of outcome, of predicting how people react to any particular change in incentives, can be readily observed across a wide range of areas. How much impact on crime do longer prison sentences have, and how cost effective are these compared to, say, trying to increase the probability of catching the criminal in the first place by having more police? Governments around the world want to reduce carbon emissions, but how far can higher taxes on energy consumption help them to achieve their aims? The so-called Tobin tax, named after the economic Nobel Laureate James Tobin, on transactions on foreign exchange markets, is often advocated as a way of reducing the number of speculative transactions and thereby dampening volatility. Yet some studies indicate that such a tax might have exactly the opposite outcome and actually lead to markets becoming more volatile.

These examples, and there could be many more, serve to illustrate the point that the human world is complex and difficult to manage. But in all these examples, incentives are at work. When policies change, people react and some, or even all, change their behaviour. This is what economic theory says should happen. And it is what does happen. Policy makers find economics useful for many reasons, but this is perhaps the key one. Economics in this respect gives an understanding of a situation which is based upon scientific principles. It gives the policy makers levers which they can operate. And it describes the outcome of such actions.

In the public perception, there appears to be a great deal of disagreement within economics. Issues such as GDP growth, unemployment, inflation—what economics describes as the 'macro' economy—are frequently discussed in the media. At this level, it is indeed often the case that there are substantial differences of view. During the financial crisis of the late 2000s, for example, some economists were in favour of bank bailouts, others were opposed. Both groups included Nobel Laureates. The disagreements are often not simply about empirics, but about the relevant theoretical framework to use. But at the so-called 'micro' level, where the focus is on how individuals make choices amongst alternatives, such as deciding whether to go to a restaurant or to the cinema, there is effective unanimity amongst mainstream economists on the relevant theoretical approach to use when analysing a problem. This is the 'rational' model of choice, which is examined in some detail in Chapter "Economics" of this book by Ormerod, and there is little point in anticipating the details of that discussion here. The relevant point for the moment is that it is on this model that economists base the proposition that agents react to incentives.

The differences between economists at this level are essentially about the empirics, about the magnitude of any change of behaviour which has either already taken place as a result of changes to the set of incentives, or which might take place in the future in response to a change which is envisioned now by policy makers. Economics has become much more empirical at the microlevel over the course of the past two decades. In his chapter Ormerod argues that this is due to two factors [11]. First, substantial advances in statistical theory, which enables better estimates of the effects of policy changes at the microlevel. The paper by Adda and Cornaglia mentioned previously illustrates some of the abstruse but important issues involved. The Nobel Laureates James Heckman and Daniel MacFadden have been prominent in these developments. Second, the rise of *behavioural economics*. Behavioural economics looks for empirical evidence about how agents—people, firms, governments—really do behave in practice. Its focus is to try to identify ways in which their behaviour differs from the ways in which the rational agent model predicts. But as the leading behavioural economist Richard Thaler remarks in his latest book [18] 'Without the rational framework, there are no anomalies from which we can detect misbehavior' (p. 251). He goes on to say 'the real point of behavioral economics is to highlight behaviors that are in conflict with the standard rational model' (p. 261). So, behavioural economics is strongly linked to the mainstream model of economic theory. It does not discard the precepts of economic rationality and offer instead a different general model of economic behaviour.

It is not the purpose of this book to set out a root and branch critique of mainstream economics. This is why in the opening section of this chapter we have focused on an important strength of economics, and described a key way in which the discipline has moved forward in recent decades. Equally, however, economics does not by any means offer a complete description of how the world operates. It is very much a partial one. The financial crisis of the late 2000s in particular exposed weaknesses. The views of Jean-Claude Trichet, Governor of the European Central Bank during the economic crisis, have been widely quoted. In November 2010, he gave his opinion that 'When the crisis came, the serious limitations of existing economic and financial models immediately became apparent. Macro models failed to predict the crisis and seemed incapable of explaining what was happening to the economy in a convincing manner. As a policy-maker during the crisis, I found the available models of limited help. In fact, I would go further: in the face of the crisis, we felt abandoned by conventional tools'.

A fundamental feature of orthodox economics is that it is based upon an equilibrium view of how the economy functions. Economists have devoted a great deal of ingenuity in trying to explain how asset price bubbles emerge, and how massive shocks to the economy such as a global financial crisis can happen. But these efforts are set within the framework of equilibrium, in which the natural tendency of the economy is to move to a situation in which all markets clear and in which all factors of production, such as the labour force, are fully employed.

The approach of the NESS Project was built on existing economics in order to make it more realistic. This book examines how economics, in the wider context of the social sciences and policy, can benefit from incorporating the concept of non-equilibrium systems.

Section 2 of this chapter describes the contributions in the book, from the perspective of a range of social sciences. In contrast to economics, a common feature of the other social sciences is that they neither have equilibrium as a premise nor as a conclusion. For them empirical validation of theory remains fundamental, and equilibrium is not the starting point.

Section 3 considers social science in policy. The political process is different to the scientific process. Scientific truth is neither necessary nor sufficient for policy, and bringing science into policymaking is an art. Decision makers want scientists to provide single definitive answers to policy questions, even when science shows there are many possible outcomes of a policy action. In order to be relevant in policy the social sciences have to take context into account in their methods and theories. Government is itself a complex system, and the process of collective decision making is imperfectly understood. Combining science with policy making is difficult to achieve. Global Systems Science attempts to do this by providing new ways of coordinating complex systems science, informatics and citizen engagement in the service of policy making.

Section 4 concludes the chapter and brings together the findings of the NESS project as a roadmap for further research.

2 The Non-Equilibrium Social Sciences

Since equilibrium plays such a large role in orthodox economics it is instructive to survey the approaches of some other social sciences to see how they model society and social change. As will be seen, none of them shares the empirical premises of orthodox economics and none of them require the concept of equilibrium .

Each of the social sciences has a focus which makes it distinct. For example, psychology is concerned with the individual within social groups, while sociology is concerned with the behaviour of social groups composed of individuals. Geography is focussed on both, since all human activity is spatially referenced. Geographers have always been concerned with population and the evolution of human settlements in the context of the physical environment, climate and connectivity. Political science focuses on steering and managing these social systems, and the power relationships that make this possible.

These traditional social sciences are all ways at looking at the same whole. In all of them, one finds micro- and macro-levels, and meso levels in between. Their dynamics all have short and long timescales, and all cases share the perplexing ambiguity between the individual as a person and the psychology of the individual when they are playing a role in a larger social structure. As this section shows, the individual social sciences fit within the emerging science of complex systems.

2.1 Social Psychology and the Narrative Economy

There are many theories of the human mind and how and why humans act as they do. There is no theory that can consistently predict how individual humans will behave, and if there were reflexivity would allow some individuals to behave differently in order to confound or benefit from the prediction.

Social constructionism is a theory of how individuals create, change and maintain their understanding of the world. Although the world exists outside human minds, individual and collective knowledge of the world is always a human and social construction. The evidence to support this is that, in any situation, two or more people will see it differently, sometimes very differently.

This book is concerned with how social science can support policy. The chapter by Nowak et al. [10] suggests that an important part of this is the construction of narratives, stories that have a beginning, a body, and an end. Meanings arise from coordinated human action and by people interpreting their world by building models of it and how it functions. In this context, narratives provide a natural way of acquiring meanings and conveying them to others. Narratives exist at all levels of social reality. They provide the structure by which an individual can understand the world, and know how to behave. Interacting individuals construct narratives as a bottom-up social process, with group narratives being a synthesis of stories describing individual experiences. Shared narratives allow people to find commonality in their experiences, providing coherence and enabling coordinated action.

At the macrolevel narratives define the system and its common culture. Sometimes narration may have more impact on an economy than hard data. Even the choice of which facts we refer to and those we do not may determine the leading narrative and hence the behaviour of people. Socio-economic processes can and should be analysed in line with narratives linking individuals, organisations and societies to better understand what is happening in the whole economic system.

2.2 Sociology and Non-Equilibrium Social Science

Equilibrium is not a key concept in sociology. In this book Anzola et al. [3] argue that sociology is multi-paradigmatic with significant disagreement regarding its goals and status as a scientific discipline. Despite this, sociology aims at identifying the main factors that explain the temporal stability of norms, institutions and individual practices; and the dynamics of institutional change and the conflicts brought about by power relations, economic and cultural inequality and class struggle.

Today, sociology embraces complexity principles through its growing attention to complex adaptive systems and non-equilibrium sciences, with human societies seen as highly complex, path-dependent, far-from equilibrium, and self-organising systems.

Agent-Based Modelling provides a new and coherent inclusion of complexity principles into sociology. Agent-based sociology uses data and statistics to examine the generative sufficiency of given microlevel hypotheses by testing the agreement between ‘real-world’ and computer generated macrostructures. When the model cannot generate the observed macrolevel behaviour, its underlying assumptions do not provide a strong candidate explanation. The separation between the explanatory and pragmatic aspects of social science has led sociologists to be highly critical about the implementation of social science in policy. However, agent-based modelling allows systematic exploration of the consequences of policy assumptions and makes it possible to model much more complex phenomena than previously. It has proved particularly useful in representing policy-relevant socio-technical and socio-ecological systems, and offers formalised knowledge that can appear familiar to policymakers. Computational sociology through agent-based modelling is likely to become increasingly more influential in policy.

2.3 Geography Far from Equilibrium

Pumain’s chapter in this book [12] explains that geography makes little use of the concept of equilibrium. Geographical inquiry is based on the recognition of differences and asymmetries among regions and civilisations, and the search for explanations to the great variety of landscapes and ways of life.

Modern geographers study both the 'vertical' interactions between societies and their local milieu and the 'horizontal' interactions between cities and regions. This involves two opposing causes of territorial inequalities, spatial diffusion of innovation and urban transition.

Whereas diffusion of innovation alone might result in homogeneity, combined with the dynamics of city formation the result is increasing heterogeneity and inequality. The phenomenon of increasing returns with city size is explained by higher population densities and connections multiplying the probability of productive interactions, as well as by adaptive valuation of accumulated assets.

While there may be great wealth, in some urban agglomerations large informal settlements of slums and shanties are still expanding. Global societal evolution is an open process with no fixed asymptotic point in the future: there is no final equilibrium state for the world to reach. Open evolution may hamper the quality of predictions that can be made about the future, but geographical knowledge of past dynamics may help to make forecasts more certain. Powerful analytical tools have been developed in the last five or six decades that greatly improve the quality of geographical work and its ability to provide stakeholders and decision makers with clearer insights for exploring possible territorial futures.

Detailed geographical information from many data sources enables a shift from a macro-static view to a micro-macro dynamical view that is necessary for management and planning policies in a non-linear world. In this, geography is at the forefront of computational modelling for policy, and as a science geography remains deliberately far from equilibrium.

2.4 Cities in Disequilibrium

Batty's chapter [4] shows that, although cities may seem to be largely stable in spatial structure over long periods of time, this is a superficial perception. To a large extent, this view of cities in equilibrium is borne of thinking about them physically. Cities are always in disequilibrium. They are in fact far-from-equilibrium, being maintained through a tension between many countervailing forces that break down and build up on many different spatial and temporal scales, thus all coalescing in strong volatility and heterogeneity in urban form and function.

We should think of cities as being far-from-equilibrium structures and allude to ideas about innovation and technological change that condition their dynamic entirely. What happens in cities is increasingly disconnected from their physical form. This is particularly the case in the contemporary world where changes to the built environment are ever out-of-sync with changes in human behaviours, activity locations, patterns of movement, and globalisation.

2.5 International Relations

Root's chapter in this book [14] illustrates the powerful hold of equilibrium thinking on international policy. Convergence theory, developed in the West for half a century, is based on the hypothesis that there are irresistible forces driving the world to converge towards an inevitable equilibrium state—and the world will eventually be made up of liberal capitalist democracies like those in Western countries.

Steps towards this include the failure of Soviet communism as an efficient system for the production and distribution of goods and services, the structural crisis of Swedish socialism, the reversal of French socialism, and the increasing if limited economic liberalisation of China

Modernisation theory sees the way to achieve this as being through the adoption of free market capitalism tied to optimal forms of democratic governance. In this way all countries in the world will converge to an optimum equilibrium state.

As Root shows, although the evidence is against the inevitability of convergence, this theory is the basis of conflicts in the Middle East initiated by Western powers that did not achieve their policy objectives. The failure of international policy can either be viewed as a setback on the way to the optimum global liberal capitalist free market democracy, or as a series of steps into the unknown. Root makes a comprehensive argument against convergence theory and concludes that divergence is a response to heightened interconnectivity. Thus the science of complex systems offers a way to provide insight into the mechanisms of international development, and overcome the limitations of conventional analysis in political economy.

2.6 Systems, Networks and Policy

Johnson, Fortune and Bromley's chapter [9] introduces the formal concept of a system as a set of interacting parts. Systems thinking has a long history and a variety of methods to capture the dynamics of systems to better understand them. Feedback is a fundamental property of systems and can make them highly unpredictable. Complex systems have multilevel network dynamics with bottom-up and top-down feedback and understanding these better is essential for policy. Often computer simulation is the only method to investigate the future behaviour of many systems, and since they are invariably sensitive to initial conditions, it is necessary to run many simulations to map out the space of future possibilities. In general it is impossible to give a prediction that a social system will be in a particular state at a particular time, but it is possible to investigate the range of possible futures through systems modelling and network science.

2.7 Complexity Friendly Economics

Squazzoni's chapter in this book discusses the limitations of orthodox equilibrium thinking in policy and explores more complexity-friendly alternatives [17].

If societies and markets are viewed as complex non-equilibrium systems, for policy purposes it will be necessary to understand the nonlinear, adaptive and evolving patterns that emerge from agent behaviour in networks. This requires improved realism of the behavioural and social foundations on which policies are based. Also it is necessary to reconsider incentivisation, institutional design and the top-down regulation that typically dominates conventional policy. Recent cases of financial market regulation and health policies illustrate the subtle ways in which people or organisations behave when exposed to social influence, and pre-existing social norms and network externalities.

2.8 The Information Economy

The chapter by Zhang outlines a novel theory of the consumer market, in which information plays the key role [19]. It is assumed that consumers know only part of the available business offers and cannot ascertain the quality of the products they desire. Businesses have even less knowledge of what consumers desire. Thus, in the market consumers and businesses must find a match with severely deficient information. Instead of optimisation under constraints, the theory focuses on how the information constraints can be gradually reduced. Constraint-reduction does not lead to the full information limit typically portrayed in mainstream economics. Instead both consumer wants and business offers expand with concomitant new information deficiencies. Therefore the consumer market is always in non-equilibrium and information will always be deficient. As a consequence, wealth is created in the dynamic pursuit to reduce information constraints, and this is the main driving force that powers economic growth.

2.9 Towards a New Economics

Ormerod's chapter [11] addresses the question of whether the commanding position of orthodox economics in the policy making process is justified by its scientific achievements. Despite the failure of its macro-level Dynamic Stochastic General Equilibrium models to provide useful guidance following the financial crash of 2008, at the microlevel economics provides the general law that individuals react to changes in incentives. The foundational behavioural assumptions of orthodox economics are increasingly called into question in the twenty-first century, especially in the context of decisions taken in cyber space. For example, alternatives are being proposed to rational choice theory, which assumes agents have stable preferences, their preferences are independent of others, and they can gather and process large amounts of information.

Herbert Simon challenged the orthodox approach. He proposed that agents make choices by bounded rationality which depends on the particular problem, the information available, agents' cognitive limitations, and the time available to make a decision. This involves the use of heuristics to find candidate solutions, and satisficing. The concept of satisficing in the sense of Simon is fundamentally different to what it has come to mean within mainstream economics. In the latter, agents carry out limited search activity and find a satisfactory rather than the optimal solution, judging that the costs of gathering more information outweigh the potential benefits. In contrast, Simon argued that agents do not attempt to optimise in many contexts. 'Satisficing' means adopting a heuristic decision rule which gives satisfactory results. Although Nobel laureates Akerlof, Stiglitz, Kahneman and Smith developed Simon's programme in the 1960s and 1970s, economists have sidestepped the implications of bounded rationality in the sense of Simon by asserting satisficed solutions can be improved incrementally, rather than there being no optimum.

Economics does not stand still. For example, it has embraced the concept of asymmetric information, where buyers and sellers may have different knowledge of what is on offer. The notion of market failure followed this, the idea being that if the world did not correspond to the model, then policy intervention was need to correct this failure in the market. One common policy response today is regulation to provide consumers with more information to reduce the asymmetry, for example in the oligopolistic retail markets of power and telephony.

Ormerod concludes that key areas of research include: agent decision making rules; heuristics to identify decision types in any given context; network percolation of imitation, incentives, ideas, beliefs, influence and sentiments; networks evolution; the policy implications of different modes of behaviour; fundamental theory and tools to operationalise narrative dynamics; computational theories of narratives, including Big Data; tools for processing narratives and sentiment; and predicting the emergence of narratives.

3 Social Science in Policy

3.1 Complexity Science and the Art of Policy Making

Rosewell's chapter [15] views policy making as a combination of science and art, with complexity science bridging evidence-based science and the art of balancing hypotheses which are not or cannot be tested. First she contrasts the nature of proof in science and decisionmaking and shows that, although there is scientific modelling in the economic analysis of public policy, the decisionmakers can privilege tradition over evidence and proof e.g. by favouring one form of model over another, or arguing that ‘we have been doing it this way for years so it must be right’. Second she looks at optimisation, in the context of a widespread belief that the benefits of policy investments can be optimised. A complex systems approach suggests that individuals do not optimise but use strategies such as copying to get good if not perfect outcomes, while firms may not optimise, for example due to risk aversion or lack of information. Thirdly, she considers the ‘do nothing’ policy option. An equilibrium approach suggests that doing nothing will leave things unchanged, but as a complex systems perspective suggests, the world will change even when the policy maker does nothing, possibly for the worse. It is concluded that risk free investments and policies are not possible, and the important thing is to have a strong story backed by strong evidence. Creating that story is a combination of art and science.

3.2 The Complexity of Government

Fisher’s chapter [8] argues that we have an imperfect understanding of collective action and, until we do, considerations of the role and scope of government will be based on crude impressions or ideologies. The economic success of capitalist countries can in part be attributed to people being free to form organisations. Such collective action includes social governance, defined here as all forms of institutions whose role is to facilitate, or enable, collective action. There are different levels of collective action in governance, with national governments at the highest level cascading permissions and power to other organisation forms in public and private sectors. Government and libertarianism have a natural tension in the balance of power at all levels. In democracies it is necessary to have effective means of preventing those with partial power using it to gain total power. This includes non-elected organisation, e.g. today some multinational companies have greater wealth than some countries and use their financial power to support regimes sympathetic to their corporate interests. The dispassionate science of complex systems could provide a fresh perspective on what has been an historically emotive and inconclusive debate.

3.3 Context-Dependency in the Social Sciences

Edmond’s chapter [7] discusses how *context* is crucial for understanding social phenomena, but sometimes context is absent leading to spurious averaging generalisation, while sometimes contextual detail is everything but there is no generalisation.

Three ways forward are proposed. (1) Using data mining techniques to look for patterns whose output fits behaviours across a range of target behaviours, and combining these overlapping models to create a context. (2) Context-dependent simulation modelling, with the memory of the agent being context-sensitive, and context-relevant knowledge and behaviours being applied in decision-making. This architecture has advantages in terms of agents learning or reasoning, but may require more knowledge in order to specify the agent behaviours for all the relevant contexts. However, it is argued that this is necessary for the adequate representation of behaviour. (3) Combining qualitative and formal approaches. For example, agent-based modelling can use qualitative evidence to inform the behavioural strategies that people use in given situations, with simulations based on microlevel behaviours producing numbers for comparison with macrolevel quantitative data. This supports experimentation to understand emerging processes, and investigate the qualitative assumptions and the quantitative evidence.

Explicitly recognising and including context-dependency in formal simulation models allows for a well-founded method for integrating qualitative, quantitative and formal modelling approaches in the social sciences. Formal simulation models can include qualitative ethnographic, observational and interview data, and can enrich quantitative analysis, leading to better models and understanding of human behaviour and more effective ways of collecting, integrating and analysing data.

3.4 Global Systems Science and Policy

The chapter by Dum and Johnson discusses how complex systems science can be integrated with policy [6]. 'The vision of Global Systems Science (GSS) is to provide scientific evidence to support policy-making, public action and to enable civil society to collectively engage in societal action. Policy makers suffer from an intrinsic difficulty when addressing challenges such as climate change, financial crises, governance of pandemics, or energy sufficiency since the impact and unintended consequences of public policy action are increasingly hard to anticipate. Such challenges are global and connect policies across different sectors'.[1]

There are many reasons why social systems cannot be predicted in a conventional sense. The science of complex systems provides new computer-enabled approaches to exploring the consequences of policy. Global System Science combines policy-driven questions with the interdisciplinary science of complex systems, policy informatics as the integration of that science into useful policy computer tools, and the engagement of citizens to drive and legitimate policy.

GSS clarifies the relationships between scientists, policy makers and citizens. The normative aspect of policy—how the world *ought* to be—is the legitimate concern of citizens and policy makers. Whereas science is essential for evidence-base policy, it must be accessible to policymakers and citizens. Policy informatics provides a practical means for this by requiring science to be presented in comprehensible ways through computer-based tools and interfaces. In this way scientists

[1] https://ec.europa.eu/digital-single-market/en/global-systems-science.

can help citizens and policy makers to generate and investigate the consequences of policy options. As this book makes clear, there is rarely an optimum solution and policy problems have to be satisficed. As Rosewell's chapter suggests [15], choosing between options is an art rather than a science. The job of scientists is to make the options and their likelihood as clear as possible, but not to make the decisions.

4 Conclusion: A Roadmap for Further Research

In this section we summarise the key themes that emerged from the NESS project, and signpost community-driven directions for future research. A central challenge is to develop areas of work which have the potential to unify much of the analysis carried out in the different social sciences.

We agree with a basic premise of mainstream economics that explanations of phenomena which emerge at the meso or macrolevels must be grounded in the microlevel foundations of the rules of agent behaviour. However, the underlying assumptions of economics are much less relevant in the twenty-first century, and existing social science is either unable to explain events to policy makers, as during the financial crisis, or its theory gives misleading advice. There is no point in pursuing research which is solely based upon agents behaving as optimisers subject to constraints—a paradigm which has now been tested to destruction. Based on the experience of the NESS project we propose research to develop the new paradigms of complex systems science and computational social science for policy.

4.1 Research Theme 1: Realistic Models of Agent Behaviour in the Twenty-first Century

There is now a vast proliferation of alternatives from which consumers can choose, e.g. in New York City there are 10 billion (!) different products and services available [5]. The huge explosion in ICT means that consumers are much more aware of the decisions, actions and opinions of others. Our world is radically different from that in which modern economic theory was first formalised in the late nineteenth and early twentieth centuries. Two classic articles in economics by Alchian in 1950 [2] and Simon in 1955 [16], argued that, under most circumstances, agents cannot optimise. Even *ex post*, often it is not possible to identify what the optimal decision would have been. Both Alchian and Simon came to the conclusion that, in a rapidly changing environment, agents use instead simple rules of thumb to make decisions. In particular, imitation of some kind will often be a good decision rule. This conclusion is supported, decades later, by the social learning tournament reported in Science [13].

Key streams of research to support are:

- Identification of the decision making rules followed by agents in the twenty-first century, in particular how and when agents imitate the decisions of others, and when they do not
- Developing heuristics which enable us to identify which of these rules predominate in any given context
- Expand our knowledge of networks, especially how choices between alternatives spread, including products, innovations, ideas, and beliefs. Much is now known about this when the behaviour of nodes and the topology of the network are fixed, but this needs to be extended to evolving behaviours and topologies
- To articulate the policy implications of these different modes of behaviour. In particular, if imitation is a stronger motive than incentives, the policy implications for policy are profound

4.2 Research Theme 2: Multi-level Systems

Although mainstream economics correctly insists on micro foundations of meso and macrolevel phenomena, in general it lacks feedback across these different levels, and lacks a scientific formalism for this. A distinguishing feature of Global Systems and Complex Systems Science is that there are multiple feedbacks in a system, a concept present in policy debates for many years, e.g. in the 1970s work on Limits to Growth.

Key streams of research to support here are:

- New mathematical methods for representing multilevel systems and inter- and intra-level dynamics.
- How to model 'necessary' and 'sufficient' combinations to generate particular outcomes
- How data can be selected and collated to capture both levels and change through time
- Large scale demonstrators involving stakeholders, including policy makers

4.3 Research Theme 3: Policy Informatics

Complex Systems Science has been mostly been funded by the European Commission through FET (Future and Emerging Technologies) which had a focus on ICT in FP7. In Horizon 2020 the mission of FET has been extended but still includes a strong emphasis on ICT.

The concept of policy informatics is central to Global Systems Science and policy-oriented applications of complex systems science. Much of our research requires very large-scale computation using very large data sets across very large communications systems (although it is important to explore parallel policy analysis based on small-scale complexity models). With notable exceptions, our research community has not connected well with policy makers.

Key streams of research and coordination to support here are:

- Use of computers to support policy at all levels of government
- The interface between scientists, technologists, business people, citizens and policy makers
- Visualisation (visual analytics) to present technical outputs in intuitively understandable ways.

4.4 Research Theme 4: Narratives and Decision Making Under Uncertainty

In many situations, decision makers are faced with genuine uncertainty. Little or no information is available on the probability distribution of outcomes. This is particularly the case with decisions that are difficult to reverse, and which have consequences which extend beyond the immediate future.

In finance, standard and behavioural theories are a hindrance—perhaps a defence against the anxieties created by uncertainty and lack of control. They miss the point that although financial assets must ultimately depend on some kind of 'fundamental', human beings have to use their interpretive skills to infer what these values are. They have no given value in and of themselves. The value depends on buyers' and sellers' reflexive views as to the future income streams generated by the fundamentals of the underlying entities.

Under uncertainty, decision makers require narratives which give them the conviction to act, rather than being paralysed into inactivity. Narratives—how the facts are perceived—are crucial in many contexts. For example, in the current debate over austerity, the impact of a change in fiscal policy would depend upon how this was perceived by the markets, and how this perception translated into interest rates on government bonds.

Key streams of research to support here are:

- Fundamental theory and tools which operationalise the concept of narratives
- Computational theories of narratives, including Big Data
- Tools which develop our understanding of how narratives either spread or are contained
- Tools to enable early prediction of narratives which have the potential to develop traction

4.5 Research Theme 5: Validation of Agent-Based Complex System Models

For policy makers, a key attraction of recommendations based on economics is that economists claim that their models are scientifically validated. There is a shared belief across economists as to what constitutes a valid model. This is missing for complex systems approaches such as agent-based modelling, and is essential for complex systems science.

The key stream of research to support here is:

- To fund the development of agreed criteria in this community for what constitutes a valid scientific model. This is essential in order to instil confidence amongst policy makers in the recommendations arising from these models.

4.6 Research Theme 6: Global Systems Science

Global Systems Science adds to the themes above by clarifying the relationship between scientists, policy makers and citizens. The research themes above are necessary for complex systems science to give better understanding how social systems work, and GSS can be instrumental in making its new scientific knowledge accessible to citizen-engaged policy.

Key streams of coordination and research to support here are:

- Coordinating complex systems scientists, policy makers, citizens
- Creating exemplar GSS projects involving scientists, citizens, other stakeholders and policy makers addressing real world problems

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Economics

Paul Ormerod

Abstract Economics is by no means an empty box. For example, it offers what is possibly the only general law of behaviour in the social sciences, namely that agents react to incentives. Over the past two decades or so, at the micro level, the level of individual agent decision making, the discipline has made progress. Developments in the econometric theory of the analysis of large longitudinal data bases and the rise of behavioural and experimental economics have made the discipline much more empirical. However, at the macro level, economics has, if anything, gone backwards. The main intellectual effort since the 1980s has been to import the concept of equilibrium into macroeconomics. It is no surprise that policymakers during the financial crisis of the late 2000s found the mainstream economic models to be of little or no help at all. In the 1950s, there was an active debate about the computational limits which agents faced when making decisions. The polymath Nobel Laureate Herbert Simon was prominent in arguing that the rational model of choice, the core model of economic theory, was not realistic in many situations because of these limits. Even after the event, it may not be possible to determine what the optimal decision would have been at any given time. The world is in general too complex. Mainstream economics gradually lost sight of this fundamental challenge to one of its key assumptions. The rise of cyber society and Big Data mean that Simon's challenge is more relevant than ever. Looking to the future, new models of 'rational' agent behaviour are required which are better suited to the cyber society of the twenty-first century. Key areas of research include: agent decision making rules; heuristics to identify decision types in any given context; network percolation of imitation, incentives, ideas, beliefs, influence and sentiments; networks evolution; the policy implications of different modes of behaviour; fundamental theory and tools to operationalise narrative dynamics; computational theories of narratives, including Big Data; tools for processing narratives and sentiment; and predicting the emergence of narratives.

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1 Introduction

Economics occupies a commanding position in the policy making process. Central banks and finance ministries have their teams of economists, as do a wide range of government departments and international bodies. Following the pioneering work of Nobel Laureate Gary Becker in the 1970s [2] the reach of economics has extended to areas such as crime, family organisation, racial discrimination and drug and alcohol addiction.

A great deal of policy is now filtered through the lens of economics. Obviously, an appreciation of the potential effects of policy on the economy has always been important within government. But the massive growth of the influence of the formal discipline of economics is illustrated by the example of the United Kingdom. Fifty years ago, the UK government machine employed no more than a dozen or so economists. The newly elected centre-Left Labour government added to their numbers, perhaps doubling them. Now, the Government Economic Service in Britain employs well over 1000 economists, not counting the teams employed in the central bank and in the various regulatory bodies.[1]

We might reasonably ask whether this expansion is justified by the scientific achievements of the discipline. Certainly, this does not seem to have been the view of Jean-Claude Trichet, Governor of the European Central Bank during the economic crisis. In November 2010, he gave his opinion that "When the crisis came, the serious limitations of existing economic and financial models immediately became apparent. Macro models failed to predict the crisis and seemed incapable of explaining what was happening to the economy in a convincing manner. As a policy-maker during the crisis, I found the available models of limited help. In fact, I would go further: in the face of the crisis, we felt abandoned by conventional tools" [23].

Trichet was of course referring to the macro aspects of the discipline. The American humorist P. J. O'Rourke rather neatly captured what has traditionally been the distinction between micro and macro economics in his book *Eat the Rich*, a very thoughtful and entertaining reflection on why some countries are rich and others poor, 'One thing that economists do know is that the study of economics is divided into two fields, 'microeconomics' and 'macroeconomics'. Micro is the study of individual behaviour, and macro is the study of how economies behave as a whole. That is, microeconomics concerns things that economists are specifically wrong about, while macroeconomics concerns things economists are wrong about generally.' [17]

Within economics itself, however, over the past three or four decades, the primacy of microeconomics has been firmly asserted. Modern economic theory is

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[1] See http://www.civilservice.gov.uk/networks/ges/assistant: 'The GES [Government Economic Service] is the UK's largest recruiter of economists, with over 1400 professionals in more than 30 Departments and Agencies'.

essentially a theory of how decision makers[2] choose between the alternatives which are available in any given context. Macroeconomics—the study of, for example, movements over the business cycle in the total output of an economy (GDP)—still exists as an area of study, but it is deemed essential for macro models to have micro foundations.

The models criticised by Trichet developed from work on so-called real business cycle models by Kydland and Prescott in the 1980s, for which the scholars received the Nobel Prize in 2004 [18]. The more modern versions of these models have the exotic description of *Dynamic Stochastic General Equilibrium* (DSGE). The formidable mathematical apparatus which envelops these models is essentially based upon a description of how individuals choose to allocate their time between work and leisure. A good discussion of the synthesis between macro and micro in mainstream economics is available in Woodford's 2009 paper [24]. Despite their conspicuous failures during the financial crisis, DSGE models remain ubiquitous in central banks, international bodies and finance ministries.

At the micro level, however, economics does give powerful insights into how the world operates. Indeed, it provides us with what is probably the only general law in the whole of the social sciences: *individuals react to changes in incentives*. In other words, if the set of incentives which an individual faces alters, the agent (a generic term for the individual in economics) may alter his or her behaviour. An everyday example of incentives is the behaviour of drivers when approaching a speed camera. Even the fiercest critic of economic theory is likely to slow down. The driver may have been exceeding the speed limit, but the probability of detection by the police, certainly on high speed roads, is low. The probability rises sharply when a speed camera is present. The incentives faced by the driver have changed, and his or her behaviour changes as a result.

2 The Core Model of Economic Theory: 'Rational' Choice

2.1 The Background

Within economics agents are postulated to react to incentives in a specific way, that of the so-called *rational agent*. It was a great presentational coup by economists to describe their theory of individual behaviour as 'rational'. By implication, any other mode of behaviour is irrational. But it is very important to realise that this usage

[2] It is important to note here that the decision maker in economic theory is not just the individual person, but the concept extends to firms and governments. It is not that economists are unaware that the decision making process within a firm, say, can be complex and involve many individuals. But from a theoretical perspective, what matters in economics are the decisions the firm takes which impact on the economy, so it is a reasonable simplification to treat the firm as a single decision making unit in this context.

conflates the normal meanings of the words ‘rational’ and ‘irrational’ in English with the particular scientific definition of the word within economics. Within the discipline, ‘rational’ has a very specific, purely scientific meaning, and refers to a set of hypotheses about how individuals take decisions. As we shall see below, in many contexts in the social and economic world of the twenty-first century, these hypotheses may not be valid. It may very well be irrational, using ‘irrational’ in the usual sense of the word, to behave in a rational way, using ‘rational’ in the specialised way in which it is used within the science of economics! It is to these hypotheses which we now turn.

Economic theory was formalised in the late nineteenth and early twentieth centuries. The main aim was to set out the conditions under which a set of prices could be found which would guarantee that supply and demand would be in balance in all markets. Such a world would be efficient, since all resources would be fully utilised. If individuals were observed who did not have work, this would be because of their preference for leisure over work at the prevailing wage rate (the wage being the price of labour to the employer). They would be choosing not to work. As we saw above briefly in the discussion of modern macroeconomic theory, this concept has exercised a very powerful influence on economics ever since.

During the twentieth century, a major task of economic theory was to refine and make more precise the conditions under which prices which cleared all markets could be found. The task was not to solve this problem for any actually existing economy, but to establish theoretically whether a solution could be found. This concept, known as *general equilibrium*, was of fundamental importance. Seven of the first eleven Nobel prizes were awarded for work in this area.

In many ways, it was a very strange problem for economics to focus on. The theory refers to the most efficient allocation of resources in a purely static world. Given a fixed amount of resources of all kinds, including labour, could a set of prices be found which would clear all markets. It was strange because by the late nineteenth century, the Industrial Revolution was a century old. For the first time in human history, a social and economic system had emerged in which the total amount of resources available was being continually expanded. There were short term fluctuations in total output, but the underlying trend was unequivocally upwards. The Industrial Revolution is called a ‘revolution’ because it was precisely that, of the most dramatic kind. No other system created by humanity in its entire existence had succeeded in generating additional resources on anything remotely approaching this scale. The problem of why economies do or do not grow is a very difficult one, which even now lacks a satisfactory solution, although some progress has been made. We return to this issue below.

2.2 The Key Assumptions

The building block of this formalisation of economics was a set of postulates about how individual agents make choices. Like any scientific theory, assumptions have to be made in order to simplify the problem and to make it potentially tractable. The question really is whether the assumptions are reasonable approximations to reality.

Two assumptions are of critical importance to rational choice theory. Without them, the task of obtaining analytical solutions to the models being developed would have been impossible, given the tools available in the late nineteenth century. So from a purely utilitarian perspective, there were good reasons for making these assumptions.

The first assumption is that

> each agent has a set of preferences about the alternative choices
> which are available, which is fixed over time.

The actual decisions which an agent makes will depend upon the relative prices of the alternatives, and upon constraints placed upon the agent such as his or her level of income. But the preferences are assumed to be stable over time. If today I prefer Coca-Cola to Pepsi at a given relative price of the two products, I will always prefer Coke at the same relative price level.

This assumption is still embedded deeply in the psyche of most economists. There is a long standing dispute, for example, about the value of survey data on how people might react in various hypothetical situations. Such surveys have been used extensively in the marketing world, for example, but economists remain deeply suspicious of them. The leading *Journal of Economic Perspectives*, for example, recently carried a issue with several papers related to this theme. Hausman, an econometrician who has done very distinguished work in his field, put the issue very clearly: "I believe that respondents to... surveys are often not responding out of stable or well-defined preferences, but are essentially inventing their answers on the fly, in a way which makes the resulting data useless for serious analysis (Hausman, 2012)" [8]. In other words, in mainstream economic theory, the assumption is made that agents have fixed tastes and preferences. These preferences are revealed not through answers to hypothetical questions, but through how they actually respond to changes in the set of incentives which they face.

The second assumption is related to the one of fixed preferences:

> agents make choices independently, and their preferences are not
> altered directly by the decisions of others .

The choices which other people make may influence an agent indirectly, via their impact on the price level. If large numbers of people, for example, buy bananas, the price may rise because of the level of demand. This in turn may affect whether or not the agent buys bananas. But the fact that many others like bananas does not lead the agent to become more enthusiastic about bananas (at a given price).

These two assumptions effectively remain at the heart of modern mainstream economics, despite the advances made in the late twentieth century, which will shortly be discussed. A third assumption was required to make the theory complete. This was that

> the agent both gathers and is able to process complete information about
> the alternatives when making a choice in any given situation.

Over a 100 years ago, when the theory was being first developed, the idea that there might be limits on the ability of agents to process information did not really have traction, and the assumption was simply that complete information was available. The unbundling of this into its information-gathering and information-processing components is a useful distinction to make.

So, an agent exercising independent choice, with fixed preferences, gathers and processes complete information about the alternatives on offer. With these assumptions, the agent is able to make the best possible choice—the 'optimal' one, as economists prefer to say. The choice will be the one which most closely matches the preference of the agent, given the relative prices of the alternatives and the income of the agent. It is an obvious thing to say, but none the less important to note, that the choice of the agent is based upon the attributes of the alternatives.

All scientific theories are approximations to reality. They may be extremely good approximations, as is the case with, say, quantum physics. But they are not reality itself. There will be some divergence between the theory and reality. So how reasonable were the assumptions made about agent behaviour when the fundamentals of economic theory were being developed over 100 years ago? An argument can be made that even then they were at best poor assumptions and at worst positively misleading. Fashion, for example, seems to have existed almost as long as humanity itself. For example, In the Hittite empire of some 3500 years ago, certain kinds of pottery appear to have been more fashionable than others [21]. And in fashion markets, people select to a considerable degree simply on the basis of what is already popular, what is fashionable, rather than on the attributes of the alternatives themselves. As I write these words, the Christmas season is upon us, and every year one toy becomes especially desirable, simply because many other children have demanded it for their present.

However, in the late nineteenth century, even in the most advanced capitalist economies, fashion was not something which concerned the vast majority of the population, even though, for the first time, many ordinary people had money to spend on products other than those required for the bare necessities of life. True, it was in this period that branded goods first began to proliferate, and the modern advertising industry was created. But the products were simple and easy to understand. The content of advertising focused on the attributes of the products—"Pears soap washes you clean"—rather than on the elusive promises of personal fulfilment portrayed in much modern advertising. So perhaps it was a reasonable approximation to reality to assume that people could obtain and process complete information about alternatives, and that they exercised choice independently with a fixed set of preferences. During the first half of the twentieth century, the basic postulates of the theory of rational choice remained unchanged. Large steps were taken in making the theory more formal, but the core of the theory was unaltered.

2.3 A Challenge

During the late 1940s and 1950s, a major challenge arose to this theory of rational decision making. A multi-disciplinary debate took place involving many leading scholars, financed to a substantial extent by the US military at think tanks such as RAND. Philip Mirowski's book *Machine Dreams* chronicles this in impressive detail [11]. A key point at issue was whether the economic agent possessed the necessary computational capacity to make optimal decisions. Even if the other assumptions of rational choice theory, such as fixed and independent preferences, were reasonable approximations to reality, and even if large amounts of information were available, it might not be possible for agents in the way prescribed by rational choice theory because of their inability to process the information.

The major figure to emerge within the social sciences from this debate was Herbert Simon. He was not himself an economist, holding a chair in industrial management at Carnegie Mellon University. Simon was awarded the most prestigious prizes in several disciplines. He received the Turing Award, named after the great Alan Turing, the father of modern computers, in 1975 for his contributions to artificial intelligence and the psychology of human cognition, and in 1978 he won the Nobel Prize in economics for 'for his pioneering research into the decision-making process within economic organisations'. In 1993 the American Psychological Association conferred on him their Award for Outstanding Lifetime Contributions to Psychology.

Perhaps his most significant intellectual contribution was in creating virtually single-handedly the whole field of what is today known as *behavioural economics*, although as we shall see, his main message is still very far from being accepted by the mainstream economics profession. His seminal article was published in 1955 in the *Quarterly Journal of Economics*, entitled 'A Behavioral Model of Rational Choice' [22]. The article itself is theoretical, but throughout the paper Simon makes explicit the fact that his choices of assumptions are based upon what he considers to be empirical evidence which is both sound and extensive. This truly brilliant article, is the basis for the whole field of behavioural economics, and is worth quoting at some length.

Simon begins the paper with what by now will be familiar material: "Traditional economic theory postulates an 'economic man' who, in the course of being 'economic', is also 'rational'. This man is assumed to have knowledge of the relevant aspects of his environment which, if not absolutely complete, is impressively clear and voluminous. He is assumed also to have a well-organised and stable system of preferences and a skill in computation that enables him to calculate, for the alternative courses of action available to him, which of these will permit him to reach the highest attainable point on his preference scale".

So far, all very relaxing and soothing to economists. But then came his bombshell: 'Recent developments in economics, and in particular in the theory of the business firm, have raised great doubts as to whether this schematised model of economic man provides a suitable foundation on which to erect a theory—whether it be a theory of how firms do behave, or how they ‘should’ rationally behave ... the task is to replace the global rationality of economic man with a kind of rational behavior which is compatible with the access to information and computational capacities that are actually possessed by organisms, including man, in the kinds of environments in which such organisms exist’.

2.4 Developments

This quotation essentially defines the research programmes carried out from the late 1960s and 1970s onwards by future Nobel Laureates such as George Akerlof, Joseph Stiglitz, Daniel Kahneman and Vernon Smith.

There are three distinct strands, two of which have been extensively studied within economics. First, the consequences for models based on the standard rational agent when either agents have incomplete information, or different agents or groups of agents have access to different amounts of information. With their predilection for grand phrases, economists refer to this latter as being a situation of *asymmetric information*. The second strand blossomed into experiments with economic agents, drawing heavily on the methodology of psychological experiments. The approach here was to examine how agents really did behave, rather than making a priori assumptions about how a rational agent ought to behave. Daniel Kahneman is the most famous scholar in this area, and his work relates to Simon’s injunction to base theoretical models on agents which have ‘computational capacities that are actually possessed by organisms’. In other words, to place realistic bounds on the ability of people to process the information which they have, regardless of whether it is complete. The jargon used by economists dresses this up as *bounded rationality*.

The first major advance came about through the work of George Akerlof and Joe Stiglitz during the late 1960s and 1970s, along with that of Michael Spence. The Americans were jointly awarded the Nobel Prize in 2001 for their work. They relaxed the assumption that agents have complete information about all the alternatives when contemplating a decision. Not only might agents have imperfect information, but different ones might very well have different amounts. This latter idea, the so-called question of asymmetric information, has been very influential not just within academic economics but in practical policy making. For example, as the press release for the award of their Prizes stated “Borrowers know more than lenders about their repayment prospects. Managers and boards know more than shareholders about the firm’s profitability, and prospective clients know more than insurance companies about their accident risk”.

These points may seem obvious enough when written down. The achievement was to incorporate the assumption of imperfect information into the core model of economic theory. In this world, agents still had fixed preferences and chose independently, and they still made the optimal decision given the amount of information which they had. But instead of having to assume that decision makers have complete information about the alternative choices, the much more general and realistic assumption could now be made that they often do not.

A very important concept in policy making emerged from this work, namely the idea of *market failure*. Other aspects of developments in theory have contributed to this, but imperfect information has been the key one. Economists have a description of the world which, if it obtained in reality, would possess a variety of apparently desirable characteristics. They slip rather easily into saying that this is how the world *ought* to work. And if in practice that is not what is observed, there must be some 'market failure'. The world must be changed to make it conform to theory. So they devise schemes of various degrees of cleverness to eliminate such failures and enable the market to operate as it 'should', to allow rational agents to decide in a fully rational manner. And a crucial aspect of this is to improve the amount of information which is available to agents.

The concept of market failure has come to pervade policy making in the West over the past few decades, over a very wide range of policy questions. The role of the policy maker, in this vision of the world, is to ensure that conditions prevail which allow markets to work properly, and for equilibrium to be reached. Ironically, mainstream economics, with its idealisation of markets, now provides the intellectual underpinnings for government intervention in both social and economic issues on a vast scale.

The second major development arising from Simon's work has impressive empirical achievements, but has made relatively little theoretical impact on economics.[3]

This, as noted above, is essentially based upon experiments grounded in the methodology of psychology. Agents are studied in an experimental context to see how they actually take decisions in particular circumstances. There are many examples in this literature of observed deviations from rational behaviour. However, it cannot be stressed too strongly that this work takes as its reference point the rational choice model of economics. This is presumed to be how agents ought to behave, and the experiments measure the extent to which agents deviate from the rational norm.

The concept of *framing* is an important example. This means that the choice a person makes can be heavily influenced by how it is presented. Volunteers in an experiment might be confronted with the following hypothetical situation and asked to choose between two alternatives. A disaster is unfolding, perhaps a stand is about to collapse in a soccer stadium and you have to decide how to handle it. Your experts tell you that 3000 lives are at risk. If you take one course of action, you can save 1000 people for certain, but the rest will definitely die. If you take the other, there is a chance that everyone will be saved. But it is risky, and your advisers tell you that it only has a one in three chance of working. If it doesn't, everyone will die. Simple arithmetic tells us that the expected loss of life in both choices is 2000, for on the

[3] A point made clearly in the recent *Forum on the Role of Bounded Rationality versus Behavioral Optimization in Economic Models* in the *Journal of Economic Literature*, **51**(2), June 2013.

second option there is a two out of three chance that all 3000 will be killed. When confronted with this, most people choose the first course of action.

The problem is then put in a different way, it is ‘framed’ differently. This time, you are told that the same first choice open to you will lead to 2000 people being killed. The second will cause the deaths of 3000 people with a chance of two out of three that this will happen, and one out of three that no one will die. The outcomes are identical to those set out above. Yet in this context, most people choose the second option.

Just as with the work on asymmetrical information, these experimental results have had a substantial influence on the conduct of policy. They extend the potential power of incentives as a policy tool to alter behaviour. There are many examples, and here are just two. Yale academics Dean Karlan and Ian Ayres set up the website stickk.com designed to help people reach their goals. A person who wants to lose weight, say, makes a public commitment on the site to lose at least a specific amount by a specific date. He or she agrees a test to be carried out, such as being weighed in the presence of named witnesses, to verify whether or not the goal has been reached. But the person also puts up a sum of money, which is returned if the goal is met. If not, the money goes to charity. The second example is the ‘dollar a day’ plan in Greensboro, North Carolina, aimed at reducing further pregnancies in teenage girls under sixteen who have already had a baby. In addition to counselling and support, the girls in the pilot scheme were paid a dollar for each day in which they did not become pregnant again. Of the sixty-five girls in the scheme, only ten of them got pregnant again over the next 5 years. Of course, there are many criticisms of these and other such ‘nudge’ concepts. A persistent and strong one is that the people who really do want to lose weight are the ones who make the commitment, the girls who really do not want to get pregnant again are the ones who join the scheme. In others words, those who sign up to ‘nudge’ schemes are those who were likely to adopt this behaviour regardless. Nevertheless, ‘nudge’ remains an influential concept.

Behavioural economics advances our knowledge of how agents behave in practice. The theory of choice under imperfect information extends the realism of the model of rational choice. But both of these sidestep the most fundamental challenge which Simon posed to rational economic behaviour. He argued that in many circumstances, we simply cannot compute the ‘optimal’ choice, or decide what constitutes the ‘best’ strategy. This is the case even if we have access to complete information. In many situations it is not just that the search for the optimal decision might be time consuming and expensive, it is that the optimal decision cannot be known, at least in the current state of knowledge and technology, because we lack the capacity to process the available information.

This is an absolutely fundamental challenge to the economic concept of rationality. In such situations, which Simon believed to be pervasive, he argued that agents follow not optimising but *satisficing* behaviour. By this he meant that agents discover a rule of thumb in any given context to guide their behaviour which gives ‘satisfactory’ results. They continue to use the rule until for, whatever reason, it stops giving reasonable outcomes.

Many economists nowadays choose to interpret Simon's work in ways which are compatible with their theories. They argue that there are often limits to the amount of information which people gather, the amount of time and effort they take in making a decision. But this is because agents judge that the additional benefits which might be gained by being able to make an even better choice by gathering more information, spending more time contemplating, are offset by the costs of such activities. Agents may well use a restricted information set, and make an optimal decision on this basis. An even better choice might be made if more information were to be gathered, but not one sufficiently better to justify the additional time and effort required. This is how modern economics uses the term 'satisficing'.

But this whole argument completely misses Simon's point. He believed that, in many real-life situations, the optimal choice can never be known, even *ex post*. It is not just a question of being willing to spend more time and effort to acquire the information so that the truly optimal choice can be made. We simply cannot discover it.

Ironically, it is game theory rather than Simon's views on computational limits, which has become very influential in economic theory. The foundations of modern game theory were essentially laid down in the American research programme of the immediate post-war years. Seminal games such as the Prisoners' Dilemma were invented. And the fundamental concept of the *Nash equilibrium* in game theory was discovered. This equilibrium, which pervades many theoretical discussions in economics, arises when no agent has an incentive to change his or her strategy, given the strategies of other agents [12].

In a sense, game theory can be thought of as a reaction by economists to the assumption that agents make decisions independently of the decisions of others. There are many situations in which agents are closely involved with each other, and not simply interacting indirectly through changes in prices in an impersonal market. Companies, for example, will often find themselves competing closely with perhaps just one main rival, and the strategy the firm adopts will be influenced by the actions taken by its rival. The major developments in game theory were in fact motivated by the Cold War, and the direct conflict between the United States and the Soviet Union. So, in a way, game theory recognises that agents may interact rather more directly then through a market in which there are many participants.

The problem is that the informational demands placed upon agents by game theory are enormous. In a pure Nash equilibrium, for example, agents are required to have complete knowledge of the strategies of other agents. The concept has been generalised to allow for incomplete information, but the difficulties of using it in any practical context are still very considerable indeed. As the International Encyclopaedia of the Social Sciences remarks "in applying the concept of Nash equilibrium to practical situations, it is important to pay close attention to the information that individuals have about the preferences, beliefs, and rationality of those with whom they are strategically interacting" [12].

2.5 The Current Situation

Modern economics is far from being an empty box. As noted above, the idea that agents react to changes in incentives is a powerful one, which appears to be of very general applicability. Developments during the past 50 years concerning how agents behave have expanded the usefulness of this key insight, and play an important part in both social and economic policy.

In other respects, economics has not stood still, and has tried to widen the relevance of its theories. For example, the theory of why international trade takes place goes back to the early nineteenth century and the great English economist David Ricardo. Ricardo demonstrated a result which is far from obvious, that even if one country can produce every single product more efficiently than another, trade will still take place between them and both countries can benefit as a result [20]. This principle has been a key motivator of the drive to open up international trade throughout the whole of the post-Second World War period. One problem for the theory, however, is that it found it difficult to account for the fact not only that most trade is between the developed countries, which are at similar levels of efficiency, but that much of this trade is in intermediate goods. That is, goods which are not purchased by consumers, but are simply used as inputs into the production of other goods. But trade theory has now been developed to take these key empirical issues into account.

In fact, in the past 10 or 20 years, purely empirical work has become much more important within economics. Such work is usually not empirical in the sense of trying to test the validity of a particular aspect of economic theory. Rather, the theory is taken as given, and the research involves very detailed statistical investigation of data, often of one of the very large data bases which are increasingly becoming available.

Social and economic data bases often raise very challenging issues in statistical analysis. Just to take one example, there is the question of self-selection bias which we encountered above in the study of teenage pregnancy. In essence, were the women who participated in the programme truly representative of the relevant population as a whole, or did they self-select in ways which leads this particular sample to be a biased representation? This is a key problem in the evaluation of many social programmes. The Chicago econometrician James Heckman was awarded the Nobel Prize for his work in developing statistical techniques which enable questions such as this to be tackled.

There is no doubt that in terms of the techniques required for statistical analysis of what are termed cross-sectional and panel data bases, economics has made very substantial progress in recent decades. Cross-sectional data refers to the characteristics of a given sample of individual agents at a point in time. Panel data follows the same individuals and the evolution of their characteristics over time.

The same cannot be said for the statistical analysis of time-series data in economics. Typical examples of time-series data are national output, or GDP, unemployment and inflation, and this type of data has a macro-economic focus within economics. It is not that techniques have stood still. Far from it, a particularly important one being the concept of co-integration, for which Clive Granger and Robert Engle were awarded the Nobel Prize. This is rather technical and details can be found readily in, for example, the Wikipedia entries on *co-integration* (https://en.wikipedia.org/wiki/Cointegration) and the related concept of *error correction model* (https://en.wikipedia.org/wiki/Error_correction_model). In essence, it goes a long way to avoiding obtaining purely spurious correlations between time series variables. Many of these, such as the level of GDP, have underlying trends, and the potential dangers of looking for correlations with the data in this form have been known for some 40 years (see for example Granger and Newbold [7]).

However, time-series analysis has made very little progress in resolving disputes within economics. For example, a fundamental concept, and one which is of great policy relevance at the current time, is that of the *fiscal multiplier*. The idea was developed by Keynes in the 1930s, during the time of the Great Recession when GDP in America and Germany fell by nearly 30 %. Suppose a government decides to increase spending permanently by, say, £ 1 billion a year. What will be the eventual increase in overall GDP as a result of this? As people are brought back into work as a result of the additional spending, they themselves have more to spend, and the effect spreads—multiplies—through the economy. Of course, there will be so-called 'leakages' from this process. Some people will save rather than spend part of any increase in income. Some of the additional spending power will go on imports, which do not increase the overall size of the domestic economy.

This seems straightforward. In the current policy context, there are fierce debates about austerity, of restricting rather than expanding government spending during the current economic recession in many EU countries. If the above were the whole story, it would be obvious to abandon austerity and increase government spending. But the question is much more complicated. The government will need to borrow more to finance the increase in expenditure. This may, for example, have consequences for interest rates. If they rise sharply, negative effects will be created on confidence, personal and corporate borrowing will become more expensive, and the initial positive impact of the extra government spending may be eroded, in part or even completely.

The point is not to arbitrate in this debate. Rather, it is that economists still disagree strongly about the size of a fundamental concept in macroeconomic theory, the fiscal multiplier. In principle, constructing models of the economy by the statistical analysis of time-series data could answer the question. Indeed, many such models exist which do indeed provide an answer to the question. But the answers themselves are different.

In essence, although economics has made progress, its foundations are still those of the theory of how rational agents behave, in which agents have stable and independent preferences, and are able to gather and process large amounts of information. There are, of course, papers which relax the assumptions of stable and independent tastes in order to address issues such as fashion. But these are seen very much as exceptions to the norm. The world in general, to orthodox economists, remains explicable with the rational agent model.

This is all the more so, given the relaxation of the basic assumptions which enables agents to hold asymmetric and imperfect information. The experiments of behavioural economics provide many examples of agents not behaving in the way proscribed by theory, but such behaviour is seen as arising through imperfections in the system. It is the task of policy to remove such impediments to agents behaving in the rational manner as defined by economics.

The challenge posed by Simon in the 1950s, that agents in general lack the computational capacity to operate as rational agents, has been safely neutered. Simon's concept of satisficing, of agents using behavioural rules of thumb which give satisfactory results, has been absorbed into the discipline, but given an entirely different meaning which is completely consistent with rational behaviour as defined by economics.

Macroeconomics is recognised, certainly by the more thoughtful conventional economists, as leaving much to be desired. Neither models constructed using statistical analysis of time series data, nor DSGE models, with their foundations based on rational choice theory, are regarded as being entirely satisfactory. But this serves to reinforce the primacy of microeconomics within the discipline. Economics is fundamentally a theory of how agents behave when they make choices under various constraints.

3 Moving Forward

3.1 The Core Model of Behaviour

The key issue is the empirical relevance in the cyber society of the twenty-first century of the main assumptions which underlie rational choice theory:

- Agents have preferences which are stable over time
- Agents have preferences which are independent of those of other agents
- Agents are able to gather and process substantial amounts of information

For the purpose of clarity, it is also worth repeating that the economics literature does contain examples of models in which these assumptions are not made. However, the corpus of economic theory is very substantial indeed, and such models only make up a tiny proportion of the whole.

Both twentieth-century technology and now the internet have completely transformed our ability to discover the choices of others. We are faced with a vast explosion of such information compared to the world of a century ago. We also have stupendously more products available to us from which to choose. Eric Beinhocker, in his book *The Origin of Wealth*, considers the number of choices available to someone in New York alone: 'The number of economic choices the average New Yorker has is staggering. The Wal-Mart near JFK Airport has over 100,000 different items in stock, there are over 200 television channels offered on cable TV, Barnes &

Noble lists over 8 million titles, the local supermarket has 275 varieties of breakfast cereal, the typical department store offers 150 types of lipstick, and there are over 50,000 restaurants in New York City alone.' [3]

He goes on to discuss stock-keeping units (SKUs) which are the level of brands, pack sizes and so on which retail firms themselves use in re-ordering and stocking their stores. So a particular brand of beer, say, might be available in a single tin, a single bottle, both in various sizes, or it might be offered in a pack of six or twelve. Each of these offers is an SKU. Beinhocker states, 'The number of SKUs in the New Yorker's economy is not precisely known, but using a variety of data sources, I very roughly estimate that it is on the order of tens of billions.' Tens of billions!

So, compared to the world of 1900, the early twenty-first century has seen quantum leaps in both the accessibility of the behaviour, actions and opinions of others, and in the number of choices available. Either of these developments would be sufficient on its own to invalidate the economist's concept of 'rational' behaviour. The assumptions of the theory bear little resemblance to the world they purport to describe.

But the discrepancy between theory and reality goes even further. Many of the products available in the twenty-first century are highly sophisticated, and are hard to evaluate even when information on their qualities is provided. Mobile (or cell) phones have rapidly become an established very widely used technology (despite the inability of different branches of the English language to agree on what they should be called). In December 2014 Google searches on 'cell phone choices' and 'mobile phone choices' revealed, respectively, 57,500,000 and 114,000,000 sites from which to make your choice. Three years earlier, in December 2011, I had carried out the identical searches and the numbers of sites were then, respectively, 34,300,000 and 27,200,000.

So even over the course of a very short period of time, there has been a massive expansion of available choices. And how many people can honestly say they have any more than a rough idea of the maze of alternative tariffs which are available on these phones?

So here we have a dramatic contrast between the consumer worlds of the late nineteenth and early twenty-first centuries. Branded products and mass markets exist in both, but in one the range of choice is rather limited. In the other, a stupendous cornucopia is presented, far beyond the wildest dreams of even the most utopian social reformers of a century ago. An enormous gulf separates the complicated nature of many modern offers from the more straightforward consumer products of a mere 100 years ago. And, of course, we are now far more aware of the opinions and choices of others.

In many situations in the world of the twenty-first century, the key postulates of rational choice theory in economics seem wholly implausible. Preferences are altered directly by the observed behaviour, actions and opinions of others, and evolve over time. Agents are quite incapable of processing more than a small fraction of the amount of information which is available to them.

There are still areas of economic activity, however, where rational choice theory may very well still be valid. In mature consumer markets, for example, people have had a long time to become familiar with the various alternatives on offer, and understand the differences in their attributes. ‘Mature’ is used here not in the sense of the age of the consumers in a particular market, but how long the market itself has existed. Washing machines, for example have been around now for decades. Improvements are still made, but the basic technology remains unaltered. It seems reasonable to think that most purchasers in this market have reasonably stable preferences, and are able to distinguish between the attributes of the different brands on offer.

One research task is therefore to develop an effective system of classifying different areas of the economy in terms of whether or not the rational choice model may be appropriate. Again as noted above, all scientific theories are approximations to reality. This is especially the case in the social rather than the natural sciences. The question is not so much whether a particular theory seems very close to reality, but whether it seems closer than alternative theories.

With the anthropologists Alex Bentley and Mike O’Brien, I published an initial attempt to make such a classification [4]. The underlying arguments can be summarised diagrammatically in the form of a ‘4-box’, beloved of management consultants the world over. The horizontal axis represents the extent to which the choices of an agent are influenced directly by those of others. At one extreme, the agent makes a purely independent choice, as assumed by the rational choice theory of economics. At the other, the choice of an agent is formed completely by the choices of others. This latter situation may seem initially implausible, but a moment’s reflection is sufficient to realise that is relevant to many popular culture markets on the internet. The popularity of photographs posted on Flickr, for example, seem to bear little connection to the objective attributes of the photograph.

On the vertical axis, we have the ability of the agent to distinguish between the attributes of the available alternatives. These may be difficult to distinguish for several reasons. For example, there may be a relatively small number of choices, but the products are complex and hard to understand. The products may be essentially simple, but the companies which provide them create layers of complexity around them. Mobile phone and utility tariffs are obvious examples here. Or there may, quite simply, be a very large number of alternatives which an agent cannot hope to be able to evaluate.

The rational agent model is located in the top left hand quadrant of the chart. At the extreme left hand edge, each agent decides whether or not to choose a product based strictly on a personal assessment of the attributes of the available alternatives. An implication of the above is that we need different models of ‘rational’ behaviour in different circumstances. The economic concept of rationality is by no means a general model. The cyber society of the twenty-first century is the embodiment of Simon’s view that agents lack the computational capacity to optimise in the way prescribed by the economic model of rational choice (Fig. 1).

The most important challenge in economics is to construct ‘null models’ of agent behaviour which are applicable to the increasing number of circumstances in which the conventional model of rational choice is no longer valid. By ‘null’, we mean the basic model, which can be adapted as required to particular situations. Simon

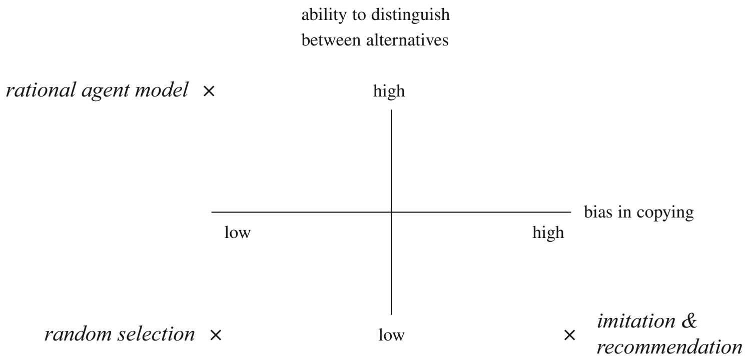

Fig. 1 The rational agent model assumes perfect information and no copying

believed that agents use rules of thumb, heuristics, as decision making rules. But it is not very helpful to try and construct a plethora of different rules, each unique to its context. We need some basic principles, which can then be 'tweaked' as required.

Guidelines as to the nature of the null models are already available. A remarkable paper was published by the Chicago economist Armen Alchian as long ago as 1950 [1]. Entitled 'Uncertainty, Evolution and Economic Theory', his paper anticipates by decades advances in the mathematical theory of evolution in the 1990s. At the time, however, the tools required to formalise Alchian's insights were not available, and the paper failed to get traction within economics.

The purpose of Alchian's paper was to modify economic analysis in order to incorporate incomplete information and uncertain foresight as axioms. He argues, in a way which is now familiar, that 'uncertainty arises from at least two sources: imperfect foresight and human inability to solve complex problems containing a host of variables even when an optimum is definable'.

Alchian recognises that humans can imagine the future, act with purpose and intent and consciously adapt our behaviour [16]. He postulates that, even in the face of uncertainty, at least a local optimum might be found if agents follow what we would now term a Bayesian learning process. However, for convergence to an equilibrium, he argues that two conditions need to be satisfied. A particular trial strategy must be capable of being deemed a success or failure *ex post*, and the position achieved must be comparable with results of other potential actions.

Alchian argues that it is unlikely that such conditions will hold in practice, for the simple reason that the external environment of a firm is not static but changing. Comparability of resulting situations is destroyed by the changing environment. An important *Science* paper by Rendell et al. in 2010 confirms this intuition [19]. Economic theory certainly contains models in which imitation is the main driver of behaviour in, for example, herding models. But, as noted already, these are seen as a special case compared to the more generally applicable model in which agents have fairly stable preferences and select on the basis of the attributes of the alternatives which are available. Alchian argued, all those years ago, that under changing external environments—under uncertainty—the model in which agents imitate the behaviour of others is the general principle of behaviour, and not just the special case.

3.2 Networks

The heuristic of imitation, or copying, raises immediately the concept of networks. If this is the driving force of behaviour in any given situation, which other agents is the agent copying? Economists are at last starting to appreciate the potential importance of networks. For example, central banks are showing great interest in the networks which connect banks through the pattern of assets and liabilities, and the possibility that a cascade of failure might percolate across the network. An issue in 2014 of the leading American Economic Association journal, the *Journal of Economic Perspectives*, carried a symposium of papers on the topic of networks.

Networks in fact were a central part of the thinking of two great economists of the mid-twentieth century, Keynes and Hayek. The differences between them on policy issues tend to command attention, obscuring deep similarities in their thinking about the economy and society. Of course, the mathematical theory of networks (or graph theory as it is also known) scarcely existed at the time, and neither Keynes nor Hayek formalised their models in this way.

For Keynes, the long-run expectations of firms were the most important determinant of the business cycle through their impact on investment.[4] The long-run expectation of a firm at any point in time is not the result of a rational calculation of the amount of profit which an investment is expected to yield. Rather it is a sentiment, the degree of optimism or pessimism which the agent holds about the future.

There appear to be two components in Keynes' implicit model of how such expectations are generated. Most importantly, sentiment is altered across the network of firms as a whole by 'waves of irrational psychology'. Keynes also writes of changes in sentiment being generated as the 'outcome of mass psychology of a large number of ignorant individuals'. This is the key feature of long run expectations. In addition, an agent seems to have the ability to change its optimism/pessimism spontaneously without regard to external factors, including the sentiments of other agents. Keynes writes of 'spontaneous optimism' and a 'spontaneous urge to action rather than inaction'. This is the context in which his famous phrase 'animal spirits' appears [10].

[4] We now know, thanks to over half a century of national accounts, that in practice it is indeed the fluctuations in investment which in general make the major quantitative contribution to movements in total output over the course of the business cycle.

In modern terminology, we have agents on a network which at any point in time are in one of k states of the world, where k is the degree of optimism/pessimism. There is some kind of threshold rule by which individual agents alter their state of the world according to the state of the world of their neighbours.

An illustration of Hayek's thinking is given by a somewhat different illustration. In his 1949 essay 'The Intellectuals and Socialism' [9], he considered the question of how ideas of planning and socialism had come to a dominant position in the market-oriented economies of the West. He attributed this to the role of intellectuals. By the word 'intellectual' he did not mean an original thinker. Rather, for Hayek, intellectuals were 'professional second-hand dealers in ideas', such as journalists, commentators, teachers, lecturers, artists or cartoonists.

Hayek was very clear on how such a small minority can set so decisively the terms of debate on social and cultural matters. He writes: '[Socialists] have always directed their main effort towards gaining the support of this 'elite' [of intellectuals], while the more conservative groups have acted, regularly but unsuccessfully, on a more naive view of mass democracy and have usually vainly tried to reach and persuade the individual voter.' He goes on later in the essay to state, 'It is not an exaggeration to say that, once the more active part of the intellectuals has been converted to a set of beliefs, the process by which these become generally accepted is almost automatic and irreversible.' Again, in modern terminology, he is describing what is known as a scale-free network. In other words, a type of network in which a few agents have large numbers of connections, and most agents have only a small number. Simply because an agent has a large number of connections, he or she has the capacity to exercise a disproportionate influence on outcomes. But Hayek is implicitly going rather further, and positing a weighted scale-free network, in which the influence of the highly connected individuals is weighted, in part or in whole, by the number of their connections. So their influence is doubly powerful, by virtue of being connected to many agents, and because their potential influence on these agents carries a relatively high weight.

Modern network theory has made massive developments in the past two decades in terms of understanding how a different behaviour or opinion might or might not spread across a network of any given type. Sophisticated strategies have been worked out as to how to either encourage or prevent such percolation. Another key task for economics is to absorb this work into the discipline (see, for example, [15]).

But there is a wider research agenda with networks. Economics is too important to be left simply to the economists. Most of the advances in network theory have been obtained with the assumptions that both the behaviour of the nodes and the topology of the network are fixed. The nodes are the points in the network, which in a social science context are the agents, and the topology describes the system of connection in the network, which agents any given agent can in principle influence directly.

But a great deal needs to be done to extend our understanding of how the percolation properties of networks are affected when these assumptions are relaxed. In real life, the pattern of connections between agents itself evolves, and agents may choose to adopt different behavioural rules over time. This is a multi-disciplinary challenge, to which economics can in fact bring its own contribution. Namely, to consider the role of incentives in the evolution of networks over time.

3.3 Growth and the Business Cycle

Networks have an important role to play in advancing scientific knowledge of the behaviour of the economy at the macro level. It is here that conventional economics is at its weakest. The modern market-oriented economies ushered in by the Industrial Revolution of the late eighteenth century have a distinguishing characteristic which is not shared by any other form of economic organisation over the entire span of human existence. There is a steady expansion of the total amount of resources which are available. The underlying growth of output over time is the key feature. For example, per capita income in real terms, even in the most advanced societies, was not very much different in, say, 1700, than what it was of in the Roman Empire at its peak in the first and second centuries AD. But since then there has been a massive and dramatic expansion of living standards.

Around this growth trend, there are persistent but somewhat irregular short-term fluctuations in output, a phenomenon known as the business cycle. It is this which the DSGE models, for example, discussed in Sect. 1 above, purport to be able to explain.

But economics lacks a satisfactory scientific explanation of these two distinguishing characteristics of capitalism at the macro level, growth and the business cycle. In terms of growth, theories developed in the 1950s remain the basis of attempts to understand the phenomenon, even in their more modern versions. These theories essentially link the growth of output to changes of the inputs into the process of production, particularly capital (machines, buildings etc) and labour. Progress has been made. The extensive empirical investigations carried out using mainstream growth models show that most of economic growth in the advanced economies is in fact unexplained in this way! Economists attribute this to what they describe as 'technical progress'. In more everyday English, this refers not just to inventions but, more importantly, to what we can think of as innovations, the practical diffusion of such scientific inventions.

The time series data on the business cycle, the movements of total output (GDP) from year to year, when plotted appear to bear little resemblance to the word 'cycle' as it is understood in the natural sciences. The fluctuations are clearly more irregular than regular. A key reason why economists speak of the 'business cycle' is because the different sectors of the economy tend to move together during booms and recessions. The correlation is not perfect, but in a period of sustained expansion, for example, most industries will be growing, and in a recession most will be in decline. The implication is that there are general factors which drive the movements of the various sectors of the economy. This does not mean that a particular sector might not experience a sharp rise or fall in output for reasons specific to that sector. But the co-movement of output suggests general factors operating across the economy as a whole.

However, existing models have great difficulty in explaining many of the key empirical features of the business cycle. For example, the correlations between the growth in output in any given year and growth in previous years are close to zero. But there is some structure and, specifically, there tends to be weak but positive correlation between growth in this year's output and growth in the immediately preceding year. The first wave of real business cycles and DSGE models were completely unable to account for this, because they postulated that the cycle was caused by random shocks which were exogenous to the economy as a whole. In terms of the pattern in the frequency of the fluctuations, there is evidence of a weak cycle, in the scientific sense, of a period roughly between 5 and 12 years.[5] By incorporating imperfections which prevent markets from operating properly, the latest versions are sometime able to replicate this feature, but it is a struggle.

But there are other features which existing models find very hard, if not impossible to replicate. Looking at the Western economies as a whole and synthesising the evidence on their individual experiences, certain key pieces of evidence have highly non-Gaussian distributions. For example, both the size and duration of recessions, and the duration between recessions. Most recessions are short, with quite small falls in output. But occasionally, there are recessions which last for a number of years and which exhibit deep drops in output. This latter obtains at the moment in several of the Mediterranean countries.

3.4 Sentiment, Narratives and Uncertainty

An important reason why macroeconomics has been unable to make progress in resolving key issues is that sentiment and narratives affect the impact of a given change in any particular policy instrument. Consider, for example, the current question of austerity in the UK. Suppose the British government were to abandon its policy of fiscal restraint, and expand public spending. What would the impact be? We could simulate the policy on a range of macro models and, as noted above, each would give us a different answer. But, in general in economics, there is a one-to-one correspondence between the inputs into a model and the output. The same inputs in the same set of initial condition will always give the same answer. In the real world, this may not be true at all.

At the moment, the UK government has a reputation for fiscal prudence. The facts themselves tell a more ambiguous story. On coming to power in 2010, the UK government projected that borrowing in the financial year 2014/15 would be just

[5]Of course, given that the power spectrum is the Fourier transform pair of the autocorrelation function, the weakly determined nature of the latter means that the former is only weakly determined.

under £ 40 billion. It was around £ 100 billion. What is more, over the first seven months of the 2014–15 financial year, borrowing was even higher than it was in 2013–14. The increase was not great, £ 3.7 billion according to the Office for National Statistics, but it is still up, not down. In 2015 the stock of outstanding government debt was around 80 % of GDP, a figure similar to that of Spain. Yet the markets believe the government is prudent, and at the time of writing the yield on 10 year UK government bonds is under 2 %. In Spain it is closer to 6 %.

Now, if there were a fiscal expansion in the UK, and the bond yield remained low, the fiscal multiplier is likely to be substantial, and GDP would receive a distinct boost. But if the change in policy were received differently, and bond yields rose to the 6 or 7 per cent levels which countries such as Spain and Italy have experienced, the outcome would be completely different. The crucial issue would be the *dominant narrative* which emerged in the financial markets. If we could re-run history many times, from the same initial conditions we would observe a wide range of outcomes, dependent upon the sentiment and narrative which predominated.

Economics essentially deals with the questions raised by the concepts of sentiment and narrative by the theoretical construct of rational expectations. Agents form expectations about the future using what is assumed to be the correct model of the economy. All agents share the same knowledge of this model which they use to form expectations about the future. Over time, these will on average prove to be correct. They may not necessarily be correct in every single period. Indeed, it is possible that they will be wrong in every period. The key point is that the agent is presumed to be using the correct model of the system with which to form expectations. Any errors that might emerge are therefore purely random, and will cancel each other out over time. On average, over an unspecified but long period of time, the expectations will prove correct.

So in considering the impact of a change in fiscal policy, all agents will anticipate the potential outcome and adjust their behaviour appropriately. In one version of this type of model, expansionary fiscal policy cannot have any impact on total output. An increase in public spending could be financed by an equal rise in taxation. But this would serve to more or less cancel out the impact of the spending increase, because personal incomes would be reduced. Alternatively, the increase could be financed by an issue of government bonds. But this implies higher taxation in the future, to meet the stream of interest payments on the bonds and, eventually, the repayment of the principal. An agent using rational expectations will therefore increase his or her savings in order to provide for the higher taxes in future. The effect will be just the same as an increase in taxes now.

We might reasonably ask how agents come to be in possession of the true model of the economy. There is a large and highly technical literature on this. But, essentially, it is held that agents will eventually learn the correct model, because of the costs of making non-optimal decisions through using an incorrect model. There are many problems with this approach. But a very practical one is the simple observation that economists themselves are far from being in agreement about what constitutes the correct macro model of the economy. For example, in the United States at the height of the financial crisis, one eminent group of economists argued that the banks should be bailed out, and another believed the exact opposite, that they should be allowed to fail. Both groups included several Nobel Prize winners.

A fundamental point is that in many situations, especially in macroeconomics, there is unresolved uncertainty about the model itself. More generally, within the statistics literature, there is a widespread understanding that model uncertainty is often an inherent feature of reality. It may simply not be possible to decide on the 'true' model. Chatfield is widely cited on this topic [5]. In an economic context, for example, in a 2003 survey for the European Central Bank of sources of uncertainty by Onatski and Williams concluded that 'The most damaging source of uncertainty for a policy maker is found to be the pure model uncertainty, that is the uncertainty associated with the specification of the reference model' [14]. Gilboa et al. [6] note that 'the standard expected utility model, along with Bayesian extensions of that model, restricts attention to beliefs modeled by a single probability measure, even in cases where no rational way exists to derive such well-defined beliefs'. The formal argument that in situations in which the external environment is changing rapidly, it is often not possible for agents to learn the 'true' model even by Bayesian process goes back at least as far as Alchian in 1950 [1].

In short, in situations in which there is uncertainty about the true model which describes the system, it may not possible for agents to form rational expectations. As a result, agents are uncertain about the probability distribution of potential outcomes.

It is useful to refer back briefly at this stage to the '4-box' chart. The chart sets out a possible heuristic about the types of model which might best describe the behaviour of agents in different situations. As we move down the vertical axis, the distinction between the attributes of the various alternatives becomes harder to distinguish. We gave several reasons why this might be the case in the immediate discussion of the chart. However, a very important additional one is that for choices which have implications well into the future, the potential outcomes become inherently uncertain. In situations in which there is uncertainty about the model which best describes the system under consideration, there is uncertainty about the probability distribution of potential outcomes. Agents will be unable to distinguish between alternatives because they lack knowledge of the system.

Economics needs to work with other disciplines, especially psychology, in order to understand how agents are able to make decisions under conditions of model uncertainty see, for example, [13]. In essence, agents are motivated by a mixture of excitement and anxiety, excitement about potential gain and anxiety about potential loss. More generally, the importance of narratives, which break down the one to one correspondence between the inputs and output of any particular set of conditions in the economy, must be understood much better. How and why do certain narratives spread and why do others get little or no traction? This is of great importance for the conduct of economic policy, and as yet very little formal work has been done in this area.

4 Summary and Conclusion

Although economics has not stood still in recent decades and is by no means an empty box, the central building block of the entire theoretical edifice, the so-called rational agent, seems less and less relevant to the inter-connected cyber society of the twenty-first century.

A central challenge is to develop areas of work which have the potential to unify much of the analysis carried out in the different social sciences. The fundamental building block of all social science is the behaviour of the individual decision making unit, the ‘agent’ in the jargon of economics and computational social science.

The basic premise of mainstream economics, that explanations of phenomena which emerge at the meso or macro levels must be grounded in the micro level foundations of the rules of agent behaviour, seems sensible. However, the underlying assumptions of economics are much less relevant in the twenty-first century, and existing social science is either unable to explain events to policy makers, as during the financial crisis, or its theory gives misleading advice.

There is little point in carrying out further research which is solely based upon agents behaving as optimisers subject to constraints. The underlying hypothesis is empirically false, and this paradigm has now been tested to destruction.

In the context of agents making decisions, the key research streams to develop are:

- Identification of the decision making rules followed by agents in the twenty-first century, in particular how and when agents imitate the decisions of others, and when they do not
- Developing heuristics which enable us to identify which of the types predominate in any given context
- Expand our knowledge of networks, and in particular to how choices amongst alternatives, whether these are products, innovations, ideas, beliefs, are either spread or contained across networks. A great deal is now known about this when both the behaviour of nodes and the topology of the network is fixed, this needs to be extended to evolving behaviours and topologies
- To articulate the policy implications of these different modes of behaviour. In particular, if imitation is a stronger motive than incentives, the implications for policy are profound

In many situations, decision makers are faced with genuine uncertainty. Little or no information is available on the probability distribution of outcomes. This is particularly the case with decisions that are difficult to reverse, and which have consequences which extend beyond the immediate future.

In finance, standard and behavioural theories are a hindrance—perhaps a defence against the anxieties created by uncertainty and lack of control. They miss the point that although financial assets must ultimately depend on some kind of ‘fundamental’, human beings have to use their interpretive skills to infer what these values are. They have no given value in and of themselves. The value depends on buyers' and sellers' reflexive views as to the future income streams generated by the fundamentals of the underlying entities.

Under uncertainty, decision makers require narratives which give them the conviction to act, rather than being paralysed into inactivity. Narratives—how the facts are perceived—are crucial in many contexts. For example, in the current debate over austerity, the impact of a change in fiscal policy would depend upon how this was perceived by the markets, and how this perception translated into interest rates on government bonds.

In the context of narratives and sentiment the key research streams are:

- fundamental theory and tools which operationalise the concept of narratives
- computational theories of narratives, including Big Data
- tools which develop our understanding of how narratives and sentiment either spread or are contained
- tools to enable early prediction of narratives which have the potential to develop traction.

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Social Psychology and the Narrative Economy

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Abstract Economics can benefit through adopting various ideas from social psychology. Social and economic processes can be analysed at different levels: the microlevel (individuals), mesolevel (system structures), and macrolevel (whole socioeconomic system). Contrary to classic economic models, when making decisions, people do not consider all available information at the microlevel—this is not possible. Decisions may have many competing dimensions and there may be no single optimum. Whereas in traditional economy the main difference between the levels is the degree of aggregation, *social constructionism* studies how individuals cooperatively create, change and maintain their understanding of the world. Meanings arise as a result of coordinated action of humans who interpret their world by building models of it and how it functions. A natural way of acquiring meanings and conveying them to others is through *narratives*—stories that have a beginning, a body, and an end. Narratives exist at all levels of social reality. They provide the structure by which an individual can understand the world, with their roles in narratives individuals suggesting how to behave. Interacting individuals socially construct narratives bottom-up. Group narratives emerge from integration of stories describing individual experiences of actors. Shared narratives allow actors to find commonality in their experiences, find coherence in the flow of events and allow them to coordinate in common actions. At the macrolevel narratives define the system and its common culture. Sometimes narration may have more impact on an economy than hard data. Even the choice of which facts we refer to and those we do not may determine the leading narrative and hence the behaviour of people. Socio-economic processes can and should be analysed in line with narratives linking individuals, organisations and societies to better understand what is happening in the whole economic system.

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1 Introduction

In the traditional approach to economy models of *rational choice* describe individual decisions, where it is assumed that each individual makes decisions independently of the others, maximising his or her utility. It is also assumed that choices of individuals can be summed at higher levels of aggregation, with the laws operating on the group and societal levels being directly derived from the rules that govern individual behaviour. A further assumption, that economic systems are at equilibrium, underlies the formal orthodox descriptions of the properties of economic systems.

Recent empirical research has challenged the theoretical assumptions of classical economic theory, while the inability of these theories to predict the economic crisis of 2008 has called into question the practical utility of equilibrium-based economic theories. Although useful as a 'thinking tool', traditional models of economy need to be open to knowledge derived from other scientific disciplines.

In this chapter we will focus on how economics can benefit through adopting various ideas from social psychology. We will explore the view that economic processes are in fact emergent social phenomena where the dynamics of group processes drive market dynamics [1]. We will argue that because most social phenomena cannot be well described by the concept of equilibrium we need to go beyond the concept of equilibrium to understand market dynamics. We will pay special attention to the *constructivist* view [5], which states that social reality is constructed and maintained in the interactions among individuals. We will consider how social and economic reality, especially its symbolic level, is constructed by narratives [13].

We argue that economy is driven to a large part by psychological and social dynamics and examine the mechanisms by which processes operating at the level of individual and social group affect economic processes. First we will discuss different levels of the system showing how social phenomena interplay between micro-, meso- and macro-levels, then we will describe the *new agent* whose behaviour is far more complex than traditional economy assumes, and finally we will elaborate on the notion of *narrations* and how they may influence economic systems.

2 Levels of the System

It is clear that social and economic processes can be analysed at different levels: microlevel corresponding to individuals, mesolevel representing the structures of the system, and the macrolevel being the whole socioeconomic system [10, 11]. In traditional economy it is assumed that the main difference between the levels is in the degree of aggregation. Phenomena at mesolevel represent the summation of individual processes, and the macro-level phenomena represent aggregation of phenomena happening at the lower levels. According to this view the same rules operate at each level, and the levels differ mainly in the degree of aggregation. For example, individuals maximise utility in their decision-making, social groups maximise utility as the sum of the individual utilities, and this sums to the optimisation of the utility at the system level.

In reality, however, processes occurring at each of the levels are very different. For example, individuals' attempts to maximise the utility of their decisions at the microlevel can result in groups reaching poor outcomes at the mesolevel when the interdependence between individual decisions resembles the prisoner's dilemma [45]. Processes occurring at different levels are different from each other and are governed by different laws. Processes at different levels can interact with each other, and there is constant feedback between all levels [43] due to processes at one level influencing and modifying processes at other levels.

The levels of social reality differ not only structurally, but also in terms of content, and types of processes that occur at each level. At the individual level individuals are represented as agents. They take decisions, but also they experience emotions, remember events, have opinions and attitudes, have multiple values and goals, perform actions, and are subject to social norms. In fact, a variety of psychological processes occur at the individual level. Knowing the unrealistic assumptions of the rational choice model, [25] proposed their famous *prospect theory* where the description of the decision making process takes into account psychological factors such as risk aversion, e.g. people gain and lose weight differently (Pratt, 1964). Social psychology gives also evidence that people often make choices based on emotions and not cold calculation [9, 63].

3 The Myth of Rational Decision Making at the Microlevel

Contrary to classic economic models, when making decisions, people do not consider all available information, but are subject to *cognitive closure* [28]. Even if at first individuals are open to new information, when they make a decision this openness disappears and is replaced by selective searching only for information to support their decision, with any contradictory information being dismissed. Research also shows that people are vulnerable to psychological biases affecting their assessment of situations and influencing their economic behaviour. Broadly described in the literature (e.g. [15, 26, 61]) are following the biases:

- *anchoring*—when making decisions, people tend to rely too heavily on one piece of information, even if it is not the most relevant
- *framing*—people make different choices depending on how a dilemma is presented to them
- *wishful thinking*—people have an unrealistically positive view of their situation and abilities
- *self-attribution*—people tend to take credit for successful events, while blaming external factors such as 'bad luck' for any shortcomings or failures

to name but a few. Research in social psychology has shown that people do not act according to the rational choice model, but rather base their decisions on *schema* (e.g. [3, 48]).

For example, children working as street vendors in Brazil, who can ably calculate using money when selling goods on the local street, are unable to repeat the same arithmetic operations on abstract numbers when asked in a laboratory environment [7].

In traditional economic thinking humans are perceived as entities trying hard to maximise their outcomes defined in terms of expected value. However, when making a decision, people often do not want to maximise their outcomes only in one dimension, but are interested to reach the maximum outcome in many various fields. Herbert Simon calls this *satisficing* where outcomes on qualitatively different dimensions have to be traded off against each other [51]. For example, when buying car individuals may want a convenient and reliable means of transport at the lowest possible cost while trying to win popularity among their friends or attract new partners by having a car at the highest possible cost. Buying an inexpensive car is irrational on the popularity dimension while buying an expensive car is irrational on the transport dimension. A compromise of buying a medium price car could be irrational on both dimensions. Hence decisions that seem irrational from the perspective of one goal may turn out to be very rational if only we take other goals into account.

Furthermore, many times people do not make any decisions at all, but simply copy decisions of others, making the dynamics at the microlevel even more difficult to capture [4].

All the above processes take place at microlevel [27], with consequences that shape the whole system at higher levels. Realistic representation of the agents is the basis for understanding how social economic systems work. Agents are connected by social relations to other agents, and they belong to groups and organisations. This gives rise to structures at the mesolevel.

4 The Mesolevel

From the perspective of Non-Equilibrium Social Science (NESS), the mesolevel is the most interesting, since it determines the relationship between micro and macro. The mesolevel is blurry, changing and heterogeneous. In fact, it is an agglomerate of various kinds of very different structures. It is composed, first of all, of formal structures like firms, organisations, associations, etc. It also contains informal structures like friendship circles or coalitions. It involves not only stable social structures, but also intermittent ones, which exist only for a short time such as meetings and gatherings, temporary alliances, etc. The mesolevel can be characterised not only by the social structures it contains, but also by different types of content and processes that exist at this level. Social groups have identities, and these identities have strong influence on how they behave [53]. Social groups converge on their view of reality, and their shared reality is the platform for group action. Most typically, reality is understood in terms of narratives [41]. Narratives are constructed, circulated and evolve in social groups [17]. They decide not only how groups understand reality, but also which decisions groups make and which courses of action groups take [58].

5 The Macrolevel

Although the macro level, the level of the whole system, can be described in terms of its own rules, from the perspective of NESS, it is most revealing to analyse the macro-level in terms of the dynamics produced by the interaction of the entities present at lower levels of the system. The macrolevel is never exactly at the equilibrium [43]. It may oscillate around an equilibrium or fixed-point attractor, but sometimes it may jump abruptly between different attractors of the social system [8]. Moreover, the equilibria or attractors are not static but change in time. Instead of trying to characterise a system in terms of its stable equilibrium, the perspective of NESS suggests viewing the system at different timescales. For example individual sentiments may change on a fast time scale, while the system's attractors may change on a longer time scale. From this perspective the rules governing the system may not be stable. They result from the processes operating at the mesolevel, which are constantly evolving, and from properties of individuals which also change in time. Viewing societies and economies as multi-level systems allows us to go beyond characterizing the current state of the system to understand the complex dynamics composed of periods of relative stability, but also changes, which sometime are catastrophic in nature [29, 56].

6 The New Agent

An agent is connected, not isolated. An agent is connected by multidimensional links to other agents and many mesolevel structures. Relations of passing information, social influence and social interdependence connect an agent to his or her social context [57]. An agent often relies on others for getting information. Also individuals influence each other with respect to making opinions forming attitudes, etc. Although agents sometimes take decisions by processing information, comparing alternative courses of action and maximising expected outcomes, often they simply copy the decisions of others to whom they are connected by social relationships [4]. This is especially true in our complex modern world, where for most economic decisions the number of alternatives is far too high to evaluate them all. Often the nature of an agent's purchasing decision is that of whose choice to follow, rather than deciding which product best satisfies their needs. Social laws may thus better explain economic decisions, than cognitive rules. By copying, choices of some individuals get multiplied which can result in cascades of adoption. Agent's choices change the payoff structure of other agents. This forms interdependence relations. Game theory focuses on analyzing social interdependence and decisions of dyads or groups of agents interconnected by interdependence relationships [30, 42]. The most famous type of interdependence is the prisoners' dilemma [45], but many other types of links have been investigated in the context of structures of interdependent decision makers [60].

Agents are heterogeneous in many aspects. They differ in their knowledge, position in social networks, values they try to maximise, social orientation (e.g how cooperative or competitive they are), personality traits, etc. It is especially interesting how the dynamics of social and economic processes differ with respect to power, impact and narratives.

The behaviour of an agent is largely guided by the narratives they have adopted or created [58]. Agents strive for coherence with others to whom they are connected by relations, or with the mesolevel structures they are connected to [49]. Through mutual influences, agents form a shared reality that provides a mutually agreed upon social representation and evaluation of the world they live in. Since individuals tend to represent themselves and their surrounding world in the form of narrations, social representation usually takes the form of shared narratives.

Agents and their relationships change in time where some changes are due to the developmental process of maturation and ageing, but the changes are mainly the result of events and interactions [12]. Agents learn. Agent's past experiences and their own decisions influence their current decisions and behaviours. They acquire new information. They form new opinions, attitudes and identities [41]. Although maximisation in most theoretical approaches is the main principle that guides agent decision making, a crucial question is 'what does an agent maximise?' What are the goals and values of an agent? In most situations agents have multiple goals and different values guide their actions. Goals go far beyond monetary outcomes, are likely to involve social motives such as winning in competition, achieving higher status, strengthening friendship, or may be guided by empathy. Some values cannot be related to each other, e.g. what is the price of the life of one's child. Multiple goals, values and motives form multidimensional configurations. What influences individuals is not only the summary utility of all the goals that a choice will satisfy, but also the configuration of the ensemble. For example, individuals are more likely to choose courses of action that will satisfice all their goals, although other choices may lead to higher summed utility. Individuals also may avoid alternatives that lead to violation of important values or norms. There are reasons to believe that decisions are made not only on the basis of their outcomes, but also properties of the decision process. For example individuals may prefer choices made by a simpler or more coherent process, such as one that requires less cognitive effort, or one that avoids having to deal with conflicting values.

7 Narratives

Social constructionism studies how individuals cooperatively create, change and maintain their understanding of their world, and common knowledge of their reality [5, 16]. According to this theory meanings arise as a result of coordinated action of humans who interpret their world by building models of it and how it functions. Berger and Luckmann [5] state that any social order is an 'ongoing human production'. The main medium in this process of reality construction, negotiation and transmission is language [13]. Knowledge of reality is not inherent and given to people, but comes from and is reinforced by social interactions [19, 40, 46, 50, 59]. In order to persevere it has to be continuously reaffirmed.

Narratives are stories that have a beginning, a body, and an end. They have a plot. They describe temporal sequences of actions performed by agents and events and their consequences. Agents have roles, they try to achieve goals, have intentions and plans. They are connected by relations to other agents. Narratives may be simple or multithreaded, i.e. composed of interrelated simpler narrations.

Agents differ with respect to their relationship to narratives. Agents adopt narratives. Agents share narratives with other individuals in the social structure they belong to [5]. They attach their personal narratives to the narratives of the groups they belong to. They also change existing narratives and create new ones, usually in interactions with others, in a social process.

Narratives provide the structure by which individuals understand the world, in which they live. They tell individuals which elements and processes are related to each other, how to structure their experience, how to evaluate the other individuals, objects and processes. By knowing their roles in narratives individuals know how to behave [5]. Narratives also tell individuals how others are likely to behave. Narratives lead to actions and they are thus causally linked to behaviours.

Narratives exist at all the levels of social reality: micro, meso and macro. At the individual level they are an essential element of self-structure, telling an agent what is his or her identity, what are his or her relations and obligations to others, what are the expected actions of others, what is the meaning of an object action or event, and what actions should be performed [34, 44, 52]. They also inform the achievement of goals and the consequences of actions.

Narratives developed by individuals about themselves, where author of a narrative is also the foreground hero of it, are called *auto-narratives* [58]. Auto-narrative schemas determine the behaviour of individuals' social as well as economic actions, and influence the contents of narrative identity [33, 44, 52]. Special types of auto-narratives are simulations of the future, rich in scenarios for possible and desirable events. They can positively impact on the direction of attention and thinking, selectivity of the memory and subjective probability of implementation of plans [61]. These effects can increase an individuals' engagement in the realisation of a plan.

The 'meaning of life' created by narratives helps individuals better understand the mechanisms underlying their actions, thereby causing a greater sense of control over the environment and their own life [54]. Actions are more organised and more effective [55]. This results in building willpower and maintaining goals and plans, even in difficult circumstances. It also helps implement long-term plans [20].

At the mesolevel the main role of narratives is the integration of elements into wholes capable of coherent action. They play a key role for building mesolevel structures and are platforms for coordination of collective actions [47]. Narratives are the primary tools for building collective identities [19, 23, 39]. Who are we? What are our values and goals? What are our norms? How do we act? How do we relate to each other? Who are our friends? Who are our enemies? What is our history? What is our future? What other objects are important to us? Narratives typically answer these questions. Narratives represent the main element of content existing at the mesolevel. They construct mesolevel entities. We are together, although we may be different, because we belong to the same story. Narratives define the culture of organisations.

Narratives also link events in networks. Successive events may be seen as related or unrelated, depending on the narrative in which they become embedded. Narratives also define which actions and events are connected by causal links, and thus provide a structure for prediction and goal achievement.

Narratives can also be created on purpose and transmitted in a top-down process by high-status actors with power and authority, as for example the mission statements of a company, or its official history. These represent the official narratives of an organisation. They serve the purpose of controlling the dynamics of the organisation and impose interpretations of the organisation both within and outside of the organisation.

Interacting individuals also socially construct narratives in a bottom-up process. Group narratives emerge from integration of stories describing individual experiences of actors. Shared narratives allow actors to find commonality in their experiences, find coherence in the flow of events and allow them to coordinate in common actions. Unofficial narratives are built in relation to the official narratives. They are either built in agreement with the official narratives, serving as their instantiations, or they are built in opposition to the official ones, rebelling against them.

At the macrolevel narratives define the system and its common culture. Lack of an adequate narrative for Europe is cited as one of the causes of its current weakness, and a cause of problems with EU integration [2]. Creating the common narrative for Portugal, in a poem ‘Os Lusíadas’, by Luis de Camoe has been seen as one of the main causes for the rise of Portugal as a nation separate from Spain. In Poland, the poetic narrations of the romantic poets Mickiewicz, Slowacki and Norwid are seen as one of the reasons why Poland was recreated by the efforts of its citizens after more than a 100 years of non-existence [22, 62].

Narratives have different sources. Each culture is built around some common narrative schema such as fairy tales, themes of books and movies, or passed across generations as family histories [18]. These narrative schemas provide the basic plot to specific narrations, *inter alia*, concerning work, economic injustice, wealth etc. In the USA, for example, the most common narrative story is ‘an actor achieved his or her goals despite great obstacles' [33]. This narrative schema shapes personal stories, is embodied in the plots of books and movies which in addition to telling a specific story also strengthen the narrative schema. It also influences behaviour, telling the actors that difficulties are to be expected, that they can be overcome by persistence, and that the goals can be achieved. Another US narrative schema is redemption [31–33, 35–38]. In this schema an actor, who initially has negative characteristics, is radically transformed by a person or an experience and achieves very positive characteristics. Robinson Crusoe and some of the novels by Jack London conveyed a narrative of early capitalism, showing how the actor becomes progressively richer by sustained hard work. Depending on which narratives dominate (be they secular or religious) in the given community, we can expect people to act according to them.

Narratives also emerge from shared experiences [6]. This is the bottom-up route to the formation of narratives. Actors share stories and relate them to each other. Similar stories merge into shared narrations providing a shared interpretation of common experiences. In this process, individuals may internalise experiences that never occurred to them and treat them as their own. Also, choices of individuals based on random factors (such as an exposure to a product) may become included in personal and subsequently group narratives and start to shape decisions and actions.

Narrative schemas, though their repetitions in narratives, provide a common ground for values and norms of a culture [17]. They also become schemas for the construction of personal narrations, which structure the experience of individuals. Adopting a narrative is quite different from learning about a narrative. In contrast to narratives that individuals 'just know about', adopted narratives guide emotional reactions, reasoning, and action. There are different levels of adopting a narrative. At the first level narratives become accepted or rejected. Deciding that a narrative describes reality moves it to a deeper level of acceptance. At a very deep level of adoption a narrative becomes included in a person's self-structure. It becomes a part of their personal identity, is used to structure and give meaning to personal experience and guides their decisions and actions [52]. The role an individual has, thanks to narrative, become a source of their identity and they enact this role in what they do.

Some narratives are easier to evolve and adopt than others. How easy it is to adopt a narrative depends both on the features of the narrative, on the social context in which it is passed and on the relations of the narrative to the culture of the narrative group, mostly the already existing narratives [14, 24]. Narratives that contain tension are more interesting and easier to pass on than boring narratives. Narratives that adhere to exiting narrative schema are better remembered and more easily accepted. Narratives emerging from bigger narrative communities are easier to adopt and evolve.

Narrative power, the power to edit and control narratives, is an important source of control in social processes. There are several mechanisms determining narrative power. Authority is an obvious source of narrative power [21]. Both societies and organisations have rules assigning power to modify narrations. In the extreme version it may involve a right to censor the narrations of others. Authority also gives means for propagating narratives such as the control of the media or official communication channels. Reputation, often based on the history of producing successful narratives, is also an important source of narrative power.

The rise of the Internet and especially social media have to some degree decoupled narrative power from traditional authority. Companies, for example, feel that Internet reputation and recommendation systems dramatically decreased their power to control the narratives concerning their companies and products. In a similar vein, politicians in totalitarian countries are discovering that they have lost their monopoly for constructing shared narrations. The events of the Arab Spring clearly show how the loss of the monopoly for constructing shared narrations, which in this case was caused by social media, can led to coordinated social action against the authorities.

Narrative power is related to the access to both official and unofficial communication channels, e.g. large personal networks, or high number Twitter followers. It is also related to credibility and trust. A related characteristic is the power to edit narratives. The capacity to capture attention is a major factor in the ability to create a popular narrative. The power to edit and change narratives is more related to credibility and trust. It is also the case that narratives define who has the power to edit narratives. Narratives establish reputation and credibility, such as to say who has the best judgment, who has firsthand knowledge, who is honest, etc. The power to edit narratives is critical for preventing damage to reputation caused by narratives.

One of the main questions for understanding social dynamics is how information is transformed into knowledge. Information by itself does not lead to action. For action, information needs to be transformed into knowledge. Narratives play a critical role in transforming information into knowledge by structuring it, placing it in context and linking it to prediction. For example, the Polish economy is one of the healthiest in Europe. It is the only economy in Europe that did not join the recent recession. Yet, most of the Polish population feel their economy is in a state of catastrophe and periodically there are massive demonstrations demanding the recall of the government and impeachment of the prime minister. Here the Polish opposition has succeeded in generating a narrative of failure [62]. In contrast, the case of Ireland provides a different story. Until the catastrophic crisis of 2008 economists and politicians in Europe believed that the Irish economy was sound, just because Ireland was Northern and Germanic. As another example, the government debt rates of Spain, Germany and Great Britain are very similar. However, the interest on these debts are vastly different, much lower in the case of Great Britain and Germany than in Spain. Clearly, opposite narratives can be built on the same information.

This raises two distinct sets of questions. The first is related to narratives. What is the relation between narratives and information? Under which circumstances and to what extent does information restrain building narratives? How does information facilitate, or hinder the propagation of narratives? The second set of questions is related to how to extract knowledge from information. It is based on the assumption that knowledge provides a basis for decision-making. How can information be transformed into knowledge? How can that knowledge be propagated? How can we create knowledge? The capacity to turn information into useful, unbiased knowledge is one of the principal factors deciding the success of firms.

As we can see, sometimes narration may have more impact on an economy than hard data. Even the choice of which facts we refer to and those we do not may determine the leading narrative and hence the behaviour of people. In physical systems there is no meaning. In economics, we cannot afford the comfort of relying only on calculus as what is happening in the economy is happening in the world of meanings. Here the equilibrium models showing supply-demand balance are of no help (unless they are analysed as possible narratives). From the perspective of the NESS, socio-economic processes can and should be analysed in line with narratives linking individuals, organisations and societies to better understand what is happening in the whole economic system.

8 Conclusions

In conclusion, not only do social processes govern the dynamics of economic processes. They also determine a constructed social and economic reality, which is maintained and changed by the process of constructing shared reality. The dynamics of narrative play a major role in this. Social processes are not driven by equilibrium dynamics, and it follows that economic processes in a large part are non-equilibrium.

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Sociology and Non-Equilibrium Social Science

David Anzola, Peter Barbrook-Johnson, Mauricio Salgado, and Nigel Gilbert

Abstract This chapter addresses the relationship between sociology and Non-Equilibrium Social Science (NESS). Sociology is a multiparadigmatic discipline with significant disagreement regarding its goals and status as a scientific discipline. Different theories and methods coexist temporally and geographically. However, it has always aimed at identifying the main factors that explain the temporal stability of norms, institutions and individuals' practices; and the dynamics of institutional change and the conflicts brought about by power relations, economic and cultural inequality and class struggle. Sociologists considered equilibrium could not sufficiently explain the constitutive, maintaining and dissolving dynamics of society as a whole. As a move from the formal apparatus for the study of equilibrium, NESS does not imply a major shift from traditional sociological theory. Complex features have long been articulated in sociological theorization, and sociology embraces the complexity principles of NESS through its growing attention to complex adaptive systems and non-equilibrium sciences, with human societies seen as highly complex, path-dependent, far-from equilibrium, and self-organising systems. In particular, Agent-Based Modelling provides a more coherent inclusion of NESS and complexity principles into sociology. Agent-based sociology uses data and statistics to gauge the 'generative sufficiency' of a given microspecification by testing the agreement between 'real-world' and computer generated macrostructures. When the model cannot generate the outcome to be explained, the microspecification is not a viable candidate explanation. The separation between the explanatory and pragmatic aspects of social science has led sociologists to be highly critical about the implementation of social science in policy. However, ABM allows systematic exploration of the consequences of modelling assumptions and makes it possible to model much more complex phenomena than previously. ABM has proved particularly useful in representing socio-technical and socio-ecological systems, with the potential to be of use in policy. ABM offers formalized knowledge

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that can appear familiar to policymakers versed in the methods and language of economics, with the prospect of sociology becoming more influential in policy.

1 Introduction

This chapter examines the connection between sociology and Non-Equilibrium Social Science (NESS). Sociology is one of the most general and diverse of the social science disciplines. This diversity has important implications when discussing the way new developments can have an impact on practices within the discipline. Moreover, there is no one definition of the principles of non-equilibrium thinking. Thus, as we show in this chapter, the potential links between sociology and NESS depend on what assumptions and goals are attributed to both of these traditions. The chapter is divided as follows: the first section provides a brief introduction to sociology. It focuses on the distinctive features of the discipline, in comparison with other social sciences. The second section discusses the links between sociology and non-equilibrium social science. It argues that NESS and sociology can be connected in two different ways, but only one of them has significant implications. The third section introduces agent-based modelling, a social science method that has strong links to NESS. The aim is to show how this method can help in articulating the principles of sociology and NESS. Finally, the fourth section addresses the connection between sociology and policymaking. It describes the way in which sociologists have linked the discipline with the public arena and the potential role agent-based modelling can play in policy-oriented sociology.

2 Sociology in a Nutshell

Giving a brief introduction to sociology is not an easy task. There is significant disagreement among practitioners regarding the goals and status of sociology as a scientific discipline. Sociology can be described, following Ritzer (1975, [28]), as a 'multiparadigmatic' discipline. The different paradigms underlie diverging conceptualizations of the subject matter of the discipline, resulting in the application and production of different methods and theories. However, of all the social sciences, it is sociology that has scrutinized stability and change, order and conflict in society as a whole most closely. Although different paradigms have populated sociology since its inception, the discipline has always aimed at identifying the main factors that explain, on the one hand, the temporal stability of norms, institutions and individuals' practices; on the other, the dynamics of institutional change and the conflicts brought about by power relations, economic and cultural inequality and class struggle.

At the same time as anthropologists were travelling around the globe observing and understanding exotic or foreign groups, sociology emerged as an attempt to make sense of the deep social transformations that were occurring between traditional and modern societies. The first sociologists lived in a transitional period, which they understood as the passing from one stage of social evolution to a new and completely different one: from mechanic to organic forms of social integration [9]; or from mainly communitarian, face-to-face interactions (Gemeinschaft) to more impersonal and indirect interactions (Gesselschaft) [34].

The distinctive lack of unification in sociology is partly due to the fact that the discipline has not achieved the overall level of formalization that is common in the natural sciences and other social sciences such as economics and psychology, but also to some interesting factors regarding the way knowledge is produced within the discipline. The first of these is that the process of knowledge production in sociology is highly contextual. Sociology was developed following a general concern with the impacts of the many socio-demographic changes of the nineteenth century, (e.g. population growth, the emergence of democracy, capitalism, industrialisation and urbanisation). Yet, these changes were approached differently, depending on the principles of diverse intellectual traditions. For example, German rationalism and idealism strongly influenced German Sociology. American sociology, in comparison, was more influenced by positivism and the analytical Anglo-Saxon tradition.

Sociology is also a discipline that has retained a strong connection with its founders. In other social sciences, the classics have mostly historical value; in sociology, many important discussions are still traced back to foundational thinkers. It is thought that these thinkers are a source of both insights and inspiration for contemporary social issues. The contemporary relevance of the classics is due in part to the overarching character of grand theory that characterizes sociology's early days, but also to the fact that the lack of formalization of sociological theory allows constant reformulation of classical social theory. This particular trait of sociological theorization, where prior literature and developments are constantly reinterpreted and reformulated, has led to a constant reshaping of the tradition. There is widespread agreement in contemporary sociology on the foundational role played by Marx, Durkheim and Weber. However, the value attached to these and other early sociological thinkers has changed significantly depending on the place and time. During the first decades of the twentieth century, American sociology, for example, paid more attention to Comte and Spencer than to the three founding fathers, which were introduced later in the century. Likewise, early textbooks and articles gave the role of founding father to a great diversity of authors such as Adam Smith, who are no longer taken into account in contemporary sociology [3].

Despite its multiparadigmatic nature, some common and permanent topics in sociology can be identified. One of them is 'complexity', since sociology has always dealt with the ever increasing complexity of Western Societies [6]. For instance, for Durkheim [9] the distinctive aspect of modern societies was its organic structure of interactions brought about by the increasing social division of labour. For him, as the functional specialisation of the constituent social units begins to increase, the frequency of social connections or interactions also increases (what he refers to as the *moral density* of society). In his words: "The division of labour develops ... as there are more individuals sufficiently in contact to be able to act and react upon one another. If we agree to call this relation and the active commerce resulting from it dynamic or moral density, we can say that the progress of the division of labour is in direct ratio to the moral or dynamic density of society" [9, p. 257].

For this classic sociologist, the internal differentiation of society (i.e. division of labour) produces more and more inter-dependence among the differentiated units. The increasing division of labour and the resulting inter-dependence of the units are what hold modern societies together. Durkheim's understanding of modern societies is similar to what is known today as *functional complexity*, a concept deriving from biology and a revived systems theory [32]. This concept relates complexity to organisational transitions and the evolution of new properties from the interaction of more basic or lower level units. Coveney and Highfield [8, p. 6] claim that "complexity is the study of the behaviour of macroscopic collections of (basic but interacting units) that are endowed with the potential to evolve." Unsurprisingly, Durkheim's theory has been influential for several contemporary thinkers who have lead the complexity turn in sociology and connected sociology with non-equilibrium sciences [36].

3 Sociology and Sociology and Non/equilibrium Sciences

The notion of equilibrium has not played the same role in sociology that it has played in economics. In economics, it has been historically linked to the analysis of price fluctuations derived from the interaction between supply and demand. It has been conceptually constrained within the boundaries of market dynamics and has led to the formulation of a formal apparatus that focuses entirely on the economic factors related to these dynamics. Thus, the concept of equilibrium has led to the identification of a few crucial relevant factors, in both classical political economy and the neoclassical paradigm, which allowed for the articulation of a formal apparatus for its study. In recent decades, some authors have reacted against the assumptions underlying this conceptual and methodological apparatus and developed non-equilibrium economics (e.g. [25]).

In contrast, the domain of sociology is wider and the conceptual and formal apparatus of economics has not penetrated into it. Sociologists considered that this apparatus could not sufficiently explain the constitutive, maintaining and dissolving dynamics of society as a whole. Instead, the foundational role played by the idea of equilibrium in economics has been, to a certain extent, played by the notion of *order* in sociology [1]. However, there is a key difference between the two concepts.

In its most general formulation, the inquiry around order is a hypothetical question about the emergence of society as such. This general approach is visible, for example, in Parsons' *The Structure of Social Action* [26]. Yet, 'Order' has been more commonly used to describe particular aspects of social dynamics that allow for the existence of social life. Attention has been paid, to name a few cases, on whether order depends on the existence of social institutions (e.g. [33]), on how order emerges from the dynamics of interaction (e.g. [22]) and to whether a state of sociality is achieved by conflict or consensus (e.g. [21]).

The diversity in the approaches to what order is and how it is achieved and maintained has led to a more complex conceptualization of the emergent character of social dynamics. The question of the transition from equilibrium to non-equilibrium thinking is not easily answerable as there is no dominant theoretical-methodological framework in sociology. However, it can be asked of specific approaches within the field. Garfinkel's [12] ethnomethodology, for example, was developed as a micro-focused account of social order, in explicit opposition to the macro approach of Parsons' [27] structural-functionalism. The former examines how order is built from everyday interaction, whereas the latter investigates the maintenance of order as a system property. Ethnomethodology can be better at explaining the emergent nature of order, but it falls short in its account of the long-term dynamics of social phenomena. Structural-functionalism provides more tools to explain long-term dynamics, but lacks the tools to explain the formation and maintenance of order at the micro-level.

If NESS is taken in a wider sense to mean a shift to a focus on non-linearity, processes, mechanisms, emergence, computer modelling and so on, then it could be argued that a more significant departure from traditional mainstream sociology might be needed. Initially, the relationship between sociology and NESS in this wider sense, and complexity theory in general, is one of cross-fertilization. Several key concepts from NESS were introduced early in mainstream sociology. 'System' is the paradigmatic case. The concept entered sociology in the mid-twentieth century, thanks to Parsons, who was particularly interested in the newly developed fields of cybernetics and system theory. Subsequent developments in sociology, such as [18] work on autopoiesis, fed back to general system theory. In the same way, some sociological contributions, for example, to social network theory, have proved fundamental for the application of the complexity framework in social and general science.

In addition to this relationship of cross-fertilization, some contributions from classical sociology, such as Marx [5], Durkheim [30] and Foucault [24], have been reinterpreted through the lens of complexity theory, with the suggestion that there is common ground between their work and complexity theory. Yet, the fact that very different contributions can be interpreted as containing complexity thinking should serve as a warning of the issues that might arise when linking sociology and NESS in a wider sense. While it is true that sociology has a diverse theoretical-methodological foundation, the discussion about how much traditional sociology can inform complexity theory should always be approached critically. A critical stance is also needed because some of the philosophical principles put forward by NESS are not new in sociology. In its challenge to the traditional approach to abstraction and generalization in social science, NESS shares some of the philosophical principles of schools or movements that are rarely associated with complexity theory, such as postmodernism [7].

To summarise, sociology has not faced the same constraints and difficulties that economics has faced due to the latter's commitment to the notion of equilibrium. Although the more general focus on order and the low level of formalization have led to the development of several theoretical paradigms and sub-disciplinary areas that do account for some of the key features in NESS in the wider sense (e.g. symbolic interactionism and figurational sociology emphasize processes, and historical sociology emphasizes non-linearity and path dependence), there has not yet been a wide-reaching account that addresses them all together. However, more recent work in the study of complex social phenomena in computational sociology begins to address this issue through the prism of a specific methodological approach, namely, agent-based modelling.

4 Sociology and Agent-Based Modelling

Over the past 30 years, agent-based modelling (ABM) has increasingly been used in sociology as a research tool. ABM is a modelling technique well-suited to formalising and testing explanations of social dynamics. Explanations can be based on ideas about the emergence of complex adaptive behaviours from simple and local activities [2, 10, 14].

In comparison to alternative techniques, such as variable-based approaches using statistical or mathematical modelling, ABM allows modellers to simulate the emergence of macroscopic regularities over time from interactions of autonomous and heterogeneous agents [13]. In such models, individual entities, their decision-making rules and interactions are directly represented. The emergent properties of an ABM are thus the result of 'bottom-up' processes, the outcome of agents' interactions. The absence of any form of top-down control is a hallmark of ABM, since the behaviours and interactions at the agent-level bring about the observed regularities in the system. With this technique, sociologists can study properties of emergent orders that arise from interactions among a multitude of autonomous heterogeneous agents. And they can understand the ways in which such emergent orders influence or constrain the decisions and actions of the agents.

The interest in ABM also reflects the growing attention to complex adaptive systems and non-equilibrium sciences by sociologists; that is, the possibility that human societies may be described as highly complex, path-dependent, far-from-equilibrium, and self-organising systems [6, 20, 23]. Complexity theory and the accompanying trappings of complex systems provide the theoretical basis for ABM. For this reason, while modellers are usually interested in addressing specific theoretical questions and working in particular substantive areas, they almost invariably draw on complexity concepts when using an agent-based approach. Because agents' actions are not independent and agents are autonomous, it may be impossible to predict whether a system will achieve equilibrium. In these models, a continuous interplay between the emergent structures and the agents' actions takes place, altering the dynamics of the system and sometimes moving it towards unpredictable states. Therefore, the emphasis on processes and on the relations between entities that generate macroscopic regularities, both of which can be examined by these models, accounts for the developing link between complexity theory, ABM research and NESS.

ABM involves two main components. Firstly, these models include a population of agents. The agents are the computational representation of some specific social actors—individual people or animals, organisations such as firms or bodies such nation-states—capable of interacting, that is, they can pass messages to each other and act on the basis of what they learn from these messages. Thus, each agent in the model is an autonomous entity. The artificial population can be heterogeneous with agents having differing capabilities, roles, perspectives and stocks of knowledge.

Secondly, ABM involves the definition of some relevant environment, the virtual world in which the agents act. It may be an entirely neutral medium with little or no effect on the agents, as in some agent-based models based on game theory, where the environment has no meaning. In other models, the environment may be as carefully designed as the agents themselves, as in some ecological or anthropological agent-based models where the environment represents geographical space that affects the agents' behaviour.

The use of ABM by sociologists has consolidated an emerging disciplinary branch: agent-based computational sociology [31]. In this subfield, one of the main objectives of ABM is to test, by experimental means, the hypothesised mechanisms that bring about the macroscopic phenomenon the researcher is interested in explaining. A mechanism describes a constellation of entities (i.e. agents) and activities (i.e. actions) that are organised such that they regularly bring about a particular type of outcome [19]. Therefore, sociologists explain an observed macroscopic phenomenon by referring to the mechanisms by which the phenomenon is regularly brought about.

In ABM these mechanisms are translated as the model microspecifications, the set of behavioural and simple rules that specify how the agents behave and react to their local environment (which includes, of course, other agents). Once the population of agents and the environment are defined, sociologists working with ABM can implement the microspecifications and run the computer simulation in order to evaluate whether these rules generate the macro phenomenon of interest, over the simulated time. The motto of ABM is, then: "if you did not grow it, you did not explain it" [11]. When the model can generate the type of outcome to be explained, then the researcher has provided a computational demonstration that a given microspecification (or mechanism) is in fact sufficient to generate the macrostructure of interest. This demonstration, called *generative sufficiency* [11], provides a candidate mechanism-based explanation of the macro-phenomenon. The agent-based sociologist can later use relevant data and statistics to gauge the generative sufficiency of a given microspecification by testing the agreement between 'real-world' and the generated macrostructures in the computer simulation. On the other hand, when the model cannot generate the outcome to be explained, the microspecification is not a viable candidate explanation of the phenomenon and the researcher has demonstrated the hypothesized mechanism to be false.

Note that, in this perspective, there is a sharp distinction between generative explanations and the mere description or discovery of regularities. It is not sufficient to identify, for instance, a statistical association between two or more variables. In ABM, what defines an explanation is the explicit representation, in computer code, of the underlying generative mechanism, which is a deeper reconstruction of the social regularity [16] agent-based models can be used to perform computational experiments that explore plausible mechanisms that may underlie observed patterns. That is one of the promises of ABM: given the limitations of experimental methods and the complexity of social phenomena, agent-based models are important for this kind of endeavour [17]. ABM allows systematic exploration of consequences of modelling assumptions and makes it possible to model much more complex phenomena than was possible earlier. ABM also allows more applied models to be developed. They have proved particularly useful in representing socio-technical and socio-ecological systems. In this mode agent-based models become policy models, with the potential to be of use in policy making.

5 Sociology and Policy

The relationship between sociology, the public arena, and policy-making has been a controversial one. The emergence of sociology in the nineteenth century crystalized a widespread disenchantment with modernity. As described above, early sociologists focused on the consequences of the major social changes of the eighteenth and nineteenth centuries. They were adamant about the necessity for an intellectual response to the social turmoil generated by these changes. The most distinctive character of this response was that it needed to come from the application of the scientific method. The implications of belief were not always conceived in the same way. Early positivism, for example, put forward a very radical approach. Comte [15] was particularly frustrated by what he thought was an unscientific discussion about social issues in the public arena. He considered this discussion should be discarded in favour of sociology, which should be transmitted to the public through the formal education system. He believed sociology, by unveiling the laws of social phenomena through the application of the scientific method, would achieve a truth status higher than any opinion about public matters. While Comte's radicalism found few followers, the alleged formative character of sociology's findings has been a distinctive trait of the discipline and one that has significantly influenced its connection with the public agenda. Sociologists have often operated with the idea that there is something about sociology that is of value to everyone, including those in charge of policy. This idea is grounded on two interconnected assumptions: first, that sociology provides 'useful knowledge' i.e. sociologists consider that the discipline is publicly relevant because it answers questions that people, including policy-makers, ask in their everyday life. The second assumption is that sociology, because of its scientific character, constitutes a key source of information for anyone interested in having an informed opinion about the social world [35]. These two assumptions about the ubiquitousness and reliability of sociological knowledge, however, have not led to a fruitful relationship between sociology and policy.

Developing sociologically grounded policy is difficult for many reasons. From its earliest days, sociologists have been concerned with justifying the scientific character of sociology. This has not been easy because of the constant comparisons with more developed and established disciplines and the multiple obstacles for the professionalization of the discipline, e.g. departments of sociology were not common before the second half of the twentieth century. The conditions of professionalization are important in another way. On many occasions, the subject matter of sociology has been defined by highlighting the opposition between the roles of social scientist and politician. The former is allegedly meant to focus on the explanation of social issues, whereas the latter is meant to use these explanations in a pragmatic and responsible manner, in order to induce social change. A sociologist involved in policy issues would thus not be doing sociology, but politics [37]. This separation between the explanatory and pragmatic aspects of social science has led sociologists to be highly critical about the implementation of social science in policy, e.g. through economic models based on an instrumental and rational approach to individual action.

However, in the UK at least, this may be changing as the impact agenda creates new incentives for sociologists to engage with policy-making and the public sphere. The increasing popularity of NESS and particularly methods such as ABM offers hope to those wishing to see a greater influence of sociology on policy. ABM offers a more formalized form of knowledge that can appear familiar to policy-makers versed in the methods and language of economics. Many policy-makers, in response to the 2008 economic crisis, are in search of more nuanced understandings of 'the social' than those that neo-classical economics can provide. Moreover, the turn towards the language of participation in politics creates an expectation of actual participation. Methods such as participatory modelling, where stakeholders are brought into model development and evaluation, offer powerful tools for bringing together communities and the public into decision-making [4].

6 Concluding Remarks

This chapter addressed the relationship between sociology and NESS. It was argued that sociology is a multiparadigmatic discipline: different theories and methods coexist temporally and geographically. Thus sociology's relation to NESS depends on what one takes both to be. NESS, understood as a move from the formal apparatus for the study of equilibrium, does not imply a major shift from traditional sociological theory. However, if NESS is a shift towards complexity theory, then the relationship becomes less clear. Even though some complex features have long been articulated in sociological theorization, the discipline has not yet embraced the principles of NESS as a whole.

The chapter considered agent-based modelling as an approach that provides a more coherent inclusion of NESS and complexity into sociology. Finally, the relationship between sociology and policy-making was discussed. It was suggested that agent-based modelling is a method that can bring together the concerns of traditional sociologists and those interested in complexity theory, NESS and influencing policy.

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Geography Far from Equilibrium

Denise Pumain

Abstract Geography makes little use of the concept of equilibrium. Unlike economics, geographical inquiry is based on the recognition of differences and asymmetries among regions and civilisations. In this it does not refer to general mechanisms that would be equivalent to the market for fixing prices and equilibrating supply and demand. Early geographers searched for explanations to the great variety of landscapes and ways of life that were observed all over the planet. Modern geographers study both the 'vertical' interactions between societies and their local milieu and the 'horizontal' interactions between cities and regions. This involves two opposing causes of territorial inequalities, spatial diffusion of innovation and urban transition. Whereas diffusion of innovation alone might result in homogeneity, combined with the dynamics of city formation the result is increasing heterogeneity and inequality. The phenomenon of increasing returns with city size is explained by higher population densities and connections multiplying the probability of productive interactions, as well as by adaptive valuation of accumulated assets. While there may be great wealth, in some large urban agglomerations large informal settlements of slums and shanties are still expanding. Global societal evolution is an open process with no fixed asymptotic point in the future: there is no final equilibrium state to reach for the world. Open evolution may hamper the quality of predictions that can be made about the future, but geographical knowledge of past dynamics may help to make forecasts more certain. Powerful analytical tools have been developed in the last five or six decades that greatly improve the quality of geographical work and its ability to provide stakeholders and decision makers with clearer insights for exploring possible territorial futures. Geographical Information Systems are now universally used in all kind of administrations dealing with localised services. Detailed geographical information from many data sources enables a shift from a macro-static view to a micro-macro dynamical view that is necessary for management and planning policies in a non-linear world. As a science geography remains deliberately far from equilibrium.

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1 Introduction

Geography as an academic discipline tries to meet a splendid but difficult challenge: understanding and explaining how human societies use and transform the earth-atmosphere interface for their own survival, reproduction and quantitative or qualitative expansion. In this research program the science of geography makes little use of the concept of equilibrium. Unlike economics, geographical inquiry was based from its very beginning on the recognition of differences and asymmetries among regions and civilisations of the world. At first initiated by curiosity for the accounts and discoveries of travellers and explorers such as Ibn Battuta, Marco Polo, it developed into the creation of scholarly associations and geographical societies that appeared from the middle of nineteenth century. Geographical knowledge also was developed at first for preparing wars, and then for managing and exploiting colonial conquests. It was valued precisely because it supplied knowledge of a variety of resources that were unknown in the country of origin.

So it is not surprising that when geography was set up as a branch of knowledge in universities at the beginning of twentieth century, the first scientists extended this intellectual interest by searching for explanations to the great variety of landscapes and ways of life that were observed all over the planet. Sources of differences and strangeness were at first thought to reflect different conditions of climate and topography, as well as the ability of societies to exploit them. Subsequently the geographical situation relative to major routes and spatial concentrations of power and population was considered to be a major explanatory factor, especially center-periphery constructions at all geographical scales that are continuously changing and never were conceived as being in equilibrium. Even today, where one could think of a possible unification of the world through tourism and business travel, and where global and instant diffusion of communication world news tends to diminish the strangeness of distant countries, geographers still maintain a strong belief that 'space matters', and there is nothing like a 'flat world'. Despite the dominant cultural industries, the aspirations to imitate lifestyles of the richest, and the apparent ubiquity of information flows through Internet, new differences emerge from the complex dynamics of territorial systems. These include path dependence effects that lead to accentuated disparities that work against homogenisation.

As a science, geography remains deliberately far from equilibrium. Therefore, geographical models that help decision makers in their choices for developing territories or undertaking specific activities always share two major characteristics: (1) they never are considered as providing optimal solutions, but leave open a plurality of possible future paths, and (2) whatever the scale under consideration, they always are contextualised, to a given specific place or situation. Consequently, geographical models and interpretations can favourably counterbalance inadequate representations based on a concept of general equilibrium.

2 Local or Temporary Stabilities Instead of General Equilibrium

Due to the widespread influence of mechanistic Newtonian equilibrated models imported into all sciences, the ‘classical’ geographical schools in Europe and America were not totally immune to the temptation to identify situations of equilibrium. Even so,they were deeply influenced by Darwinism and evolutionary concepts. One could perhaps detect equilibrium ideas in the regional descriptions of the first half of twentieth century, in areas of human geography that considered mostly agrarian societies to be more or less stable *genres de vie* adapted to particular conditions of a given natural milieu, with recognisable original landscapes and combinations of economic productions and cultural features. A similar temptation would be to interpret some work in physical geography as using equilibrium concepts, e.g. when botanical geography elaborated the concept of ‘climax’ for defining the persistent adaptation of a subset of species to local conditions of climate, relief and soil. As another example in geomorphology a theory relying on balanced processes was conceived by the American geographer Davis [2] introducing the concept of ‘erosion cycle’. According to his view, the surging of mountains due to tectonic uplift was normally followed by stream erosion reducing the landscape to a flat plain at an altitude close to sea-level. Indeed his epistemological reference is an evolutionary theory following a mixture of Darwinian or Lamarckian conceptions.

Among most geographers there remained a strong sense of the diversity of the world, and a desire to explain it. A very simplified version of the history of geography emphasises two possible sources of explanation that were more or less successively explored.

At first, the diversity of local ‘natural’ conditions of climate, topography and soil was thought to be the reason for a variety of landscapes and ways of life. Types and abundance of vegetal and animal resources, their exploitation for sustaining life, and local geology providing materials for building houses were suggested as determining production factors to explain the unequal success of different regions. ‘Success’ was usually as measured by population densities, directly similar to the concept of fertility rent by Ricardo [9]. Here the notion of equilibrium is often used, in a metaphoric sense, to identify more or less stable combinations of population densities, types of human habitat and systems of resource exploitation, mainly for agricultural systems linked with specific ‘terroirs’ and local climates.

But of course in this explanation geographers do not refer to any general mechanisms that would be equivalent to the market for fixing prices and equilibrating supply and demand. The possible balance between human densities and local resources is regularly revised by changes in production and organisational techniques that are periodically driven by demographic pressure or famine events. There is never any mention of a possible convergence between economies that are evaluated at different levels of geographical success. The inquiry is directed towards avoiding a too simplistic ‘determinism’ and enriching the explanation of inequalities by considering different ways of societal organisations that enable more or less intensive types of production.

From the 1950s, a second source of explanation was more systematically investigated by exploring not only the ‘vertical’ interactions between societies and their local milieu, but also the ‘horizontal’ interactions between cities and regions. The diversity of geographical situations respective to circulation axes (large valleys, maritime bays and river estuaries for harbour sites, road and railway networks, airline hubs), to existing concentrations of population and activities (center-periphery models) and spatial discontinuities (political or economic borders) is considered as constraining the potential for local developments, sometimes in a much stronger way than the available resources in the local environment.

This explanatory path, sometimes named *spatial analysis*, roughly identified two major processes that may have contradictory effects on territorial inequalities: spatial diffusion of innovation, and urban transition.

The trend towards spatial diffusion of innovation could result in a convergence between places where a new and profitable activity or technological device or feature of the way of life emerge and places where they are imitated and adopted later. Indeed, many characteristics of ‘modernisation’ have been widely diffused in very large parts of the world. For instance, it could be concluded that a major transition, the *demographic transition*, has transformed the human condition through the diffusion of health care and reproduction practices, from an ancient ‘equilibrium’ with high fertility and mortality rates and short life expectancy towards a new one with low fertility and mortality rates and much longer life expectancy. However, this demographic transition over two centuries has also completely changed the size of world population, doubling it during the last 50 years and even if stabilisation is predicted for the middle or end of the present century this can hardly be conceived as the effect of any ‘equilibrium’ between human societies and their resources. Meanwhile, the temporal delay in the process between more advanced countries and those where the transition is occurring later and faster has dramatically modified the spatial distribution of population of the world by increasing the proportion of Asia and Africa compared to Europe and America.

Indeed, the second major transition that occurred in the world during the last two centuries, the so-called *urban transition*, while networking almost all places on earth has created entirely new inequalities in population densities, wealth and living conditions between the towns and cities that have proliferated across the planet. The spatial distribution of world population has been dramatically transformed at all scales of observation: between urban places and rural areas; city centres and their peripheries; and attractive regions and abandoned ones. The ranking of cities in terms of demographic weight is more volatile: although New York and Tokyo remain today among the largest urban centres, several other major urban concentrations above twenty millions inhabitants have emerged, especially in China around Shanghai, Beijing-Tianjin or Guangzhou and in India in the urban regions of Delhi, Mumbai and Kolkata. The urban world however does not generate chaos as is sometimes lamented, but certainly it drives the world on a path that goes further and further away from any ‘equilibrium’.

3 Increasing Inequalities with Urban Development

If we accept for a while to adopt the vocabulary of economic science that implicitly refers to the concept of equilibrium, we could suggest a principle of geographical evolution as a possible global convergence, e.g. the availability of some technologies, health care, life expectancy, aspects of the ways of life, and information diffusion. However, whatever the scale, local or global, there is no possible reference to any equilibrium of any sort since, as in biology (although much more rapid), global societal evolution is an open process with no fixed asymptotic point in the future: there is no final equilibrium state to reach for the world, and at local levels quantitative as well as qualitative differences between places are expanding.

3.1 Asymmetries in the Accumulation Process

Geographers call ‘urban transition’ the universal historical change in the way human societies are colonising the earth. There was a phase transition from a rural to urban world. Rural settlements linked mainly to the development of agriculture since Neolithic times generated a human habitat made of small concentrations. These population nodes were similar in size (a few hundreds to a few thousands inhabitants at maximum) and widely scattered all over the surface of the earth. By contrast, urban settlements are a much more concentrated and heterogeneous way of inhabiting the planet including agglomerations of much more diverse sizes between 10^3 and 10^7 inhabitants. Urbanisation seems an ineluctable process that has remained a latent trend for seven millennia but has accelerated greatly during the last two centuries, since about 1800 in the now developed countries and 1950 in the rest of the world. While the rural economy was based on using local resources and human and animal energy, the hierarchised systems of cities depends on exchanging resources over much longer distances and structuring networks of secondary and tertiary activities, manufacturing and services, that have become more and more complex.

Why and how have such huge concentrations of population and wealth become possible? They were generated mainly through incremental historical processes of accumulation relying on persistent asymmetries. Among them, the political domination of ‘centres’ of power established through societal organisations of various kinds and the inequitable pricing of goods and wages that was often linked to it. The ‘increasing returns with city size’ now widely acknowledged, even by economists, is generated by higher populations densities and connections multiplying the probability of productive interactions. Nowadays, two trends are reinforcing the hierarchical qualitative and quantitative inequalities among cities: the higher level of complexity of activities (functional diversity and historical advances in technologies) and the skill of the labor force (sometimes referred to as higher 'creativity') are attracting profitable innovation to the largest urban centres where the increased speed of transportation systems short-circuit the smallest settlements.

From a geographical and historical perspective it may even be argued that spatial inequalities are a resource that sustains the growing dynamics of the system. Globally, it seems clear that wealth can be created by integrating populations of former poor countries (but not yet the poorest) into the consumption markets. Increased land values are generated at the peripheries of metropolitan areas of emergent economies by incorporating cheaper agricultural or nomadic land into the urban realm, where parcels are sold at prices that are tens to hundreds times higher than before.

3.2 Increasing Divergence in Accessibility as Transportation Speed Increases

Another source of the creation of inequalities between geographical places is the increase in transportation speed that has been especially effective and spectacular during the last two centuries. Regular stagecoaches, then trains and then airplanes have dramatically reduced the time for connecting the places. In parallel, the cost of transportation has been lowered and the mobility of people and goods has considerably increased. But if every location has gained in accessibility, there are growing inequalities in the accessibility level of places: as rapid transport systems are organised in networks having less and less nodes the more rapid they are, the more the differences in transportation times from one point to another one are increasing. The world in space-time terms is together becoming smaller, shrinking and shriveling (Waldo Tobler [10]). There is an historical shift from a world of homogeneous slowness towards a world of much more differentiated swiftness.

Inequalities appear to be growing at world scale but are sometimes difficult to measure according to the heterogeneity of cultures and statistical systems. Despite this, two examples of increasing differences can be quoted as examples of economic divergence at lower geographical scales. In the European Union where compensation systems are conceived for reducing inequalities, it was demonstrated that if the general economic level had a converging trend at the scale of member states, the gap in wealth production and consumption would increasing between places at regional level [5, 6]. At a much more local level, it is increasingly observed in large urban metropolitan areas that there are growing social inequalities leading to higher social fragmentation and steeper price gradients in the richest metropolises of the world. Be that as it may, in some large urban agglomerations of the poorest countries, in Africa or South-East Asia, large informal settlements of slums and shanties are still expanding, leading the sociologist Mike Davis to write his book *Planet of Slums*, whose French title *Le pire des mondes possibles* translates as 'the worst of possible worlds' [3].

3.3 Continuous Proactive Adaptation in an Open Evolution

Urban resilience is often mentioned as desirable in policies aimed at sustainable development, including policies in favour of economic growth, social cohesion and preservation of resources for the future generations. But the process towards urban resilience is not the homeostasis that would mean coming back to some equilibrium: it is on the contrary a continuously adaptive process inducing permanent changes in the quantitative and qualitative aspects of urban development and urban life. Such a dynamic is self-sustained by the positive feedback loops linking urban accumulation and societal innovation. The emulation between urban actors aiming at maintaining or increasing the value of their local assets drives them also to imitate or anticipate the innovations of all kinds that are created in other places. It is a permanent constraint on their decisions for adapting and innovating because otherwise there is a risk of losing value for their previous achievements.

Such dynamic properties are interdependent because tightly connected urban systems generate an open evolution that is full of uncertainties. It is sometimes difficult to understand the discrepancy between the intentions of individual actors who try to optimise their action (often inspired by equilibrium theories of influential economists!) and the collective outcome of their work that is sometimes revealing counterintuitive or even ‘perverse’ effects. As a consequence, there are ‘bifurcations’ in the evolution of territories at local level such as the long decay or very difficult recovery over many decades of specialised cities that were among the richest during the first and second industrial revolution. Examples include Detroit linked to the automobile manufacturing, or the Ruhr region specialised in coal extraction and steel industries. Inside cities, some neighbourhoods loose attraction and value whereas others, especially close to waterfronts, central business districts or formerly abandoned industrial zones were happily renovated and consequently gentrified. At upper geographical scales, bifurcations are transforming the fate of large territories as in the case of the so called *BRICS countries* including Brazil, Russia, India, China and South Africa that shared very rapid growth rates since the end of twentieth century leading the group to institutionalise in 2009 and 2011 [7].

Many other transformations can be expected in the future evolution of the world in its different parts. The fact that it is an open evolution may hamper the quality of predictions that can be made about its future, but the geographical knowledge of its past dynamics may help to reduce the uncertainties of forecasts and indicate some more promising directions. Powerful analytical tools have been developed in the last five or six decades that greatly improve the quality of geographical work in its ability to provide stakeholders and decision makers with clearer insights for exploring possible territorial futures.

4 Geographical Tools for Managing and Anticipating the State of the World

Many concepts of modern geography may be used for guiding decision making. Geographical science, knowledge and skills, could be used more intensely for thinking about policies of territorial development and habitat or landscape management.

A first feature is a sense of 'place'. Because geographers are convinced of the intrinsic diversity of the world and because they share an evolutionary perspective that recognise the effectiveness of path dependence in spatial changes, they will always emphasise the importance of 'place' and this helps stop them applying undifferentiated solutions independently of the local situations. This does not imply the irreducible singularity of each territory or local problem, but is merely a plea for adapting models and policy processes to identify peculiarities that can improve the impact of decisions.

In this respect, huge progress has been made in equipping geographers with relevant tools. Computer-based Geographical Information Systems are now universally used in all kind of administrations dealing with localised services. Since emerging in the nineteen seventies they have been progressively enriched with analytical tools for spatial analysis that refine, for instance, the computation of distances from as-the-crow-flies measurements to sophisticated estimations of travel time combining several transportation modes including waiting times. Such measurements of accessibility can be applied to all kind of services and be adapted for subpopulations, building high-performance instruments for solving location-allocation problems.

Mapping is essential in land and regional planning. Recent progress in developing dynamic models *in silico* enables simulation of a wide variety of scenarios. Estimates of societal needs are translated into projected changes in dedicated land surfaces allocated in different places according to the most probable land-use transitions. This uses computerised visualisation tools with 'cellular automata' to display the possible local future consequences of planning decisions. These models can include many local bifurcations that are displayed as animated maps, which helps in understanding the non-linear effects of urban growth or spatial movements.

The usefulness of Geographical Information Systems is linked to their power to integrate many different data sources, including satellite images, statistical services, and new sources such as static or mobile sensors in the environment [4]. When coupled with adapted simulation models the recent availability of these 'Big Data' has extended the capacity of these geographical tools to represent emergent phenomena between micro-level events or behaviour and spatial structures at macro-level. Thus *geocomputation* has become a widely developed activity that is now able to generate series of validated and reproducible dynamic models using, for instance, open simulation platforms such as OpenMOLE [8] for reconstructing the development of urban systems at different geographical scales in a variety of countries, and the agent-based Simpop models (http://www.simpop.parisgeo.cnrs.fr).

Indeed, from scientific geographical knowledge including the spatial dynamics of innovation, stylised facts of spatial evolution have been identified and make part of future transformations predictable. An example is the delineation of probable gradients of gentrification inside wealthy urban areas, following a process reducing the 'rent gap' between the urban core and the previously less favoured neighbourhoods. Another example is the evolving spatial international division of labour between the rich and poor countries: after the rise of the GDP level per inhabitant in emergent countries, the wages of local workers are increasing, and manufacturing activities migrate towards poorer countries. For example, Chinese enterprises have already located some of their production units in Vietnam, Indonesia or Ethiopia.

Other applications of geographical knowledge can be found in the domain of epidemiology. For example, [1], commenting on the rapid victory over the SARS epidemic due to the network information system established by the WHO, highlight "the exploratory power of animated and interactive maps as spatial surveillance tools ... to reveal local and global dynamics of a given epidemic, ... underline the complexity of the epidemic process and the high variability of local situations that a 'smooth' global pattern can be composed of. Two crucial parameters - amongst many - we need to control before building any diffusion model. Anyway, a major GIS shift has to be achieved if we want to carry on, from data management to data analysis ... leading to more realistic and efficient identification of underlying patterns" [1].

As Mike Batty often recalls, detailed information about geographical processes helps in shifting from a macro-static view to the micro-macro dynamics view needed for correctly advising management and planning policies in a non-linear world.

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Cities in Disequilibrium

Michael Batty

Abstract Our perceptions of cities until quite recently were that they were largely stable in spatial structure over long periods of time, decades, even centuries, and that this suggested that they were in equilibrium. Cities appeared similar from generation to generation and although there were superficial changes due to fashion and technology, their overall structures were unchanging. To a large extent, this view of cities in equilibrium is borne of thinking about them physically but as soon as we unpack their dynamics, we realise that this a superficial perception. Cities are always in disequilibrium. They are in fact far-from-equilibrium being maintained through a tension of many countervailing forces that break down and build up on many different spatial and temporal scales, thus all coalescing in strong volatility and heterogeneity in urban form and function. Here we first review the concept of equilibrium and dynamics, and then we introduce ideas about discontinuity drawing on ideas from catastrophe and chaos theory. We argue that we should think of cities as being far-from-equilibrium structures and allude to ideas about innovation and technological change that condition their dynamic entirely. Our conclusion is that what happens in cities is increasingly disconnected from their physical form and this is particularly the case in the contemporary world where changes to the built environment are ever out-of-sync with changes in human behaviours, activity locations, patterns of movement, and globalisation.

1 Introduction

If you slightly abstract your casual knowledge of a city by considering its physical form as a map or even a description of how its various activities, land uses and transportation systems are configured, and you then examine how these images have changed over past generations, you could be forgiven for thinking that cities are fairly stable in their form and function. They appear to be long lasting in their structure and change only slowly from decade to decade or even century to century. In one sense, cities of the medieval era have the same structure as those

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of today—relatively well-defined urban cores or central business districts (CBDs as they are now referred to), inner areas that house industries and poorer populations who are crammed into places near their work, and more open lower density tracts which form their suburbs. Of course the medieval city was a microcosm of today's industrial and post-industrial city and of a very different scale. Its technology was massively different and consequently as populations could only travel limited distances—no more than 6 miles or so to work each day—cities were very much smaller. Only did they break through the one million population threshold when mechanical technologies were invented and disseminated for movement from the early nineteenth century onwards, but their structure has remained much the same to this day. However we now stand at another technological threshold with respect to the city and what it will be like in the future but before we engage in this debate, let us begin by describing what we know about cities in terms of their stability and dynamics over space and time.

From what we have said, cities appear to be in some sort of equilibrium over time in terms of their structure and even if this equilibrium were changing, a common assumption has been that this is a stable equilibrium. Perturb it a little and the city will return to its current state or a state only a little different from the one that existed before the perturbation. Evidence of this is all around us: look at a large city like London in 1915 and the same city today in 2015 from aerial imagery and you would see the 'same' kinds of clusters of urbanisation at the two periods, the first much smaller than the present but their spatial structure being much the same. Yet despite these evident similarities, there are little chinks in the armour of this notion that cities are in equilibrium which come from other casual observations. Old photographs show very different forms of behaviour in cities at different time periods, styles of dress differ markedly, and the way people travel has changed. Much has been reinforced from earlier eras but there has also been substantial change. In fact the notion that cities are in equilibrium has become something of a convenient myth. It has been reinforced somewhat by the fact that much of quantitative urban theory is predicated on explaining how urban markets work to produce patterns of population and employment densities, rents and transport costs that tie people to particular places in the city and generate profiles that suggest populations decline monotonically in density as they locate further and further from the core of the city. Such theories suggest that negative feedbacks reinforce these patterns and the very notion that we use the market as the economic mechanism to resolve the way people make decisions, forces us somewhat to assume that markets tend to clear with equilibrium being their dominant state. Living with markets in disequilibrium is something that we have found hard to articulate. Moreover, there has been little theorising about how cities might grow and change to account for radical discontinuities in technology and behaviour, at least other than in the most general conceptual terms.

Yet when you look at cities across wide spans of time, everything is different. Although cities look rather inert with respect to their physical form, the activities that take place in their buildings and locations differ markedly from generation to generation. For example in 1900, there were 75,000 manufacturing jobs in the City of London which then had a residential population of 27,000. In 2015 there were hardly any such jobs and the City's population had fallen to 8100. During this period service jobs hardly grew at all but their composition changed dramatically to be dominated by financial services. The City has been rebuilt some three times since the second world war during the various building booms but the street pattern is more or less the same as it was in medieval times before the Great Fire in 1666. This makes for some confusion over the notion of what equilibrium one is trying to capture. In fact there are many types of equilibrium that might be sought in defining cities and as a corollary, many types of disequilibrium. In some respects, it is a fruitless task to try to merge all these different perspectives and to achieve any clarity in this kind of non-equilibrium social science, we must take one step back to go two steps forward in our discussion.

2 Equilibrium, Steady States, Feedback and Urban Dynamics

By the mid-twentieth century, the systems approach was in full ascendency in the social sciences with the notion that cities as well as many other functions of modern society were systems in equilibrium, maintained by strong negative feedback loops that returned the system to its steady state if perturbed. The notion that this steady state could evolve was also consistent with this concept of equilibrium since such a steady state could incorporate various kinds of progression in the form of new technologies, new behaviours and so on but at the end of the day, negative feedback would prevail. The steady state to which the system returned was much the same, perhaps differing by some quantitative measure but was not qualitatively different from any former equilibrium.

The notion of negative feedback is central to this concept of equilibrium. The city was regarded as something that was well-behaved: if new activities were added to its structure, then multiplier effects would work themselves out and provide a new equilibrium but not one that was intrinsically different from before. Most land use transport models, housing market models, and macro economic input-output models were fashioned around this concept of equilibrium being the product of multiplier effects that eventually and rather quickly died way. This conception of the city as being well-behaved was deeply ingrained in our mid-twentieth century mind-set so much so that planners and politicians never ever considered the fact that their schemes would not be absorbed into a willing medium and that they would bounce back in deleterious fashion: the notion of the city and society being dominated by such wicked problems was borne of such disastrous experiments [8]. At the pinnacle of the systems movement, the idea that the city could be seen as a machine and that planning might be regarded as a controller in cybernetic fashion was widely held, as evidenced in such books as McLoughlin's (1973) Control and Urban Planning [19].

In this field, it is important to distinguish between questions of statics and dynamics and questions of equilibrium. If a city is in equilibrium, then we can assume its spatial structure can be simulated at a cross-section in time where any dynamic is subsumed by the forces that determine the equilibrium. In this sense, a simulation would be comparatively static, meaning that changes in the magnitude of the forces involved would produce a new static structure which would be closely related to the existing structure: the generic nature of the forces would not change, and it is this that makes predictions with such static equilibrium models only relevant to situations where there would be immediate, probably marginal change in the very short term. The first models of cities built 50 years ago such as that by Lowry (1964) for Pittsburgh were regarded as producing an 'instant metropolis' [16]. In these early days, there was much discussion about making such models dynamic but not so much about equilibrium per se. Two key issues were reflected in the discussion at that time. First there were several attempts to make such simulations semi- or pseudo-dynamic by exploiting the multipliers embedded in their equilibrium structure, that is by matching multipliers to increments or decrements of change and using the same model to simply add or subtract changes over time where these changes were simulated using the equilibrium model [3]. A second development was more theoretical and was based on assuming well-behaved dynamics which led to an equilibrium over time where the trajectories followed well-known paths such as those based on capacitated exponential (logistic) growth (and any subsequent decline). Forrester's (1969) *Urban Dynamics* model was based on such a dynamic equilibrium but being more of a thought experiment—albeit based on the computational language of systems dynamics—than an empirical and operational application of any of the contemporary theories underpinning the ways cities were spatially and economically structured [12].

There were however many voices questioning this ideology of equilibrium. It was always felt that the equilibrium was precarious and if the boundaries of the problem changed a little then cities would look as they were in disequilibrium. The evidence for this however came both from what was happing to cities from the mid-twentieth century onwards as well as from intellectual responses to the then prevailing scientific view that equilibrium was the product a well-behaved dynamics. From the 1950s, western cities were racked with ethnic riots which flared spontaneously from multiple causations. Technology change was also evident in the way they began to sprawl while changes in employment structure reflecting de-industrialisation, globalisation and the rise of information technologies had substantial impacts on their spatial structuring. In fact, long standing monocentric structures did remain focussed on the CBD but new centres grew on the edge of cities and cities began to merge with one another in the denser urbanised regions. The picture now is one of much greater polycentricity everywhere.

Dynamics for the most part prior to the mid-twentieth century was mainly concerned with how physical phenomena changes in a continuous, largely smooth fashion. But there were many instances in the physical sciences were change was discontinuous and abrupt. Indeed various examples of functions which were continuous but not differentiable (such as Weierstrass's function) had been discovered in the nineteenth century and the mathematics of irregularity was slowly beginning to be put on a stronger foundation. By the late 1960s, the idea that systems could change 'catastrophically' had been articulated. The notion that a system might continue quite smoothly for a long period of time manifesting a well-behaved trajectory but then suddenly switch largely as a confluence of tensions in the background conditions, was explored by Thom (1972) who invented catastrophe theory [22]. Immediately examples in the social sciences were identified such as prison riots, movements in share prices and related cycles which no longer appeared smooth. Over much longer time spans, this theory was also used to simulate the dramatic decline of cities and civilisations.

In the 1970s, ideas about equilibrium thus came under scrutiny with developments in catastrophe and bifurcation theory (which we will note below) that enabled those thinking about cities to introduce an entirely new set of dynamics that mirrored many features of cities in- and out-of-equilibrium. The notion that smooth change could give rise to discontinuities was clear enough but identifying conditions under which such changes could be explained was more problematic. Consequently many of the first forays into thinking of cities as dynamic non-equilibrium systems tended to demonstrate these notions using hypothetical examples. One of the best examples is Wilson's [24] speculation of what happens when there is a switch in the relative balance of travel costs associated with travelling on public and private transport. Essentially this thesis suggests that if the cost of public transport rises substantially relative to private, then travellers will switch to private transport perhaps continuously in proportion to this change but also perhaps discontinuously all at once. But if the cost of public transport falls back to its initial level, travellers will not switch back to public transport, largely because they have found some hidden advantages in private travel— convenience and so on—which do not tend to be reflected in transport costs. Wilson demonstrated that you can model this as a cusp catastrophe and his argument seems appealing relative to what we know about mode switching and the decline in the patronage of public transport. His demonstration is purely hypothetical and it might be hard to find data for fitting such a model, but nonetheless the point is clear. Discontinuities in switching can be modelled using such strategies and this suggests that this kind of mechanism is likely to dominate many other changes in the structure of urban systems to which it might be applied.

3 From Catastrophe and Bifurcation to Chaos

Many hypothetical applications of this kind of non-equilibrium dynamics were applied to urban systems in the 1970s and 1980s with Amson [2] and Wilson [25] leading the way in applications of catastrophe theory. This was paralleled by a very different form of dynamics associated with urban systems that was reflected in the non-equilibrium thermodynamics pioneered by Prigogine [21] who introduced the very basic notion that a system which was embarked on a smooth trajectory of change might suddenly deviate onto one of a number of paths—essentially bifurcating onto one of several different paths dependent upon local conditions and probabilities of change that pertained to the system in question. Technological change and innovation provided the pertinent examples but in cities, the notion of rapid changes in some growth of activities such as retail and commercial centres—edge cities—provided the most obvious examples. The theory was pursued and demonstrated by Allen (1997) and simple models were applied to real urban systems such as Brussels [1]. Empirical work however has been minimal in applying these ideas for actual applications, being more like toy models developed with some fine tuning to real situations to demonstrate something a little more realistic than pure thought experiments.

Prigogine's approach was strongly counter-intuitive with respect to physical systems in that it is based on turning around the laws of thermodynamics, introducing what to all intents and purposes is a reversible thermodynamics. The strong logic of thermodynamics is based on the notion that energy is continually used up in a workable form as it is converted into heat and that eventually the universe will reach a state of random disorder where its entropy will be at a maximum and no useful work is possible. This is the equilibrium that is implied in statistical physics. Prigogine argued that in social systems the opposite was the case. Order was always increasing as life continued to use energy to maintain, if not increase this order. Of course life in this interpretation is a local pocket of order in a sea of increasing disorder and in that sense, Prigogine's theory did not fight against the general laws of thermodynamics. In the long run, the heat death of the universe is still incontrovertible, notwithstanding the fact that at this point in space and time, our own actions tend to counter the general increase in entropy that comes from the conversion of energy.

It is in this sense then that we can think of cities as being far-from-equilibrium. We will return to this view in the next section but it is useful to show these kinds of dynamics in cities that were demonstrated both in theory and through various stylised facts as these ideas were developed. Both [1] and [25] produced demonstrations that indicated how rapid changes in locational activities might occur using the kind of dynamics of bifurcation that could be associated with how an activity such as a shopping centre might suddenly sprout from a pattern of spatial population demand defined in the hinterland of any centre. In 1992, Garreau [13] published his important polemic on the edge city—cities that quickly grew as large retail and commercial centres on the edge of big cities competing for pride of place with the original CBDs around which most cities were formed. These centres tended to develop rapidly or not at all. Some were stillborn and it took some scrutiny of urban conditions to identify centres on the edge of cities that failed but the whole range of development possibilities pertained to such centres.

To an extent, the notion of retail development being associated with a bifurcation in activity locations fitted the conception of edge cities rather well. In fact, Wilson developed this concept of rapidly generated retail centres well before Garreau produced his commentary, for Wilson's work was very much related to how one built supply-side dynamics into retail models [25, 26]. All we can do here is give a sketch of how he proceeded. Essentially he argued that cross-sectional equilibrium models of spatial interaction produced a picture of how the demand for facilities—in this case retail and commercial facilities—was stable at any point in time. The supply of these facilities was not typically part of these models for the dynamics of developer behaviour were hard to model and were for the most part excluded from such simulations. What Wilson did was to suggest that the development cycle might be approximated by a logistic supply equation which generated a level of activity through time to a capacity limit. So he embedded a spatial interaction model of the demand-side into a Lotka-Volterra style of logistic equation which mirrored how development might take place, that is how development might be supplied. What he demonstrated was that in such a nonlinear system of equations, one could produce dramatic growth in certain locations and none at all in others by tweaking the demand parameter of the model which was highly sensitive to radically changing the predicted pattern under certain parameter regimes. In short his extended equation system could be used to explore the different parameter values which would give rise to discontinuities (rapid changes which in fact were continuous in some sense) and might be seen as being edge city-like in form and function.

At much the same time, other approaches to characterising disequilibrium in social systems were being pursued. More fundamentally, several researchers explored the notion that certain very standard nonlinear logistic growth equations could generate bifurcations with respect to their trajectories, leading to oscillating equilibria which in the limit became chaotic, seemingly without rhyme or reason. The usual form for a population logistic is that it converges on the capacity limit as the system grows but for certain parameter values, this convergence becomes a regular oscillation. As the value of the parameter continues to change, this oscillation becomes more and more chaotic and in a limit, truly chaotic. If you were to observe a system changing in this way, it would be hard to figure out that one were dealing with a capacitated nonlinear system. In fact few instances of such systems have been observed in nature although some predator-prey systems appear to follow such oscillations. Most exploration has been intent on demonstrating paths to chaos and generalising such equations to a wider class leading to systems which have sensitive dependence on initial conditions. Feigenbaum [10] is accredited with identifying such chaos in the first instance in 1974 although others such as [17] and [18] amongst many, were involved in developing these ideas simultaneously from entirely different directions. In the late 1970s and 1980s, these ideas led to the science of chaos [14] with many speculations that social systems in general and city systems in particular contained the seeds of such instabilities. In this way, a new form of dynamics pertaining to cities emerged based on discontinuities in equilibria that were generated as catastrophes and bifurcations, often revealing themselves as chaos.

4 Cities as Far-from-Equilibrium Structures

We have already introduced the problem posed by Prigogine who introduced the theory that human systems in general and cities in particular are systems that preserve and attempt to increase order in the wider face of it being destroyed by nature. It is already pretty clear in this chapter and indeed throughout this book that the concept of equilibrium can change dramatically dependent upon its application. It is entirely likely that a system can be in equilibrium in one sense, out-of-equilibrium in another, in disequilibrium, and far-from-equilibrium all at the same time. Indeed our earlier example—the City of London—whose physical structure has remained somewhat inert and stable with respect to the street pattern but whose buildings are continually being regenerated and whose populations are forever changing dramatically in type and composition is such a case. Here however we will concentrate on a very different kind of equilibrium that is being maintained in the fight for order against chaos with respect to how cities use energy and introduce innovations. This is the idea of a system that is far-from-equilibrium that we can best articulate with respect to its physical form.

Excellent examples of very highly ordered cities are those that must be completely controlled from the top down. Ideal cities such Frank Lloyd Wright's mile high tower *The Illinois*, Le Corbusier's various schemes for *The City of Tomorrow*, and Dantzig and Saaty's *Compact City* are examples where considerable energy needs to be continually expended to keep the planned structures intact and to avoid any individual changes to the urban fabric and its organisation [5]. Wright's tower contained everyone in his ideal city—some 100,000 persons—while Le Corbusier suggested a city of 60 storey tower blocks centred in wide open parkland surrounded by residential blocks of some six storeys high housing some three million. Dantzig and Saaty suggested a more compact but equally fictitious proposal based on compressing activities horizontally and to some extent vertically for a city of some 250,000 which could be expanded segmentally to two million persons but located in a large empty hinterland. In each case if we were to divide the city expanse into small zones and allocate population accordingly, most of the land would be empty and where it was occupied, it would be extremely dense.

We might approximate such structures with a set of probabilities of occupation where most were zero and a few or even only a single cell in the limit were unity. In the Wright example, if the formal probabilities of allocation were given by p_i where $\sum_i p_i = 1$, then we would have $p_i = 0, i \neq 1, \forall i$ and $p_1 = 1$ where location 1 was the tower itself. In contrast imagine a city where everyone was spread out evenly and where there was no advantage or preference for locating in any one of n cells compared to any other. Then $p_i = 1/n$. If we now compute the Shannon entropy $H = -\sum_i p_i \log p_i$ for Wright's mile high city where the entire population lived in the tower, the entropy would be zero; for a city spread out evenly—a flat sprawling city—the entropy would be $\log n$. So the most disordered structure is the flat sprawling one while the mile high tower is the most ordered with an entropy of zero. To keep everyone in the mile high tower would involve a massive amount of energy—material and psychic—while letting everyone live where they wanted would involve very little organisation. So the mile high tower in this context is far-from-equilibrium but the sprawling structures are essentially random and disorganised and in effect represent the traditional kind of thermodynamic equilibrium.

We might categorise all cities on this spectrum from order to chaos. A more visually structured example is reflected in a physical model of growth which is a diffusion limited by the space into which the phenomena might expand. It is well-known that such a diffusion-limited aggregation (DLA) model produces dendritic structures that reflect a system far-from-equilibrium. We can demonstrate how such a structure can be relaxed to imply ever more disordered equilibria—more compact and uniform structures compared to highly constrained forms which require severe constraints on where development can locate. It is worth illustrating how this kind of constrained structure can be simulated and in Fig. 1, we show a sequence of how the model to generate these kinds of structures actually works. We need to talk the reader through this to understand how such a structure emerges for we will then illustrate various examples of real cities that imply how such structures actually emerge.

In Fig. 1a, we plant a seed at the centre of a space and this represents the fixed core—the CBD, say—from which the diffusion begins. Imagine that this seed continues to throw out units of development—growth—on a continuing basis but that these units have no capacity to locate on the seed site. They need to diffuse to nearby sites where there is space. If there are no constraints on such a structure, they will simply diffuse to the nearest vacant sites and there is nothing to constrain or limit the diffusion. It will simply spread in a random circular fashion around the source. We could quite easily ensure that the places closest to the source or seed had the capacity to take higher densities, thus mirroring the kind of competitive structures that exist in real cities but this would involve a degree of external constraint or organisation that would reduce the entropy from that associated with the purely random diffusion. We show the circular random diffusion and its growth in Fig. 1b, noting that as the number of cells increases the entropy rises as Shannon's formula varies with the size of the system.

When we begin to impose constraints on where units might diffuse to, we lower the entropy in relative terms. The classic diffusion-limited aggregation model essentially imposes the condition that a cell that becomes developed must be already connected to the growing structure. Moreover the method of selecting a cell is one where the unit moves randomly amongst the empty cells in the space and as soon as it reaches an occupied cell, it sticks, forming part of the growing structure. To articulate this process, then we must assume that the unit of development is projected from the source to the periphery of the system and then begins its random walk in search of a cell that is adjacent to the growing structure and might then be occupied; or we need to compute a set of probabilities of occupation of the empty cells that are dependent on the relative positioning of all occupied and unoccupied cells, and use this field to determine the allocation.

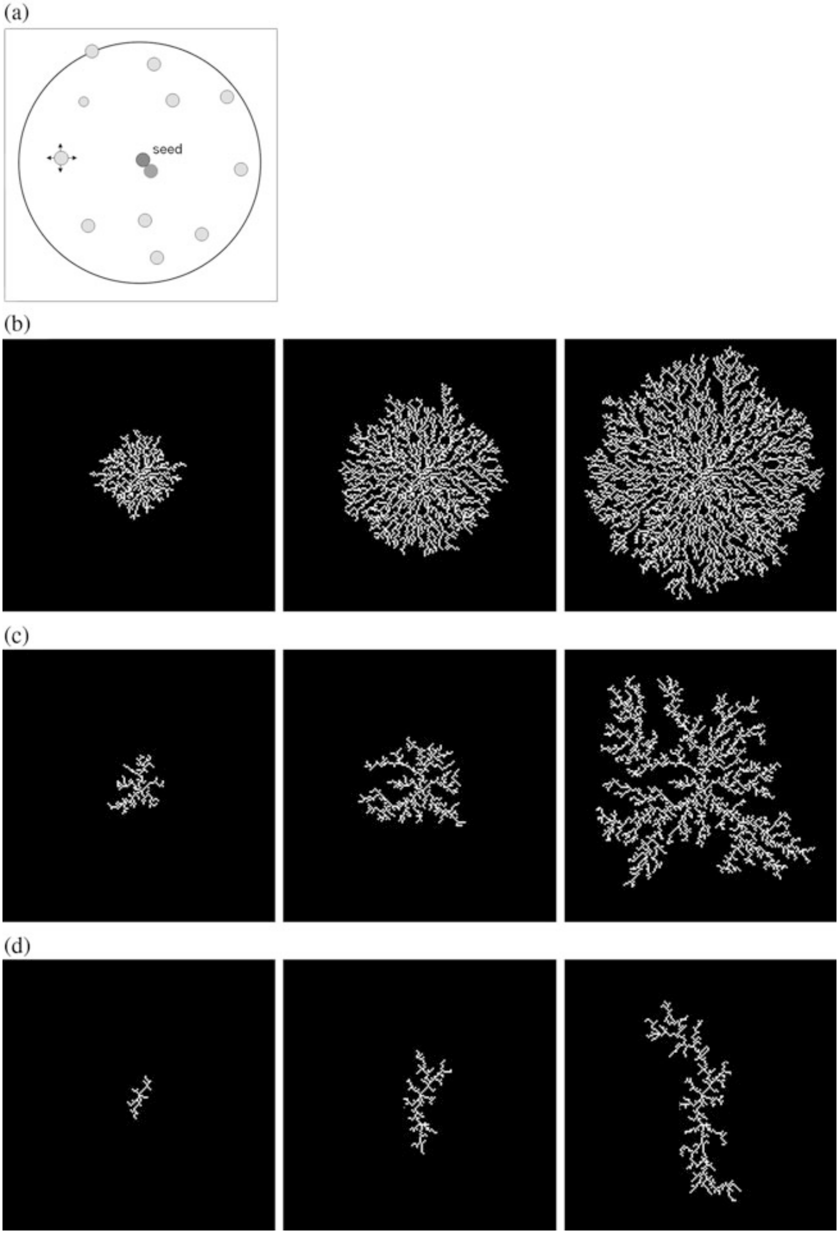

Fig. 1 Far-from equilibrium structures: analogues to city forms generated by diffusion from a central seed source. (**a**) We plant a seed (the *central dot*) at the source site (the CBD) and at each time interval, it generates units of development (the *light grey dots*) that are projected onto the periphery. The unit then searches for an occupied site (which in the first instance is the seed site) by randomly walking across the space, where the *dot with the arrows* indicates such as random walk. Once it finds an occupied site, it sticks. Another unit is spawned and the walk begins again. In this way, the city is generated with a dendritic structure which is the default morphology

This relative positioning gives added weight to those cells adjacent to the growing structure and particularly on the tips of the dendrites and lesser weight to those further away and the probabilities are computed so that this field is balanced. A walker or development unit once spawned from the source begins its walk across the existing structure and when it reaches an unoccupied cell, it selects this cell for fixing its location according to the occupation probability of this cell. Once this occurs, the probability field is altered and recomputed.

The process of random walking from the periphery—the former version of the model—is DLA, while the latter where the probability field is continually computed is the process of dielectric breakdown (DEB) but in essence, they lead to the same formations. When this sort of model is used to generate the growing structure, the kind of physical form that is produced is a dendrite where resources are clearly conserved by ensuring that those branches that have already been established become increasingly attractive to growth. The model contains all the elements of a far-from-equilibrium structure: emergence, path dependence, fractal structure, and positive feedback. We show this process in Fig. 1c where it is clear that the entropy lies between the more evenly spread random structure and the result that would occur if every unit of development were generated and planted on the source cell.

To illustrate the formation produced when the amount of order is much greater, one has to structure the probabilities of occupation to reflect this order. For example if everyone were required to live on the source site—in Wright's mile high tower—then this would mean the probability of occupying this site were equal to 1 and all other cells zero. Another idealised structure might be a linear one where the probability of location were structured according to a linear routing to the central source site. Imagine a cell occupied by the source site. The probabilities of location in the immediate neighbourhood of this first cell are then equal to one another. If one is chosen randomly, thus breaking the symmetry, then the occupied cells provide a line of two cells. The probabilities are then determined by how close they are to this line—assuming the line of two cells marks out a transport route. Then the cells at each end of the line have higher probabilities of occupation than those anywhere else adjacent to the line because they are closer to transport to the source. If we proceed in this way, we generate a linear city as we show in Fig. 1d and the entropy of this structure is near zero largely because it takes a much greater amount of organisation to ensure that this kind of structure is developed.

When we examine the structures in Fig. 1, we can compare their entropies and recognise that those in (c) and (d) are farther-from-equilibrium than (b), their entropies are low in comparison to the more random equivalents such as the circular structure in Fig. 1b. One way of illustrating how close these kinds of structure are to those that we observe in real life is to choose a set of examples that reflect the skeletal structure of cities in terms of different space-filling regimes that clearly characterise the way development has taken place. The pure dendrite is not a structure that we see very often, perhaps not at all, although there are structures that approximate it. More likely we observe something that is not present in our diffusion model and that is a hierarchy of routes that we see quite clearly in many cities [4]. Moreover cities at different scales do show different dendritic forms despite the fact that there is strong self-similarity in structure across different levels due to the fact that cities tend to be fractal [7]. Without labouring the point, we have simply selected four cities that manifest different degrees of dendritic structure colouring in the land that is developed and making sure that the key dendritic structures that support land development—that move materials, people, and energies of various physical kinds from one location to another—are clearly visible (as we shown in Fig. 2).

To an extent, these approaches to equilibrium do not exist without an explicit dynamics. Models of these dynamics relate quite strongly to a whole class of models that partition cities into cells and then apply transition rules that mirror the fractal-like processes generating far-from-equilibrium forms that we have pictured in the abstract and in the real in Figures 1 and 2 [4, 23]. We simply point to the existence of this class of dynamic model which are very different from those that we introduced, albeit rather briefly, when we dealt with comparative static models earlier in this

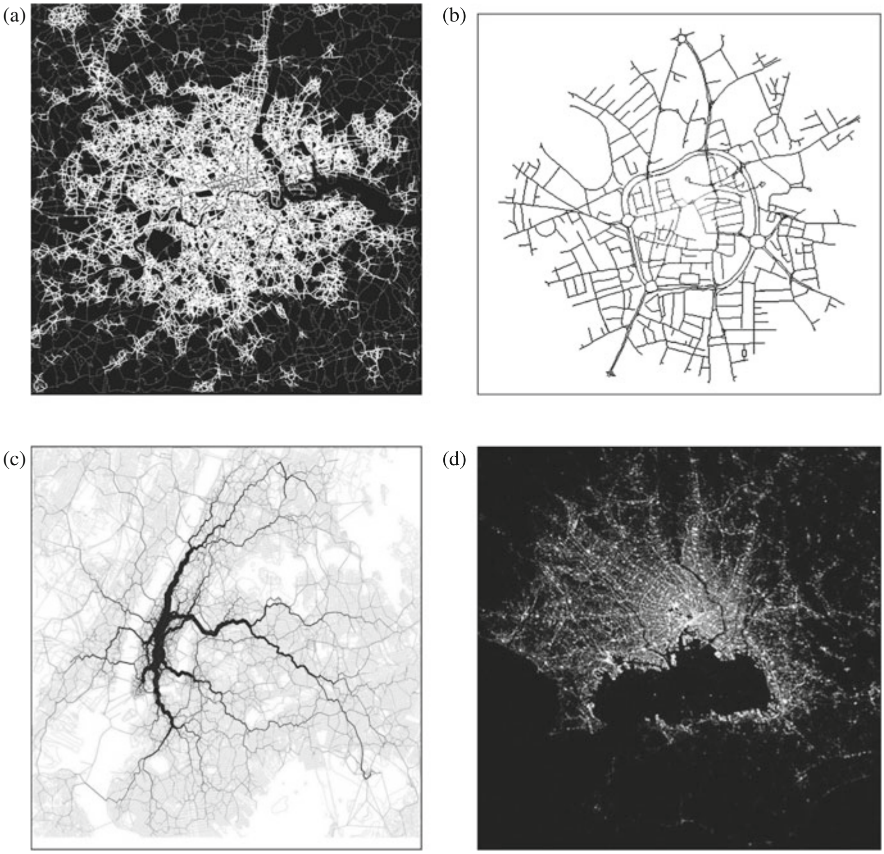

Fig. 2 Fractal city forms at various scales. (**a**) London. (**b**) Wolverhampton. (**c**) New York. (**d**) Tokyo

chapter. In fact agent-based models can be easily generalised from these cellular models. The diffusion model shown in Fig. 1 is essentially an agent-based model where the agents interact with each other and with the cells that they visit and occupy and there is a whole host of models that spin-off from these approaches that invoke a much richer dynamics and related concepts of non- and dis-equilibrium [9, 20]. These are important developments that add to the array of different kinds of equilibria in city systems but to conclude, we must examine those that pertain to really radical change and massive discontinuity that can be seen as being part of the dynamics of urban systems over much longer periods of time.

5 Creation and Destruction: Radical Change From Innovations in Technology

Dramatic change in cities usually takes place over long periods of time that relate to scientific and technological advances, to cultural movements, and to migrations of population associated with climatic or other physical conditions. Here we will focus on technology change because over the last 200 years and in modern times, we can easily observe the impact of new technologies on cities. But in past ages, cultural and economic change has been significant. For example, most of the cities of the ancient world are no longer in existence. Of the top 50 cities by population size known 500 years or so before the common era (BCE), none exist in the top 50 today and most have simply disappeared. Indeed there are only six of the biggest cities in the top 50 from the time of the Fall of Constantinople in 1453 in the top 50 today. This implies very substantial change in terms of an urban dynamics and by and large this has little to do with technological change. Rome reached about one million persons in the second century AD but the Empire could not hold, for cultural and political tensions as much as technology sealed its fate. The collapse that set in did not see a revival of cities until the Middle Ages, perhaps even as late as the modern era from the onset of the industrial revolution when the dynamic really did begin to change.

Apart from noting the dynamics pursued by Forrester [12] who essentially simulated a capacitated exponential growth for an hypothetical inner city system, most of the dynamics we have introduced do not follow cycles of any kind. When it comes to historical cycles, it is economic cycles that appear to coincide with technology change and over the last 200 years, the mechanical, electrical, and information revolutions based on the relevant inventions appear to have dominated successive waves of innovation. At present, the biosciences revolution appears to be dominant but so does the all-pervasive revolution in communications and computing that sets the current time apart from the previous three revolutions. The mechanical revolution dating from the steam engine dominated the world until the mid to late nineteenth century and this was then succeeded by the electrical with its invention of telecommunications, radio and television. By the mid-twentieth century, the revolution in computing had begun. These eras led to quite dramatic changes in the structure of cities: first as pointed out earlier, once the steam engine had been utilised for land transport, cities broke through their one million population capacity limit for the first time and megalopolis came onto the horizon. At first, this led to street car suburbs but then as mechanical technologies became all pervasive in the automobile, cities began to sprawl to the limits of daily travel to work. Electrical technologies merely reinforced this. Only in the last 50 years have they begun to change the nexus of communication in cities—the glue that holds the physical fabric together—but this has been as much due to the revolution in computing and communications, all based of course on electricity.

In terms of the physical built environment, we can define two broad stages in the evolution of cities from the pre-industrial era: first the city built around fixed rail and transit lines, and then the city built around the automobile. The first is public or collective transport, the second individual transport, both dependent on the use of material energies to power these technologies. We are fast entering a third era when information technologies in the form of media, email, web services and the great array of invisible communications that defy physical distance to a large extent are beginning to make an impact. These are reminiscent of the cycles or eras defined by Florida (2010) in his book *The Great Reset* [11]. How they are impacting on the physical form of cities is extremely difficult to unravel because many of these technologies are not easily visible in the same way as material technologies. We might then map these changes which we can see in the physical form of the city, albeit the most recent being most problematic, onto other cycles that appear to characterise urban change.

First, there is the material revolution in energies that really divides the last 200 years into the industrial and post-industrial age with the latter reflecting the transition from energy to information, from atoms to bits. And then there is the notion that the various sequence of technologies can be broken into a finer set of cycles—the most obvious being cycles of around 50 years first identified by Kondratieff [6]. These cycles involve changes in technologies that can be defined in terms of an innovative ideas phase, followed by development and thence some form of downswing to a kind of depression during which a new upswing in terms of inventions can be discerned. To this, Schumpeter added the idea that technology creates and then destroys perfectly workable infrastructures, even ideas, perhaps even information as the economic system supporting these changes seeks ever greater value from the products that are created [15]. This produces another layer of complexity dynamics with respect to cities. It reinforces the idea that cities can only be appreciated from multiple perspectives through multiple ideologies. The idea of equilibrium is everywhere one looks as is the idea of disequilibrium, and thus there is no such thing as a single equilibrium or disequilibrium as we have attempted to argue and portray in this chapter.

6 Reflections

Our thesis in this chapter has been that there are many types of equilibrium which we can recognise in city systems and consequently anything that departs from the steady state can be defined as a disequilibrium. Collectively all these characterisations might be brought together under the title non-equilibrium. In this chapter we have taken an explicitly physical approach to our social science. Cities are naturally viewed as physical and spatial systems and their patterns provide an obvious entry point into their study, their design and management. Indeed one of the reasons there is so much interest in cities is that we can use them to encapsulate many of the problems of modern society and attempt to understand them from the perspective of their form and function. Although it is controversial, solutions to these problems are often reflected in ways that we might alter the physical form of cities rather than attempting to change the behaviours more directly that have led to some of these problems. In a sense, this is a highly contentious point because it means that to solve urban problems, cities must be pushed out-of-equilibrium, out of their current condition to move to new equilibria that implies some better level of optimality.

The most promising perspective that we have indicated here is the idea that cities are far-from-equilibrium. Disentangling the concept of equilibrium from optimality is a very important consequence of thinking of cities as being out-of-equilibrium, far-from-equilibrium, or in non-equilibrium. In many senses, moving from equilibrium models of cities that have dominated the way we have thought of them during the last 50 years or so is an advance, and many of the ideas in other contributions in this book are also pointers to the progress in thinking of social systems in terms other than equilibria. It is not that equilibrium is an outdated concept for it still represents a baseline which is a point of stability in our understanding of cities. But it is a point of departure rather than an end in itself as we have argued in diverse ways through the various perspectives we have introduced here.

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Global Political Dynamics and the Science of Complex Systems

Hilton L. Root

Abstract Do the complex dynamics of international relations resemble the long-term evolution observed in living systems? This chapter will try to identify the mechanisms associated with those dynamics, and to determine if the science of complex adaptive systems can aid in the understanding of international development.

It tries to address the weaknesses of current theories of international political economy to adequately explain global diversity and queries its empirical and theoretical limitations. Providing insight on the mechanisms by which divergence is a response to heightened interconnectivity, complexity theory offers a way to overcome the limitations of conventional political economy analysis.

We find that at a qualitative level the dynamics of the international system resemble known aspects of biological behaviour, speciation and intermittent behaviour. The next frontier for the study of social development is to find quantitative measures that define these processes.

1 Introduction: Interaction, Co-evolution and Specialization as Sources of Diversity in Highly Interconnected Societies

Global development is both a process and a condition according to most contemporary political economy analysis, and is attained via strategies of convergence with the successful models and strategies being held up as objects of emulation and imitation.

Convergence theory has characterised thinking in the developed West for more than half a century. It's underlying theoretical position is that irresistible forces are driving the world to converge towards an inevitable equilibrium state. Then the argument is that this equilibrium state will eventually be a world made up of liberal capitalist democracies like those in Western countries such as the USA. This chapter will question the underlying assumption of inevitable convergence to a global optimum. It will show the destructive power of convergence strategies as

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seen today in the perplexing conflicts in the Middle East following well-meant but massively disruptive interventionist military policies by Western powers that did not produce the anticipated balance of political and economic development. In today's far-from-equilibrium world a new theoretical underpinning is urgently required to address the short and long-term problems ahead. It will be argued that the dynamic perspective of complex systems provides that underpinning [17].

At the end of the Cold War, systematically describing modernisation as a process of convergence, gained considerable validation from empirical trends such as the collapse of the Soviet Union, the structural crisis of Swedish socialism, the reversal of French socialism, and democratic movements in the Confucian domains of East Asia. In 1989, when Francis Fukuyama declared history to be over, the global hegemony of democracy and market economies seemed certain to continue.[1]

In the teleological logic of modernisation theory countries in transition could only go in one direction, toward liberal democracy, its rivals on the world stage being routed.

Since 9/11 contrary empirical evidence has accumulated. Contemporary global political economy is increasingly defined by diversity and both the process and the end point of development are contested: the presumption that there is no alternative to liberal democracy seems discredited. There is no longer a consensus on what economic, social and cultural variables development refers to, or what the process of attaining it is. Living standards are rising in many regions without the accompanying features of modernisation. In countries as diverse as China, Saudi Arabia, Russia, Singapore, and Turkey the economic gap with the West is closing but not the gap in political order. Living standards are converging but progress on political liberty is scant. A China that enjoys the advantages of international law and organisation continues to contest the legitimacy of liberal internationalism's core values. Market rules and economic competition do not ensure the rest of the modernisation sequence will follow. Regime diversity not only persists but new forms of governance not known during the cold war period have appeared. Much of the former Soviet Union has lapsed into authoritarian governance. Political Islam has arisen in an economically open Turkey and is spreading throughout the Middle East. New forms of democracy have little in common with prior variants.

[1]Twenty-five years after proclaiming history to have ended, Francis Fukuyama has not blinked; writing in the Wall Street Journal (2014) [4] he concedes it's not the 'end of history' yet. Models of national development that have a strictly materialist focus that seem robust today will ultimately lose their appeal, failing to address the inherent human drives for recognition and self-expression. Even China, the 'single most serious challenge to liberal democracy in the world today' [3, pp. 56–57] he predicts will converge, its path will be multigenerational, taking more time than originally anticipated—nevertheless inevitable. No matter how effectively its one party state fulfils materialistic needs, its failure to satisfy other universal needs will make its influence on the world stage transitory: 'The emergence of a market based global economic order and the spread of democracy are clearly linked. Democracy has always rested on a broad middle class and since the ranks of prosperous, property-holding citizens have ballooned everywhere … Once societies get up the escalator of industrialisation, their social structure begins to change in ways that increase the demands for political participation'.

Increasingly regimes that call themselves democratic lack traits that are essential to a democracy, such as competitive, multiparty elections, competitive political parties, free speech, the right of assembly, an independent judiciary, and a free media. The behaviour of the middle classes in many of the world's emerging urban clusters is short-term and authoritarian rather than equitable, sustainable or participatory. Economic strategies that raise living standards often defy the logic of successful patterns of the past.

The dominant paradigms in global political economy do not effectively describe these patterns of diversity. Modernisation theory can explain some global convergence but not the prevalence of different paths to the modern world with its many variations of democracy and authoritarianism. All of these trends raise a simple question: *is the system of international relations entering a period of hectic reorganisation and does anyone really know which way developing countries are trending?*

2 Global Political Economy and Development

Yet, convergence to a global liberal democracy remains a core organising principle in global political economy and defines a normal and healthy process of socio-economic development in most theories of global development. Its pervasiveness is assured when concepts from microeconomics are applied to the study of international systems. Microeconomics postulates that growth occurs as more efficient technology, institutions, regulations or firms supplant less efficient variations. It predicts that competition will direct policy to the same set of optimised solutions, prompting societies to evolve towards the same end point or fitness peak. Encouraged by the pressures of external competition, firms and governments facing the same optimisation problems will select the same sets of solutions and will organise production according to a single optimum that represents the global peak.

The most cohesive statement of convergence is *modernisation theory*. It addresses not only the system of production but politics and individual behaviour and it offers a view of social change that links a nation's economic growth with its receptivity to liberal values: as societies industrialise, urbanise and prosper, experiencing convergence towards a free market economy, they will also converge to optimal forms of democratic governance.[2]

[2]Theories of interdependence in global political economy link the proliferation of liberal regimes to enduring stability, and link increased economic exchange and interconnectedness to peace. They date to the European Enlightenment of the eighteenth century and are frequently associated with Emanuel Kant's (1795) notion of 'perpetual peace'.But they have been the bedrock of US foreign policy and have defined US engagement with the world since the time of Jefferson's presidency (1801–1810). With the exception of the Eisenhower (1953–1961), Nixon (1969–1974) and Ford (1974–1977) administrations, post World War II foreign policy has actively sought

As populations become wealthier, urbanised, and educated 'political development' would direct countries away from authoritarian and towards more democratic forms of organisation. Convergence theory made a comeback as a popular quasi-scientific theory in the post cold-war political and economic climate. The collapse of the centrally planned economies in the Middle East, India and the demise of the Soviet Union all seem to lend it renewed validation. Its projections of eventual convergence are closely linked to liberal institutionalism and its notions of building a more humane and stable world than that projected by power politics approaches.[3] In retrospect the modernisation sequence it anticipates seems to have been based on a parochial selection of cases.

The most sophisticated formulation of convergence theory is *neoclassical institutionalism*, e.g. the Oxford Handbook of Political Economy defines its subject matter to be 'the methodology of economics applied to the analysis of political behaviour and institutions' [22, page 3]. It conceives of a natural continuum initiated by external competition or global competitiveness that runs from economic rationality, to the design of optimal forms. The strong pull of a single attractor or best way ensures a smooth transition process [2].[4] But if the agents all follow a rational decision-making behaviour to maximise their goals, then why is institutional adaptation rarely a smooth process?

3 Political Science and International Political Economy

The global quest for economic development is central to the study of political economy, but falls between two subsidiary branches of Political Science. *International relations* is that sub-discipline that deals explicitly with the interactive relations among states and it is where the methodology to examine the systemic relations of states is elaborated, and where the varieties of state behaviour are studied in relation to each other. It covers both 'power in the system', who has influence over system dynamics and structure; and the 'power of the system' over its constituent parts; it seeks to understand how different configurations of states, networks of norms, trade and the linkages between military power and industrialisation effect outcomes.

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global convergence toward liberal values in the hope of facilitating cooperation and rendering the international system less anarchic.

[3] Liberal institutionalism explores how self-interested parties can cooperate on the basis of rules and norms when there is no central authority. It is often identified with the writings of Keohane [10]. It has influenced scholars of international relations to explore the many ways that institutions can help overcome barriers to cooperation.

[4] External competition, in a global environment of market liberalism will drive all firms and nations, to similar regulatory structures, similar standard of living and eventually similar systems of domestic governance. To attain this peak, the best organisational norms will be selected; the convergence of productive capacity will produce convergent living standards, which will create a global middle class with the same culture of efficiency and the same aspirations for democratic participation.

Assessing the differences among the politics of countries is the central concern of another branch, *comparative politics*. Challenges to the convergence hypothesis in global political economy are much more likely to arise from within comparative politics. It is rich in case studies that reveal the durability of distinct institutional and social configuration. Hence its practitioners are unlikely to be surprised by the persistence of diversities within countries, across countries and regions, and over time. Some of the best comparative work reveals why a great deal of diversity is still observable despite the deepening of globalisation and the frequent cross-national diffusion of ideas and behaviours [11]. In the narratives constructed by comparativists, transition processes are rarely smooth and the path toward development is without a fixed end point or best way. But because these conclusions are embedded in many different cases and arrived at inductively, research in comparative relations is less likely than international relations to shape the theories about interactions or system-level patterns.[5]

Comparative politics distinguishes rival forms of democracy and illuminates the trade-offs in the range of variations and political responses to opportunities and challenges. Comparativists methodically study how interests, identities and institutions at the country level produce particular developmental trajectories. But they are unified more by a common method than by a shared theory of global order or the change processes that shape it. While revealing the endless possibilities that arise from the detailed interactions between local political and economic institutions, it often takes the broader context of globalisation as given. It is not the place to find general principals for the overall dynamical behaviour of evolution in the global system. It does not separate the dynamical features of a regime's evolution or fitness from the nature of the ecology created by the system's co-evolutionary dynamics. The answer to why and how diversity is a consequence of increased interactions in that system must be sought elsewhere.

The study of the political economy of development falls into the gap that exists within political science between international relations and comparative politics, leaving both without a plausible explanation for the observed variation. Political scientists that try to take into account the connection between international and domestic politics have insufficient theory to explore this connection.

To fill this gap we will explore whether regularities observed from the study of Complex Adaptive Systems, can also be applied to the properties, behaviours, interactions, and dynamics in the evolving system of international relations. Do the evolutionary dynamics found in the complex adaptive systems created by nature match the processes of complexity in the global economy?

Complexity science shares a number of important values with comparative politics. Both address how feedback shapes interactions among agents in a local environment, and both explore the interactive feedbacks of local actions on the global context. Comparativists also highlight the path dependent properties of

[5]International relations theorists are more likely than comparativists to use 'large *n*' statistical investigations, to determine a proposition's applicability to a wide number of cases.

national legacies, and seek to explain why new norms and social values do not necessarily replace the old, but evolve through adaptation. Nevertheless, complexity science goes further in elucidating mechanisms of change, and rigorously specifying the relationship between diversity and interconnectivity.

4 The Evolutionary Dynamics of Densely Connected Societies

Research by complexity theorists reports that the dynamics of a living ecology is strongly influenced by the system's complexity. A critical pattern in natural ecologies is that interconnectivity increase species abundance. Because the individual characteristics of a species are coupled with its environment instead of convergence towards the fittest or most complex form there is co-evolution between species. This same pattern can be observed among nations that share high volume of trade in goods and services [17, pp. 165–216].

Evolutionary systems are comprised of parasitic, predatory and collaborative relationships. As the pace of interconnectivity increases, the number of successful mutations will also increase. This in turn, accelerates responses among neighbouring systems, causing an increasing degree of differentiation to occur and these differences foster responses that move the system into a new basin of attraction. There is no equilibrium, the system's coevolutionary dynamics produce regular change cycles. Fluctuations caused by interactions can trigger a switch from one stable period to another [6]. Intermittency is a fundamental property of the evolutionary dynamics of complex systems in nature that are found as well in man-made systems. Bifurcation and intermittent behaviour in the global system are closely related since they change each other as they interact. Seemingly stable systems can be interrupted by sudden shifts to an alternative state.

5 The Behavioural Mechanisms of Policy Diffusion: Decision-Making, Collective Learning and the Persistence of Objectively Inferior Choices

Essential to understanding a system's evolutionary dynamics are the underlying behavioural mechanisms. In convergence theory the underlying motivation is emulation and imitation of the fittest designs. The principal streams of positive political economy assume that policy-making involves a search for a single solution that is objectively better than its alternatives. This implies that social institutions and policies came into being because the individuals who introduced them applied relevant information to fixed preferences, weighed the alternatives, and then selected optimal choices, calculating the future course of their actions with full knowledge of costs and benefits. It assumes that agents are fully rational and act on full knowledge of the future consequences of their actions, including the responses of other agents.

The assumption that individuals are fully rational and always choose the optimal solution is not realistic. Human rationality and cognition is bounded, asserts organisational theorist and Noble Laureate Herbert Simon. Decision-making by individuals is limited by the quantity of information they can gather, their finite information-processing capacity, and the amount of time they have to make a decision. To avoid information overload, people seek solutions that are satisfactory rather than optimal: they satisfice rather than optimise [19–21]

Convergence theories of global development also presume that the mechanisms of collective learning by imitation will ensure that the norms and institutions of the most successful nations are the most likely to be copied. This idea, which has been a staple of international relations theory since the European Enlightenment of the eighteenth century, is often associated with Kant's (1795) 'Perpetual Peace' [7].

But copying has many psychological motivations beyond top-down emulation. People may decide to copy just in order to remove the burden of basing their choices on a thoughtful assessment and a comparison of options. British economist Paul Ormerod makes this original proposition in *Positive Linking* [14] where he shows that copying may reduce the likelihood of a qualitatively better result. This is because copying is the way individuals in social networks gain confidence in their decisions, hence they are more likely to copy familiar examples, those closest to their own circumstances rather than highly successful models, regardless of whether they are making the best decision. Thus, when individuals copy they reduce the range of available options and increase the likelihood that they will select objectively inferior alternatives. This increases the probability that bad choices will proliferate. However, copying provides a practical heuristic for making acceptable decisions.

The development of norms, policies and institutions through copying is far more complex than convergence theory shows. For an optimal model to influence behaviour depends is not just a question of demonstrating the most effective of several solutions: it depends also on interactions and the choices made by the actors with whom one may interact.

Imitation of peers is a response to uncertainty that may help to explain the overwhelming empirical evidence that income convergence does not correct macro-level imbalances among nation states [15]. Economists sometimes explain the observed pattern of divergence with the idea of conditional or club convergence in which countries that share intrinsic characteristics tend to cluster around a living standard that is specific to their cluster while different clubs converge to a local standard, divergence between clubs dominates the macro pattern. Ormerod's notion that people imitate those most like themselves can be an exclusionary mechanism that bars members of clubs from converging to the higher living standards of alternative clubs.

6 Parallel Processing

If agents make decisions totally independently from each other then convergence is more likely to emerge, but in environments of complex interdependence and interaction agents conduct parallel processing: each agent acts both independently, in pursuit of their own advantage, and also interdependently, as they react to and produce adaptive responses in their neighbours. Agents make their decisions simultaneously, both influencing and limiting others' actions (parallel processing). This makes it difficult to identify cause-effect relationships and explain how one variable can affect another. The need for such processing increases with the frequency of interaction. When multiple agents engage in parallel processing, they can change the behaviour of the whole system.

7 Fitness Landscapes: How Ecology Affects Decision-Making

Fitness landscapes are a metaphor that can apprehend how the topographic contours of a local ecology can shape the formation of priorities. It is widely used in evolutionary biology to help to visualise how the reproductive success of various populations depends on the properties of their respective environments.

The peaks on a fitness landscape represent highest fitness, valleys the lowest; landscapes vary in their degrees of ruggedness. If the landscape is smooth there will be an unlimited view of the horizon, all paths will lead to the highest peak, and all populations can conclude their adaptive searches at the same end point, or global peak, regardless of their starting point or selected path.

However, on rugged landscapes the many local peaks may conceal the highest peaks, and only some paths lead to the highest fitness. A population can end up on a local peak and never be able to find the global peak. Since no two landscapes are rugged in the same way, populations facing different landscapes are unlikely to evolve the same way: adaptive climbs on local peaks involve different degrees of difficulty and offer different perspectives of the wider landscape. Evolutionary outcomes on different landscapes will lead to non-convergent variation; this same logic can be applied to international relations. If the populations are countries that do not begin their fitness walks from the same starting points they are unlikely to end up at the same end point or global peak. Due to the different topological impediments that arise from fitness landscapes of differing degrees of ruggedness not all populations will see the same set of alternatives. Thus populations that share a landscape or ecology will not necessarily have the same number of good designs or policy options to choose from. Differences that can be traced to the initial starting point will motivate leaders to optimise (or satisfice), on differing dimensions.

8 Niche Construction Theory: Global Development Through Variation

Analogies of the process of niche construction in evolutionary biology challenge another pillar of convergence theory in social evolution. Niche construction theory explores how local resource distribution in an ecosystem alters subsequent evolution. Each species tries to survive by creating or defending its own niches, a specific set of biological traits that enables it to exploit the resources of the environment.

Biologists observe that in densely connected ecosystems niche construction increases the number of genotypes able to thrive in a particular environment.This finding has relevance for both theories of economic growth and for the system of international relations. Both envision a process with competition among many providers leading toward the same end point or fitness peak. More efficient social technology, institutions, regulations or firms would supplant variations that are less efficient at providing the market, consumers or regimes with the optimised products it demands.

But if we analogise from what happens in natural systems from increased interaction and interconnectedness the result is unlikely to be towards a common optimal framework of institutions and values. Instead in a highly interdependent environment, niche construction multiplies the existence of groups with well-separated traits. Each new niche that is created can foster the possibility of a new set of interactions and exchanges with a multiplier effect that encourages new specialisations and refinement of existing strategies, organisations and institutions. Thus, the optimal strategy for evolution is not to delete but to increase variety.

As market size increases, niche construction by one group seeking to alter its environment to its own specification creates new adaptive possibilities, through co-evolution, variation and specialisation with a multiplier effect that leads to an increasing diversity.[6] As interrelatedness associated with globalisation increases, many co-evolutionary niches that form networks of interactions result. For example, the experience of South Korea's large export-oriented chaebols exemplifies how a country can attain global competitiveness by strengthening local institutional uniqueness. Oligopolistic insulation from competition at home generates surplus revenues that are used to respond competitively to global prices.

Our analogy with natural ecologies leads to the hypothesis that the growing density of global connectivity associated with globalisation will enable diverse populations to succeed because they are well adapted to a particular environment, rather than because they represent the most optimised or best set of institutional

[6] Complexity theorists, like [5], a computer scientist, and [8, 9], an evolutionary biologist, explain growth and change in social systems by niche construction. They contend that a global economy powered by accelerated interconnectivity will not drive all societies to an optimum value or set of structures, but with more nodes, fosters an increasing number of intersections that can create a combinatorial explosion of possibilities.

arrangements. We conclude that for global political economy convergence is just one option.

9 Convergence is Just One Option

This elaboration on how species in ecological systems co-evolve by self-organisation, variation and specialisation rather than top-down control or bottom-up mimicry, has significant implications for understanding the probability of convergence toward optimal designs in human societies. Our analysis first explores the linkages of individual decision-making and collective learning and finds that together they are likely to result in cognitive processes that may lead to non-optimal outcomes. Then we observe that in both social and natural systems, diversity results from the coevolutionary interaction and increased connectivity in global networks.

What complexity science can contribute to the study of global politics is insight about the ways the local resource distribution in an ecosystem can alter subsequent evolution and how developmental processes within a population (microevolution) can influence evolutionary change at a system level (macro-evolution).

Applying complexity theory to global political economy we speculate that processes of interaction, co-evolution and specialisation in a highly interconnected global society can produce behaviours and institutions that operate far from the optimum and that can persist for decades and centuries. A global economy powered by accelerated interconnectivity will not drive all societies towards a common or optimal set of institutions. Complexity theory emphasises external competition will stimulate trial and error processes that take place in a local context, and give rise to myriad hybrid outcomes. Accordingly, convergence towards a liberal model that encompasses free market economies and democratic governance appears to be just one of the possible options among the many trends in global development.

This insight runs contrary to conventional models of modernisation that presume the competitive pressures of globalisation will delete deviations from ‘best practice’ driving all economies to produce the same optimised set of goods and all polities to adapt to the same optimised rules and regulations and it leads us to suggest strategies for evolutionary stability that are at variance with much contemporary global policy.

10 Evolutionary Stables Strategies in Political Economy: What Should Global Public Policy Optimise?

Convergence theory gained policy relevance at the outset of the Cold War as part of a search for a non-communist alternative to development that would safeguard the stability of the system of international relations and assist in the struggle against insurgency. It attained prominence in political economy at time when both scholars and the public debated the changing role in global affairs of the newly independent nations. Initial evidence for the theory was based primarily on anecdotal methodology. As their reference point they had in mind the success of the Marshall plan in reversing the tide of communism in post-war Europe and from the apparent success of the allies in establishing stable democracies in Germany and Japan.

Scientific validation came later from studies conducted by economists such as W.W. Rostow seeking consistent and universal laws of development [18]. These studies argue consistently that democratisation is an inevitable and possibly necessary stage for economic growth to fully materialise. However, the studies rarely explored the role of contact with peers among would be developing nations. They took an essentially top-down perspective both within nations and among nations that is understandable when global trade was predominantly North-South, and when global elites had often been educated by the nations that they were colonised by. Expectations for the future trajectory of developing nations were premised upon observations from a relatively small sample size of already industrialised nations.

Rising powers today have different expectations and see post-World War II developments from a different perspective. The convergence of Germany and Japan to liberal norms occurred at the expense of their sovereignty being clipped by immersion in international arrangements and occupying troops stationed on a semi-permanent basis. Rising powers like China or India do not want to end up as semi-sovereign states denied the possibility of exercising international power warranted by their distinct economic success. This difference in perspectives between rising and incumbent powers has significant implications for the future of global order.

Although it does not sit well with emerging powers convergence theory continues to resonate with the conceptions and aspirations for global stability of the incumbents. It gains enough scientific rigour from statistical regressions to appear scientific to specialists familiar with only the view of one discipline, able to see only one dimension of the problem of development.

Political economists of all persuasions continue to assert that without convergence to liberal institutions, economic development will produce stunted and dysfunctional nations that are inherently unstable.[7] Convergence theory is also endorsed by more culturally oriented analysis. Scholars that emphasise values and the role of culture such as Fukuyama assert that convergence conforms to instinctual and irresistible psychological forces and therefore represents a necessary and normal sequence of social development.[8] The introduction of complexity theory to considerations of global development will open a debate over what development policy should optimise. Economics defines optimisation as seeking

[7]Frequently cited examples are [12, 13] and [1].

[8]Political scientists do not always specify what quantity or values the system of international relations can or should optimise. Those inspired or reliant on the judgment of economists prioritise efficiency, but realists and constructivists generally tend to have different priorities.

the most efficient path to a fixed end point. Its faith in objective ‘best practices’ nurtures a belief in the inevitable triumph of liberal market democracy as a global norm-setter. This sets global development a challenge of correcting inferior choices (digressions from optimality) in which catching up means copying and imitating. Complexity framed international relations theory, by contrast, will seek a balance between order and disorder in a symbiotically evolving environment and stresses the role of experimentation adaptability, resilience, collective learning and collective problem solving.

Complexity science suggests that benchmarking that tries to match a country’s evolutionary fitness with strategies of incumbent powers, or that searches for best practice, increases the risks to global stability. It warns us that aiming for homogeneity may drive out healthy diversity from the global system. If all countries pursue efficiency and use the same criterion to define it, this is likely to undermine system level resilience and reduce the prospects for evolutionary periods of stable growth.[9]

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[9] A failure that may arise from efforts to copy the developmental trajectories of the most successful, such as the White Revolution launched by the Shah of Iran, may have an injurious impact on domestic stability [16].

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Systems, Networks, and Policy

Jeffrey Johnson, Joyce Fortune, and Jane Bromley

Abstract Systems theory is fundamental to understanding the dynamics of the complex social systems of concern to policy makers. A *system* is defined as: (1) an assembly of components, connected together in an organised way; (2) the components are affected by being in the system and the behaviour of the systems is changed if they leave it; (3) the organised assembly of components does something; and (4) the assembly has been identified as being of particular interest. *Feedback* is central to system behaviour at all levels, and can be responsible for systems behaving in complex and unpredictable ways. Systems can be represented by *networks* and there is a growing literature that shows how the behaviour of individuals is highly dependent on their social networks. This includes copying or following the advice of others when making decisions. Network theory gives insights into social phenomena such as the spread of information and the way people form social groups which then constrain their behaviour. It is emerging as a powerful way of examining the dynamics of social systems. Most systems relevant to policy have many levels, from the individual to local and national and international organisations and institutions. In many social systems the micro, meso and macrolevel dynamics are coupled, meaning that they cannot be studied or modified in isolation. Systems and network science allow computer simulations to be used to investigate possible system behaviour. This science can be made available to policy makers through *policy informatics* which involves computer-based simulation, data, visualisation, and interactive interfaces. The future of science-based policy making is seen to be through Global Systems Science which combines complex systems science and policy informatics to inform policy makers and facilitate citizen engagement. In this context, systems theory and network science are fundamental for modelling far-from-equilibrium systems for policy purposes.

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1 Introduction

A major challenge for policy makers is the confidence they can have that a policy will deliver the intended outcomes and not generate unintended consequences. For millennia the projected outcome of policy has been based on conviction, rhetoric, evidence, logical analysis and calculation. Modern information and communication technologies provide powerful support for the last three of these, based on the organising principle of ‘system’.

A *system* is a collection of interacting elements, with them all affecting and being affected by the behaviour of the whole. Systems may have intermediate levels of organisation as subsystems. People are the key elements of *social systems*, but they may also include physical objects such as buildings, machines, and infrastructure such as airports; biological objects such as plants and animals; and natural subsystems such as the land, oceans, and the atmosphere. Together these components often form complex multilevel systems.

The definition of system in this chapter includes knowing why the system is of particular interest. In policy-driven science this is an essential guiding principle for deciding which elements and relationships are relevant.

Over the last quarter century the notion of interaction in systems has become much better understood through the development of network science. Networks have generic properties that can make the behaviour of systems more understandable. These include many structures and properties based on concepts of connectivity, and ways of representing communities and their interactions.

Social systems have such variety and combinatorial complexity that their trajectory through time may never be repeated. Although some patterns may be discerned, precise outcomes are unpredictable.

Unpredictability is a fundamental problem for policy—how can one choose between policies when their outcomes are uncertain? Systems and network theory attempt to answer this question. Systems diagrams can give insights into the dynamics of systems including making more apparent their interacting feedback loops. Since these can become very complicated computer programs are often needed to investigate their behaviour and examine possible system futures by iterated computation.

When systems behave ‘normally’ their variables may stay within narrowly defined bounds and be close to equilibrium. The policy challenge for science is not to say what will happen when a system is behaving ‘normally’ or close to a predictable equilibrium, but to say when a system will behave ‘abnormally’ and change its behaviour to another equilibrium or even non-equilibrium state.

Systems and complex network theory give policy makers a way of investigating the possible outcome of their policies. They can inform policy makers when social systems are close to equilibrium but are more concerned with the far from equilibrium dynamics of local and global change and extreme events *Evidence-based policy* aims to use the best scientific knowledge with the best available data. This requires interdisciplinary complex systems science which aims to integrate knowledge from all domains in support of policy. This chapter shows how systems and network science can contribute to this.

2 Policy

Policy involves making a decision to change a system, and planning and managing the execution of that decision. In the words of Herbert Simon, it is taking action to make the system as it *ought* to be [31]. How a system 'ought' to be depends on the interests of its stakeholders. In democracies the conflicting interests of stakeholders are resolved through constitutions, custom and elections. Here the focus is on modelling social systems in order to best inform policy making.

The outcome of a policy is usually monitored. If a system is not evolving as anticipated new interventions may be made to 'put it back on track'. 'Take action, monitor outcomes, respond with new actions, monitor outcomes,. . . ' is an example of a *feedback cycle* as explained in the next section.

Policy requires a view of systems that overcomes the academic divisions between social, economic, political, biological, physical, medical, and engineering systems. For example, a policy decision to build a new hospital could involve all of these and others too, such as the legal, planning and transportation systems. How can systems with such heterogeneous parts be represented in the policy process? In particular:

> *How can policymakers be confident that a policy will deliver the intended outcomes, and not generate unintended consequences?*

Systems and network theory aim to provide methods to help answer this question.

3 Systems

Of many more or less equivalent definitions of systems, Bignell and Fortune [8] define a *system* as

1. an assembly of components, connected together in an organised way;
2. the components are affected by being in the system and the behaviour of the systems is changed if they leave it;
3. the organised assembly of components does something; and
4. the assembly has been identified as being of particular interest.

These characteristics are particularly applications-oriented where policy considerations determine what is of particular interest and what the system does that is of particular interest. This guides the identification of relevant system components by asking does a candidate component affect what the system does and how is that component affected by being part of the system? Then there is the question as to how the components are connected—how they are related to each other, and how they are affected by being part of the system. This leads to the question of how the organised assembly does those things that are of particular interest. In other words how does the system behave? If this is known there is the possibility of taking action to make it behave in specific ‘desirable’ ways.

3.1 System Diagrams

Systems diagrams have evolved as a way of providing a pictorial overview of systems and their dynamics. Typically the relationships between the elements of the system are drawn as arrows between them. The process of drawing systems in this way can be very illuminating to the analysts and provides a way of communicating to others the insights gained.

3.1.1 The Bovine Tuberculosis—Badger Culling System

The ‘Bovine Tuberculosis (BTB)—Badger-Culling’ system has been identified of particular interest by UK farmers who want to eradicate wild badgers because they can infect their cows, thus causing their herds to be slaughtered. The system components include badgers, cows and bovine tuberculosis and they are connected by the propositions that badgers infect cows and that removing badgers from the system would change its behaviour by removing bovine tuberculosis. Badgers are a protected species and to kill badgers legally it is necessary to have a licence, so the farmers need culling badgers to become government policy.

To test this policy option the then Labour Government commissioned a *Randomised Badger Culling Trial 1998–2007* [9]. This study concluded that badgers do contribute to the spread of bovine tuberculosis but culling is unlikely to make a significant difference, and better animal management practice was recommended to impede the spread of the disease. Badgers are territorial animals and killing less than 70 % disrupts their social structures with survivors roaming further afield, exacerbating the problem. On this evidence the then Labour government decided not to proceed with a cull.

Following the 2010 election of a Conservative-led coalition more sympathetic to the farming lobby, in 2011 it was decided to allow badger culls [11]. However, any official badger cull had to expect violent animal rights protests requiring a major commitment of police and security resources, thus extending the policy-relevant components and relationships in this system, and increasing its complexity.

In 2012 the programme of badger culling had to be abandoned. As the Under-Secretary of State explained: “The exceptionally bad weather this summer has put a number of pressures on our farmers and caused significant problems. Protracted legal proceedings and the request of the police to delay the start until after the Olympics and Paralympics have meant that we have moved beyond the optimal time for delivering an effective cull. We should have begun in the summer.” [16]

Thus the policy-relevant components in the BTB—Badger Culling system suddenly included the Olympic Games and the weather! This illustrates the 'messy' reality of the systems policy makers need to consider. Here the objective scientific evidence (biological) was just part of a wider social system that behaved in unexpected ways. A better understanding of the interacting social systems could have spared the policy makers an expensive and embarrassing reversal that pleased neither friends nor opponents.

Systems theory makes extensive use of diagrams such as that in Fig. 1. The words, often enclosed in boxes, represent the components of the system and the arrows the interactions between the components. To the right of the dashed line is the relationship that drives the whole system: badgers cause BTB. This results in sufficient farmers losing their herds for their representatives to put intense pressure on the Government for a badger cull. The farmers argue that a badger cull will reduce a badger population, thus removing a cause of BTB. The Government responds to the pressure by authorising a badger cull and paying farmers to implement the cull. However there is also the relationship between the animal rights protesters who will disrupt badger culls, and the police and security services who are expected to contain and control this disruption so that the cull can go ahead. All this was the basis for the 2011 policy to go ahead with the cull.

To the left of the dashed line is the July–August 2012 London Olympic games which is an important part of this system. It had been known for a long time that security considerations would stretch the police and security services to the limit, but the 2011 policy document [11] made no mention of this. Also not mentioned in the policy document was the prospect of bad weather disrupting the proposed cull, again to the left of the dashed line in Fig. 1.

When these two components are included in the system it is clear that the badger cull cannot begin before late August 2012 because the police and security services

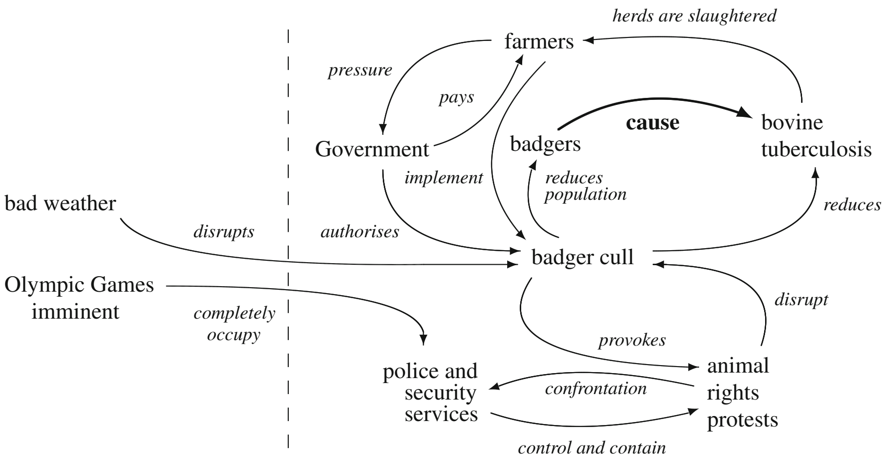

Fig. 1 A system diagram for the badger-cull policy

would be pre-occupied with Olympic games but the bad weather meant that the farmers and others licensed to execute the cull were not in a position to do so. Hence the cancellation of the cull announced in October 2012 [16].

3.2 Feedback

3.2.1 Negative Feedback

Negative feedback, as illustrated in Fig. 2, is well-known to policy makers and those who execute policy. It is how they 'steer' the system and keep it 'on course' towards the desirable outcomes. It is analogous to driving a car when, for example, monitoring performance shows it is going too far to the left, requiring the corrective action of steering to the right until it is going in the desired direction. 'Negative' means that the corrective action is in the 'opposite direction' from any observed error.

In social systems interaction takes time, and network dynamics often include delays. For example, after making a policy intervention, it takes time before monitoring will show any effects. It will take time to determine any deviations from what is desired and to plan new policy actions. After that it will take time to implement the plan. Delays can be fundamental to a system's dynamics, and they are represented by two short parallel lines on the interaction arrows.

3.2.2 Positive Feedback

Positive feedback reflects escalating change, e.g. a run on a bank. Figure 3 shows concern that the bank will crash causing people to queue to withdraw their money. The sight of a queue outside the bank causes even more people to join it, causing greater concern that the bank will crash, causing even longer queues until eventually the bank does indeed fail. The '+' signs near the arrow ends signify increasing effects. The 'R' in a circular arrow signifies a *reinforcing* feedback loop, spiralling with ever increasing effects. Positive feedback cannot go on forever and eventually the system changes, sometimes catastrophically such as it crashing or flying apart.

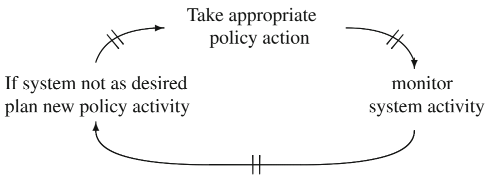

Fig. 2 Negative feedback is usually used to keep systems close to a desired state

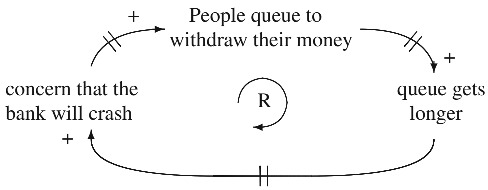

Fig. 3 Positive feedback during a run on the bank

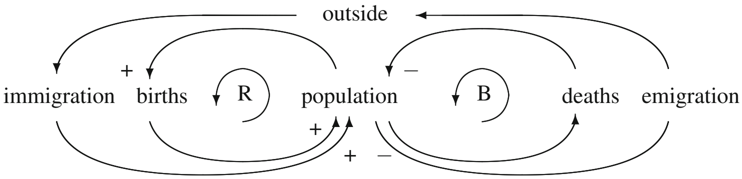

Fig. 4 Interacting feedback loops

3.2.3 Interacting Feedback Loops

Real systems normally have combinations of positive, negative and mixed feedback loops. For example, Fig. 4 shows the reinforcing feedback loop of births interacting with the *balancing feedback* loop of deaths, signified by the letter 'B' inside a circular arrow. If the numbers of births and deaths were perfectly balanced the population would be in *equilibrium*, but this is rarely the case. The population also depends on immigration and emigration. This system has a number of interacting feedback loops, and this can make short and long-term forecasts of future population difficult.

3.2.4 Oscillating Feedback Mechanisms

Figure 5 shows two interacting positive feedback mechanisms. On the left is a bull market with people believing that prices will increase and buying, the increase demand causing prices to increase. On the right is a bear market with people believing that prices will fall and selling, causing a surplus supply and falling prices.

In practice these two subsystems tend to oscillate as 'market sentiment' transforms the belief that prices will increase to the belief that prices will fall, and *vice versa*. The dynamics of these changes are partly due to the narratives circulating as the system evolves, as discussed in the chapters by Ormerod and Nowak in this volume [27, 29].

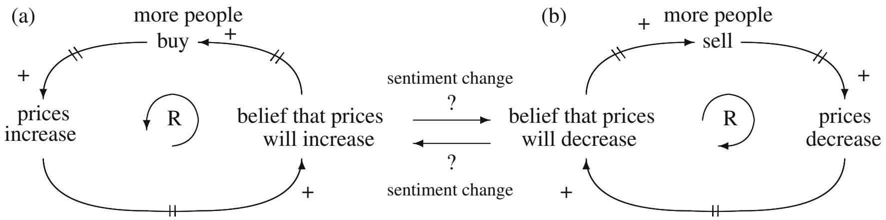

Fig. 5 Oscillation between two positive feedback loops linked by the dynamics of sentiment change. (**a**) Bull market. (**b**) Bear market

3.3 Computing System Behaviour

Feedback is a major cause of systems complexity. When the behaviour of systems emerges from many interactions with many coupled feedback loops, there are no formulae that can predict it. *Computer simulation* by iterative computation based on data has been developed in complex systems science as a systematic way to investigate how heterogeneous multiple feedback interaction systems might behave.

3.3.1 Coupled Populations

Figure 6a uses data from the Hudson Bay Company to show predator-prey interaction between the populations of snowshoe hares and Canadian lynx. When the number of hares increases the number of lynxes increases, but more lynxes means that more hares are eaten reducing the population of hares. Figure 6b shows the observed populations of hares and lynx from 1845 to 1925. This shows that, far from there being an equilibrium, the coupled populations fluctuate considerably due to the time lags of the population interactions. Other predator-prey systems have been studied extensively by computer simulation and they show the same oscillations in populations as those in Fig. 6.

3.3.2 Computing State Transitions

If the *observed state* of a system at various points in time is recorded in some way the resulting data almost always contain measurement errors, and the observed state is always an approximation to the 'real' state.

Computer simulation involves modelling systems in *discrete time*. It is assumed that a clock is ticking and that, given the knowledge of the state of the system now, it is possible to compute the state of the system at the next tick of the clock. This assumes each element of the system has a state recorded in some way, and that the *transition* from one state to a state one tick ahead can be computed for the next tick of the clock. This computation depends on the current state of the particular element

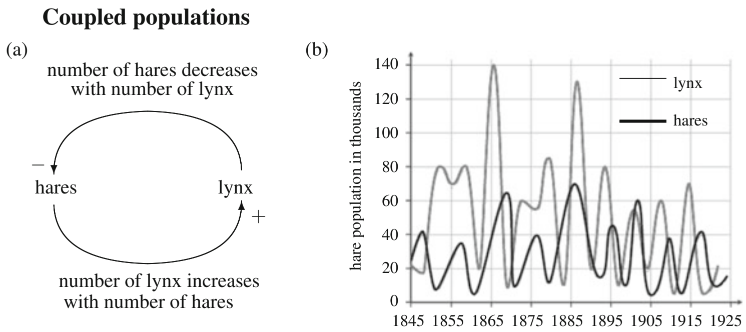

Fig. 6 The co-evolution of coupled populations. (**a**) Coupled feedback loop. (**b**) Coupled populations of snowshoe hares and Canadian lynx

and all the states of all the elements it interacts with. Then the state of the particular element can be *updated* at each tick of the clock.

After the first computation, another will give the state of the system after two ticks of the clock. In general many iterations of the computation will give the state of the system many ticks later. For iterated computations the assumed state of the system at the beginning is called the *initial state* or the *initial conditions* of the system.

The state calculated for any particular time in the future could be considered a *point prediction* of the state of the system at that point in time. A single point prediction generated by iterated computation may be very different from the observed state of the real system, and by itself of little use in policy making.

3.3.3 Boundedness and Phase Change

The variables representing a system are said to be *bounded* if they always stay within a finite range. In practice this means that they do not diverge to infinity and get so large that the system flies apart.

For example, the populations in predator-prey systems may become very large but system properties ensure they will reduce in the future. The maximum level of the population of prey is bounded above by the rate of predation. Similarly the maximum level of the population of predators is bounded above by the number of available prey. The minimum populations of both predators and prey are bounded below at two animals, one male and one female, to breed.

Sometimes in simulations the populations of both prey and predator die out. This is an extreme example of a *phase change* [3], where the system ceases to exist. Other example of phase changes in social systems include: the transition from high speed low density traffic to a low speed high density traffic jam; divorce, riots; bankruptcy; change of government; and disruptive technological innovation.

3.3.4 Sensitivity to Initial Conditions

Sensitivity to initial conditions means that a small change in initial conditions can result in a big change in system behaviour. For example, if you had left home 5 min earlier you would have caught the flight and not been a day late. A system is said to be *sensitive to initial conditions* if a small difference in the measurement of its state now causes a big difference in the point-prediction of its state at some future time.

A continuous system that is bounded and sensitive to initial conditions is said to be *chaotic*. This means that after some time-horizon its state will be *unpredictable*, e.g. after some period of time the precise rain-or-shine weather on a given day in many parts of the world cannot be predicted, although the likelihood of particular weather states can be usefully estimated.

For discrete systems that are sensitive to initial conditions, a single point prediction based on iterated computation has almost no value after some time-horizon. However, many point predictions may give an overview of the 'space' of possible futures at future times, and this can be useful to policy makers. For example:

1. if the desired outcome of a policy is never generated by iterated computation this is strong evidence for a policy maker that the action proposed may not work
2. iterated computation may generate outcomes that had not been envisaged and give insights into 'unknown unknowns'
3. iterated computation may show that the space of possible futures for a policy contains some very bad or dangerous outcomes, and taking a bet on that policy would be irresponsibly risky
4. iterated computation may show that a policy is indeed highly likely to achieve its objectives.

Sensitivity to initial conditions thus means that systems have to be simulated across a wide range of initial conditions to give an insight into the space of possible futures. Sometimes these are very different, and there may be no way of knowing which is most likely to occur. However, it can be very useful to discover that systems have behaviours not previously imagined and simulation can give insights into them.

3.3.5 System Dynamics

The theory of *system dynamics* developed by Forrester [14] quantifies the states of the elements and the interaction transitions between them. The underlying idea is that components of the system have properties represented by numbers, that the *state* of the system at any time can be represented by those numbers, and the interactions between the components can be represented by mathematical functions that map the state at one tick of the clock to state at the next. Figure 7 shows two computer simulations based on a systems model and the iterated computation [14].

Forester's systems dynamics was the basis of the study by the Club of Rome resulting in the publication by Meadows et al. of the controversial report *The Limits*

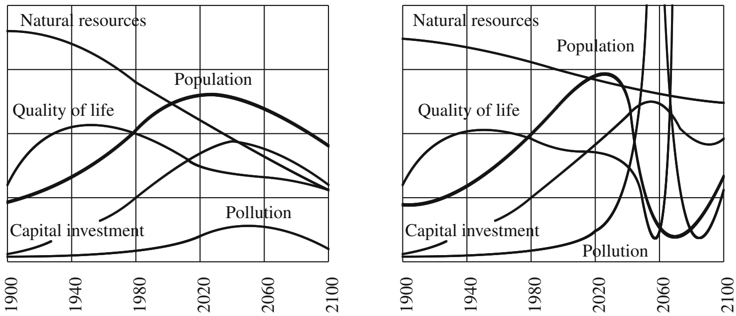

Fig. 7 Part of Forrester's 1971[14] simulations of world dynamics

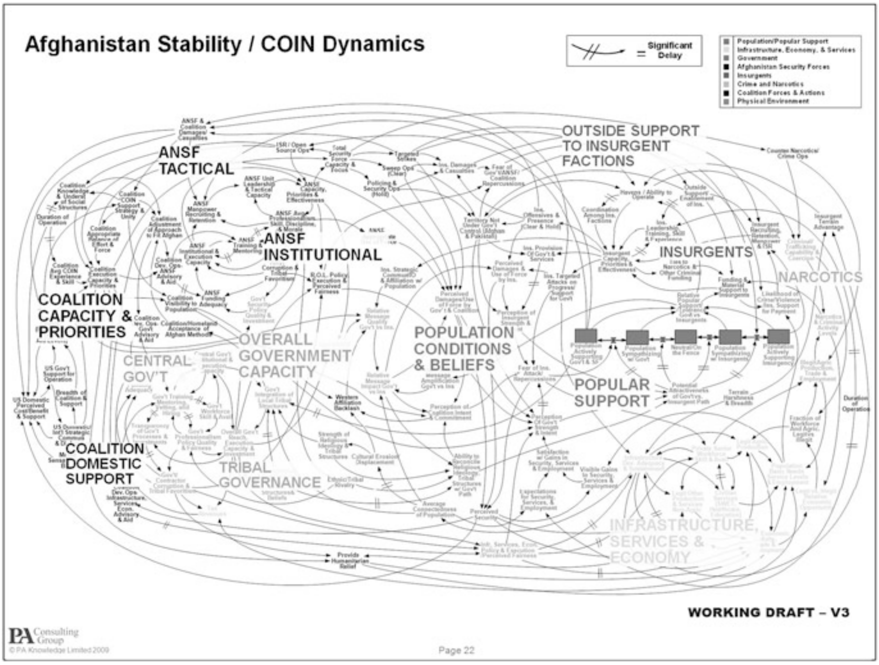

Fig. 8 Complicated systems diagrams can be hard to understand

to Growth [22, 23]. This study has been widely criticised from technical and policy perspectives but most critics miss the point that the purpose of this early study was to use systems dynamics to explore possible futures rather than to predict any particularly likely future.

In another application of systems dynamics, when US Gen. McChrystal, the US leader in Afghanistan, was shown the diagram portraying American military strategy in Fig. 8 The New York Times wrote that it looked more like a bowl of spaghetti and that General McChrystal had remarked 'When we understand that slide we'll have won the war'.

In a robust defence of the diagram, published in the Times Newspaper [26], Jon Moynihan of PA Consulting Group wrote

> You printed what has been dubbed on the internet a ‘spaghetti’ chart, depicting the current Afghan environment ? However, ours was far from being over-simplistic PowerPoint, using instead a well-known technique – system dynamics – to review a highly complex situation. Unlike linear thinking, the default mode of the human brain, system dynamics thinks about repercussions and occasionally unintended consequences of actions. . . . do we really want simplistic philosophies to win out . . . Do we want strategies developed that take no account of complexity and the sometimes counterintuitive outcomes of well-intentioned actions?

The ‘spaghetti’ criticism is easy to make, but assuming systems diagrams contain relevant components and relevant relationships, whether or not a systems approach is taken, this information is necessary if not sufficient to understand systems and their dynamics.

3.4 Equilibrium

The idea of equilibrium can be illustrated by a displacing a ball bearing in a bowl as shown in Fig. 9a where gravity restores it to an equilibrium at the bottom of the bowl. Here gravity acts as a negative feedback mechanism that forces the ball back to its equilibrium state. Figure 9b shows a ball balanced on a point. This a *dynamic equilibrium*. Any slight deviation from the equilibrium will result in the ball falling and equilibrium being lost. Here gravity induces positive feedback.

A problem with equilibrium theory for a social system is that it would never change. This is taken into account by the theory of *punctuated equilibrium*, which allows that systems may remain in more or less the same state for long periods of time and then change to a new equilibrium as shown in Fig. 9c. For example, a price may be stable for a long period of time and then can change considerably with the advent of a new technology.

In equilibrium systems it is not necessary that what is being measured is constant. It is sufficient that it remain close to the equilibrium state. For example, the price of petrol in a city may vary from place to place, but market forces will keep it in

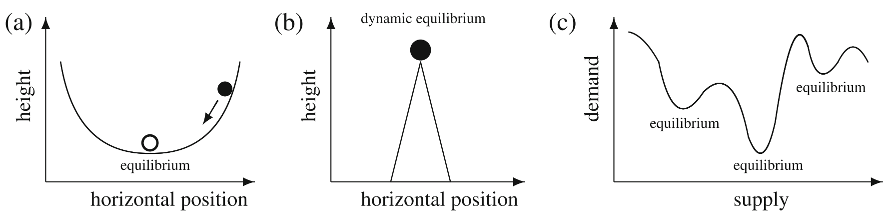

Fig. 9 Equilibrium between variables in systems. (**a**) Ball in bowl. (**b**) Balanced ball. (**c**) Punctuated equilibrium

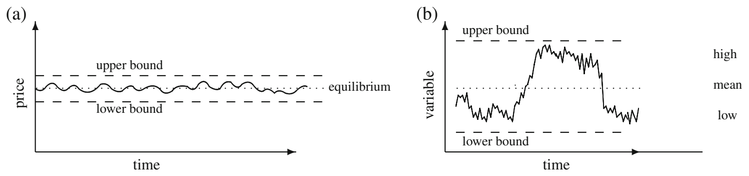

Fig. 10 Bounded systems and equilibria. (**a**) System within bounds close to equilibrium. (**b**) Multiphase bounded system

bounds close to an equilibrium price Fig. 10a. One outlet is unlikely to be able to charge twice the price as another for any length of time.

Figure 10b shows another bounded system variable. Here there appear to be two equilibrium states, one high and the other low, on either side of the mean. From a policy perspective the important question is if and when the system will move from one 'equilibrium' phase to another.

3.5 Multilevel Systems

The UK currently faces a crisis in its hospitals due to 'bed blocking' by elderly patients whose clinical treatment is complete but who cannot manage by themselves at home and for whom there is no place in the non-clinical welfare system [17].

Statistics from the Department of Health show that in a year 680,000 elderly people treated by the National Health Services (NHS) can be detained on wards for weeks, even though they are well enough to be looked after in a care home or at home with social services support. It is reported that "the loss of almost 50,000 council and private care home beds over the last 5 years, rising demand and social services budget cuts are blamed for the shambles. Meanwhile, cancelled operations—directly linked to a lack of beds—have soared from 3733 during the first quarter of 2000–to 4881 today (2015)." [21]. The opposition Labour Party blames the delays and bed-blocking on cuts of £3.5 billion to social care budgets since 2010 that have caused more elderly people to be admitted to hospital instead of being cared for at home. [25]

The problem is that the NHS pays when patients are in hospital, but when they are in community care the local council pays. The NHS and councils have different staff, separate budgets, and different priorities. Also, when a patient is transferred to a hospital in another county, another NHS trust must pay for them. To further complicate matters, if an elderly patient from one town is admitted to hospital in another they cannot access community care services there because they are not a resident. Instead, they must wait for someone from their local authority to come to assess them and organise care in their own community. This process can take a long time and it means patients can be stuck blocking a hospital bed for weeks.

This problem illustrates the nature of multilevel systems in policy. On the one hand the government funds directly and is responsible for the NHS, while on the other local authorities provide social care alongside many other services. Here the NHS subsystem and the Local Government subsystem have different funding structure, different cultures and different incentives. In particular the Local Authorities have been subjected to major cuts in government grants under the austerity policy introduced in 2010, and they make these cuts according to local priorities.

The 'Better Care Fund: Policy Framework' [5, 15] gives details of the plan to make Department of Health and the Department for Communities and Local Government work together to improve care in general and solve the bed-blocking problem in particular. The stakes are high—if the current problems with bed blocking are not resolved it could be a determining factor at the next election. An important question for the UK Government is whether or not this policy will work?

The analysis of this system in the policy document is mostly verbal, including discussion of new budget allocations. There is no discussion of the micro or meso-level dynamics of hospital and local councils working together. In particular there is no requirement for the welfare subsystem to provide sufficient beds to allow hospitals to discharge all patients from clinical beds into the community. With the information available one cannot know how this complex heterogeneous multilevel system will behave.

4 Networks

According to the definition in Sect. 1, every system can be represented by a *connected network*. The elements of the system form the vertices of the network, usually represented by a small circle referred to as a *node*. When two elements interact a line, referred to as an *edge* or a *link* is drawn between them. Figure 11a shows an *ego network* for the centre node, similar to a person surrounded by their friends. Figure 11b shows a *clique* with all the vertices connected, as with a tight social structure of friends or associates. There are six vertices so this is a 6-clique. Weaker kinds of clique are also possible such as groups of people connected to all-but-one of each other. Figure 11c shows a network in which every node is connected to every other node. Two elements are *connected* if there is a path between them. The *distance* between two nodes is the number of links in the shortest path between them, e.g. the distance between A and B is 14 links. The *diameter* of a network is the longest distance between all pairs of its nodes. In this network the longest shortest paths have length 14, so the network has diameter 14.

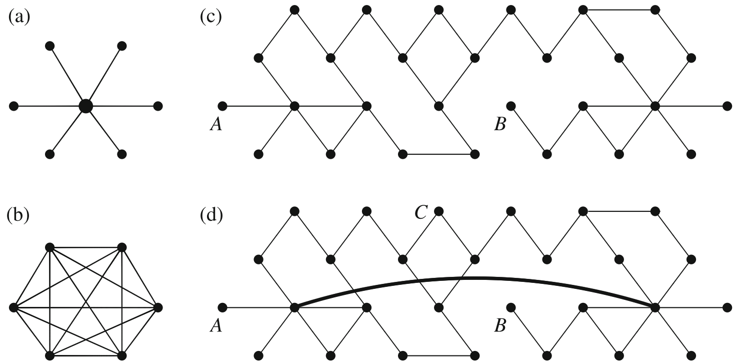

Fig. 11 Links may be curved, and long links reduce path lengths and the diameter of networks. (**a**) An ego network. (**b**) A clique. (**c**) A network with diameter 14, the length of a path from *A* to *B*. (**d**) A long link in a small world network

4.1 Small World Networks

The *degree of separation* between two people is the number of steps or links that connect them. Remarkably, for most pairs of people in the world this is about six. This is called the *small world property*. It occurs when vertices for local community structures are connected by short paths, and there exist a few *long links* connecting distant communities. For example, Fig. 11d shows a *long link* as a curved line. It reduces the diameter of the network from 14 in Fig. 11c to 9 in Fig. 11d, the longest path now being between *B* and *C*. In social systems long links would correspond to a friend having an aunt in Australia, or a colleague in Washington or a schoolfriend living Thailand.

4.2 Statistical Properties of Networks

The number of links attached to a vertex is called its *degree*. For example, the central vertex in the ego network in Fig. 11a has degree 6. In many social networks the distribution of degrees has a *long tailed* distributions as illustrated in Fig. 12b. This is because in most social structures a few people have many connections and many people have a few connections.

Traditionally social science focussed on statistical properties of populations which have well defined peaks such as the bell shaped normal curve and its skewed variations, e.g. the height of the population, age at first marriage, and number of attempts at the driving test. Complex systems science has shown that many distributions do not following this pattern but have long tails, or are *scale free*. E.g., a person new to an area might try to meet a person who already knows a

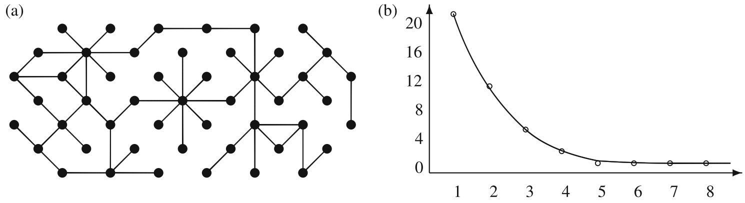

Fig. 12 Many social networks have long tailed distributions of their vertex degrees. (**a**) A network. (**b**) Long tailed distribution of degrees

lot of other people, thereby increasing further the number of people that gregarious person knows.

Barabasi proposed *preferential attachment* as a possible mechanisms underlying the long tailed distributions [4]. For example, an airline in a small town is likely to prefer having a new route to a large city airport rather than another small town airport. In general, when new links are made in the system, they attach to vertices which already have high degree. An equivalent of this is the rich getting richer!

4.3 Orientation and Relational Asymmetry

Often the order of edge vertices matters, e.g. $\langle a, b\rangle$ represents a lending money to b, this is different from b lending money to a. When $\langle a, b\rangle \neq \langle b, a, \rangle$ the edges are said to be *oriented*. Often this is represented in network diagrams by arrows for edges.

4.4 Percolation

Information transmission can *cascade* through networks as one person interacts with others. Social networks support other kinds of transmission, including the spreading of diseases, gossip, and opinions. Things pass from one person to another according to their network structure, e.g. good jokes rapidly cascade through a population. In some cases you do not even need to know the other person, e.g. to catch flu you only need to be linked by being in the same place at the same time. Transmission of anything through networks from one vertex to another is known as *percolation*.

4.5 Motifs

Network motifs are meaningful substructures that appear in networks, e.g. cliques. Figure 13a shows an old fashioned 'Male-Female three couple' dinner party motif. Figure 13b shows a 'gang of boys with leader' motif. Removing the leader destroys

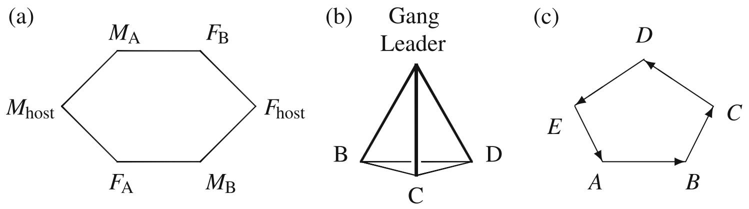

Fig. 13 Motifs as meaningful substructures appearing in networks. (**a**) dinner party motif. (**b**) Gang motif. (**c**) Remuneration motif

this stable structure unleashes unpredictable succession dynamics as the remaining substructures reconfigures to a similar leader-led motif [18]. Figure 13c shows an 'old boys network' motif in which company directors discretely sit on each other's remuneration committees and award each other high remuneration packages.

4.6 Multiplex Networks

Simple conventional networks are defined by single relations such as two people being friends but often there are many interacting relations determining the behaviour of systems. For example a 'family system' relation can interact with an 'employment structure' relation to create the phenomenon of 'nepotism'. When modelling social systems it is becoming increasingly important to take many relations into account. For example, when forecasting road traffic, relations such as those between people and their jobs, children and their schools, shoppers and shops combine, as illustrated by a parent driving their partner to work, dropping of the children at school, calling in at the supermarket and ending their trip at the golf course. Networks that include many relations are *multiplex networks* [20].

4.7 Hypergraphs and Simplicial Complexes

To date network theory has focussed on relations between pairs of entities. Certainly many social relations are *binary* and involve just two entities. However there are many examples of interactions between more than two entities.

Hypergraphs [7] were an early attempt to represent relations between many things, e.g. $\{a, b, c, \}$ could be a *hypergraph edge* representing the 3-ary relation between a, b, and c. e.g. 'a is the team leader of b and c'. However, this is not that same as ' c is the team leader of a and b'. A hypergraph edge, $\{a, b, c\}$ where the order of the vertices matters is called a *simplex* and represented as $\langle a, b, c\rangle$. In general $\langle \ldots, a, \ldots, b, \ldots\rangle \neq \langle \ldots, b, \ldots, a, \ldots\rangle$. Simplices are *oriented* and generalise oriented 1-dimensional edges $\langle a, b\rangle$, e.g. $\langle a, b, c\rangle$ is a 2-dimensional 'filled in' triangle, and $\langle a, b, c, d\rangle$ is a solid 3-dimensional tetrahedron.

A set of objects is related under a higher dimensional relation if removing any of them causes the relation to break down, e.g. remove the piano, viola, violin or cello from a piano quartet and it ceases to be a piano quartet. Thus a simplex is different to a clique. Sets of simplices have multidimensional connectivity, e.g. two high dimensional simplices can be connected through a triangular face, and simplices can be connected through a chain of intermediate triangle-connected simplices [2].

4.8 Hypernetnetworks

As with networks defined by binary relations, complex social systems require many higher relations to be taken into account in order to make sense of them. This can be done through the notion of *hypersimplex* in which the particular relation is explicit in the notation, e.g. $\langle a, b, c, d; R_{\text{playing\_bridge}}\rangle$ and $\langle a, b, c, d; R_{\text{debating}}\rangle$. These hypersmplices have the same vertices but different relations. Any collection of hypersimplices is called a *hypernetwork*. Hypersimplices can represent *wholes* formed from their vertices as *parts*, and hypernetworks are an essential first step towards a way of representing the dynamics of multilevel systems [19].

5 Networks and Policy

Research over recent years has shown that much human behaviour at the microlevel takes place within and is constrained by networks. Furthermore analysis of social networks can provide information for policy in both the public and private sectors.

This is examined in some depth in Ormerod's book *Positive Linking* [28] which gives many examples in which people's economic and social decision making is determined by networks through influence and imitation. These include Asch's 1951 experiment [1] in which groups of eight subjects were asked to match the length of lines. The experiment was arranged with one subject and seven 'confederates'. The confederates answered first followed by the subject. In the first two rounds the subjects and the confederates all gave the correct answers. In the third round some of the confederates gave the same incorrect answer, but this time some of the subjects also gave the incorrect answer. Even though they were obviously wrong, three quarters of the subjects also gave the wrong answer at least once. This copying effect depends on the number of people giving the incorrect answer. "In one condition they put 16 naive persons in a room and had two confederates give wrong answers. The group responded with amusement at their errors. " [30].

In their book 'I'll have what she's having' Bentley et al. give an anthropological and social perspective on copying as an advantageous strategy [6]. They list some of the more well-studies strategies as: copy the majority; copy successful individuals;

copy if better; copy good social learners; copy kin; copy friends; and copy older individuals. They illustrate this by saying that they themselves had copied this list from their colleague Kevin Laland, who himself had copied a list and added to it. And it is copied again here.

As Ormerod's chapter in this book makes clear, when it comes to making choices, copying is a much more convincing explanation for the decisions made than rational choice with perfect information [29]. This insight is of great potential value to policy makers because it gives new network-based methods of understanding the possible outcome of policy, and can help to shape policy. For example, many policies attempt to control behaviour by price applied to individuals (the vertices in networks) even when that behaviour is actually determined by social relationships (the links in networks). Sections 5.1–5.4 give examples of this.

5.1 The Use of Financial Services

A 2004 study by Meadows et al. is an early example of network ideas applied in policy [24]. In the context of Government proposals to eliminate financial exclusion, this research investigated the one in ten British adults not using mainstream financial services. Even though most of them were not in paid employment, many had bank accounts. It was found that non-consumers of financial services are distinguishable from consumers only by belonging to social networks where financial services usage is relatively low. The policy question was whether the financial institutions were reluctant to serve low-income customers, or whether the non-customers did not know that the services were available. By considering networks this study shed light on this question. "Use of financial services by the members of an individual's social network has a strong influence on their behaviour. Non-users are disproportionately drawn from social networks where few or no members have bank or building society accounts. This suggests that conventional marketing methods are not very successful in delivering information about financial services to non-users, and that there is an important information failure in these groups in the population" [24].

5.2 Obesity

In England 62 % of adults and 28 % of children aged between 2 and 15 are overweight or obese. Health problems associated with being overweight or obese cost the National Health Service more than £5 billion every year. The UK government's policy is that by 2020 there will be a downward trend in the level of excess weight in adults; and a sustained downward trend in the level of excess weight in children. [12] To achieve this it proposes to: encourage and help people to eat and drink more healthily, and to be more active. Its policy also includes giving advice on a healthy diet and physical activity, improving labelling on food and drink, and including calorie information on menus.

These policies address individuals as isolated vertices, but being overweight is a network phenomenon. The ego network of an obese person is likely to include more obese people than the ego network of a thin person. Despite the external social pressure against being overweight, cliques of people can be mutually forgiving when ordering another slice of cake, sharing a packet of biscuits, or eating chocolates.

In contrast to the government's approach, the private sector has developed a very effective method of weight control through the *Weight Watchers* organisation. Individuals wanting to lose weight can join Weight Watchers and immediately become part of a social network focussed on weight control. This involves imparting information not to the individual but to the group. Losing weight is a group objective, and individuals are encouraged by the success of others, formalised by ringing a bell when someone has achieved a milestone in their journey to achieve their desired weight. Instead of an isolated individual receiving impersonal advice, Weight Watchers have deliberately created mutually supportive locally networked communities in which the individual gains strength from the network.

5.3 Smoking

For more than a century it has been known that smoking cigarettes is a serious health hazard. Nonetheless, generation after generation have become smokers. In the post-war nineteen fifties and sixties smoking became fashionable, and the habit cascaded throughout populations. Half a century later, after decades of misinformation, many individuals addicted to smoking are trying to quit.

Christakis et al. write "The prevalence of smoking has decreased substantially in the U.S. over the past 30 years. …Network phenomena appear relevant to smoking cessation. Smoking behavior spreads across close and distant social ties; groups of inter-connected people quit in concert; and smokers are increasingly marginalized socially. These findings have implications for clinical and public health interventions to reduce and prevent smoking" [10]. So, following network pressure in earlier decades to start smoking, today cascades of networked people are quitting smoking.

5.4 Searching for Sadam

When the American-led coalition invaded Iraq in 2003 one of the objectives was to capture Sadam Hussein and those who had played a major role in his regime. Towards this end the US Army produced a pack of playing cards to help troops identify the most-wanted targets, mostly high-ranking members of the Ba'ath Party and members of the Revolutionary Command Council. The cards reflected an approach based on political and administrative structures, but over time it became evident that those in this network structure did not know the whereabouts of Sadam Hussein. Another approach built a picture of the family and tribal networks and this led to the identification of an otherwise insignificant individual whose capture provided information on Saddam Hussein's whereabouts that led to his capture [32].

6 Systems and Networks Theory Informing Policy

Systems and network theory inform policy in complementary ways. Systems theory provides a way of modelling systems with many parts and many interactions and provides associated concepts, e.g. that feedback can be a reason for social systems having complicated behaviours that make them unpredictable. Systems theory is able to give powerful insights into possible futures that can usefully inform policy makers in their decision making.

In contrast networks provide structural insights into the behaviour of social systems. It is known that many social networks have long tailed degree distribution. This simple fact enables policy to be formulated in terms of identifying individuals with high degree since this may enable the formulation of more effective policies. For example, inoculating a high degree individual in a network of face-to-face meetings will be more effective at limiting contagion that inoculating people at random.

Another simple fact can guide policy makers, namely that some behaviour depends on individual vertex attributes while other behaviour depends on network attributes. For example, if I get a parking fine I may change my parking behaviour without consulting my social networks. In contrast, policies to discourage binge drinking may only be effective if they address whole networks.

In the era of big data, network motifs are useful in discovering structures and unearthing latent information. These are used extensively by companies like Google and Amazon to target people with information or advertisements. Generally motifs are structural relations on more than pairs of thing, i.e. they are hypersimplices in multilevel multiplex hypernetworks.

Systems and network theories are part of the wider science of complex systems science. In this book Dum and Johnson explain how this new science can work in the service of policy through *Global Systems Science* [13]. GSS adds to Complex Systems Science by providing a framework for scientists to work with policymakers. In particular it identifies *policy informatics* as a major means to connect science with policy, where this includes computer-based simulation, data, visualisation, and interactive interfaces. Importantly, GSS includes citizens in the science-based policy making process.

7 Conclusions: Systems, Networks, and Policy

This chapter has introduced some basic ideas from systems theory. A major insight for policy makers is that social systems have feedback loops and that, even if they are all known, the interactions between them can be very complicated and difficult to comprehend without building a computational model. The dynamics are sensitive to small measurement errors, precluding precise predictions. Sometimes system diagrams give sufficient insight for policy purpose, but modelling and computer simulation are required to explore the possible future behaviours of complex multilevel social systems.

Modern network theory has given deep insights into the dynamics of systems, both in terms of the formation and loss of relational links, and the changing patterns of numbers over the vertices and edges. In particular it has been shown that the behaviour of individual human beings is highly dependent on their social networks. Network science adds to systems theory through its connectivity-based theory and structures.

Systems theory and network theory are fundamental tools for policy makers. Without them the outcome of policy is guesswork. Policy needs complex systems science but the science alone is not sufficient. To be effective, complex systems science has to provide policy makers and citizens with usable computer tools and data through policy informatics as developed in Global Systems Science.

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Towards a Complexity-Friendly Policy: Breaking the Vicious Circle of Equilibrium Thinking in Economics and Public Policy

Flaminio Squazzoni

Abstract This chapter aims to discuss certain limitations of the dominant equilibrium thinking in policy and explore more complexity-friendly alternatives. If societies and markets are viewed as complex, non-equilibrium systems, understanding nonlinear, adaptive and evolving patterns emerging from agent behaviour in network structures is fundamental for policy purposes. This requires improved realism of the behavioural and social foundations on which policies are based. We must also reconsider the mantra of incentivisation, institutional design and the top-down regulation that typically dominates conventional policy. Recent cases of financial market regulation and health policies can help us to understand the importance of looking at the subtle ways in which people or organisations behave when exposed to social influence, and pre-existing social norms and network externalities. Changing the current policy narrative and exploring complexity-friendly concepts, instruments and methods requires a shift of focus of policy-making from forecast and prediction of system equilibrium in order to understand and manage complex social systems better.

1 Introduction

These are hard times for policy-making. Today, policy makers are asked to cope with serious challenges, such as financial instability, environmental sustainability, demographic change and migration. All of this is occurring in periods of increasing interdependence between explosive technological innovation, real-time communication and new social behaviour. The implications of this interdependence are difficult to predict and control by anyone (see for example [53]). Extreme events, such as local wars, financial meltdown, humanitarian crises and environmental disasters, continue to capture the headlines dramatically affecting public opinion. Policy makers are condemned to cope with these events by referring instruments which

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look at a world of order, equilibrium and predictability, where problems can be compartmentalised into specific domains.

However, recent evidence indicates that these problems are interconnected and that extreme events might be the result of certain inherent dynamics of social systems rather than the consequence of external or individual causes [30]. For example, the Global Risks report released in January 2011 by the World Economic Forum argued that extreme events are due to systems' interdependence in determining global vulnerability.

For example, let us consider the 'water-food-energy' nexus. In this case, the rapid rise of global population and growing prosperity are putting unsustainable pressure on natural resources, with shortages, high volatility and dramatic increase of resource prices. This in turn provokes social and political instability, also due to migration pressures, geopolitical conflicts and environmental damage. Price volatility and competition for resources create fiscal pressures in advanced economies and possibly social instability in emerging economies. Under these situations, economic disparities lead to short-term responses in production and consumption that undermine long-term sustainability in a vicious circle.

Another example would be the 'illegal economy' nexus, which is also nurtured by global governance failure and growing economic disparity. Increasing opportunities for illegal activities, also thanks to the availability of advanced information and communication technologies, are all contributing to the fragility of states. This is caused by increasing corruption, eroding trust in public institutions and fewer resources for the welfare state and public goods. This also generates a series of disadvantages for legitimate economic activity by increasing transaction and capital costs and pressurising disadvantaged competitors to participate in corrupt practices. This in turn erodes social capital and the moral and legal bases of market societies and also traps some countries in cycles of poverty and instability [54].

All these examples indicate that the behaviour of social systems is neither random, as if God were playing dice with the world, nor entirely regular. Social systems are complex evolving systems whose behaviour depends upon links between many agents, all with heterogeneous beliefs, preferences, information and social structural positions that interact in subtle ways over significant space and time scales [26]. If policies do not consider these factors, interventions may miss their mark and create or reflect a world that does not exist [19].

This chapter aims to reconsider the current state-of-the-art of policy making in view of these new challenges. The second section discusses the limitations of the theory of human behaviour behind conventional policy and the weakness of methods and instruments generally used for policy-making. First, behavioural research indicates that policies assume that people behave in ways they do not. Secondly, policies only take a top-down approach, i.e. policy inputs versus decision makers, without considering the existence of a horizontal dimension, i.e. individuals are embedded in a social context that endogenously reacts to policy inputs through peer-to-peer effects.

Furthermore, there are certain methodological problems that are intrinsic to the anti-complexity approach of the dominant paradigm. Policies are a deductive exercise based on presupposed knowledge more than an experimental endeavour. As such they are informed at best only by econometric estimations of longitudinal data on individual aggregates. These data incorporate a simplistic notion of social aggregates as the mere sum of individual data, such as states, characteristics or choices of individuals, households or organisations. These black-box data do not take into account all the complex interaction effects characterising social systems, and they overestimate past trends and underestimate the likelihood of extreme events (e.g. Room [39]; Geyer [24]; Squazzoni [47]).

The third section presents some examples of problems in economic and public health policies. They show that policies can be ineffective if they underestimate the effect of complex networks, social norms and socially constructed choices. Looking at the way in which individuals or organisations are connected helps to contemplate more complexity-friendly approaches that could increase policy effectiveness.

Finally, the last section looks at the prospects and challenges of complexity-friendly policy. The argument is that a new research-policy interface is required, with new scientific methods and instruments in the policy domain, but also a shared capability of involving stakeholders in a common endeavour that points to understanding and management more than prediction and external regulation.

2 The Mechanistic Approach of Conventional Policy

Conventional policy typically follows a mantra of incentivisation, institutional design and top-down control. This is part of the intellectual background of the Newtonian, mechanistic, prediction and context free-oriented tradition of science, organisation, management and policy [19]. The concept follows the belief that observers, policy makers in our case, are outside the reality they want to change and deal with closed systems with given equilibrium states, which can be known in advance and modified through a linear cause-effect manipulation, e.g. policy intervention. According to this view, policy takes place 'off-line' and outside the system of interest (e.g. Finch and Orillard [22]). Policy is not seen as a component of a system behaviour interacting with other components such as individuals or organisations, and policy is not jointly engaged in a constructive process that determines the way systems behave [17, 47].

Policies typically start from predicting people's behaviour and end up by setting up appropriate incentives, promulgating regulations or providing information that are designed to alter individual behaviour towards predefined goals. For instance, by modifying the price of certain goods or services or subsiding certain industry sectors, policy makers underline decision makers' preferences in order to change the system equilibrium to a predefined level.

When a government passes a new regulation that extends or reduces detention for a given crime or prescribes anti-discrimination regulations in private companies, the crime rate is expected to decline along with inequality in the workplace. This is because people are expected to respond predictably and rationally to manipulated cost-benefit options. In the first instance, introducing a negative incentive is expected to modify the cost-benefit perception by delinquents who are supposed to rationally evaluate whether to commit a crime or not. In the second case, the prescription is expected to induce human resource managers to hire disadvantaged minorities and majorities more equally in order to avoid lawsuits by employers or applicants.

Unfortunately, this does not always happen for a variety of reasons. First, decision makers do not have a unique cost-benefit decision framework. Recently, behavioural research indicated that decision makers are not rational and are more heterogeneous than predicted by rational choice theory. This is because decisions are biased by various sources of bounded rationality (e.g. backward-looking heuristics, selective attention and habit) and subject to various social pressures (e.g. social imitation and conformism) [43]. Evidence suggests that people make biased choices, are past-driven and follow simple behavioural heuristics even when they have perfect information and have to decide from only a few options [12, 13]. Not only can decision makers be irrational, they also have heterogeneous beliefs, preferences and threshold choices that are hard to predict. This indicates that even well-designed policy options could provoke unpredictable responses if behaviour is not considered.

For example, many crimes are perpetrated under emotional circumstances and the probability of committing a crime is not determined by the same cost-benefit analysis for everyone. Secondly, there are unforeseen contextual and systemic factors that might lead to unintended consequences. Consider the case of the weak impact of sexual harassment policies on reducing gender bias in organisations [52]. In this case, while these policies were originally designed to reduce gender bias in the workplace, they actually strengthened traditional discrimination norms (e.g. they reinforced males' prejudices that females are protected by law because they are less competent), increased paternalistic stereotypes in organisations and induced females to correspond to the typical male stereotype of victims in order to take advantage of these norms. Here the policies backfired as they did not consider the implicit signalling effect of regulations and how these signals would have interacted with pre-existing contextual factors.

However, behavioural research would indicate that, especially when social outcomes depend on decentralised cooperation by individuals or organisations, the 'bounds' of decision makers' rationality could even allow individuals to overcome their own self-interest [9]. Indeed, public good provision in competitive settings depends on the existence of social norms which make individuals pursue social rather than egoistic aims [27]. If we consider that people's behaviour is a complex mix of self-interested rationality and moral motivations, in some circumstances adding incentives or imposing external regulation can backfire by eroding social norms and mutual obligations that have been spontaneously generated in specific social contexts (e.g. [10]).

This would undermine one of the strongest ideas of conventional policy, i.e. that policies are outside-in, 'neutral' interventions. Policies are never neutral as they always enact a constructive process of reflexivity, which depends on pre-existing social relationships and moral and normative frameworks through which decision makers have interpreted them. As argued by Bowles and Polanía-Reyes [11], policies enact interpretations of policy makers' intentions by decision makers and induce people to frame the decision environment. For example, incentivisation policies might induce decision makers to frame the context as a cost-benefit, rational choice problem, thus nurturing selfishness which may erode pre-existing good behaviour [46]. Furthermore, policies can compromise a control-adverse individual's sense of autonomy, dramatically affecting the process by which individuals learn new preferences and are socially digested through peer-to-peer social mechanisms (e.g. mutual observation of reactions, imitation and information externalities among decision makers). Therefore, in certain cases, pushing incentives could lead to defection, excessive opportunism or myopic attitudes by decision makers, which could in turn be detrimental to the public good.

This would indicate that policy failures are not due to the size of the state or the magnitude of the resources, but to the intellectual framework in which policy is conceived [34]. It is worth noting that this framework is instrumental in defending the public image of politicians. Under strong political competition at all government levels, politicians need to show accountable, immediate and measurable achievements to manage public opinion. This reinforces the tendency of conceiving policy as a top-down control exercise and nurtures the misplaced expectation by policy makers that scientists, experts and consultants can provide silver-bullet solutions.

This attitude also pays off traditional views and old-boyism in political life. The same attitude is also embodied in the state-of-mind of most economics, law or engineering-trained public officials and technocrats. Their position and role often lead them to overemphasis external regulation against context-dependent factors and self-organisation processes typical of complex social systems.

Believing that people are rational and predictable and the idea of policy as a top-down regulation exercise go hand-in-hand with policy makers general lack of interest in the possible advantages of behaviourally informed experimental approaches to test policy options.

In this respect, the recent establishment of behavioural 'nudge' policy units by the US and UK governments is a significant progress. The nudge idea is that, rather than assuming that people are fully rational, with a potentially predictable set of preferences that could be altered by manipulating incentives, individuals can be induced to make more rational choices simply by providing additional information that can tweak the decision context [50]. This idea has robust experimental evidence that suggests the use of experimental procedures to test policy options before implementing them [43], for example by submitting different types of information to randomised control and treatment groups of individuals. This indicates that an experimental 'epistemic culture' has started to penetrate the political inner circles. Yet, as we will see below, this is not sufficient.

3 The Underestimation of Complex Network Effects in Economic and Health Policies

Some key examples of specific limitations of conventional policy are the regulation of financial markets implemented by the US government and EU market authorities after the global financial crisis of 2008 and the typically static approach of public health policy. In both cases, the problem was the underestimation of the complexity of these systems. Specifically they indicated the the lack of understanding of how things are connected to each other and how they interact together in a dynamic network structure. In the first case, the presence of complex connections between banks and financial institutions was not considered. In the second, the traditional view of one-cause-one-disease-one-treatment did not look at the biological and social network determinants of diseases.

3.1 Network Implications for the Regulation of Financial Markets

After the systemic implications of the collapse of Lehman Brothers in September 2008 and the huge amount of taxpayers' money used to bail out hundreds of banks worldwide, the problem of how system risk can be mitigated in financial markets has been at the top of the agenda for policy makers and market authorities. To answer this, the so-called 'macroprudential regulation' and the Basel III principles have followed a recipe based on the idea of external controllability, i.e. setting up regulations that increase bank capital requirements and extending the regulation authorities' margin in order to manoeuvre when necessary.

By considering the role of financial networks in endogenously generating system risk, recent studies on financial networks have shown that this policy is not sufficient or even counterproductive [51]. For example, using an empirical dataset on the USD 1.2 trillion FED emergency loans programme during 2008–2010, Battiston et al. [6] built a DeptRank indicator that mapped the links between financial institutions in terms of financial dependence (e.g. dept distribution and equity investment relations) and, similar to PageRank and other feedback centrality indicators, measured the impact of a distressed node (e.g. a bank) across the whole network. Results showed that systemic risk is a network property of the financial system and not the property of a single financial agent or an exogenous factor. They found that a group of 22 financial institutions, which received most FED funds, were so deeply connected that each of the nodes could be a potential source of network vulnerability. This implies that a systemic default of the market could also be triggered by small dispersed shocks in the network.

Thurner and Poledna [51] used the same rank to analyse the impact of transparency on the interbank liability network. They built two simulation scenarios. The first one mimicked the current situation in that banks did not know the systemic impact of other banks Credits were traded with the conventional inter-bank offer rate. The second one was built to test a regulation scheme that allowed banks to know the DebtRank value of their counterpart and trade first with less risky partners. The results showed that by making bank's systemic risk values transparent, the financial network restructured its shape by distributing risk better throughout the system and minimising the chance of a systemic failure. Furthermore, this did not negatively affect credit volume or trading volume in the real economy.

Poledna and Thurner [37] built certain simulation scenarios where they tested the implications of imposing a negative incentive on markets, i.e. a risk transaction tax imposed on any transaction that was proportional to the expected systemic losses that the transaction could bring according to the DebtRank. Empirical data of nation-wide interbank liabilities was used to calibrate their model. By comparing a scenario (1) where banks ignored their contribution to systemic risk and traded credits in a way similar to the practice today with (2) one where the systemic risk tax was imposed, they showed that the tax was capable of reducing the probability of financial collapse and minimising the size of potential cascading failures. The tax was capable of inducing financial networks to restructure in less risky ways, and without lowering the system's credit volume.

They also compared their tax with the Tobin tax, which many analysts and politicians suggest as a solution to this problem. The results showed that the latter could reduce risk in the same way as the former, but only by drastically reducing the credit volume and without restructuring the network. It is worth noting that current market regulation causes banks with the highest systemic risk to be subsided while the majority of taxes are imposed on those with the lowest level of risk.

To sum up, these studies provide a more realistic picture of the complexity of financial markets, by emphasising the importance of considering their real structure. This is one of the main sources of market opacity which impedes understanding and regulation. They suggest that (negative and positive) incentives and regulations can be more effective if they can induce markets to self-organise themselves in less systemically risky ways. The adoption of data-driven, real time network metrics and visualisations, which are both available and are not difficult to implement, could help policy makers and market authorities to explore more adaptive, context-based policies [42]. Obviously, the challenge here is to overcome the nested interests that link big financial institutions and political power towards perpetuating conventional thinking.

3.2 The Network Medicine Approach to Public Health Policy

Health policies have traditionally followed the idea that diseases are individual constructs, mostly one-cause-related, which can be compartmentalised and treated with single targeted therapies. These therapies are usually experimentally assessed through randomised clinical trials and analysis of cost-effectiveness performed exclusively at population level. Recent studies in health have suggested that a systemic approach may help to identify the genetic and proteomic networks which explain specific diseases clusters. This approach allows us to consider the relevance of the social environment in generating disease risks [3]. Furthermore, complex systems analysis techniques have been recently used as a different approach not only in research but also for planning health care policies.

The idea that complex information such as the distribution of disease in a population, could be better recognised as systemic pattern tracing back to the end of the twentieth century. Indeed, studies have shown that diseases are not independent of each other as they aggregate and co-occur in the same individual due to a common network background [32]. Furthermore, diseases are strongly influenced by the way individuals are socially connected [14, 17].

For instance, in the Framingham Heart Study, obesity was evaluated in 12,067 participants assessed periodically over 30 years. Christakis and Fowler [15] found that obesity tends to cluster in particular social communities and that friends have a higher effect on the risk of obesity than genes do. This means that social ties might influence an individual's perception of the acceptability of obesity and thus food consumption. As a result, network externalities can contribute to generate unpredictable patterns of the obesity epidemic in the population. This also explains why weight-loss interventions that provide peer support are more successful than those that do not, independent of the magnitude of the specific health programmes.

A similar effect of social network externalities on health was found in studies evaluating smoking [16], food choices [36], alcohol consumption [25, 35] sexually transmitted diseases [5, 8, 23, 40] In these cases, the social determinants of lifestyles and habits, pre-existing social norms and social influence pressures explain the diffusion of unhealthy behaviours and the related diseases.

On the one hand, these findings indicate that the typical single-minded focus on one-cause-disease and single-target drugs that characterise the modern view of medicine can be misleading. On the other hand, it also calls for reconsideration of the dominant health policy thinking, which is too deterministic and not equipped to take into account the interconnected nature of many diseases as well as their social determinants [4]

Furthermore, looking at specific networks as determinants of health or disease allows us to reconsider the relationship between genes and environment. For instance, by analysing data on genetic structure in a large scale population provided by the National Longitudinal Study of Adolescent Health and the Framingham Heart Study, Fowler et al. [23] showed that the genetic structure may be less determined by reproduction constraints (e.g. kinship or geographical proximity of mates) than by social ties. Indeed, ceteris paribus, they found that people's friends have similar traits on a genotypic level as if individuals were 'metagenomic' with respect to their social ties. This means that disease can derive from a complex interplay between genes and social environment, in which the latter is expected to play a crucial role which was not empirically observed in past research. For instance, genetic properties of friendship groups could predispose or prevent individuals against certain diseases and confer fitness advantages or disadvantages that are also fundamental for gene selection.

These results have important implications for designing and improving health care services. First, significant outcomes could be achieved if we extend the outlook and the interventions from individuals or aggregates to social networks. Rather than the micro level or macro level, looking at the meso level becomes essential as we can observe how biological and social networks interact. Furthermore, by intervening on the social environment we could help to exploit social network externalities, which could be less costly than traditional programmes. If we look at diseases as complex networks including genetic, proteomic and metabolic sub-networks, as well as interconnections among biological, social and environmental systems, we could exploit the synthetic function of social ties on these network diseases. Indeed, social networks may act on a set of interrelated nodes at different hierarchical levels (e.g. genetic, proteomic and metabolic levels), thus triggering (positive or negative) effects on the entire biological network. Therefore, mapping these networks effects and simulating the potential impact of therapies or interventions considering possible space-time externalities could provide valuable insights to test options and inform policies.

Finally, this approach also suggests we should reconsider the traditional cost-effectiveness approach in health policy. Given that network externalities can trigger the cumulative effects of a therapeutic or preventive intervention by directly targeted individuals to their social ties, mapping and measuring the systemic effects of interventions can help us to evaluate outcomes of certain interventions more systematically [44]. Indeed, certain interventions or treatments which are economically impractical if considered at the individual level alone could become effective once network externalities at are considered.

4 Challenges Towards a Complexity-Friendly Policy

Complexity-friendly policy is the application of complexity science approaches, methods and instruments to policy making. The global challenges we have to cope with call for a collaborative effort by scientists, policy makers and stakeholders in innovating policy concepts, methods and instruments. A new research-policy interface is needed that connects science with stakeholders' vision, knowledge and priorities. The limitations of linear and basic science-technology relations when accounting for the intricate interplay between science and technology [21], must also be considered for the science-policy relation.

The lack of an interface between science, policy and stakeholders has been suggested by many analysts as being one of the major obstacles for coping with economic, social and environmental challenges. This is because it rewards inertia and incremental change in policy and nurtures a lack of understanding of the imperfect, experimental nature of science by policy makers and the public opinion [1, 29, 41, 49]. Given the intrinsic complexity of human affairs, a complexity-friendly experimental policy can help to impose the idea that policy options must be empirically and/or artificially tested before to be implemented. In this respect, as already said, the recent establishment of behavioural 'nudge' policy units by the US and UK governments is significant progress.

Yet, it is not enough. The idea of nudges must be considered more seriously, as not only can policy makers can nudge people towards better informed choices—in social life people also nudge each other. The 'behavioural' side of these new policies must be complemented by a 'social' side [48]. Adding network simulation and computational modelling of complex social systems, where individuals or organisations interact in complex ways, is needed to embody the idea of social complexity in policy making. This would also help us to complement the limitations of a randomised controlled trial approach of standard experimental tests by considering contextual and social factors This would extend the typical scale limitations of any experimental procedure and complement them for unfeasible experimental procedures. These complexity instruments could also provide a virtual test-bed for policy options on the large scale and help to scale up interventions.

The time is ripe for policies to capitalise on the new universe of technological innovation in digitalisation and computing in every sphere of life, including science, markets and social relations [30]. We also need to increase our use of advanced computational and data mining instruments which allow us to map the structure and behaviour of the social systems of interest more inductively and experimentally. The advantages of this approach have recently been suggested for developing complex behavioural and network indicators that look at systemic effects in humanitarian and environmental disasters, energy policies and financial markets [1, 18, 30]. This can help us to contemplate new types of collaboration with stakeholders at all levels, from sharing data and domain knowledge to coordinated implementation and distributed management of change processes.

Exploiting advanced complexity-friendly computational instruments would also help us to redefine the individual unit focus of cost-effectiveness that dominates policy implementation and evaluation. This is a critical point addressed by network medicine to study human disease but also has implications also for public policy in general. First, computer simulation and real-time data that integrate various levels of analysis could add a context-based dimension and map possible network externalities when testing policy options. Secondly, it could help us to include scenario visualisations of expected outcomes on more complex space and time scales. This would extend the limits of individual cost-effectiveness analysis to include network externalities and systemic effects. Reconsidering the efficacy and economic sustainability of more systemic, network-informed options could help us to consider interventions that would not even be contemplated when looking solely at an individual level [44]

Finally, we need a complexity-friendly policy narrative. While the conventional narrative is based on a top-down, outside-in control mantra, the new narrative should be based on simple ideas, drawn from complexity studies in a variety of fields, from markets and organisations to urban development [2, 7, 33].

The first is the 'less–is–more' concept. In each system, whether natural, technological or social, a recurrent finding of complexity studies is that there is no linear relation between cause and effect, so that the magnitude of input and expected output is not proportional [33]. This is because of the influence of initial conditions, the presence of interaction and systemic factors and the emergence of threshold effects and tipping points that are endogenously generated by the system of interest when it reacts to the external input [20].

This must also be the case for the policy-system relations. For example, let us consider the failure of economic theory driven, outside-in development programmes in under-developed countries from the 1950s [31], the success of small-scale, self-organised, asset-based community development (ABCD) initiatives in the 1990s in the US [45] or the famous case of the positive deviance approach in solving childhood malnourishment in Vietnamese villages, which also had relevant business and management implications [28].

In each case, we found the disproportionate effect of external manipulation on system outcomes. In all positive cases, more than the magnitude of the policy input, the secret of the success was intensively collaborating with stakeholders in all stages of the policy process, adapting policy plans to system behaviour and setting up sequential, bottom-up processes of improvement [38]. For example, this was the real lesson of the positive deviance policy by Save the Children in Vietnam. In this case, after years of failures of outside-in, top-down programmes, the situation of childhood malnourishment was significantly improved simply by discovering and amplifying existing good practices developed spontaneously in certain villages. The same was found in asset-based community development initiatives in the US in the 1990s, where exploiting existing assets and internal forces more than establishing top-down programmes which generated positive externalities on the communities involved, such as social capital, self-confidence and trust among people Thus solving one problem led to solving others relatively spontaneously [45]. This was also the lesson that Albert O. Hirschmann drew from the failures of the big development programmes in the Third world in the 1950s when he suggested the importance of working on bottom-up complementarities [31].

This naturally leads to the second idea, that of working on ‘conducive’ conditions and exploiting bottom-up forces of social systems. The State-market dichotomy in which the State sometimes plays an active role with big programmes and sometimes leaves everything to market forces, leads to underestimating the strength of social norms and social systems self-organising in reaching collective results. The challenge here is to explore the positive role of pre-existing domain conditions, including social norms, in order to accompanying positive self-organisation processes by encouraging diversity, heterogeneity and leveraging ground strengths [19]. More than a prediction lever, here what can make the difference is transforming policy into constructive, adaptive processes of bottom-up management [47]. This could also help us to understand when top-down incentives and external push can make a difference and when they are detrimental.

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The Information Economy

Yi-Cheng Zhang

Abstract In this chapter we outline a novel theory of the consumer market, in which information plays the key role. Consumers know only part of the available business offers and cannot ascertain the quality of the products they desire and businesses have even less knowledge of what consumers desire. In the market consumers and businesses must find a match with severely deficient information. Instead of optimisation under the constraints, our theory focuses on how the information constraints can be gradually reduced. We show that upon constraint-reduction we do not come closer to the full information limit typically portrayed in mainstream economics; rather both consumer wants and business offers expand with concomitant new information deficiencies. Therefore the consumer market is always in non-equilibrium and information will always be deficient. We argue that in the dynamic pursuit to reduce information constraints wealth is created and this is the main driving force that powers economic growth.

1 Information as Bottleneck for Economic Transactions

On historical accounts, both consumer wants[1] and businesses offers expand, and this powers economic growth. Consumers and businesses seek each other in the market, either on their own or are helped by various third parties to find better matching. Whereas mainstream economics bypasses the information problem in its supply-demand law,[2] our theory will focus on how consumers and businesses find each other, and how they tackle the *information deficiency* problem. It will be shown that when more wants and offers are found and matched, still more will be created.

[1]In economics consumer *wants* are are needs or desires that can be satisfied by the consumption of business *offers* including goods, commodities, services, and leisure activities.

[2]Notable exceptions can be found in George Akerlof's [1] work on information asymmetry, and Joseph Stiglitz's [9] work on information imperfections.

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As consumers become overwhelmed by the ever more complex world around them it is unrealistic to expect them to increase their information by even more diligence. Significant improvement actually comes from information institutions that enable individual consumers to be better informed. As discussed below, the most effective information institutions can empower consumers by collecting and organising scattered information that isolated consumers already possess, and can achieve information improvement by sharing and channeling information to the right person in the right context.

The new theory goes beyond the mainstream supply-demand law by considering a *cognitive gray area*. If consumers become better informed, more of their potential wants and the offers of business can be revealed and matched. Our postulate is that, besides the actual transactions, there must be an inexhaustible pool of potential wants and offers that can be gradually revealed and satisfied as information continuously improves.

Our main thesis is that *information improvement will power economic growth without limit over time*. The enhanced transactions in general will benefit both consumers and businesses, and we can speak of a *magic pie* of wealth that would be created as if out of the thin air. The concept of a 'magic pie' implies that economic transactions should not be zero-sum-games, and economic problems should not be treated as optimisation under constraints.

2 The Gray Cognitive Zone

The focus is now on defining the *gray cognitive zone*. First we note that information is very unevenly distributed among people, with everyone knowing some things better than other people. A single individual can also have their own personal gray zone, since personal knowledge can be both explicit and implicit and the latter far outweighs the former.

It is not surprising that businesses won't share information fully with consumers and present only a selective view of their products. Among consumers, the available but unevenly distributed knowledge is an inexhaustible resource for their information improvement. When you and I know something well, sharing it is an obvious way to enhance our information coverage. This will be called the *Information Division of Labor* (IDOL). It can be identified as the main mechanism to empower consumers to be better informed.

There are various reasons why consumers share information among themselves. Firstly they have idiosyncratic motives beyond pure economic calculation—people volunteering cooperation and giving each other tips can be motivated by non-economic incentives, and yet the people power of IDOL can have huge economic consequences. Secondly the harder consumers scrutinise businesses, the more businesses can improve their offers. In fact it is much easier for businesses to expand the variety and quality of their offers than it is for consumers to change their needs or wants, an asymmetry discussed in details below. Therefore while the interests of businesses and consumers are at best partially aligned, consumers see themselves more as fellow tastemates than competitors.

Businesses have hidden information that they may never expose to the outside world, but the effects can manifest nonetheless. Each firm has its own resourcefulness known only to itself, but upon external selection pressure, it may tap into its hidden depth to make its offers more competitive in quality and/or price. Such depth is uneven across businesses, with more innovative and efficient firms better able to survive the competition and dominate.

The second type of cognitive gray zone is implicit knowledge within a single person, which is particularly relevant for expanding consumer wants. People know much more about their desires than they can explicitly articulate. Polany [7] studied implicit knowledge more than half century ago, and many marketing business models actually deal with implicit knowledge using a variety of refined tools. Implicit knowledge is by definition the knowledge you have but cannot easily recall. Although we cannot explicitly recall all our own preferences, what is implicit may become explicit on suitable stimulus and contexts. In fact many marketing strategies aim to convert selectively our implicit needs into commercial transactions.

3 Information Institutions

Individual consumers cannot cope well with ever more numerous and complex business offers; they are hard pressed to compare products and determine their quality and suitability. In fact there are many information institutions that we shall call matchmakers who help consumers and/or businesses to find suitable matches. IDOL is an important mechanism that enables consumers to be better informed, but it is only when combined with matchmakers that IDOL can realise its full potential. Take tripadvisor.com as example. Its evaluations of hotels and restaurants are by consumers themselves, but the matchmaker's role is vital in connecting millions of travellers to these evaluators as if they were the quality inspectors from a powerful quality control agency.

Many more matchmakers empower consumers. Online auctions site like eBay lets buyers and sellers rate each other, and their reputation systems keep people relatively honest and trusting when they buy things sight unseen. Amazon lets its customers rate books and countless other products, and the experience and expertise of a small minority of insiders can enlighten millions consumers. Information institutions can apply the latest advances in big data science to recommend relevant items to consumers by figuring out the implications of networks implicit in the data. In fact online matchmakers will be able to leverage IDOL, reputation, and recommendation to empower consumers much further in the future.

Matchmaking institutions play a central role in modern markets, often one that is not conspicuous. We find most products and services on our own, or so it may seem. There are many institutions that enhance consumer's search and evaluation capabilities, while helping businesses to target advertisements. Matchmaking institutions enjoy an obvious advantage: a given product will be repeatedly scrutinised many times by many different consumers, allowing a potential customer to benefit from this rich information by studying only it once. Therefore matchmaking institutions can be very efficient in overcoming the information deficiency problem. However, as will be seen, they are not necessarily neutral arbiters sitting between consumers and businesses; often they choose to help one side more than the other, and they have much leeway in doing so. For a better understanding the dilemma of who to favour in providing help, we look to a well known mathematical model for insight.

4 Matching with Partial Information, SMP Revisited

In this section we focus on an academic research program that underlies much of the current and future business models of matching consumers' wants to businesses' offers.

Gale and Shapley [3] first found a solution to the so-called *Stable Marriage Problem* (SMP). Let us first consider their original model and then extend it to matching consumers and businesses. Suppose there are N men and N women wishing to marry a member of the opposite sex, that each knows all the N members of the other side and ranks them, and each person's ranking list is independently distributed. Let each man propose to the women one by one from the top of his preference list downward, and let each woman evaluate the proposals and keep temporary the best candidate on her preference list. The rounds continue until each is matched to a single partner. The final matching can be shown to be stable, in the Pareto sense.

We can define a happiness parameter to measure the quality of the matching. If your mate is at the top of your preference list, your happiness is maximal; if your mate is ranked at the bottom of your list, your happiness is zero. Though the Gale-Shapley solution is proven to be stable, the collective happiness is far from being maximised. In fact if both men and women take initiatives to propose to each other in a symmetrical fashion, the combined collective happiness can be much higher than that of the GS algorithm of men-initiatives alone [6]. Moreover, if a matchmaker arranges the matching it can be shown that the best combined happiness can be obtained, beyond the capabilities of those directly involved.

The unrealistic assumption of perfect information in the SMP, that each man and woman knows all the members of the other side, can be relaxed. Suppose each person knows just a partial list of the available candidates. The Pareto stability criterion will be violated for some pairs, but satisfactory solutions (in the sense of Herbert Simon) can be achieved with a higher combined collective happiness than the GS stable solution. Recent research shows that as partial information is improved, with each person knowing more candidates, the collective benefits increase [10].

To apply this to the problem of matching consumer wants versus business offers requires some important modifications to the standard SMP model [4]. Firstly we note that the supply-demand relationship is not necessarily one-to-one, it is more often one-to-many, i.e. one firm produces for many consumers. Secondly consumers face a severe information deficiency problem [1] and both consumers and businesses have very limited knowledge of the other side. Thirdly, unlike in SMP where both sides have fixed attributes and wish lists, in the economy consumer wants and business offers can change and expand endlessly. Therefore we must deal with a *dynamic matching problem*.

There are many mutually beneficial solutions to matching problems, but the benefits are not necessarily split equally between the two sides. Due to the severe knowledge limitations knowledge of both, consumers and businesses rely heavily on third parties for their information requirements. This gives matchmakers considerable leeway in deciding which side to help most. The prevailing matchmaking business models favour businesses. This is because businesses are more analytic and more willing to pay the matchmakers for their information services. Consumers on the other hand prefer free information services, for example many internet companies such as search engines give information services for free to consumers and target them with advertisements on behalf of their business sponsors.

The reasons for businesses being more willing to pay matchmakers can be traced to the consumer theory of Tibor Scitovsky [8]. He suggests that businesses are specialists while consumers are generalists, and that specialists are by definition more analytic and can evaluate the difference that a matchmaker can make. Moreover, consumers are much more numerous than businesses and it is easier for matchmakers to establish contracts with businesses [2].

There is one major problem with the asymmetrical service by the information matchmakers. Both consumer wants and business offers can expand without limit but the latter is significantly easier. Helping one side means exerting a higher selection pressure on the other side. The problem is that consumer wants are relatively less expandable than the business offers. Surprisingly, the prevailing matchmaking business models are actually at odds with long term trends because of the following asymmetry.

5 The Fundamental Asymmetry

Above it was emphasised that our theory differs in a crucial way from mainstream economics. Instead of maximising under fixed constraints, we consider changeable constraints. As has been argued, consumer wants and business offers are constraints that can be expanded. In this section we posit that while constraints on both sides can be shifted, it is much easier to shift the constraints of the business side. We call this the *fundamental asymmetry* that underlies any dynamic theory of markets.

When pressed, businesses have more opportunities to revise their offers than consumers can expand their wants, even though in principle the latter are also boundless on historical accounts. The asymmetry manifests itself in the ease, scope, and speed of constraint-shifting.

Consider how each side can shift the constraints. Upon increased consumer selection pressure aided by information institutions, businesses are forced to revise their offers. In the short term they will cut prices and/or improve quality of their products. In the long term they must find new and more efficient ways to produce their current products, as well as look for new products anticipating consumer demand, thereby diversifying their offers. Here, direct pressure actually comes from the competition, which is only effective when empowered consumers exercise enough discerning capabilities. Therefore the ultimate driving force that obliges businesses to dig into their reserves comes from consumers.

Consider see how consumers' wants can be expanded. Since each person's income is limited (though people's income may increase with expanding business offers, in a growing economy both sides expand commensurately), his or her wants can expand slowly. There is also the factor that the price of consumer products typically drops between their inception and maturity. Hence even with a fixed budget a consumer's wants may change.

Businesses try hard to obtain consumer intelligence but they achieve only limited results. The difficulties stem from the following facts. While businesses and their products are public information, consumers' preferences are private, so businesses and their marketing agencies can only get a glimpse on what consumers really desire. Secondly consumers' wants may be implicit or hidden, i.e. even when they are willing to express them, they can only articulate a tiny fraction of their potential wants. Thirdly, businesses don't have sufficient incentive to know individual consumers as their wants are seldom or never repeated. Hence once a want is met it is saturated and it is of no further interest to the vendor. In other words it's much easier to know a business offer that is relatively stable than to know a consumer's needs which may recur infrequently, if at all.

Therefore businesses will be content with superficial data on consumers, such as gender, age, etc., even though such aggregate data are far from drawing the full picture of the individual, since they allow businesses to target a large group from which some individuals will turn out to be buyers. The fundamental asymmetry manifests in another aspect, the tolerance of substitutability. If a consumer specifically needs a blouse, you cannot just give her a hat instead. But instead of one particular consumer, any buyer replacing her will be just as good to the vendor.

Since businesses can more easily expand their offers than consumers can expand their wants, and the increased offers by definition are matched—businesses cannot unilaterally increase offers without commensurate wants. Therefore the asymmetry translates into differences in selection pressures on the each sides. In other words consumers should be assisted whereas businesses should be subject to strong selection scrutiny.

According to the fundamental asymmetry between consumer wants and business offers, the latter have a much larger scope to expand than the former. Since each side faces selection pressure by the other side, the asymmetry results in a long term trend that businesses cede more easily than consumers. The prevailing matchmaking business models helping businesses to put selection pressure on consumers seem to be glaringly at odds with this epic trend. However, elsewhere [11, 12] we show in detail that many new emergent business models do go with the trend.

From an optimal matching point of view a matchmaker should enable the maximal combined benefits of the two sides. But there are both short term and long term reasons they don't. The short term reason is that one side is more willing to pay, but it is the wrong side in view of the epic trend. The long term reason is that matchmakers should not merely aim at the current maximal combined benefits, as the other side can more easily expand. Hence they should align with one side (consumers) and exert strong discerning pressure on the other (businesses). Therefore matchmakers' short term profits and long term prospects are in head-on conflict: the former would make them align with the one side and the latter with the other.

The fundamental asymmetry not only is relevant for business models but also determines the long term trend of economic evolution. In the short term a business or its marketing institutions may choose to use clever marketing tools to squeeze consumers for profit because this is easiest to do, but the fundamental asymmetry deems that businesses have much greater room to expand their offers than consumer have to expand their wants. The more innovative entrepreneurs will be encouraged to align their vision and business models with the prevailing trend, and will dig deeper into their resourcefulness. In the long run whoever is going with the trend will reap sustainable rewards and whoever going against the trend may get short term profits but have less chance of long term prosperity.

6 Diversification

Our thesis is that *information can be always improved and that this in turn can power economic growth by expanding both offers and wants*. The next question is that what the expanding economy looks like. We argue below that upon information improvement, not only are there more transactions, but also products tend to diversify.

The following reasons favour product diversification. The first is that if consumers have higher information capabilities for choosing and determining businesses' offers, they have a higher chance of finding suitable products for their personal tastes. We postulate that people have a native predisposition of individual preferences that are far more diversified than suggested by past transaction statistics. With the increasing discerning power consumers reveal more diversified wants. Their information capabilities are regarded as the bottleneck towards full diversification, and luckily the bottleneck is being gradually reduced. This doesn't imply one day we may have perfect information, rather the improvement of information capabilities will herald new business offers with concomitant new bottlenecks. In short, even though consumers will forever have information deficiency, products will not only evolve from the old to new, but also from a few to many.

Businesses also have incentives to diversify their products. This may sound less obvious since mass production is far more efficient than personalisation. The direct cause is that with improved consumer information capabilities, competition becomes more effective. Heightened competition obliges businesses to go to new production frontiers where competition will be less severe. Not all businesses embrace diversification. Those that are efficient but risk-averse will look for the most popular products to fight the competition head on. More innovative businesses try to avoid crowded product spaces whenever they can, and take calculated risks in new fringe areas.

What trends do the diversifying products represent? When the economy is in a depressed state, such as a deep recession or after a world war, consumers' wants are limited to merely surviving. In general, when the economy is more prosperous, consumers' other non-essential needs can be viable. We can speak of lower wants versus higher wants. Lower wants are related to survival whereas higher wants can be hobbies, sports, entertainment, pastimes—a list that goes on without end. The higher wants tend to be (1) more personal, (2) more numerous, and (3) more implicit than explicit. These three characteristics make them difficult for businesses to detect. Since higher wants tend to differ from person to person, unlike survival needs such as food and shelter, it's harder to discover who wants what. Because they are inhomogeneous across the population, the aggregate number of higher wants is bound to be more numerous. Any single person will have an unlimited number of higher wants, i.e. those non-essential needs hidden in our gray cognitive zone that may be activated by the right stimulus in the right context.

The selective awakening of our implicit wants by marketing tools is the focus of business models in the current information economy. Abraham Maslow, the late American psychologist, first introduced the concept of a hierarchy of human needs [5]. We closely follow his definition in spirit but limit ourselves to commercial wants which are only a fraction of Maslow's higher human needs. Maslow suggested a pyramid to represent hierarchical needs, with the higher needs on the summit of the pyramid. To represent the much larger number of the higher wants versus that of the lower wants, we instead use an inverse pyramid for hierarchical wants. Moreover, the top is open ended as more can be added without limit (Fig. 1).

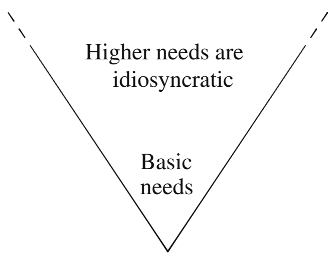

Fig. 1 Hierarchical wants represented by an inverse pyramid with an open expandable top. Lower wants are fewer and better known; higher wants are much more, personal. From the cognitive point of view determining the higher wants is a greater challenge

We expect the economy to grow by an endless process of matching consumers' increasing higher wants to business offers, followed by uncovering more implicit wants to be satisfied by new business offers, and so on.

7 Conclusion: The Non-equilibrium Paradigm

Mainstream economics is essentially a static theory that treats economic problems as optimisation under constraints. In this essay we have outlined a new theory that deals with the gray cognitive zone and focuses on information improvement therein. Information improvement not only reduces the current bottlenecks and thereby increases transaction volumes, but also helps discover new consumer wants and business offers. Our new theory follows throughout this line of argument by proposing a new paradigm in which allocation and creation cannot be separated.

The neoclassical paradigm of allocation underlies mainstream economics. The new paradigm postulates that any allocative acts will move the constraints, creating the new opportunities and risks. As a consequence of the new paradigm we cannot pretend to solve any particular problems without paying attention to changing constraints, so that optimisation is in principle not possible. What will follow is a genuinely dynamic theory where there is no fixed goal to be attained, and temporarily perceived goals will be shifted by current processes. While this conclusion may sound frustrating for theorists versed in the hard science tools for solving optimisation problems, it offers the evolutionary prospective that *there is no pre-determined target towards which our economy will converge*. There is still a lot we can do and should do, as the future is not completely unknown. Any progress towards conquering the gray cognitive zone will not eliminate or even reduce it, but push it further into newer frontiers. But the effort will not be in vain, as information improvement is the main driving force for an expanding economy. Our theory provides a detailed account how this general statement actually bears out.

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Complexity Science and the Art of Policy Making

Bridget Rosewell

Abstract What should be meant by a scientific approach to policy and how it might help create a more appropriate way of reaching decisions? Many years in practical policy making show that it is part science and part art. Complex systems science, as a form of story telling, can create links between them. Three aspects of policy making are considered: (1) the nature of proof in science and decision making, and how introducing new science into decision making is an under appreciated problem; (2) optimisation and that, despite optimal solutions not existing, policy makers want a single solution with unintended consequences left for future generations of policy makers; and (3) *ceteris paribus*—other things being equal, and the problem of deciding which things can be left alone and over what time periods. In policy, proof is an argument required by investors, regulators, and other decision makers. Proof must satisfy the beliefs and traditions of the decision maker, even when the former contradict observation and the latter are flawed, e.g. 'we have been doing it this way for thirty years so it must be right'. In policy, the belief in *optimisation* is particularly strong, within a tradition that focusses on parts and ignores wholes. Arguably, individuals do not always optimise and often make decisions by copying others, opening up new ways of nudging people towards compliance. Also firms may not optimise due to risk aversion, lack of information, or just focussing on survival. Even if optimisation were possible, a narrow view on what is being optimised can lead to missed opportunities, as in the case of the multiple returns of agglomeration. Also, although innovation is a pillar of economic policy, its necessary dynamics are incompatible with equilibrium theories. Equilibrium also suggests that 'do nothing' is a policy option for no change, rather than drifting into the unknown. However, 'doing something' has the *additionality problem*, namely showing the benefits over doing nothing or something else. All investment impacts are on the balance of probabilities. Risk free investment and risk free polices are not possible in a complex world. What matters is to have a strong story, backed up by strong evidence on the main elements of the story. Then take a bet.

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1 Introduction

If science is about experiment and testing to ensure only correct hypotheses are accepted, then art might be about balancing hypotheses which either are not or cannot be tested and making choices on the basis of broad brushes in primary colours. There is a strong tradition, at least in English-speaking countries, of seeing art and science as oppositional, with different cultures and different standards [13]. Complex systems analysis can be seen as sitting between these traditions, and indeed some proponents of complex systems analysis have seen it not as a science but as a form of storytelling, which provides a way of describing the one path of history with all of its contingencies and feedbacks.

In this chapter I want to get behind seeing complex systems analysis as a form of storytelling and consider how we can use complex systems thinking to create links between what we think of as science and as art. In other words, complexity science can offer the potential to cut through between the traditions of science and art and even to join them up. In addition, I want to use this way of thinking to take forward how policy making and policy choices can be improved.

I will do so by considering three aspects of policy making and how they might be changed and developed by the application of relevant aspects of complex systems analysis. In doing so, I want in particular to expand our appreciation of what should be meant by a scientific approach to policy and how it might help create a more appropriate way of reaching decisions.

My policy experience has been largely based in the UK so I will draw on this as the basis for my argument, but it is relevant to many areas of policy decision making. The three topics I shall consider look at both concepts and at process. First, I consider the nature of proof in both science and decision making, and how this is affected in turn by history and experience. This is especially relevant to the introduction of a new scientific approach and how its proofs can be incorporated into day to day decisions. This is an underappreciated problem.

Second, I look at the question of optimisation. Policy makers want to be given a solution, not a menu. They particularly don't want a menu of choices whose outcomes are uncertain because of potential feedbacks. The offer of optimality is a powerful one, and unintended consequences can be left for a future generation of policy makers to worry about. Even scenarios are often unwelcome. It is a real challenge to incorporate an appreciation that optimal solutions don't exist in decision making.

Third, I want to consider the venerable tradition of *ceteris paribus*—other things being equal. Which other things can be allowed to be equal, and over what time period is a significant problem. The addition of complex behaviours and probabilistic rules compounds this difficulty but also allows us to think about it in a different way. In each of these areas, I give examples of policy debates and policy decisions.

2 Proof and the Force of Tradition: Transport Policy

2.1 Proof in Policy

Giving evidence one day at a Planning Inquiry into the building of a new bridge across the Thames, I was asked what standard of proof there was for my contention that increased accessibility would create jobs and encourage more residents. The planning inspector was an engineer by background and pointed out that he had standards of proof for the number of times a piece of metal could be stressed before it failed. What, he asked, was the equivalent for my models?

It has to be said that my answer did not convince him. Our models had used a combination of fuzzy logic clustering of London's locations, densities and accessibility and related the cluster centres to create a relationship between population and employment densities and accessibility that controlled for all the unknown and unmeasured reasons that might have affected the outcomes. This approach was innovative and had not previously been agreed by any planning authorities. There was therefore a risk to the planning inspector in accepting a new way of arguing.

Second, I argued that transport was a necessary but not a sufficient condition for improved economic performance. It was therefore impossible to identify a 'transport only' effect of the new bridge, since development site availability, suitable skills and training policies and the availability of jobs outside the locality would all play a part in providing the outcome. This integrated way of thinking created severe puzzlement. The reductive approach to economics in the last half century or so, supported by econometrics and multiple regression analysis, creates a mind set in which the aim and object of analysis is to separate out individual effects and to control the remainder.

In two important respects, therefore, my evidence stepped outside tradition. We lost the case (not entirely for this reason) and a necessary bridge across the Thames is still to be built.

2.2 Models, Proof and Tradition

One recommendation of the planning inspector into the Thames bridge was to construct a particular kind of model, approved by the Department for Transport. This model describes the interactions between land use and transport. It therefore incorporates at least one feedback mechanism that might be important.

Such a model, known as a *Land Use and Transport Interaction* (LUTI) model [5], starts with the traditional transport model framework. It therefore fits into a familiar framework. This framework has been built up in the UK over a period of 50 years or so and has some important features for the way in which decisions are made. First it rests on principles of welfare economics. An underlying assumption is that *public investments generate non-monetary benefits, since monetary potential will already have been captured by private profit seeking investors*. This is a very strong assumption, which I will examine further in Sect. 4. At present, I concentrate on what these non-monetary benefits might consist of. First, the separation of general economic from welfare benefits allowed the analysis of the transport system to be separated from the rest of the economy. Decisions about transport investments could be delegated to a department with control over this area. Its budget would be allocated to the best of the projects and a technology grew up to estimate these.

Welfare benefits became synonymous with the time savings that travellers could make with a new transport investment. Trip demand was separated from this, since that was determined elsewhere by other economic forces and an underlying growth assumption. The bigger the time savings, the greater the benefit and these could be set against costs to generate a benefit cost ratio and a hierarchy of projects worth pursuing.

Of course, time savings need to be monetised to be set against costs in this way, and techniques of evaluation using stated preference and some observations were created to enable a standardised method of evaluating time saved for leisure, commuting and business travellers. The current values mandated for this purpose are shown in Table 1 taken from the Department for Transport's latest guidance.

Table 1 UK department for transport guidance on values of time, 2014

Mode	*Market price*
Car drivers	27.06
Car passengers	20.52
LGV (driver or passenger)	12.18
OGV (driver or passenger)	14.35
PSV driver	14.66
PSV passenger	16.63
Taxi driver	12.96
Taxi/minicab passenger	26.13
Rail passengers	31.96
Underground passenger	26.28
Walker	20.88
Cyclist	20.78
Motorcyclist	23.11
Averages of all working person	27.07
Values of working (employers' business) time by mode (£ per hour, 2010 prices, 2010 values)	
Trip purpose	*Market price*
Commuting	6.81
Other	6.04
Values of non-working time by trip purpose (£ per hour, 2010 prices, 2010 values)	

Source: [7]

In practice, it became clear that new roads simply filled up and the putative time savings seemed to evaporate. A major investigation by the Department of Transport's Standing Advisory Committee on Trunk Road Assessment Committee (SACTRA) [4] concluded that the model was still valid as in conditions of perfect competition, time savings could be transferred into real economic benefits and thus the valuations were still relevant. Tradition could be upheld.

As a policy maker and proponent of this model once said to me; "We've been doing it this way for thirty years, so it must be right". The force of tradition thus absolves it proponents from a standard of proof, so long as the assumptions, for example of perfect competition, are held to be inviolable.

In a neat twist, SACTRA recommended that the adjustment between perfect competition and the reality of imperfect competition should be 10 %, an adjustment that can be added to any benefit calculation—and therefore means nothing at all in terms of prioritising projects.

The strength of the tradition of perfect competition is worth exploring as it has particular implications for the implementation of a complex systems approach. Everyone would admit that no such actuality exists, but the search to attain it is embedded in policy in a number of places. I will return to the implications for competition policy in Sect. 3, where its implications for optimality are very important.

Here the implication is for the feedback between the transport system and the economy. If the assumptions of perfect competition are dropped, then the separation of transport evaluation and economic benefit must also be dropped. But this is very hard for policy makers to do.

2.3 Agglomeration

A good example concerns the acceptance of the principle of agglomeration. This process, first described by Alfred Marshall [10] and rediscovered and developed by scholars such as Fujita, Krugman, Thisse and Venables [6, 8], shows how co-location can affect labour market effectiveness, innovation, and productivity. These all count as externalities to the concept of perfect competition as the existence of a firm affects the existence of other firms, contrary to the principles on which perfect competition is based. So it became possible to take these into account, and it makes a significant difference to the impact of transport systems which allow such agglomerations, principally major cities, to grow.

Marshall (8th edn., p. 223) wrote 'When an industry has thus chosen a locality for itself, it is likely to stay there long: so great are the advantages which people following the same trade get from near neighbourhood to one another. The mysteries of trade become no mystery; but are as it were in the air …if one man start a new idea it is taken up by others and combined with suggestions of their own; and thus it becomes the source of further new ideas'. Contemporary examples of this is the high-tech industry of Silicon Valley and theatre districts in cities. Marshall's arguments included the shared use of expensive machinery, the pool of specialised labour, and other advantageous factors for co-location of similar industries. Apart from these *synergies*, co-location offers the befits of *complementarity* as seen, for example, in the modern shopping mall or the departments of a large hospital. As Marshall argued so cogently, the benefits in agglomerations go beyond the befits to a particular sectors, but also to other sectors and indeed to the whole [10].

Proponents of complex systems analysis will easily see that the concept of an externality links readily to developing rule-based behaviours which can either include or exclude particular effects. The impact of one agent's behaviour on another's is also a key consideration in building any complex system, in which outcomes can follow different paths depending on how these interactions emerge.

In traditional policy analysis however, these interactions are a distraction. The process of agglomeration carries uncertainties and intuition would suggest that it intensifies with scale. Indeed, an inspection of the relationship between density and wages across the Local Authority Districts of the UK shown in Fig. 1 lends itself to this conclusion.

Such a conclusion undermines the traditional analysis of time savings which always and everywhere have the same relative values, and in which perfect competition—as the nomenclature implies—has perfect outcomes. It is instructive to consider how attempts to include this element of a complex system—the idea of agglomeration—have fared in the policy framework of the UK's transport decision making system.

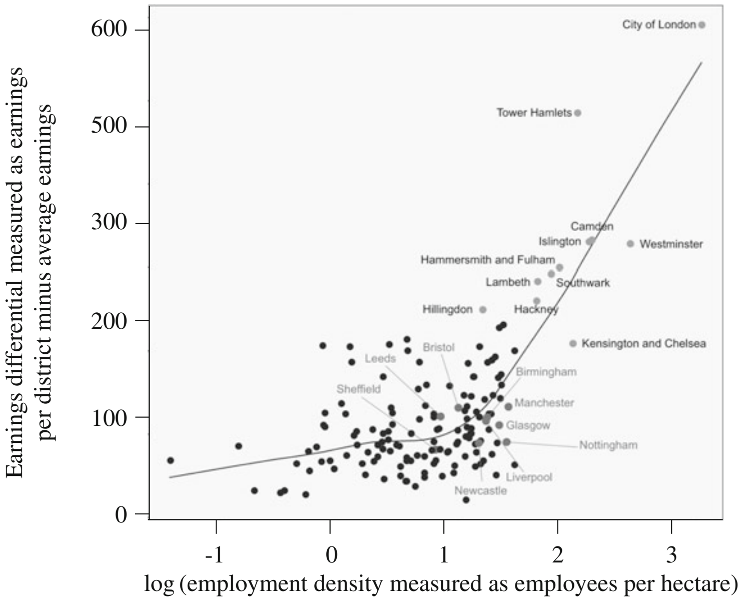

Fig. 1 Employment density against earnings differential; 2008–2012 average [17]

The framework of the idea was already present in the literature when I proposed that it should be used in the analysis of a new commuter railway in London. We produced estimates of the net additional value that could be created by being able to have more productive jobs in central London, where wages and employment density were highest. We showed that the main constraint to such job creation was the transport system.

These estimates were attacked on several grounds. The simplest was to argue that if more productive jobs existed they would be created anyway and less productive ones squeezed out so that the welfare basis for investment remained intact. The more sophisticated was to take the econometric and reductive approach. A priori, it is argued, more productive jobs will be taken by higher skilled people. These skills are independent of the location in which they are exercised and therefore we must distinguish between the return to skills and the return to the location in which they are exercised. If highly skilled people went to work in some other location, they would still reap a benefit from their expertise. A further step is to estimate these differential returns, including to individual industry sectors.

By contrast, I argued that there was symbiosis between skills and location that undermined this separation. Should the skilled and enterprising be prevented from maximising their opportunities, their skills would not remain constant but be likely to decay. In the process of agglomeration however, skills would be enhanced and rewards to qualifications increase. The reductive approach and cross section data analysis misses this.

This argument was a step too far. The reductive approach prevailed and a system of elasticities between density and output estimated. These are incorporated into guidance, just like the prescription of the values of time to be applied.

There is a twist. The traditional view, hallowed by time, has prevailed. The estimates of agglomeration are allowed as a ‘sensitivity test’. Moreover, they have been divided into two parts. One part is called ‘pure agglomeration’. This is an estimate of the impact of my productivity on yours, a density effect. It is accepted that this is not covered by the standard analysis. It can be significant but not enormous. The much larger impact is from creating new jobs which are more productive. In a recent analysis of an extension to one of London’s underground lines, the pure agglomeration effect was 15 % of the size of the impact of creating better jobs. But in the perfectly competitive world these jobs would always be created, and hence the traditional analysis still wants to ignore this. And even this impact is only a marginal one. In the traditional analysis everyone who wants to work can, and therefore it is only the net increase in productivity that can be measured.

2.4 Privileging Tradition Over Evidence and Proof

The force of tradition is clear in this story. New aspects to policy making are slow to be incorporated, and resisted. *It is much easier to follow rules than to invent new ones and it requires much energy and resources to try and change the paradigm.*

This brings me back to the question of proof. My response to the planning inspector was that in social science, where experiment was hard to do and impacts took a long time to work out, standards of proof do not exist in the same way as they do in engineering. Proof of the traditional models is as difficult as that of newer complex systems.

The traditional approach to economics assumes that all agents have the same motivation and that as a result all available opportunities will be taken up. Such assumptions can easily slip from assumptions into articles of faith which do not require proof; they are taken as being self-evident. The decision maker is much more interested in creating a rationale for decision making than in debating the distinction between an assumption and an article of faith.

The system of producing an analysis of time savings by putative travellers in the future creates a clear ranking of projects with monetised benefit cost ratios. What could be more attractive? Hallowed by decades of practice, it becomes embedded into a handbook of guidance which would, if printed, probably be high enough to sit on. Fortunately it is now web-enabled. But this in turn creates a framework which is harder and harder to challenge as each piece of the jigsaw of regulation looks perfectly sensible on its own and only becomes worrying when you realise how the assumptions build up.

LUTI models, recognised as appropriate in guidance are a case in point. They identify relationships between land use, whether for employment or residential purposes, and the transport system. They therefore rely on the ability to measure how land use changes in response to transport changes at small geographical levels. It assumes a set of trade linkages between industries to govern employment land use. There is no direct evidence for such relationships: they are entirely assumed from national data and there is no basis for assuming that such relationships hold at a local level. Equally past changes in land use are as much governed by planning regulation as by individuals' choices: such regulations are assumed constant in the models. Without a clear understanding of the source of assumptions, evaluation of models cannot be done. But if a modelling approach has been privileged in guidance, then the source of assumptions will be submerged into an assessment of the results, which in turn will rest on what seems plausible to a set of policymakers. This is no sort of proof of the validity of the results but is more akin to relying on judgement while calling it a model.

A similar process can apply even to the more venerable models of transport behaviour which are also used in the LUTI process and which are the basis of the time savings approach. Transport models assume that people will use the most time efficient route for their journey. They solve for the optimum trip patterns, given a set of origin and destination choices. Such models can become complicated and usually work in minutes of time. One minute saved is valued at the same rate per minute as 5 or 15 minutes. Wait times and interchange times are given their own multiples of minutes. Such penalties are based on observation, usually fairly limited. The more fundamental assumption is that people do indeed optimise their travel behaviour on the basis of time. Calibration of these optimising models is made against considerable amounts of data. If the optimising algorithm does not produce the travel pattern observed for the model's point of time, an adjustment vector is added to ensure that the existing travel pattern is replicated.

This clearly creates a problem for testing future transport scenarios. Is the adjustment vector held constant? Should it decay? These important decisions tend to become opaque and technical rather than recognised as privileging judgement over proof. Complex systems analysis has made some headway, but very little into these decisions. It has been overshadowed by the overarching assumption of optimality and indeed a particular form of rationality. Having examined this from the perspective of transport decisions, I now turn to how it plays out in industrial and competition policy.

3 Optimality and Optioneering: Competition Policy and Innovation

3.1 Optimality, Perfect Competition, and Policy

No aspect of policy has been more governed by the concepts of optimality and perfect competition than policy towards industry. Anti-trust legislation rests on the assumption that monopoly is bad as tending to raise profits and prices, while perfect competition with lots of small firms each without the power to affect prices will drive down costs and benefit the consumer.

In the static and stable world of equilibrium economics this makes perfect sense. Markets can be researched and understood, while firms are able to know what else is happening in their marketplace. Markets are easily defined. In this stable world, prices cannot just be set for today but in fact theory shows they must be set for all future time too In the real and messier world this paradigm leads to much effort to deciding where a market stops either in product terms or in geographical terms.

I once undertook a piece of analysis on the nature of the market for diesel-powered water pumps. These are largely used on construction sites to remove water from foundations or when there had been flooding. Was this a separate market from that for electrically powered pumps which undertook exactly the same role but were less frequently used on sites? Were larger pumps, used generally for more permanent purposes, a different market again? The boundaries are always fuzzy. With enough ingenuity, it is quite often possible to show a complete continuum of competition. Regulation has tried to cut through this with the concept of SSNIP, a *Small but Significant Non-transitory Increment in Price*. The underlying thought experiment considers the likely consequence if a firm makes such an increase. Does competition bring this back again, or is it possible for the firm to keep its gains?

All of this assumes however a market in which it is possible for consumers to be well informed and in which all firms have similar motivations. Both firms and consumers are optimising either their profits or their utility. These economic concepts are grounded in an even more venerable tradition than transport decisions.

The idea that firms seek profits and consumers seek utility go back to Adam Smith, John Stuart Mill and Jeremy Bentham.

However, the proposition that an ideal system exists in which they are maximised is of later date and was essentially created by the formalisation of the neo-classical system after the Second World War, notably by Paul Samuelson. Competition policy is based on the identification of, and imposition of, such an ideal system. The break-up of AT&T into the 'Baby Bells', prevention of various mergers and acquisitions, have all rested on this idealisation of profit and utility maximisation [12].

3.2 Complex Systems, Regulation and Decision Making

A complex systems approach to market decision making might tell a different story with potential for a different approach to regulation and decision making. I want to use three different aspects to illustrate this. However, in all three we are much further away from seeing complex systems approaches being operational than in transport analysis.

The first aspect I want to examine is market entry. Whether markets are contestable is a key feature in competition analysis. What are the barriers to entry? Do new firms survive? In a dynamic system, firm survival might be low, and yet the pressures exerted could still create market discipline for an incumbent operator. Ormerod and Rosewell [11] calibrated a model of market entry on the UK telecoms market. New firms had a choice about the scale of their entry and therefore their costs, and they faced an incumbent which had a variable rate of reaction to such entry. New entrants could not tell in advance how far the incumbent would react, and indeed the reaction itself could vary.

We showed that in many of the possible outcomes the incumbent maintained a large market share but that it did so only when it reacted in a competitive way. An inflexible incumbent would eventually be competed away and a new incumbent emerge.

The report was compiled to describe how market evolution could occur to the telecoms regulator which was suspicious that the incumbent was engaging in anti-competitive behaviour rather than in fact reacting competitively.

The research did not assume that firms engaged in profit maximising behaviour, but did assume that they were seeking profit. In standard theory such behaviour would lead to maximum profit if there are no economies of scale and everyone knows everything. A step is made in policy to say that such a position can be enforced. Indeed this is what central planning purported to do. Once the ideal amount of production has been decided upon this equilibrium set of instructions is sent out. The potential success of this is demonstrated by the failure of the USSR, but it lingers on, a subject to which I return in Sect. 4.

Here, I want to focus on whether firms or people are likely to be seeking either profit or utility. This is especially relevant to the regulation of natural monopolies, such as the water industry, electricity and gas distribution, and so on. Regulators who work on the assumption that their industry can be described by maximising behaviour can be surprised when their regulatory framework has surprising consequences.

3.3 The Myth of the Utility Optimising Consumer: Copying and Nudge

It is hard to know where the trade-off lies for consumers between quality and price. This is especially difficult if quality is binary. Either the water is safe to drink or it is not. Either the electricity system is robust and reliable, or it is not. A standard utility model suggests that all aspects of utility are divisible but this is clearly not the case. Moreover different groups of consumers not only might have different preferences as individuals but create communities of interest in which a spectrum of interests becomes polarised. The treatment of noise in aviation is a good case in point. Analysis of preferences suggests that noise can be valued such that it is relatively unimportant against the benefits of additional flights. However a reading of press coverage or attendance at interest group meetings would suggest something entirely different.

People who will tell you that they are not affected much by aircraft noise will also tell you that it is a very important issue. Copying the opinion of others appears to be just as significant as individual independent opinion. This immediately undermines a key assumption of standard analysis and means that we need a more complex systems view which takes this into account.

Unlike much of a complex systems approach, this insight has been both popularised and taken up by governments as the concept of *nudge*. Thaler and Susstein [14] produced a summary of the potential for the policy as if it were always beneficent. This is interpreted as framing policy in a way to make it more effective in changing behaviour. Curiously it has been taken up most strongly by environmental policy makers and the tax authorities. Tax collectors use variants on a theme which suggests that everyone else has paid, so you should too. Environmental policy uses a similar approach to encourage recycling and reductions in greenhouse gases. Another variant is to frame the policy choice as opting out rather than opting in: most recently to pension savings. The UK government has a *Behavioural Insights Team* (http://www.behaviouralinsights.co.uk) dedicated to finding new ways to 'nudge' its citizens towards complying with its policies.

The analysis of copying behaviour was pioneered in relation to internet behaviour, with such experiments as how music downloads were affected by knowledge of others' choices and companies such as Google, where Hal Varian is Chief Economist, have large research departments focused on such behaviours. Nudge is, however, more a mechanism for policy implementation, rather than policy making. Once a policy is decided, then how are citizens to be made to implement it? From the wearing of seat belts, to stopping smoking, to a willingness to recycle or observe speed limits, citizen compliance and acceptance is crucial. Enforcement is one route chosen by police states, in others persuasion and social norms become more important.

However, in this chapter I want to focus more on policy making than on implementation. Whatever route is chosen to ensure compliance with a policy, the prior question is whether it is the right policy to have. What this brief discussion of behavioural management does show is that to assume that consumers—or citizens—are continuously maximising an internal utility function is misplaced. What they care about is as likely to be influenced by the experience of others as by their own internalised preferences.

3.4 Policy and the Myth of the Profit Maximising Firm

What of the profit maximising firm? This construct has been both idealised and demonised. Proponents of the standard model have shown that the ideal firm, pursuing profit or shareholder value, will create the most efficient firm and produce at least cost so long as anti-competitive forces are not allowed to stand in the way. Opponents of capitalism such as the *Occupy* movement (http://www.occupytogether.org), see the pursuit of profit as undermining morality, exploiting consumers, and driving pollution and tax avoidance.

The theory of the ideal firm says that the pursuit of profit leads to an elegant solution in which the marginal cost of producing an extra unit is just balanced by the additional revenue and therefore the greatest efficiency in which only 'normal' profit can be earned. Firms don't actually need to know where this point is as competition will find it out by moving resources from less profitable to more profitable enterprises until it is found. In the real and complicated world, most businesses are not only unable to know what marginal costs and revenues are, they are concerned more fundamentally about survival. I once undertook a project which required the calculation of such marginal costs and revenues to determine whether a set of plants were at the lowest point on their cost curves (for policy purposes). It was almost impossible to know, and for most of them the potential economies of scale were such that it was hard to see that they would survive. They did not.

Talking with chief executives, finance directors and other managers over decades it is hard not to conclude that they are pursuing profit with anything like singlemindedness. Many other motivations intrude. Investments may be seen as potentially very profitable, but the risk is too scary for the management. Others may want a quiet life, and simply do what the regulator tells them. In a more realistic motivational world, neither firms nor consumers may behave as the limited rationality of the economist predicts. In this world, the policy maker faces unintended consequences of, for example, price regulation.

3.5 Innovation and Networks

The area of policy where motivational richness is most important is that of innovation. Innovation is inherently risky and most new ideas may never come to fruition. It is not the same as invention, which is having the new idea. Innovation is making it happen and spread in the wider world. It is crucial to the process of economic growth but remains outside the standard model, where equilibrium is a static concept which can be described by market shares and price competition for a known product. In practice, innovation is a major battleground for firms. Traditional enterprises will try to stifle the newcomer, or even innovators within their own ranks, while upstarts create new products or new processes which undermine incumbents.

The emerging digital economy illustrates how firms controlling older forms of communication have struggled to compete with the new behemoths of the digital age. Earlier, the advent of large scale computing undermined the producers of accounting machines and were themselves then forced to adapt to the introduction of the microcomputer and personal access to computer power. The fax machine became ubiquitous and has now almost disappeared again, to be replaced by emails.

The mechanisms by which innovation happens are neither well understood nor well adapted for policy. Neither science nor art but the blend between them and complex systems analysis has concentrated on this area (e.g. Antonelli [1]).

Innovation does not arise simply through individual decisions. That might happen with an invention but to turn an idea into an effective and widespread phenomenon requires networks. Networks in turn work through supply chains as well as peer groups. Indeed research we undertook in the Manchester region suggested peer groups were more likely to promote protection of an idea than its percolation. Supply chains were more likely to disseminate a new idea [16].

Networks can either facilitate or squash dissemination of an idea. If the first steps along the network do not pass it on, it dies. Quite a bit is now understood about different sorts of networks and their potential to generate a cascade in which the whole network is affected by something new. Neither science nor art has mastered how to characterise these in practice, and what mix of close and weak linkages are most likely to generate successful new ideas. Policy in this area has been particularly affected by the operation of vested interests which has tended to think in terms of peer groups. Similar firms are encouraged to form groups. But such networks may be as easily determined to stop innovation as to foster it, so that they maintain their current positions. A recent study of industrial clusters in the UK showed that no successful grouping of innovative industrial firms had been achieved by policy [2].

3.6 Innovation and Optioneering

Innovation is essentially a search and optioneering exercise; it is hard to imagine what might be meant by equilibrium in innovation, since successful innovation is by definition a disruptive phenomenon in which there will inevitably be losers as well as winners. Government has a tendency to confuse invention with innovation and to believe that inventors also make good innovators. This is not often true. It is more often the case that designers and inventors need business partners who can make practical their ideas, focusing on scaling production, finance and markets.

Optioneering can be interpreted as taking a systematic ‘engineering’ approach to the selection options where there is no clear optimum. It tries to put in place clear and structured processes for decision making and regulation. In the private sector the messy realities of there being no optimal solutions to complicated multidimensional problems make some variant optioneering essential if firms are to survive. As we have seen, the public sector remains wedded to the possibility of optimisation, despite the poor decisions that arise.

Complex systems approaches to these issues have made little inroad in policy, because they offer few simple prescriptions, either to what constitutes effective competition or how to promote successful innovation. A call to improve networks is hard to implement and has no easily visible signs of success. Competition is still bedevilled with the attractions of the word ‘perfect’ and ‘optimal’. The well-established results that these cannot be achieved are forgotten. A particularly important aspect to this is the focus on comparative statics, the comparison with a ‘do nothing’ outcome and a ‘do something’ policy. Benefits of do something are the difference between the two. What matters as much as whatever the policy might be is the ‘do nothing’ scenario with which it is to be compared. This brings us to the troubling question of ‘*ceteris paribus*’—other things being equal. It is to this assumption and its consequences that I now turn.

4 Other Things are not Equal: Cities, Devolution, and Growth

All modelling limits its scope. Outside the scope of the model, it must be possible to hold that no factors of importance will affect the focus of the model. In my discussion of transport models, for example, the need to make a trip is outside the model and is not affected by the provision of transport systems.

4.1 The Do Nothing *Policy Option*

The great advantage of a complex systems approach is that it challenges assumptions on what should or should not be included in the model. In doing so, it adds dimensions of *time* and *space* which are missing from the comparative statics approach in which it is fatally easy to believe that the ‘do nothing’ future is easy to understand.

If a social system were in equilibrium then the policy of doing nothing would leave it unchanged. The reality is, of course, that social systems are constantly evolving and the policy of doing nothing does not mean that the world will not change—it means that the world will change in ways that may be contrary to policy objectives.

The evolution of models of the macro-economy illustrates this. In their earliest formulations, such models, which I both learnt and taught in the 1970s, essentially excluded economic growth. This was independent of the general economy and indeed was a more advanced subject. Macro descriptions of the economy focused more on the relationship between consumers and spending, investors and savers, and how government filled the gap. Time lags were afterthoughts and add-ons. This fundamental way of thinking about the economy is still influential and can be seen in the writings of Paul Krugman [8], for example, where it seems obvious that if there is a gap between the putative and actual output of the economy, then a mix of interest rate adjustment and government borrowing fills the gap with no consequences.

4.2 Central Planning

This analysis is in turn the intellectual heir to the central planning movements influential in western socialist parties and in the socialist administrations of the Soviet and Chinese bloc. Central planning substitutes the model for the messy business of actual markets, firms and consumers. Capturing all necessary information in the model it should be possible to identify the ideal set of outputs to use all available resources and to produce the best possible outcome. Central planners can proclaim an end to boom and bust. In a static world, perhaps it is possible to envisage a model being able to capture all the information that could possibly exist about products, and all the information about consumers' tastes and preferences. Even so, the mind boggles at the computer power this might require.

Out in the real world, of course, consumers not only have a wide variety of tastes and preferences, not always consistently, and moreover change their minds. What was my favourite dish last year seems boring this year. I've just seen someone check train times on an iPhone in a minute or so and I want this new product. The messy business of markets is the non-equilibrium process of exploration. Will a new product sell? What will happen to previously existing products? The strength of market processes is that they create a mechanism for finding out which is relatively painless. Experiment is possible and consumers have direct mechanisms for making their choices known. Markets processes certainly have flaws, but they have generally served us well in creating economies with longer life expectancies, lower child mortality and where poverty is measured more in a lack of consumer durables than in malnutrition.

In spite of its clear failure in both Soviet Russia and in China, however, central planning still has adherents. The intellectual current that believes that the man from the government will know best is very powerful, especially since it is supported by the men (and some women) from the government whose role it is to do the planning and create the policies. Quite often, the bureaucratic view that competition is wasteful and profit inappropriate dominates.

It is worth examining these views more carefully as they are very important in the policy process. In addition, they interact with the important institutional context in which policy decisions are made. A good illustration of these issues relates to development planning, the role of infrastructure and local powers.

The UK is notable for its degree of centralisation. In London, for example, the Mayor of London only controls about 5 % of his budget directly and with full fiscal control. Most spending comes through central government allocations and a multiplicity of sources. A report compiled for the Greater London Authority in 2010 by the London School of Economics [15] concluded that spending allocations were so complicated they were impossible to understand and as result it was also impossible to develop local prioritisation.

In Sect. 2 I argued that, for example, transport was necessary but not sufficient for economic development. It is at a local or regional level that the interactions between transport and other policies can be made apparent and real. This is complexity in action. Lord Deighton [3], in his task force to look at maximising the benefits from investment in High Speed rail makes effectively the same point when he argued that the local authorities around each station location should have a growth and development plan to take advantage of the new connectivity. The challenge of course is that the station locations have generally been chosen to maximise the efficiency of an operational railway, rather than to maximise the economic opportunity. Not surprisingly, the relevant authorities have been coming back to say that the locations are not well placed to be fit for this purpose.

4.3 Options Versus Optimality: The Dynamics of Policy Formulation

The transport planners, on the other hand, have taken development for granted and been unable to think in option development terms. The order in which decisions have been taken have governed the range of possible options which can then be pursued. In the case of High Speed rail, the ordering seems to have started with the fastest routes between a small group of cities. This then constrains possible station locations, and in turn what development potential there might be. A different ordering of priorities could potentially produce a very different plan, and more of a debate about the trade-off between speed, stops and the line of route. However, at the outset, no-one asked the cities what inter-city transport improvements would be most effective in generating improved economic performance. That priority was only identified later. Lock in has then taken place as the drawing board is never a blank slate.

I learnt this when building the case for economic development generated by a new cross-London railway. At the outset I challenged whether this was the 'right' railway. I was still learning how complex decision making works in practice! I was advised to keep quiet about this question. I was told 'this might not be the ideal railway, but it was one we are able to build. Stop this and it will be another twenty years of re-engineering and even then it won't be 'right'' I learnt this lesson well. The best can be the enemy of the good, and the time frames for decision making, procurement and project management should not be underestimated if a project is to stick to budget.

Everybody has a tendency to think that what they do is hard, while others have it easy. Good project design and management is about the understanding that it is all hard and each discipline has its challenges. Meeting these challenges takes time and exists in locations. The right people in a meeting with the right information will make a very different decision, driving a project in a better direction than either the wrong people or inadequate information will be able to do.

The case for Crossrail indeed rested on this idea—that getting people together makes a difference to outcomes for the economy as well as for individual projects. In turn the dynamic that makes this possible includes the motivation to deliver that drives decision making. Competition and profit are part of this dynamic. In a static world, then competition is indeed wasteful and profit unnecessary. But in a world of change then competition and profit are part of a discovery process about what works and what can do well. *The world is a world of options not of optimality*.

This brings us to the challenge of understanding what makes a difference—what is additional, and what happens in any case.

5 Conclusion: The Additionality Bugbear

A complex, non-equilibrium approach to policy is not an easy one. The standard model, in which an equilibrium solution exists and can be found, is much more comforting. It is particularly noteworthy that even so, this requires setting aside the results of second best solutions. Lipsey and Lancaster [9] showed many years ago that if any part of an economic system is sub-optimal in standard terms, then making an apparently positive shift in one part cannot be guaranteed to improve the fitness of the system as a whole.

A non-equilibrium approach, by contrast, requires the policy maker to start from first principles with a description of all the relevant aspects of the problem in question. There is no presumption at the outset about maximising behaviour, and elements of the system can only be ignored if they can reasonably thought to be of minor importance.

This produces both a different description of a situation and also potentially a very different description of the impact a policy might have. This is the *additionality problem*. What is the difference between the outcome without the policy change and that with it? What additionality can be ascribed to the policy change?

In the standard model, where there is continuous optimisation, additionality is very hard to achieve. All profitable investments will be undertaken, and additions can only be made in terms of welfare which then has to be given a monetary value, e.g. reductions in obesity are valued in terms of additional years of life, which is then monetised according to earning capacity and healthcare costs.

In a non-equilibrium world, there is no reason to believe that all profitable investments will be undertaken. This is the most important conclusion to reach. However, this is not the same as the 'Keynesian' syndrome in which full employment is a matter of arithmetically adding up spending and if there is insufficient employment just adding the government ingredient. That is just as static an approach as the neo-classical one in which we are always at the only possible equilibrium.

In a non-equilibrium world, something is always changing and the *do nothing* scenario does not really exist. At the very least, it is necessary to consider whether the future is following the same path as the past. Nor is it necessary to construct complicated models to understand this. When I first became Chief Economist for the Greater London Authority, the task was to consider long term employment prospects. The narrative was simple.

Over the previous 20 years, employment in the business services sectors had grown at a steady pace, while manufacturing employment had massively fallen away. Essentially a million jobs in manufacturing had been replaced with rather more service sector posts. Since manufacturing employment was now a rump, the question became one of whether this long term service sector trend could and would persist. We concluded that London's position in the world economy and the forces of globalisation means that it could persist, so long as there were no external constraints. The most significant of these was the transport system, followed by poor school quality.

Do nothing, in other words, and there was a risk that the relatively recent upward trend in total employment could come to a halt. Address the underlying infrastructural problems, and there was a good chance that total employment could continue to rise. Policy in London focused strongly on both aspects, and increased transport investment and improved school results followed. So too did increased employment, which then followed the trend that had been identified.

This narrative remains a strong one, but it is important to note that it rests on probabilities. Can I be sure that the policies created the framework without which employment would have stalled? This returns me to the question posed at the beginning of this chapter because the answer is no. In a complex, non-equilibrium world, all policy impacts are on the balance of probabilities. For that matter, all investment impacts are on the balance of probabilities too. No investor knows in advance that her analysis of the likely outcomes is correct and bankruptcies are common.

Risk is not only inherent *ex ante* but cannot be entirely mitigated. Things do actually go wrong and portfolios contain poor investments as well as, hopefully, good ones. However, the fact that things have gone wrong does not mean that the judgement was bad in the first place. *Risk free investment, and risk free policies are* *not possible in a complex world*. What matters is to have a strong story, backed up by strong evidence on the main elements of the story. Then take a bet.

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The Complexity of Government

Greg Fisher

Abstract Two broad arguments are made. The first is that we are some distance away from having a good understanding of collective action, and until we do, claims about the role and scope of government will be based on crude impressions or ideologies. The second is that complexity science is well placed to make advances in in this area because social systems are inherently complex, as are many collective action problems. Indeed, most political ideologies impacting on public policy have emerged from a comparatively simple, mechanistic view of social systems. It is argued that the economic success of capitalist countries can in part be attributed to people being free to form organisations, which are collective acts, and can be seen as the other side of the coin to Adam Smith's division of labour. A discussion of what is meant by *collective action* will develop a broader than normal definition that includes social governance, defined here as all forms of institutions, the role of which is to facilitate, or enable, collective action. Governments are part of our social governance furniture, but have a monopoly over the use of force. The *libertarian challenge* concerning government will be used as the antithesis to the thesis that a primary role of government is to enable collective action, leading to a synthesis of the two. A speculation on the role governments should have in complex social systems *vis-a-vis* collective action precedes consideration of what value complexity science can add in the domain of collective action and government. This could be substantial since complexity science includes concepts and tools which can help advance our understanding. At the very least, the dispassionate science of complexity could provide a fresh perspective on what has been an historically emotive and inconclusive debate.

1 Introduction and Overview

Debates about the role and scope of government in social systems are often highly charged, and they seem endless. Many schools of thought exist in political philosophy, and these typically produce very different answers to these questions.

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For example, socialists advocate a substantial role for government in society, whereas extreme 'right-libertarians' and anarchists argue for its total abolition. More moderate voices among Conservatives argue for 'small government'.

But in order to answer the 'why', 'what' and 'how' of government, we first need a deep understanding of the fundamental rationale for it. In the absence of such an understanding, claims that government should be 'large' or 'small' are ill-posed.

An important premise of this essay is that a significant role of government concerns the social process of collective action. Two broad arguments will be developed: first, we do not have a good understanding of collective action, and, until we do, claims about the role and scope of government will be based on crude impressions or ideologies; second, complexity science is well placed to make advances in this area because social systems are inherently complex, as are many collective action problems. Indeed, most political ideologies, which have a considerable effect on public policy, have emerged from a relatively simple, mechanistic view of social systems. Policy decisions based on crude ideologies could have substantial costs.

Section 2 focuses on the fundamentals of interaction and collective action. It sets out the argument that the economic success of capitalist countries can in part be attributed to people being free to form organisations, which are collective acts. This might seem paradoxical but it will be shown that collective action is the other side of the coin to Adam Smith's division of labour.

Section 3 includes a discussion of what is meant by collective action in the literature and develops a broader definition than is normally used. It also includes a discussion of social governance, defined here as all forms of institutions, the role of which is to facilitate, or enable, collective action. Governments should be viewed as a part of our social governance furniture; however national governments have one crucial differentiating characteristic: they have a monopoly over the use of force.

Section 4 considers 'the libertarian challenge' concerning government. This perspective will be used as the antithesis to the thesis that a primary role of government is to enable collective action. The discussion in this section will help us form a synthesis of these two.

Section 5 speculates about what role governments should have in complex social systems *vis-â-vis* collective action. Since we emphasise in this essay that the literature dealing with social complexity is immature, these comments will be mostly speculative. The aim of this section is more to comment about research directions.

Dovetailing in to this, we consider what value the complexity sciences can add in the domain of collective action and government. This value could be substantial since social systems are complex and the complexity sciences include concepts and tools which can help advance our understanding. At the very least, the dispassionate science of complexity could provide a fresh perspective on what has been an historically emotive and inconclusive debate.

2 Interaction and Collective Acts

Societies are integrated networks of people in which interaction is both common and often significant. This interaction gives way to a substantial number of collective action challenges and opportunities, which range from the very simple to the highly complex.

Taking a step back, recent research in evolution studies has shown that under certain circumstances, evolution can favour groups of cooperating entities over non-cooperative groups. For example, Powers et al. [11] demonstrated how particular population structures, which can be selected for, confer the benefits of cooperation on the co-operators (rather than parasites). Such groups will have an evolutionary advantage over non-cooperative groups and also overcome the problem of the 'invading defector'. The complexity scientist Stuart Kauffman refers to this process as self-organisation in complex biological systems.

This argument helps to explain why many species exhibit both population structures, including familial networks resulting from sexual reproduction, and cooperative behaviour. Here we can think of the intricate, cooperative behaviour of beehives and ant colonies.

For social science, this literature provides a strong argument for how human societies have evolved to be inherently structured, or networked. In a sense, interaction is inevitable because structured groups with interacting individuals have been selected for by evolution.

Game theory offers a useful approach to thinking about interaction, especially the simpler, bilateral forms like the well-known Prisoners' Dilemma. This shows in simple terms how non-cooperative interaction lead to sub-optimal outcomes for two interacting people; and how forms of credible collective action can benefit both. In the next section we will look at which forms of collective action the economics literature has focused on; but for the remainder of this section, let us look at how collective action has underpinned the economic success of capitalism.

2.1 The Networked Pin Factory

Collective action is not only about avoiding detrimental effects like free-riding and pollution; it is also about people constructively working together, for their own benefit. Most notably, private corporations are formed by collective acts, as are all forms of organisation. This is an unusual way of thinking about private corporations, so let us look at this in more detail by re-thinking the famous example of Adam Smith's pin factory.

Adam Smith [12] wrote that the division of labour was an important source of economic wealth and growth. He famously cited a pin factory in which ten workers had specialised jobs, which had much greater productivity than the sum of ten uncoordinated specialists making pins independently of each other. Smith attributed this to the benefits of specialisation, which he called the *division of labour*.

When the pin factory is looked at from a network theory perspective, it can be thought of as a network of interactions between various specialists. Without some deliberate pattern of interaction, the pin factory would be ten uncoordinated specialists: this would probably be extremely inefficient.

Of course, it might seem like common sense to say that organisations, which are made up of specialists, also require patterns of interaction which define how these specialists relate to each other. This point is highlighted here to emphasise just how fundamental collective action is in today's economic systems. *Organisations are networks of people acting collectively*.

Given how fundamental collective action is in economic success, it is surprising that economists have traditionally focused on autonomous exchange and free markets. Honourable exceptions include the Nobel Laureates Elinor Ostrom and Douglass C. North.

With that in mind, one might ask why Smith's emphasis on the division of labour has received more attention historically than social networks in organisations[1]. In network theory terms, Smith's focus was on the nodes in the pin factory's network, not the links between the nodes. But these are two sides of the same coin.

The answer is probably that we have only had the intellectual technology to recognise and enunciate this issue in a formal sense in the past few decades. Network theory has blossomed since the 1970s and we can now understand better the value of specialised skills working in conjunction with networked interaction. Indeed, complexity scientists would say that the overall value of an organisation is an emergent (irreducible) property of the whole system: its constituent employees and the nature of their interaction. We will return to this 'new technology' point later in arguing about the value of complexity science.

In an essay concerned with government, why does all of this matter? The aim of this section is to build some of the foundations for understanding government, where: (1) relationships and interaction are inherent features of social systems; and (2) collective action is widespread in economically successful countries.

3 Collective Action and Social Governance

In defining collective action problems, Ostrom and Ahn [9] wrote:

> Collective action problems arise whenever individuals face alternative courses of actions between short-term self-regarding choices and one that, if followed by a large enough number of individuals in a group, benefits all.

[1]This is not to disregard or devalue Smith's Book *The theory of moral sentiments* which was about interaction within society more broadly.

In economics and political science, the term ‘collective action’ is associated not with organisations, as discussed above, but with problems concerning specific types of resources. These typically include public goods; commons-type resources like common land and fishing locations; externalities; and coordination problems [2].

The seminal book in this field was Mancur Olson’s [7] *The Logic of Collective Action: Public Goods and the Theory of Groups* . This book, and a lot of subsequent work, placed theories of collective action firmly in the domain of orthodox economics, including the conventional assumption of selfish optimising agents.

A classic model in this literature concerns the over-grazing of common land by rational agents, epitomised by Garrett Hardin [4] who coined the phrase the *tragedy of the commons* for such problems. This can be interpreted as a multi-agent Prisoners’ Dilemma problem. Like Olson, Elinor Ostrom argued that over-grazing (a form of free-riding) is a fundamental problem in this model but in principle it can be overcome by credible enforcement mechanisms [8]. These mechanisms constitute collective action in this literature.

A number of researchers in this field refer to Olson and Hardin’s work as the ‘first generation’ of the collective action literature [9]. In the past two decades or so, a second generation has emerged, building on new research in behavioural economics and evolutionary game theory. Advances in our understanding of human cognition (notably bounded rationality) and the evolving nature of social systems are included in this new generation.

As will be discussed in Sect. 4, Ostrom and Ahn’s definition of collective action problems (and, by implication, collective action) is somewhat narrow. It is typical of reductionist approaches to social systems where the value of the whole is seen as an aggregation of the value of the parts. Recall the pin factory where greater productivity was an emergent property and not the same as the sum of the parts.

For the remainder of this essay, we will use a broader definition of collective action, that it is about the coordinated actions of people where such actions are expected to achieve some aim. This definition is more general than the collective action of Ostrom and Ahn, which can be viewed as a subset, since it also incorporates the type of networked collective action seen in organisations.

3.1 First and Second-Order Collective Action

The literature in this field makes an important distinction between *first-order* and *second-order collective action problems*. This distinction is important here because it will help to move analytically toward an appreciation of the role of government *vis-â-vis* collective action.

First order problems are those which are immediate and localised. For example, Ostrom [8] discussed fishing rights of fishermen off the coast of Bodrum in Turkey. This was a specific, localised problem. Ostrom [8] also described a substantial number of other specific problems, all of them first-order.

Second order problems concern the setting up of institutions, or codified rules, which resolve first-order problems. In the case of fishing rights in Bodrum, if the fishermen were to self-organise, they would draw up agreements about who has the right to fish, when and where. This is a meta-problem, which is also a collective action problem because it requires people to agree the institutions of agreement. Put another way, any form of organisation which helps to resolve some collective action problem is itself a public good.

A second strand of literature relevant to this essay is that concerned with institutions. A thorough evaluation of this literature is beyond the scope of this essay but it is worth noting two points. First, this literature distinguishes between informal and formal institutions, and, second, it differentiates between emergent and deliberate institutional formation.

Informal institutions are typically associated with social norms, including concepts such as etiquette and conventions. In this essay I will use a broad definition and include ideas such as morality: general 'ought' principles which influence what we do. *Formal institutions* involve the codification of rules e.g. the drafting of laws and regulations. This literature includes a discussion of the process of formalising informal institutions, e.g. when moral principles like prohibition of murder are codified in to law.

Informal institutions are broadly synonymous with emergent institutions: those arising spontaneously within a population, in an unplanned way. Similarly, formal institutions are generally associated with *deliberate institutional formation*: the conscious planning of rules and regulations. Note, however, that deliberate institutions can also be informal in nature, e.g., when a group agrees to some systematic process like a weekly meeting.

3.2 Social Governance

Before we develop a discussion of what the role of government might look like in this context, it will be helpful first to define the term *social governance*. This will help us differentiate between institutions in general and government.

Here we will define *social governance* as any form of organisation, institution or rules that enables first-order collective action. Put another way, it is about higher orders of collective action. To understand this in more detail, let us look at a number of examples of what would constitute social governance given this definition.

Referring back to our discussion of organisations, many corporations have boards of directors, which have ultimate responsibility for running companies, including their overall corporate strategies. These boards are normally viewed as forms of governance: in the context of this chapter, these can be included in our collection of social governance.

One potential criticism of this point is that organisations, while made up of people, are singular so it makes no sense to talk about collective action within a single entity. The key point here is that this is a reification: the unit of analysis we are concerned with is the individual person, not the individual firm, which is an abstract concept.

Similarly, charities have boards of trustees that perform a similar role to boards of directors. In addition, a substantial amount of collective action occurs among civil society groups and this forms an essential part of the collective action architecture of modern civilised societies.

Other examples of social governance in the UK include:

- Associations like the Football Association, which coordinates the activities of the football leagues and agrees the rules of the sport;
- Professional bodies like the Institute for Chartered Accountants in England and Wales (ICAEW), which coordinates accounting conventions;
- Trades unions;
- The Driver and Vehicle Licensing Agency (DVLA), which ensures that cars and drivers on the roads are roadworthy; and
- The National Air Traffic Services (NATS), which is responsible for air traffic control in the UK.

It is noteworthy that the examples above range from fully private (corporations) to fully public (government departments). For example, the Football Association is independent of government whereas the DVLA is a government body. By contrast, NATS is a public-private partnership.

One special form of governance which is excluded from the above list but which plays a critical role in all civilised societies, is the judiciary. The institutions of the judiciary have a central role in enabling individuals (people and / or legal entities) to act collectively through enforcing private agreements. Importantly, a substantial amount of collective action in devolved, capitalist economies is bilateral and private in nature: the judiciary is used to enforce such contracts when necessary. Because it enables collective action, the judiciary can be included in our social governance architecture.

We could think of many more examples of social governance. The important point is that such bodies or processes enable first-order, real world collective action.

3.3 Higher-Order Governance

In thinking about collective action and forms of governance, it is helpful once more to refer to Ostrom's discussion of orders of collective action.

Ostrom [8, p. 52] mentioned that first-order collective action problems are resolved through operational rules (or norms) being realised on the ground. Such problems fail to be resolved when appropriate rules are not devised (the second-order problem again) or when they are not effectively enforced. Indeed, Ostrom noted how fishermen around Bodrum in Turkey were able to form and abide by credible agreements whereas, in the Bay of Izmir, fishermen did not, which resulted in a depleted resource. This is an important point: collective action is not guaranteed.

The second-order problem concerns what Ostrom called collective choice rules, which indirectly affect operational rules:

> '[Collective choice rules] are the rules that are used by appropriators, their officials, or external authorities in making policies—operational rules—about how [the resource] should be managed.' [8, p. 52].

Note, however, that an organisation might be formed with the responsibility and discretionary power to change the operational rules. This same organisation might also be involved in monitoring and enforcement. In the case of Bodrum's fishermen, this might simply be a monthly meeting of selected fishermen, with responsibility to make enforcement decisions, and to decide whether operational rules should be adjusted.

Note that the decisions about rules or organisations (or both) to resolve the second-order problem will be context-dependent. In predictable circumstance, rules might be sufficient; whereas in changing (unpredictable) environments, discretionary decision-making might be preferable.

Ostrom takes this thinking a level yet further, defining a third order of governance, with constitutional choice rules that:

> affect operational activities and results through their effects in determining who is eligible and determining the specific rules to be used in crafting the set of collective-choice rules that in turn affect the set of operational rules.

In the fisheries example, a constitution might be written which constrains the fishermen who make up the committee that meets monthly.

These references to higher orders of governance in Ostrom's work are important here because they show that hierarchies of governance are possible and often necessary (the counterpart risks of excessive bureaucracy and exploitation will be discussed in Sect. 4). To that end, we often see boards of directors in private corporations delegate the implementation of corporate strategies to the executive directors. Individual executives might then further devolve tactical implementation, and so on, until things are actually done. We see governance hierarchies in many other parts of social governance.

The last point to make in this section is that governments could be viewed as merely manifestations of many institutions in a society's social governance portfolio. As mentioned in the introduction, national governments have one characteristic which other social governance institutions do not have: a legal monopoly over the use of force within national boundaries. This characteristic means national governments have a special place within social governance, but it does not tell us in detail what that role should be. Before we speculate about this, let us first deal with 'the libertarian's challenge' because it raises some important questions.

4 The Libertarian Challenge

In this section we will focus on two critiques of government, which are best expressed through libertarian philosophy. This philosophy goes well beyond these two critiques but for our purposes these two critiques are useful.

4.1 First Critique of Libertarianism

The first critique of libertarians is that collective action is not necessary and, therefore, governance and government is not necessary. From this perspective, society can be viewed as merely a collection of individuals who can choose to interact or not. We can think of this as an extreme reductionist interpretation of social systems since the 'whole' of such a society would be viewed as the sum of its parts. Margaret Thatcher's famous quotation comes to mind here: 'There is no such thing as society. There are individual men and women, and there are families.' [5].

To be fair to libertarians, very few of them actually believe in this extreme opinion, so it is something of a 'straw man' (this perspective would also be more closely associated with anarchism). E.g., in his Constitution of Liberty, Friedrich Von Hayek (seen by many as the quintessential libertarian) made a powerful argument for freedom and against top-down statism; but he also included references to the need for people to self-organise, which looked a lot like collective action.

It follows from the above sections that this first critique is rejected here. It was argued in Sect. 2 that evolution appears to have selected for structured (networked) populations, which are able to cooperate (act collectively). This means interaction is inevitable, and this gives rise to certain problems. In addition, Sect. 2 also argued that corporations have had a central role in the economic success of capitalist economies, and these are forms of collective action.

4.2 Second Critique of Libertarianism

The second critique of libertarians recognises that, while collective action can have benefits, for example in the provision of public goods, governance and government concentrate power, and this will be abused. Put another way, collective action can have value but we are not very good at it.

This second critique is important because it highlights a possible downside of collective action: the exploitation of power. So far this essay has has taken a functionalist stance toward collective action: this second critique offers one counter-argument.

Exploitation of power within this process of collective action can arise in two broad ways: (1) *ex ante*, power might be exercised when rules or organisations are formed, resulting in institutions which benefit those who have power already; and (2) *ex post*, the exploitation of any discretionary power built into an institution. This second form is *ex post* because it is the agreement to concentrate discretionary decision-making which concentrates power.

These are valid risks but this second libertarian critique assumes that the exploitation of power is inevitable. Is this correct? We will argue that while power exploitation is a possibility, it is not inevitable: it depends heavily on the informal institutions (ethics, morals, norms) existing among the people concerned. Power exploitation is only inevitable if the people involved are rational egoists: the selfish utility maximisers of orthodox economics.

In terms of (1), the ex ante exercise of power, it should be clear that collective action is not responsible for any power dynamics prior to some collective act. In many circumstances, people can choose whether to act collectively or not. For example, if the richest fisherman gets most of the fishing rights in Bodrum, it still might be in the interests of other fishermen to agree to act collectively because it protects the stock of fish. If credibly enforced, such an agreement might be pareto efficient despite pre-existing inequity. Else it might be possible for the less powerful to veto the agreement if it worsens their position.

Of course, there may be circumstance where less powerful individuals will be forced into agreements which lessen their power and makes them worse off. It is impossible to generalise about this point because circumstances differ. In any case, it is far from clear that collective acts will necessarily worsen power relationships in these types of situation.

With regard to (2), the *ex post* exercise of power, this is a more difficult subject, and a detailed evaluation of all relevant arguments is beyond the scope of this essay. Nonetheless, there are a number of points worth emphasising.

First, there is an argument that it is a role of higher forms of governance to monitor lower forms, and to sanction when power is being abused. This means that the possibility of power exploitation could itself be an argument for (higher order) collective action.

Clearly, however, there is a limit to levels of oversight: we have to draw a line somewhere, and the people at the highest level might abuse their power in some way e.g. by taking bribes from the people they are monitoring. Furthermore, there is information asymmetry to consider: higher orders of governance will know less than lower orders about their environment and behaviour. This is the well-known *Principal-Agent Problem*, which implies there is a limit to the value of higher orders of governance.

Second, the second libertarian critique presumes rational egoists. Importantly, the second-generation of collective action literature, and also the literature concerned with informal institutions, have both gone well beyond this assumption. Not everybody is a rational egoist.

Ferguson [2] described how behavioural economists have moved from rational egoists to *instrumental reciprocity* where agents cooperate with others but on a contingent basis. This was described by Samuel Bowles [1] as 'hidden selfishness' because people were still viewed as essentially self-interested.

Moving beyond instrumental rationality, behavioural economics refers to *intrinsic reciprocity*, which is when agents' internal models include other agent-regarding preferences. Put another way, this is when people genuinely care about others' well-being. More broadly, behavioural economists now talk about social preferences, which Ferguson [2] described as being about other-regarding preferences, process-regarding preferences (such preferring to earn £100 over stealing £100), and inequality concerns.

So we see there is now a deep literature in economics concerned with new forms of rationality, where cognition is not merely about selfish utility maximisation. This literature undermines the assertion in the second libertarian critique that power exploitation in institutions and government is inevitable.

As previously mentioned, there is a deep literature concerned with informal institutions. These are the moral values and norms of behaviour which we inherit from (and perpetuate within) our societies. It is clear that these have an important influence on how we frame circumstances and also the choices we make. Note also the connection to formal institutions, which is the subject of this essay: certain moral values can be viewed as types of institution because they help overcome collective action problems; but they are informal, so to speak. For example, if moral values against murder and assault are pervasive then it means people do not have to take measures to mitigate the risk of murder or assault. In the UK I do not have to carry weapons or travel among armed groups for protection.

What the economics and informal institutions literatures emphasise is that the likelihood of power exploitation depends on the society under consideration. Most importantly, do informal institutions help to counter information asymmetries and the possible rewards of power abuse? In some societies it seems possible to create and maintain formal institutions where power abuse is mitigated by informal institutions such as moral principles, or emotional considerations like loyalty and patriotism. In others, it is not possible e.g. where corruption and nepotism are widespread. The crucial point here is that the ideal nature and scale of a government of some population is contingent on the informal institutions of that population.

In conclusion, the second libertarian critique discussed here is particularly important in our analysis of collective action and government. The exploitation of power by those involved in institutions with discretionary decision-making power is a risk. But it is not inevitable. Indeed, this issue helps point to the significance of informal institutions in helping to regulate and mitigate such behaviour.

5 The Complexity of Government

Given the plethora of social governance architecture in many countries, we are left asking the question: what, if any, should the role of government be? This section uses the material above to suggest a few tentative ideas. It also articulates the case for a complexity science approach to collective action, institutions, and government.

5.1 Tentative Ideas

Here we discuss eight points concerning national governments and collective action (in no particular order).

- *Doing it Versus Enabling it.*

  The foregoing discussion shows that governments do not necessarily have to do first-order collective action: they can just enable it. This might sound obvious from the above discussions but these two can be easily conflated.

  Moreover, the term ‘enabling’ can cover a number of things, depending on the context, e.g. setting up a new institution to tackle a collective action problem, funding, making changes to legislation, etc.

  Put another way, a government could play the role of second or third-order governance, or even higher orders if that were appropriate (and not bureaucratically cumbersome).

  The most obvious area where national governments should take an enabling role rather than an executive role is in regional and local government. These ‘levels’ will have their own idiosyncratic collective action problems: national governments will not be as well informed as those ‘closer to the action’ so it would be inappropriate for national governments to be executives.

  Another example of enabling collective action is the law concerning organisational forms. There are many organisational forms allowed by law in the UK, e.g. companies limited by guarantee, public companies, charities, community interest companies, etc., and the British government has a role in designing suitable legislation. Fisher and Ormerod [3] argued that the economy is constantly changing so what organisational types are suitable is also changing. Moreover, these pieces of legislation (like the Companies Act) have an important influence on the ability of people to form organisations i.e. to act collectively.
- *Doing National Collective Action*

  National governments can be involved in first-order collective action but this should apply to national collective action problems. Examples will include well-known public goods like national defence and national infrastructure planning. But more complex collective action problems like recessions and banking crises might also be considered national, requiring a national response.
- *Involvement in Inter-National Collective Action*

  With the internationalisation of societies across the globe, more collective action problems straddle national boundaries (and these phenomena might increase). Importantly, this does not mean an international government is necessary but it does mean that forums for interaction are required to help coordinate international collective action. Obvious examples include certain environmental problems (like Ozone depletion), international banking crises and international recessions.
- *Getting Out of the Way*

  Collective action across society is not only about national governments and the public sector. Most collective action is bottom-up, bilateral and private.

One aim for all governments ought to be not disrupting socially constructive forms of collective action.

Indeed, Ostrom [8] included eight "Design Principles for Enduring Common Pool Resource Problems' Institutions". The seventh Principle was:

> '7. Minimal recognition of rights to organize.
> The rights of appropriators to devise their own institutions are not challenged by external government authorities.' [8, p. 90]

These eight principles were abstracted by Ostrom from a substantial amount of empirical work concerned with common pool resource problems. This seventh principle can be thought of as an important lesson from that empirical work.

- *Disrupting Damaging Collective Action*

  Cartels and racketeering are examples of collective action which is disruptive to society as a whole. One aim of national government should be to either disrupt (directly) such behaviour; or to enable the disruption of it. In British society, many of these types of behaviour are illegal and the police are tasked with preventing it.
- *A Unique Role Concerning Enforcement*

  As mentioned above, one characteristic of national governments is that they have a monopoly over the use of force within national boundaries.

  Force is an essential component for the credibility of many institutions because without the ultimate threat of being forced to adhere to an agreement or rules, or to adhere to sanctions for reneging on agreements or breaking rules, then institutions will lack credibility. In many instances, sanctions will fall short of physical force, e.g. paying a fine for a motoring offence; however, physical force often results if a series of sanctions are evaded. If I refuse to pay a fine then a magistrate might order my bank to pay the money from my account. If I close my bank account beforehand then a magistrate might order my employer to pay it directly from my wages. If I am self-employed, I might be able to avoid this, etc. Ultimately, a judge might order that I am imprisoned by force but, *ex ante*, knowing this is likely to make me pay the original fine.

  This ultimate sanction of physical force is necessary in many agreements and it can even be used in private, bilateral contracts e.g. bailiffs are given permission by a state official (usually a judge) to use reasonable force to remove property but, importantly, they do not have discretionary power. If national governments have a monopoly over the use of force then they must play the ultimate role in the enforcement of institutions, rules, agreements, etc., across the whole of society. More often than not, such physical force is delegated to the judiciary to decide over and for the police to execute.
- *Government Scope and Informal Institutions*

  It is tempting to frame these discussions as if the role and scope of government ought to be the same in every country. However, the discussion of informal institutions above tells us this need not be true.

  We saw that informal institutions can help to mitigate the various risks of power abuse which might arise in formal institutions. This means that in countries with generally strong moral values, e.g. concerning abuses of power such as corruption or nepotism, the ideal scope of government could be broader than in countries with weaker moral values. In fact, we might say that the closer we get to people being extreme rational egoists, the closer the ideal scope of government gets to libertarian philosophy.

Clearly, of course, the weaker a society's moral values are, the more it is likely a government will try to expand its power since this increases the scope of officials to expropriate value from society. So the idea of small government in such countries might be infeasible. But what should be clear from this is that countries with strong informal institutional foundations ought not to be constrained by the assumption of rational egoists.

- *Power and Governmental Processes*

  Power exploitation is not the only risk for governments. Another is the exercise of power to shape collective action, including public policy. This has traditionally come in two forms: the funding of political parties and lobbying for particular outcomes.

  This is clearly not new. It is mentioned here to emphasise the point about power dynamics and the need for governments to mitigate these. A notorious (but certainly not the only) example of financial power influencing policy is the US Congress, where Congressmen have to raise millions of dollars to fight election campaigns and where corporate donations are allowed. This sets up a positive feedback loop for power: the financially more powerful in a society influence the institutions to give them more power.

5.2 Complexity Science

An important premise of this essay is that one of the major roles of government concerns collective action. This includes directly executing types of collective action and also enabling it when government takes on higher-order roles. This process of overcoming collective action problems also includes institutional formation. These might include rules, laws, regulations, and organisations with discretionary decision-making power.

It is useful at this point to highlight what two leading thinkers in collective action and institutions have written about their fields.

> 'until we gain a better conception of the individual actor within [policy] settings, which is likely to be a much more complex theory of the individual, we cannot move ahead as rapidly as we need to. The entire theoretical structure is likely to be one of complexity starting with complex models of individual behavior through complex models of structural interaction.' [10].

> 'The study of the process of economic change must begin by exploring the ubiquitous efforts of human beings to deal with and confront uncertainty in a non-ergodic world.' [6]

Ostrom's quotation explicitly refers to the need to develop better complex foundations for understanding collective action, whereas North's quotation is about dealing with uncertainty. His reference to non-ergodic systems is about systems that exhibit unpredictable and novel features, which means the future is not a perfect reflection of the past. This sits extremely well with complexity science because it studies such systems.

The key point to be made here is that complexity science offers a valuable way of reframing collective action and institutions, and from this better theories of government could emerge.

The study of collective action has to date been mostly non-complex. This was noticeable in the definition of collective action problems in Sect. 3: the definition implied that people make their decisions independently of each other, and that the value of collective action is the sum of all individuals' value gained from it. This is a reductionist framing.

Complexity science tell us that aggregated behaviour should not be our only concern: we must also consider *networked behaviour*. We saw this in Sect. 2 where Smith's pin factory included a social network of structured interactions which helped it achieve its aim. Complexity scientists would say that organisations are not merely an aggregation of individuals; rather we might think of them as a form of networked collective action. The value of the organisation will be an emergent property of the parts and their interaction. But this does not fit Ostrom and Ahn's definition.

Collective action is about *interaction* and *adaptation* by individuals; the *emergence* of institutions (the system organising itself), which is about *patterns*—or *networks*—of interaction; and it is about the *evolution* of this structured interaction over time, which features *uncertainty and far from equilibrium conditions*. The various italicised words in the last sentence are all concepts or subjects of study in the complexity sciences.

Reductionist strategies can only go so far to understand systems which exhibit these complex features. This includes social systems. If we are to develop better theories of government it will be important to first reframe the field of collective action, and then explore the role of government within complex social systems.

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The Room Around the Elephant: Tackling Context-Dependency in the Social Sciences

Bruce Edmonds

Abstract Context is crucial for understanding social phenomena, but is not being addressed. Contexts can become socially entrenched and acquire their own labels, allowing different social coordination systems to be developed for different kinds of situation. Three ways to avoid context are discussed. Fitting data to mathematical models which 'explain' the data using significance tests avoids the problems of context, but may average over different contexts inappropriately. 'Behavioural foundationalism', which assumes a generic model of behaviour that is valid across different contexts, avoids the context problem by producing models based on a micro-specification to see if the macro-consequences match the available data, e.g. neo-classical decision theory and some agent-based simulations. A third strategy to avoid the context problem is to retreat into specificity, providing so much detail that the context is unique with no attempt at generalisation. Three ways forward are proposed (1) using data mining techniques to look for models whose output 'fits' various target kinds of behaviour, (2) context-dependent simulation modelling, with the memory of the agent being context-sensitive, and context-relevant knowledge and behaviours being applied in decision-making, and (3) combining qualitative and formal approaches, with neither qualitative nor quantitative evidence being ignored. Agent-based modelling can use qualitative evidence to inform the behavioural strategies that people use in given situations. Simulations based on micro-level behaviours can produce numbers for comparison with macro-level quantitative data. This supports experimentation to understand emerging processes, and investigate the coherence of the qualitative assumptions and the quantitative evidence. Explicitly recognising and including context-dependency in formal simulation models allows for a well-founded method for integrating qualitative, quantitative and formal modelling approaches in the social sciences. Then some of the wealth of qualitative ethnographic, observational and interviewing work of the social sciences can enrich formal simulation models directly, and allow the quantitative and the qualitative to be assessed together and against each other. Before the advent of cheap computing power, analytic mathematical models were the only formal models available, but their simplicity ruled out context dependency, leading to a focus on what generic

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models might tell us. New information and communication technologies have resulted in a lot more data on social phenomena to distinguish different contexts and behaviours. We no longer have to fit generic models due to data paucity and limits to storage and processing, or ignore context or over-simplify what we observe to obtain and use formal models. Addressing context has huge potential for the social sciences, including: better models and understanding of human behaviour; more effective ways of collecting, integrating and analysing data; and the prospect for a well-founded means of integrating the insights from quantitative and qualitative evidence and models.

1 Introduction

That context is important for understanding social phenomena is uncontroversial, yet dealing with it has been largely avoided. Quantitative social scientists tend to fit data that originates from a variety of contexts with a single model (e.g. variants of linear regression) on the grounds that they are only interested in generic patterns. At the other extreme, qualitative researchers interested in rich descriptions of observations and experience take context seriously, ensuring that they include a lot of the context in what they record and discuss, but tend to resist any generalisations that cross contexts. The point is that a crucial issue is not being addressed: that of context-dependency itself.

Let us start by making clear what everybody knows: people behave differently in different kinds of situation, but can effectively recognise situations and use them to understand, and even predict, what people will do in these situations. For example we all recognise a lecture and know the social norms, habits, conventions, roles etc. that pertain there. If the lecture is declared finished and coffee or wine served to celebrate then something about the context has changed and everybody will behave differently. To take another example, traders in a stock market behave very differently during a bull and bear market (e.g. Kim and Nofsinger [15]). In a bull market it is relatively easy to make money and traders might seek to maximise their profits and endure quite high risk. In a bear market traders are in danger of losing their job so it might be more important not to be the worst performer in their group. In both cases understanding behaviour is much easier and more effective in the different contexts. So why don't *quantitative* social scientists pay any attention to this common-sense knowledge? Similarly, we all are able to recognise the difference between a lecture and a celebration, or traders between a bull and a bear market and, without thinking about it much, apply the appropriate knowledge to each. So why don't some *qualitative* social scientists accept the reality of generalising over particular kinds of situation?

This chapter highlights the importance of this issue, critiques approaches that seek to circumvent it, tries to make some useful distinctions and show some practical ways in which we might seek to understand it. In the process it indicates the huge potential for the social sciences, including: better models and understanding of human behaviour, better recognition of the potential for self-delusion in terms of progress, more effective ways of collecting, integrating and analysing data, and even the prospect for a well-founded means of integrating the insights from quantitative and qualitative evidence and models.

2 About Context

Context is a tricky word to use and a tricky phenomenon to pin down. Like other notorious C-words (‘complexity’, ‘creativity’) it is often used as a ‘dustbin’ concept—what one evokes when one’s normal explanation fails. Its occurrence in a paper can be effectively a ‘flag’ to indicate that the research is qualitative since context is emphasised in the qualitative social sciences yet downplayed (usually ignored completely) in the quantitative social sciences. Context is used largely informally and hence has lots of subtly different usages, as documented in [13]. Finally it is not clear that a particular context can be reliably reified and talked about as an object at all. These difficulties may explain the reluctance of researchers to engage with context, knowing it is a notoriously slippery and difficult subject—better to avoid the swamp and only play on firmer ground. However, with a little care, the idea and its manifestations can be sensibly and usefully dealt with, and the potential pay-off for the social sciences is immense.

‘The context’ can refer to the exact situation one is in Barwise and Perry [3]. This could be indicated by the exact coordinates and time, but this is not a very helpful notion. The details that could be potentially relevant to any series of events in any situation are indefinitely extensive. Rather it is usual to abstract from specific situations to kinds of situation, e.g. going home on the train, or shopping in a supermarket. The question ‘What was the context?’ implies that the speaker does not have enough information about the situation to understand an utterance or text. The answer to such a question would not be to specify the precise situation but to give enough information about it to characterise the kind of situation one was in (e.g. ‘I was talking on the phone to my mother’).

The fact that we can give enough information in a few words for the recipient to be able to infer the right kind of situation indicates that such recognition is not only feasible but also normal. It is well established that many aspects of human cognition are highly context-dependent, including: memory, preferences, language use, language comprehension, decision-making, perception and reasoning. This implies that the brain has learned to reliably recognise these kinds of situation as effectively the same kinds as others do. The cognitive correlate of the kind of situation is called the *cognitive context* [13].[1] Though we, as individuals, do this unconsciously and with great facility (at least after childhood) we do not know how the brain does this and it may be that it is very hard to replicate this

[1] ‘Internal’ factors such as emotion and current goals may also be inputs to determining this.

recognition explicitly.[2] However this ability allows for the following heuristic: to learn knowledge with respect to its cognitive context, give preferential access to that knowledge when the same cognitive context occurs. Thus when we enter a lecture we do not have to ‘sift’ through all the social norms we have learned since the relevant ones automatically comes to mind in that situation.

Although cognitive context maybe be infeasible to determine in many cases, there is one case where this may be much easier—that where the context has been co-determined across many individuals in a society so that everybody recognises the same kinds of situation. Examples include: the lecture, a celebration, commuting within a shared vehicle, religious ceremonies and an interview. Over time, specific norms, habits, language, spaces, technologies and even clothing might have been developed for that kind of situation, allowing the particular context to be more easily distinguished. Of course, the reverse also happens: the more easily a particular context is distinguished the more easily we will recognise it and develop specific practices, technologies and methods of coordination for it. Thus, over time, some contexts can become socially entrenched, acquire their own labels and be explicitly talked about. For this reason such ’social contexts’ are much easier to identify and study. Such social contexts can be very important since they allow for very different systems for social coordination to be developed for different kinds of situation. For example, how one coordinates behaviour on a fishing boat during periods of calm might be very different when a storm is approaching.

As with many social phenomena (e.g. social norms [22]), social contexts are manifested both at the level of observable practice as well as having cognitive correlates. In this case there may be both the unconscious correlate, the kinds of situation automatically recognised by individuals, as well as an explicit and conscious recognition of well-entrenched social contexts. The former might be recognisable through the fact that many aspects of behaviour change together with that context, since different habits, norms, expectations, and knowledge may be associated with the same context. Some of these will be specific to an individual, but others will be shared by more than one person. However even if they are shared only some of them will be entrenched to the degree that there is explicit conscious recognition of them.

Due to the difficulties involved in studying context, and a simple wish to avoid the extra complexity implied, researchers have tended to avoid dealing with context head on. A number of common research strategies have this effect. These will be discussed in turn before considering some positive ways in which context could be tackled.

[2]Thus it may not make sense to assume that ‘the context’ can always be reified as a distinct object that can be referred to.

3 Avoidance Strategy 1: 'Signal Plus Noise' Data-Fitting

Researchers who claim to be 'only interested in generic behaviour' may choose a model and 'fit' some data to it[3] to see how good the fit is (or whether it has a better fit than an alternative model). The variation from the models is then attributed to 'noise', which is usually represented as some kind of randomness. Typically the same relatively simple model is fitted to the whole available data set and an assessment made of the extent that it 'explains' the data and the likelihood that this fit is by chance (the, so called 'significance' tests). In the social sciences these are often variants of linear correlation models, though others variants also exist such as the use of the 'POMDP' class of models [14].

The problem with this approach is when generalisation occurs over different kinds of situation where different kinds of strategies are being exhibited. Then the generic model is averaged over different kinds of behaviour—producing a composite behaviour that might have elements of all of them, but misses essential structural information about what is being observed. Some of the variation due to the different contexts being 'averaged' over will be represented by the noise from this generic model.

A simple abstract example can illustrate this problem. Say there are two kinds of situation that occur within a sample of data: type A and type B. Within type A, variable a is strongly correlated with outcome x and variable b is weakly anti-correlated with outcome y. Within type B the opposite occurs: variable a is weakly anti-correlated with outcome x and variable b be strongly correlated with outcome y. If types A and B occurred with roughly equal frequency, a generic correlation model relating a & b to x & y fitted to the complete data set might come to the conclusion that a is weakly correlated with x and b weakly correlated with y for the whole domain at a significant level. This is illustrated below in Fig. 1. In this way a lot of valuable information has been lost compared to a composite model that fitted separate models for each type. Comparing the generic model to the composite model one would find that the generic model is not as strong, and it misses the fact that there are parts of the situation with anti-correlations. Even an approach which included a variable to say whether a point belonged to type A or B would not help unless it was able to 'switch' on and off the appropriate parts of the generic model.

If one imagines fitting a generic model over a great many kinds of situation, the expected result would be that many variables would be correlated with many others at a significant level, but only explain a relatively small level of the total variation. This is, indeed, the result of many exercises that apply generic models to data that may cover many different kinds of situation.

Not only has a lot of information been lost, but any policy based on the analysis might be much more ineffective or even counter-productive for sub-groups of the population. Consider the case where there were twice as many of type A than of type

[3]There are different measures of fit of varying sophistication, e.g. likelihood measures, but they all quantify the difference between the data and a model in different ways.

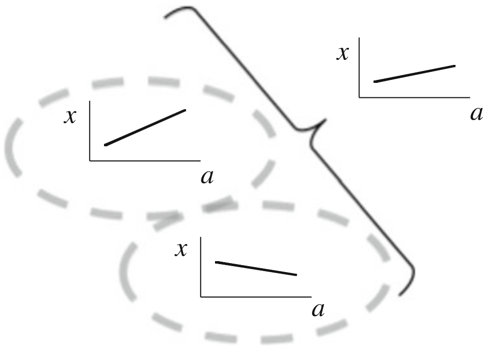


Fig. 1 An illustration of averaging out context-specific trends into a generic model

B. Then a generic correlation model fitted to the data might be such that variable a is weakly correlated with x but there is no overall correlation of b with y. If the objective of policy is to increase x and y then the inferred strategy would be to increase a only—despite the fact that this would have the contrary impact in a third of the cases. If there were a technique to detect that there were two different groups and the determine what model of behaviour fitted each this might give a finer grained understanding of data allowing a more effective targeting of policy. Of course if it turned out that there was a substantial commonality between the separate models inferred it might make sense to combine them into a generic model.

4 Avoidance Strategy 2: Behavioural Foundationalism

Producing models based upon a micro-specification to see if the macro-consequences match the available data assumes that there is some generic model of behaviour that is valid across different contexts. The idea seems to be that there must be some generic cognitive model, albeit complex, that changes when the input to that agent or unit changes. The assumption that there must be a generic underlying model will be called *behavioural foundationalism*.

For example, neo-classical decision theory reduces all decisions between choices to a single model: that of a utility comparison of the consequences of decisions. More complex or social decisions are implemented by more complex utility functions. However, this approach excludes any examination of the process by which decisions might be made.[4] These may be different in different circumstances—processes that might have very different collective outcomes from each other. For example, a process of individual consideration of the options and a social one of looking what others are doing and imitating those who are most successful might have a similar individual outcome but a very different collective outcome.

[4]This is Simon's distinction between procedural and substantive rationality [19].

If many are following the imitative strategy then there may be waves of innovations spreading across the population [9–11].

Whilst in a biological sense humans have roughly the same equipment for making decisions—the nervous system—this equipment takes years of external input and training before it is useful for making decisions. This suggests that a generic model of decision-making would have to be similarly complex and able to learn different strategies for different kinds of situation. There is ample evidence that many aspects of human cognition are context dependent, including: memory, decision making, language, preferences and perception (e.g. [16, 20]). One suspects that neo-classical economists hoped that they could produce physics-like models, by-passing the complex and messy ways people actually make decisions, to find a short-cut that deals with analytically modellable processes.[5] However it has not had good empirical success. There are now so many exceptions to the received pattern of economic rationality that we should start to question whether this is the right starting point, or whether this dogma might be better abandoned.[6]

Many doing agent-based simulations are just as guilty of assuming a simple generic model of behaviour as neo-classical economists. Again this seems to be justified by an assumption that a more abstract model will be more general.[7] This is no more than a convenient hope. Whilst it might be true that adding empirically-based detail into a model might make it less general, the reverse does not work—simplifying away detail does not mean one achieves greater generality. The reason for this is clear—when simplifying one does not know a priori what detail can be safely abstracted away. If one removes something essential to the phenomena being studied then the result is a model that does not work for any observed cases, i.e. with no generality at all.[8]

A problem here is that an abstract model may often seem to be potentially applicable to a wide range of cases, but not in a precise manner. Here the computational model is used as a kind of analogy, i.e. what the model refers to is not precisely defined but is left to each interpreter to construct 'on-the-fly', with each person interpreting it in a different way. This is in contrast to a model where its relationship to what might be observed is well defined. Analogies provide very useful ways of thinking about a situation but do not give reliable or testable knowledge. Success as an analogy does not give any guarantees that a more concrete

[5] I have sympathy for those wishing for formal models, since this allows for a developmental process of comparison, critique and improvement between researchers, and to make such models analytically tractable did require strong assumptions. However, the advent of computer simulations removes this difficulty.

[6] One might argue that wheels should be square, its just that they need the corners rounding off, just as one might have argued that planetary orbits should be circular, they just need adjustment using epicycles of other circles However at some point the evidence rather than tradition needs to predominate if we are to be a science.

[7] Although one suspects that the real reasons are more constraints of time and complication.

[8] Imagine abstracting away the variables from a linear model and just leaving the constant, this has not resulted in a more general model, but one with a greatly restricted scope.

version will be able to establish a more direct relationship with anything observable. In particular, a more abstract model of behaviour that appears to have general applicability when used as an analogy may have less scope than one that is specific to a particular kind of situation when used as a model with a defined relationship to real-world data. It may turn out that some elements of our behaviour can be understood in a generic manner, independent of the context, but this is something that needs to be justified rather than imposed.

5 Avoidance Strategy 3: Retreat into Specificity

In contrast to the previous strategies, many qualitative approaches pay a lot of attention to context—this is often described and included in their accounts and is by no means an afterthought or avoided. Indeed context is often deemed so important that any possibility of generalisation to a different context is avoided, since each context is unique. Thus one might have some high-quality observational or ethnographic work describing individual behaviour and strategies within a specific context but without any indication as to what could be learnt that might be useful elsewhere.[9] Generalisation is often left to the reader with only the mildest of generalisations made by the researchers themselves.

This is a highly defensible stance since generalisations are risky and open to criticism by others. By keeping to discussion of phenomena only within specific contexts one can counter any objection with regard to the unique circumstances within the observed contexts—contexts that the researcher has unique access to.[10] Here we have the opposite problem to over-generalisation, the situation where almost nothing is generalised at all.[11]

In order for any knowledge to be useful one needs to have some idea as to when it is applicable. Thus although detailed qualitative observations can expand our ideas of what people do in different situations, we then need to know something about the other kinds of situation where they might also exhibit this behaviour for this knowledge to be useful.

[9]The exception is negative knowledge, counter examples to assumptions made by others, but this just leads to the conclusion that we know nothing except specifics.

[10]Even if others have observed the same general kind of situation it can always be claimed that this was at a different time or involving different actors with different goals.

[11]To be precise, specific observations might be accompanied by imprecise and analogical discussion without specific referents but this is also immune to being wrong (except in many missing out a favourite dimension of a reader) and does not help in the identification of context and when knowledge can be reliably used elsewhere.

6 Way Forward 1: Data-Mining Clues to Social Context

As indicated above, one of the difficulties in dealing with context is identifying what cognitive contexts are relevant to which observed situations. Sometimes, if the context is socially entrenched then this may be obvious but at other times it will not be, even to the participants themselves, since knowledge of context is implicit rather than explicit knowledge. Context is sometimes not neatly defined, and may be recognised in a complex but imprecise fashion.

However, the recent accessibility of fine grained data on social phenomena and advances in the field of data-mining and knowledge discovery might provide an approach that would give clues to the existence of scopes of social contexts. The idea is as follows:

1. Use data-mining techniques to identify local patterns/models that fit the data, where 'local' means that the patterns/models have an explicitly identified scope (the conditions in terms of when they hold with respect to the data) [12].
2. Do step 1, for various different target variables—that is look for models whose output 'fits' various target kinds of behaviour.
3. The result of steps 1 and 2 should be a set of overlapping models 'predicting' many different aspects of the behaviour encoded in the data.
4. Within this set look for models which have roughly the same scope—that is conditions (a) within which models seems to fit the data well and (b) which marks a change of behavioural pattern in many different dimensions.
5. The conditions indicated by this 'meta-cluster' of scopes, suggests a context (Fig. 2).

The result might not be clear with a confusion of overlapping scopes of models with no obvious cluster. In this case a commonly recognised context would not be suggested since a context suggests a whole bundle of specific knowledge and habits. There may be 'areas' of the data in which no local models were found, in which case one would have to conclude that there are no accessible patterns there.[12] Also the data needs to be sufficiently fine grain and multi-dimensional for such a technique to gain purchase, but increasingly large and detailed data sets are becoming available.

The suggestions of context that may result from such a process can be combined with qualitative evidence about context in the situations being studied. The use of qualitative evidence is discussed below.

[12]This may be for many reasons: the behaviour might just be too complex, not regular, or different for different purposes. A negative result does not mean that there are no meaningful patterns, just that we cannot detect any.

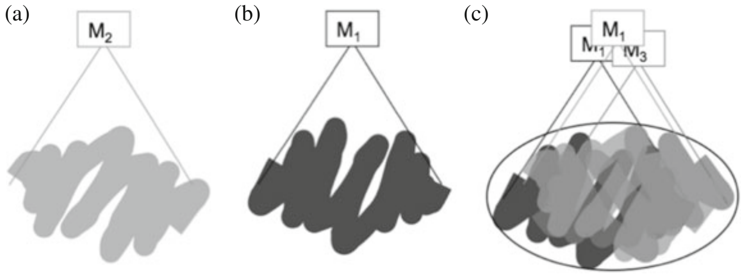


Fig. 2 Three models with different behavioural targets but coinciding scopes suggesting a context (after Edmonds [4]). (**a**) Scope of Model 1. (**b**) Scope of Model 2. (**c**) Plus Scope of Model 3 (abstract to a context)

7 Way Forward 2: Context-Dependent Simulation Modelling

Whilst it is very hard to include context-dependency within analytically solvable models, there is no reason why this needs to be the case with agent-based simulation models. However this requires a bit more 'cognitive' machinery. Instead of each agent having a fixed resource of knowledge or behavioural rules it needs to have different pools of such resources that can be selected depending on the context. In other words, the memory of the agent needs to be context-sensitive, so that context-relevant knowledge and behaviours are applied in decision-making. Although this requires some technical changes, it is quite possible to do, ending up with an architecture as illustrated in Fig. 3. This sort of architecture has major advantages in terms of the feasibility of learning or reasoning, since each of these is restricted to the relevant set of knowledge for that context. It also allows a well-structured integration between context recognition (which may leverage 'fuzzy' machine-learning techniques) with reasoning and belief recognition algorithms (which tend to be crisp, derived more from the field of artificial intelligence).

However such an architecture does impose an extra burden in terms of specifying a lot more knowledge and/or behaviours into the agent for all the relevant contexts. In the simplest case, where one knows what the relevant contexts are and how to recognise them, then the different behaviours can be simply programmed into the agent, along with how to recognise each context.[13] Of course, one does not need a specialised architecture to do this—one could just add more complex rules—but a specialised context-dependent memory might facilitate the process and its checking. In the more complex case, one may not know all the relevant contexts, and the agents might need to induce these themselves. This is more complex but possible [8, 21].

Since the behavioural rules at the micro-level of agent-based simulation can be quite specific, some existing agent-based models have implicitly taken some aspects of context-dependency into account [1, 2, 18]. Each agent in such simulations

[13]This explicit approach is that of CYC [17].

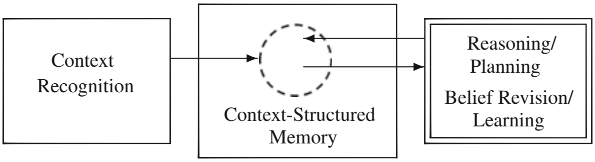


Fig. 3 The basic context-sensitive architecture for agents

does behave with respect to its local environment, and so will behave differently in different situations. However these do not distinguish context from any other perception that might influence behaviour, and hence do not specifically distinguish what can and cannot be shared between what kinds of situation.

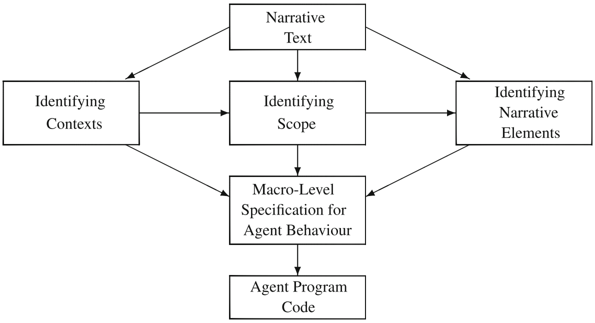
8 Way Forward 3: Combining Qualitative and Formal Approaches

A fundamental value of science is that evidence ‘trumps’ theory, in the sense that if evidence and theory clash then it is the theory that should be discarded or modified. One corollary of this is that evidence should not be ignored without a very, very good reason. Thus neither qualitative nor quantitative evidence should be ignored. Of course, one should judge the significance of data with respect to its nature and how it was derived, for example in terms of its relevance, reliability, subject-dependence, precision, biases due to observation procedure, distortions in the process of derivation and communication and context-dependency. The quality of data is judged in a multitude of ways, with different sets of data having different characteristics. Thus qualitative evidence might have a high degree of relevance and precision concerning events that occurred, but be subject to different interpretations. Quantitative data is not necessarily more reliable just because it is expressed in a formal, precise form, but it may be if the process by which it is derived is carefully controlled and well founded.

Neo-classical economics has been notorious for ignoring evidence as to how people make economic decisions. Often this is done *via* an ‘as if’ argument, which can be roughly expressed as follows: ‘we know people do not act in this way, but *en masse* we can treat then as if they do’.[14]

[14]Examples of economic assumptions that contradict common-sense have been extensively discussed, but this attitude is neatly encapsulated by a review received by Scott Moss and the author from the *Journal of Economic Dynamics and Control* which read in its entirety: “We do not see the point of not assuming that agents know the perfect model of the economy. This is not economics”.

Fig. 4 An example (from Edmonds [5, 6]) of a process of narrative analysis separately identifying context, scope and narrative elements



In the last couple of decades experiments have shown that people do not act as the theory of neo-classical economic decision making would suggest, even in tightly controlled experiments with limited information and simple economic gain.

One problem about using qualitative and quantitative data together is that it has been difficult to use qualitative data in conjunction with formal modelling methods. A second problem is that qualitative evidence is often context-dependent and hence hard to incorporate into a generic model. However agent-based modelling is well placed to use qualitative evidence to inform the menu of behavioural strategies that might be used in given situations. There is now a growing stream of work on methods to make the process of the analysis of textual narrative data into behavioural rules suitable for an agent in an agent-based simulation transparent and systematised.[15]

Once these behaviours have been incorporated into a simulation at the micro-level, the simulation can be run to produce numbers that can be compared to macro-level quantitative data. The agent-based simulation can be inspected and experimented upon to understand the process by which this occurs, and the coherence of the qualitative assumptions and the quantitative evidence investigated. Furthermore, a careful analysis of narrative data can suggest some of the context-dependency of behaviour and, if the agents in the model have a context-dependent architecture (as discussed above) this can be incorporated in a systematic manner into the model (Fig. 4).

Thus explicitly recognising and including context-dependency in formal simulation models allows for a well-founded method for integrating qualitative, quantitative and formal modelling approaches in the social sciences. This enables some of the wealth of qualitative ethnographic, observational and interviewing work that is done in the social sciences to be used to enrich formal simulation models directly, in a way that allows the quantitative and the qualitative to be assessed together and against each other. The complexity of social phenomena will require all our resources to unpick and understand, but facing context-dependency can aid the use of a wider range of evidence without abandoning rigour.

[15] See special issue of the *Journal of Artificial Societies & Social Simulation* [7].

9 Concluding Discussion

Before the advent of cheap computing power, analytic mathematical models were the only formal models available. Solving them or computing answers from them was onerous, so that only simple models were feasible. Their simplicity ruled out context dependency, leading to a focus on what generic models might tell us. Some of those who appreciated the complexity and context-dependency of social phenomena understandably reacted to this over-simplification and went to the opposite extreme, almost deifying context.

Now that we have cheap computing power, none of this is necessary. We no longer have to distort the phenomena we study in order to achieve useful formal models—we are now free to choose the most appropriate formal model, which may well be a computational model such as an agent-based simulation. Cheap computational devices have also resulted in there being a lot more data about social phenomena, both official and informal. We are starting to have enough data to distinguish the different contexts and their behaviours—we no longer have to fit generic models to it due to data paucity and limits to the complexity of what we can store/manipulate, but can retain and use such data. Finally, we can start to use qualitative and formal methods together—enriching each other. There is no longer any need to ignore context or over-simplify what we observe to obtain and use formal models. It has been a long time coming, since the old habits derived from a pre-computational age change slowly. However, the age of context-dependent modelling and manipulation is now within our reach. We no longer have to avoid it and hope for the best, but can start to grapple with its complexity, and so make better use of our data (throwing less of it away as noise) and knowledge (bringing more of it to bear on problems in an more integrated manner). It holds out the potential for more meaningful, more accurate and more useful models of social phenomena. It will seem odd to future generations that we have been so slow to do this.

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Global Systems Science and Policy

Ralph Dum and Jeffrey Johnson

Abstract The vision of Global Systems Science (GSS) is to provide scientific evidence and means to engage into a reflective dialogue to support policy-making and public action and to enable civil society to collectively engage in societal action in response to global challenges like climate change, urbanisation, or social inclusion. GSS has four elements: policy and its implementation, the science of complex systems, policy informatics, and citizen engagement. It aims to give policy makers and citizens a better understanding of the possible behaviours of complex social systems. Policy informatics helps generate and evaluate policy options with computer-based tools and the abundance of data available today. The results they generate are made accessible to everybody—policy makers, citizens—through intuitive user interfaces, animations, visual analytics, gaming, social media, and so on. Examples of Global Systems include epidemics, finance, cities, the Internet, trade systems and more. GSS addresses the question of policies having desirable outcomes, not necessarily optimal outcomes. The underpinning idea of GSS is not to precisely predict but to establish possible and desirable futures and their likelihood. Solving policy problems is a process, often needing the requirements, constraints, and lines of action to be revisited and modified, until the problem is 'satisficed', i.e. an acceptable compromise is found between competing objectives and constraints. Thus policy problems and their solutions coevolve much as in a design process. Policy and societal action is as much about attempts to understand objective facts as it is about the narratives that guide our actions. GSS tries to reconcile these apparently contradictory modes of operations. GSS thus provides policy makers and society guidance on their course of action rather than proposing (illusionary) optimal solutions.

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1 Introduction

The vision of Global Systems Science (GSS) is to provide scientific evidence to support policy-making, public action and to enable civil society to collectively engage in societal action [14].

Policy makers suffer from an intrinsic difficulty when addressing challenges such as climate change, financial crises, pandemics, or energy sufficiency since the impact and unintended consequences of public policy action are increasingly hard to anticipate. Such challenges are global and connect policies across different sectors. Faced with such highly interconnected challenges, societies still tend to address isolated subsystems and so fail to achieve systemic change. GSS can drive change by

- helping develop an integrated policy perspective on global challenges; and
- developing a research agenda to tackle the fundamental research challenges.

Societies are complex multilevel socio-technical systems. Social, economic, political and technical problems occur at all levels, and they interact between local and global levels. No single discipline can address these problems. Instead they require integrating within the new transdisciplinary *science of complex systems*.

By itself science will not solve the problems of policy unless there are ways to establish a dialogue between science and the players in policy, including policy makers and citizens. Although some policy makers and citizens have high levels of scientific knowledge, it is not easy to reconcile the need to implement policies aligned to scientific facts. First, scientific facts are rarely formulated in ways that help stakeholders to use them in a given decision and, often due to their probabilistic nature, scientific facts rarely point unambiguously in one direction towards a decision. GSS attempts to address this issue through *policy informatics*, i.e. data and informatics tools that policy makers and citizens can use in practical ways. Second, not only scientific facts but also societal values and narratives determine how a society acts and how it incorporates scientific knowledge in its course of action. GSS therefore embraces policy formulation and implementation as a *design process* where input from science (models and data) is only one of the pertinent factors. Policy takes place in the context of societal values and narratives of what is required, what constraints there are, why possible solutions will or will not work, and why it is ‘right’ to apply selected or alternative policies. In this context, GSS embraces social media and online platforms as forums for discussion and even considers art as a means of communication and coordination between science, technology, policy makers and citizens.

In democracies the policy makers are the elected politicians supported by technical officers and other officials. There are also unelected policy makers, including the officials of the E.C. and The World Bank. However, in many countries there is a widening disconnect between citizens and those who govern. *Citizen engagement* is an essential element in Global Systems Science. It means that both policy makers and scientists have to enable and facilitate citizens being active in the policy making process and policy implementation.

Global Systems Science has four elements:

- policy-driven questions, policy formulation and implementation, and narratives
- the interdisciplinary science of complex systems supporting policy
- policy informatics—tools and data to investigate and visualise policy outcomes
- coordinating citizen engagement in the policy process.

In this chapter it will be shown how these elements work together to make science operational for policy formulation and evaluation by policy makers and citizens.

2 Examples of Global Systems

The term 'global' suggests that the science of global systems is restricted to phenomena at a global scale. In fact what it means is that for some systems the micro- and meso-level dynamics affect and are affected by the dynamics at the global scale. Thus Global Systems Science applies to policy questions at all levels from the local to the global. The following examples will illustrate this.

2.1 Epidemiology

Individual to individual infection drives epidemics at the microlevel, with disease passed from one infected person to other susceptible non-infected people [20]. Settlements such as villages enable disease to spread at the microlevel. Towns and cities enable diseases to spread at the mesolevel. Transportation, especially air transportation, enables disease to spread at the global level [10]. Health policy is made at all scales. At the global level the World Health Organisation's operational role in emergencies includes leading and coordinating the health response in support of countries, undertaking risk assessments, identifying priorities and setting strategies, providing critical technical guidance, supplies and financial resources as well as monitoring the health situation [41]. At the national scale, governments have committees that assess and set policies to contain epidemics. At the microlevel individuals may self-quarantine, self medicate or avoid people with symptoms of disease. Despite the complexity of epidemics, this is an area where complex systems science has been very successful [6, 12, 35].

2.2 Finance

The financial crash of 2008 showed that economic failure could rapidly cascade across institutions and national boundaries, and that banking and finance are global systems. Financial systems today have complicated networks of claims and obligations linking the balance sheets of organisations such as banks and hedge funds. Sophisticated financial products further increase the complexity. These interdependencies enable amplifying positive feedback where problems in the financial system can snowball and make things worse [8, 9, 11, 17].

Some multinational companies arrange their affairs to exploit the regulations between individual countries to minimise what they pay in tax, sometimes with governments gaming each other [30]. Taxation and tax avoidance are global systems: 'Tax fraud and tax evasion affects us all. It occurs within a country and across countries both within the EU and globally. That is why a single country cannot solve the problem on its own. The EU and Member States need to work more together and internationally to combat the problem at home and abroad' [15]. Taxation is a global system but, ultimately, tax avoidance at the global scale transfers wealth from individual people to individual people at the microlevel.

Beyond this, actors in finance do not act as predicted by the classical theory of economics. They are neither perfectly informed (as acknowledged now by economic theories of limited information) nor do they act 'rationally' in the strict sense of the word [32]. Actors in financial markets are driven by narratives and by collective behaviour (e.g. herding behaviour as the origin of financial crashes) [31]. The behaviour of actors in financial systems is influenced as much by networks as it is with them acting as individuals trying to make rational decisions [33].

2.3 Cities

Cities are systems at a global mesolevel. Top down the mayor of a city manages the many subsystems that impinge on the lives of citizens at the microlevel. Bottom-up the mayor sees the city in an ecology of other cities competing and collaborating at national and international levels. e.g. competing for business, tourism, and even the Olympic Games. Complex systems science already contributes to our understanding of city dynamics, e.g. through new simulation-based land use and transportation models [5]. Also statistical studies show that as city size increases the number of petrol stations per capita decreases, as do the lengths of roads, electricity lines, and other infrastructure. In contrast to 'sub-linear scaling', some social phenomena have 'super-linear scaling' e.g., the average wage increases with city size, as do crime, cases of aids and flu, the number of patents, and many other variables [40].

2.4 The Internet

The Internet exemplifies the 'very local—completely global' nature of global systems. At the local level there are billions of individual users accessing and interacting with the global resource of billions of web pages. There are many intermediate level structures such as companies, organisations, service providers, the Cloud, and governments. Despite its complexity and importance, the Internet was not designed top-down and no-one owns or controls all of it [29]. The Internet enables many global structures to function including finance and cities. It has supported revolutionary changes in social behaviour at the individual and group levels. These range from intense personal interaction through Facebook, to online shopping, online banking, and interactions with government agencies. The Internet makes Big Data accessible and supports an explosion in communications. It is one of the enablers of Global Systems Science.

2.5 Climate Change

The 'Anthroprocene' is *the* global system. The physical behaviour of the oceans and atmosphere is impacted on and impacts on human behaviour at every level, from the hurricanes that rage across international borders to individuals abandoning their flooded houses. The Anthropocene is a geological epoch in which humans have become a dominant driver of Earth System change. It reflects the nature, scale and magnitude of human impacts on the Earth [3]. One of the impacts of human activity is irreversible climate change [38]. The climate is one aspect of a very large very complex multilevel system. It has physical subsystems such as the oceans and the atmosphere, and it has social systems including health, finance, cities, transportation, and policy making. It took many years to get international agreement on the target of the '2 degree goal' signed in Paris in 2015 [13, 39], and it may take many more for this to result in definitive action. A related problem is the unsustainable consumption of the Earth's resources, currently running at 1.6 planets, i.e. it takes the Earth 1 year and 6 months to regenerate what we use in a year [18].

3 Narratives in Global Systems Science and Policy

'Narratives provide the structure by which individuals understand the world, in which they live. They tell individuals which elements and processes are related to each other, how to structure their experience, how to evaluate the other individuals, objects and processes. By knowing their role in narratives individuals know how to behave. Narratives also tell individuals how others are likely to behave. Narratives lead to actions and they thus causally linked to behaviours. . . . Narratives exist at all levels of social reality: micro, meso, and macro. ... the power to edit and control narratives is an important source of control in social processes' [31].

Although policy makers may be committed to evidence-based policy, scientific evidence and theory frequently gets swept up in the evolving narratives of policy. A popular narrative to counter unwelcome scientific evidence and theories is that scientists exaggerate or even falsify their results because they want the next tranche of funding—and sometimes they do!

Irrespective of what scientists say and do, the narratives of policy are evolving all the time. For example, in the UK the narrative of loss of sovereignty to Brussels has been a powerful narrative for decades resulting in the referendum to leave the European Union on 23rd June 2016. Recently this narrative has a potent variant that Britain is being swamped by welfare tourist immigrants from Europe filling its hospitals and taking all the social housing. This narrative may result in a vote for a 'Brexit', despite the counter narrative that European immigrants make a positive contribution to the British economy including staffing its hospitals. Another narrative, supported by most economists claims that the UK will suffer financially if it leaves Europe. This is countered by the narrative that economists are always wrong in their forecasts so that their prognostications are actually strong evidence that the UK will not be harmed economically by the Brexit. At the time of writing, with a few weeks to go before the referendum, the polls show almost equal support for leaving or staying, and that the contradictory narratives of each side are much more influential than science.

To be effective Global Systems Science must understand how the science of complex systems can make a contribution to policy when the logic that drives narratives is not the logic of the scientific process. This will be discussed in Sect. 8.

4 Prediction and Policy

The question as to whether or not a policy will have the desired outcomes involves some kind of *prediction*. However, for many reasons the concept of prediction that has developed in the traditional sciences is not applicable to social systems.

4.1 Point prediction

A *point prediction* says that a system will be in a particular state at a particular point of time in the future, e.g. the laws of physics predict that 1 s after dropping a pebble over a cliff it will have fallen 4.9 m. In contrast, when systems have *sensitive dependence on initial conditions*, even a perfect model is unable to predict its long term behaviour. In a classic paper on the weather, Lorenz writes "two states differing by imperceptible amounts may eventually evolve into two considerably different states. If, then, there is any error whatever in observing the present state—

and in any real system such errors seem inevitable—an acceptable prediction of an instantaneous state in the distant future may well be impossible" [27]. Sensitivity to initial conditions makes point-prediction of long term weather impossible. The best that can be done is identifying the likelihood of weather events in space and time.

4.2 Extreme Events

Conventional science makes predictions by extrapolating the past into the future. For example, the laws of physics are based on observations of the past and the assumption that the underlying phenomenology will persist into the future. Although physical science gives many examples of excellent predictions, there are areas where it does not, e.g. earthquakes and other *extreme events*. Extreme events are characterised by them never having happened before, or happening very rarely, e.g. the 2005 levee failure in New Orleans caused by Hurricane Katrina and a unique combination of design errors, maintenance failures and weather conditions [1]. The financial crash of 2008 was another extreme event, caused in part by new kinds of financial instrument, new kinds of relationship between regulators and financiers, and unknown network structures. Social systems may be predictable when they are behaving 'normally' but cease to be predictable when 'normal' regimes transition to new kinds of behaviour, possibly never seen before.

4.3 Unintended Consequences

European and US biofuel policy provides an example of policy in one subsystem having unintended and undesirable consequences in another subsystem. Motivated by reducing greenhouse gases, polices encouraging the use of biofuels have led to starvation in poor regions of the world as farmers switched from providing food for local people to biofuels for an international market. Here the polices for the European and US Transportation, Energy and Environmental subsystems had an impact on the African and Latin American Food production subsystems, described by the UN special rapporteur as a 'crime against humanity' [25]. As this example shows, apart from believing that a proposed policy will give the desired outcomes, policymakers need to know about possible unintended consequences. This is a *systems* question: will intervention in one subsystem have consequences in another.

4.4 Definitive Predictions are Impossible in Social Systems

Like the weather, the long term behaviour of social systems is also impossible to predict. Not only are many social systems sensitive to initial conditions, but the equations governing their behaviour are not known. For example, there is no formula that can guarantee your stock market investments will appreciate, there is no formula that can point-predict patterns of migration.

4.5 Exploring the Future

Although it is impossible to say definitively what will happen in social systems, it is possible to say what *might* happen and how *likely* it is. Conviction politicians assert that their policy will have one outcome with a 100 % certainty. In contrast Global Systems Science may show that a policy could have one of a number of outcomes and indicate how likely each is. It does this by taking a *systems* approach to representing the world and how it changes [34]. This enables policy makers to explore possible futures and base their decisions on the best evidence available.

5 Systems, Complexity and Prediction for Policy

5.1 Systems

Systems theory is founded on the principle that the behaviour of a system *emerges* from the interactions between the components of the system. A *system* is defined as (1) an assembly of components, connected together in an organised way; where (2) the components are affected by being in the system and the behaviour of the systems is changed if they leave it; (3) the organised assembly of components does something; and (4) the assembly has been identified as being of particular interest. In policy the objectives determine what is of particular interest. The systems approach then asks what things can affect the desired outcome, what things can affect those things, and so on. This establishes the components of the system and their interactions [24]. The *state* of a system is a snapshot of it in time. A series of snapshots give a *trajectory*. Science attempts to reconstruct the phenomenology underlying observed trajectories so that given the state of a system at one time it can determine the state of the system at a future time. The systems approach includes using diagrams representing the state of the components as annotated boxes and the effects of one component on another as annotated arrows.

System diagrams give an overview of how a system might behave, e.g. they may show there are feedback loops where the system can spiral out of control. They can be used to support qualitative reasoning about behaviours, as in Checkland's *soft systems*. Forester's *systems dynamics* quantifies the variables associated with the boxes and mathematical functions with the arrows. This enables the state of each component at one 'tick of the clock' to be calculated from the state of the components at the previous 'tick of the clock'. Repeating this process gives a computer simulation of the evolving states of the system through time. This allows exploration of the consequences of changing the system parameters on possible system futures. This approach was used in the controversial *Limits to growth* study [28] whose critics misunderstood the purpose which was to investigate possible futures rather than predict any particular future. System dynamics is an important step towards understanding the possible behaviour of complex social systems [24].

5.2 Complexity

There is no consensus on the definition of the word 'complex', but wide agreement that complexity can arise when one or more of the following apply:

– many heterogeneous parts, e.g. a city, a company, the climate, markets, riots
– sensitive dependence on initial conditions, e.g. weather systems, investments
– path-dependent dynamics, e.g. evolution, elections, personalities, famine, war
– network connectivities and feedback, e.g. gossip, epidemics, banker networks
– dynamics emerge from interactions of autonomous agents, e.g. traffic, markets
– self-organisation into new structures and behaviours, e.g. ghetto formation
– co-evolving subsystems, e.g. land-use and transport, virus software, design
– globality and multilevel dynamics, e.g. companies, the Internet, revolutions
– confounding behaviour and reflexivity, e.g. disobedience, contrarianism
– unrepeatable experiments, e.g. electing a government, war, having children

Most social systems exhibit some or all of these characteristics. Any one of them can make systems appear complex, but together they can make systems very difficult to understand, predict, control, and manage.

5.3 The Integrative Science of Complex Systems

Conventional science is compartmentalised into domains such as physics, chemistry, biology, psychology, sociology, and so on. Some scientists specialise in a single domain, knowing every aspect of it, drilling down to great depth in research. In contrast to this in-depth *vertical* science, complex systems science involves *horizontal* concepts and integrative research across the domains, as illustrated in Fig. 1. It is interdisciplinary and usually involves teams with complementary specialisms. This interdisciplinarity of complex systems science is essential for policy [19].

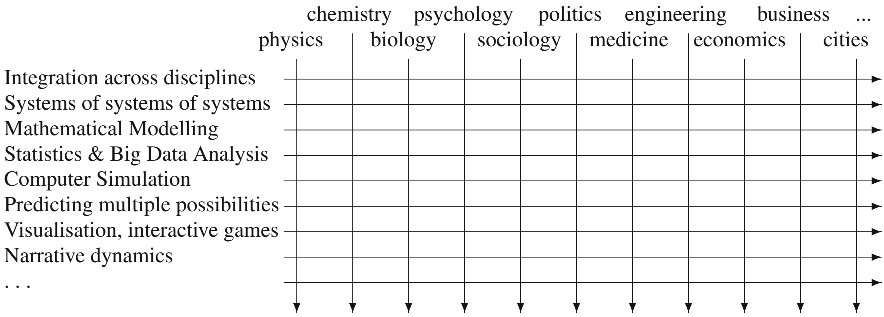

Fig. 1 Complex systems science horizontally integrates in-depth individual scientific domains

6 Policy Informatics: Tools for Exploring the Future

In making science available to policy makers and citizens the methods of Global Systems Science must be embodied in user-friendly computational systems created not by the policy makers but by scientists and professional software providers. In some areas this is already happening. For example, Geographical Information Systems have been used in the public and private sectors for years.

6.1 Data for Policy

Data is an essential part of the information systems needed to support policy. Most countries make their census and other population data available online, with or without charge, and these are the basic data for policy. In recent years completely new sources of data have emerged through telecommunications, social media, e-commerce, and so on. These 'big data' are being extensively researched by the complex systems and computational social science communities and new policy-oriented analytics are emerging.

6.2 Agent-Based Modelling for Policy Exploration

For most policy questions, where there are no formulae to predict future behaviour of the whole system, *Agent Based Models* allow future behaviours to be investigated by computer simulation. The idea is that agents such as people or companies are represented inside computers and their interactions are simulated through time [4]. For example, consider drivers as agents on a crowded road. Each driver adjusts their speed and direction according to nearby vehicles. Given this information at one tick of the clock later it is possible to model the drivers' speed and direction at the next tick of the clock when they are all in slightly different positions. In this way the behaviour of all the traffic emerges, including the 'shock waves' often experienced on long crowded roads when the traffic suddenly slows down or stops for no apparent reason [5]. Agent Based Models (ABM) are also called Multi-Agents Systems (MAS).

ABMs can be powerful tools for examining the behaviour of social systems. Following initialisation, all the interactions can be computed to find the state at the next tick of the clock, and so the evolution of the system can be simulated into the future. The dynamics of many social systems are sensitive to initial conditions and similar initial conditions may lead to very different outcomes. For this reason, simulations are run for many sets of initial conditions to give *distributions* of outcomes. When simulations are run for thousands or millions of sets of initial conditions scientists can probe the space of possible futures. Sometimes these policy-induced futures all look the same, and a policy maker can be confident of the outcome. Sometimes the policy-induced futures can vary considerably, giving the policy maker an insight into the possible outcomes of policy. If some of these outcomes are very bad the policy maker may decide that the possible benefits do not outweigh the risks.

6.3 Synthetic Micropopulations

The behaviour of many social systems requires that they be modelled at the level of individual people. Apart from census data, usually collected every decade, there are very few surveys of everyone in a community. The idea behind creating *synthetic micropopulations* is that aggregate data can be disaggregated to the microlevel with the same statistical distributions as the original data. The first synthetic micropopulations were created for modelling road traffic and air pollution by Barrett and his team at Los Alamos National Laboratory in the nineteen nineties [5, 7]. There are now synthetic micropopulations for the whole of the USA, and the CoeGSS project recently funded by the European Commission will build a synthetic population for the whole of Europe [16].

6.4 Visualisation and Visual Analytics

Visualisation is important in policy informatics since it enables lay people to see otherwise hidden patterns of system behaviour, e.g. animations provide a powerful way of understanding system behaviour, and simulations often provide ideal data streams for this. Visual analytics goes beyond this, using graphical interfaces to support analysis and reasoning about systems. It combines visualisation, human perception and cognition, data management, data mining and spatio-temporal data analysis [26].

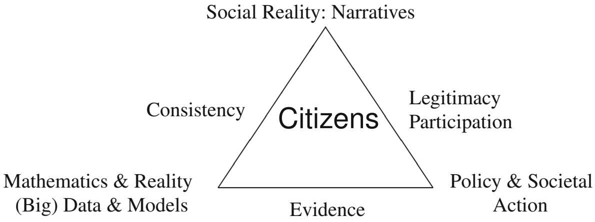

Fig. 2 Citizens in the policy loop

7 Citizens in the Policy Loop

Figure 2 shows citizens at the centre of social reality and narratives, data and models, and policy and societal action. Traditional science often assumes that it studies objective phenomena, but social reality is constructed in interactions between individuals, and these social interactions are necessary to sustain the social reality. Social constructs are the results of human decisions rather than objective reality, and narratives are a way to navigate and construct reality [2, 31].

Human behaviour is reflexive and people can respond to predictions by making them self-fulfilling prophesies or deliberately falsifying them, e.g. predicting a food shortage can cause panic buying resulting in a food shortage, while predicting that a candidate will win an election can make voters switch resulting in them losing. Also, some people are contrarian—predict that they will do one thing and they will do another. Thus policy cannot act *on* people, it has to act *with* people. Social media have given narrative power to everybody and thereby decoupled it from authority, e.g. the Twitter revolution during the Arab Spring, political campaigns on Facebook, and bloggers as opinion makers. The Arab Spring showed that people power can topple regimes but this is the beginning rather than the end of a process[36].

8 GSS Coordinating Policy Makers, Citizens and Scientists

Citizen engagement requires policy makers to actively bring lay people into the policy making process, and evidence based policy requires policy makers to bring scientists into the policy making process. Thus the policy making process requires coordination between policy makers, citizens and scientists. How can this work?

8.1 Policy Design

Like any artefact, policies are *designed* [21, 23]. The *design process* begins with a perceived problem, need, or desire, and proceeds by generating and evaluating possible solutions. A good solution is rarely found immediately and there are more iterations around the *generate-evaluate cycle*. Unlike other approaches to problem solving, it is common during design to discover that no acceptable solutions can be found, and the requirements or constraints must be changed. But this changes the problem! Thus *the design process is a coevolution between the problem and its solution and ends when a satisfactory problem-solution pair is found*.

Policy seeks to achieve the ‘best’ outcome, but in design there is rarely an absolute best or ‘optimum’. Herbert Simon called finding an acceptable compromise between competing heterogeneous dimensions *satisficing* [37]. Policy invariably involves satisficing rather than optimising.

8.2 The GSS Policy Process

Figure 3 shows how scientists work with policy makers and citizens within the GSS policy framework as a *policy team*. In the context of the prevailing narratives, on the left citizens and politicians decide how the world *ought* to be. After establishing the policy objectives and constraints, there is the creative *policy generate-evaluate cycle* shown at the centre of the diagram. This is where science can inform policy, using the tools of policy informatics shown at the centre of the cycle to create policy options and evaluate them.

Ideally a policy emerges from this process that satisfices the requirements and constraints. If not the objectives and constraints must be revisited. For example, the policy makers may decide that the budget can be increased, or it may accepted that one of the cherished objectives is not attainable. Thus the policy problem has changed and the policy team begins generate-evaluate cycle again. On finding what they think is an acceptable policy the policy team presents their plan for ratification by the elected politicians and citizens. If it is rejected the policy team must go back

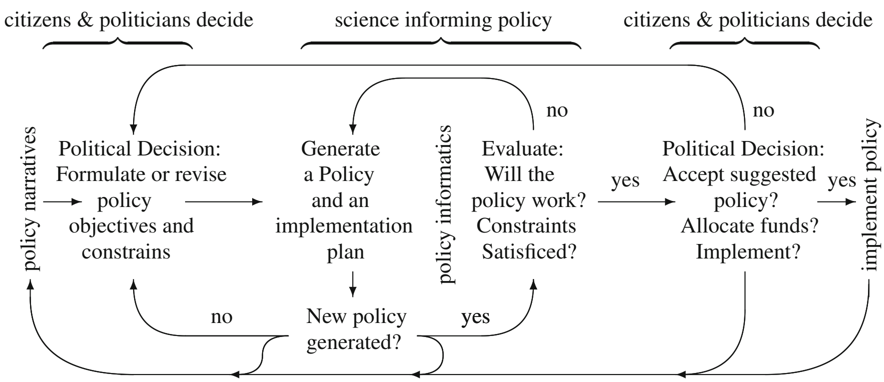

Fig. 3 Science informing policy within the Global Systems Science policy making process

to the generate-evaluate phase or even to phase of formulating the objectives and constraints.

The evolving policy narrative is shown at the left and bottom of Fig. 3. Policy objectives and constraints emerge from the prevailing narratives of how the world ought to be. Those narratives evolve while new policies are being designed. The generate-evaluate cycle at the heart of science-informed policy design is more a spiral through time than a cycle closing on itself. New information is constantly being collected, hypotheses are constantly be tested, and new information is constantly being accumulated. Whether or not feasible polices are generated or implemented this new information feeds new and evolving narratives, possibly changing the policy objectives and constraints. In evidence-based policy narrative dynamics fill any factual gaps, both removing and creating uncertainty. GSS has the challenge of creating theories of the dynamics of multilevel narrative dynamics [22].

As Fig. 3 shows, in Global Systems Science the decision-making process of policy formulation and implementation is firmly in the hands of citizens and politicians. Science makes its contribution by helping to generate and evaluate policies and providing the best possible evidence-based answers to the questions of how can policymakers be sure that their policies will have the desired outcomes and not have undesirable outcomes.

9 Conclusion

Global Systems Science has been presented as the combination of:

- policy-driven questions, policy formulation and implementation, and narratives
- the interdisciplinary science of complex systems supporting policy
- policy informatics—tools and data to investigate and visualise policy outcomes
- coordinating citizen engagement in the policy process.

GSS provides a methodology for applying the science of complex systems in policy making with citizen engagement. The rules of the game are that politicians and citizens establish how the world *ought* to be, and that scientists help them discover how the would *could* or *could not be* in the policy design process of generating and testing policy options. Scientists do this by the creation of computer tools usable by lay people, and making the output of those tools accessible to everyone as part of the policy team.

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