Agent-Based Social Systems 11

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# Advances in Computational Social Science

## The Fourth World Congress

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# Agent-Based Social Systems

## Volume 11




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# ABSS–Agent-Based Social Systems

This series is intended to further the creation of the science of agent-based social systems, a field that is establishing itself as a transdisciplinary and cross-cultural science. The series will cover a broad spectrum of sciences, such as social systems theory, sociology, business administration, management information science, organization science, computational mathematical organization theory, economics, evolutionary economics, international political science, jurisprudence, policy science, socioinformation studies, cognitive science, artificial intelligence, complex adaptive systems theory, philosophy of science, and other related disciplines.

The series will provide a systematic study of the various new cross-cultural arenas of the human sciences. Such an approach has been successfully tried several times in the history of the modern science of humanities and systems and has helped to create such important conceptual frameworks and theories as cybernetics, synergetics, general systems theory, cognitive science, and complex adaptive systems.

We want to create a conceptual framework and design theory for socioeconomic systems of the twenty-first century in a cross-cultural and transdisciplinary context. For this purpose we plan to take an agent-based approach. Developed over the last decade, agent-based modeling is a new trend within the social sciences and is a child of the modern sciences of humanities and systems. In this series the term “agent-based” is used across a broad spectrum that includes not only the classical usage of the normative and rational agent but also an interpretive and subjective agent. We seek the antinomy of the macro and micro, subjective and rational, functional and structural, bottom-up and top-down, global and local, and structure and agency within the social sciences. Agent-based modeling includes both sides of these opposites. “Agent” is our grounding for modeling; simulation, theory, and real-world grounding are also required.

As an approach, agent-based simulation is an important tool for the new experimental fields of the social sciences; it can be used to provide explanations and decision support for real-world problems, and its theories include both conceptual and mathematical ones. A conceptual approach is vital for creating new frameworks of the worldview, and the mathematical approach is essential to clarify the logical structure of any new framework or model. Exploration of several different ways of real-world grounding is required for this approach. Other issues to be considered in the series include the systems design of this century’s global and local socioeconomic systems.

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# Preface

Six years after its inception at Kyoto University, Japan in 2006, the biennial series of the World Congress on Social Simulation (WCSS) has completed its first voyage round the world, including the second conference held at George Mason University, USA, in 2008 and the third held at Kassel University, Germany, in 2010. Each of the three major societies on computational social science, PAAA (Pan-Asian Association for Agent-based Approach in Social Systems Sciences), CSSSA (The Computational Social Science Society of the Americas) and ESSA (European Social Simulation Association), has contributed to organizing one of these three events in its region. In 2012, a new cycle has started. The ball has returned to Asia, and the fourth iteration of this series was held at National Chengchi University (NCCU) in Taipei, Taiwan.

WCSS is by far the largest academic event in computational social science (CSS), which is to study computationally the social phenomena as emergent properties of complex adaptive systems. WCSS, therefore, has served to motivate the interdisciplinary research among social scientists, computer scientists and physicists. By including two special satellite events, WCSS 2012 made this feature even more evident.

The first event was the *Turing Memorial Sessions*. Year 2012 was the centennial of the birth of Alan Turing (1912–1954), who is widely regarded as the father of computer science. A session on Turing's Economics was organized by Vela Velupillai at the University of Trento to acknowledge the legacy of Alan Turing in computational social science.

The second event was the *First Asia-Pacific Econophysics Conference*. The interest of physicists in the social sciences has been growing over the last decade. Their studies on the social sciences have formed a research field, known as sociophysics or econophysics, which has many overlappings with computational social science. In some cases, CSS and sociophysics even share the same intellectual origins, such as John von Neumann's cellular automata. Under the diligent coordination of Sai-Ping Li at the Institute of Physics, Academia Sinica, the first regional conference on econophysics was launched and held together with WCSS 2012.

WCSS 2012, with these two joint events, had a total of 130 papers, presented by the participants from 22 different countries, and turned out to be the largest and the most exciting congress in this series. This new milestone points to a promising future for computational social science, with the ever increasing interdisciplinary collaborations among social scientists, computer scientists and physicists.

The great success of WCSS 2012 should not be limited to the four conference days. The WCSS series has a tradition of publishing post-conference proceedings so that the progress made can be well documented as an important step in the development of the literature on CSS. We, therefore, invited all the authors of the papers which were duly presented at WCSS 2012 to resubmit their papers for the consideration of the post-conference publication. We received 46 submissions in response to our invitation. Each of the submissions was further reviewed by two anonymous referees, and, in the end, 21 papers were accepted and published in this proceedings. We classify these 21 chapters into six parts: *on-line communities and social media* (Part I), *economic and social networks* (Part II), *behavioral finance and macroeconomics* (Part III), *demographics, health care, linguistics, and sociology* (Part IV), *participatory modeling and simulation* (Part V), and *methodology* (Part VI).

## On-Line Communities and Networks

One mainstay of the computational social science is the social interactions among agents. Two important related subjects in this regard are social network and internet. Internet is an engine for forming social networks; it provides tremendous inspirations for the development of the literature on social networks. In this volume, the advancement of computational social science along these two strands is illustrated by chapters in Parts I and II. The four chapters in Part I are devoted to different aspects of on-line communities and social media. The next three chapters in Part II are devoted to social or economic networks.

One form of social interactions is the generation of huge information flow and information exchange among agents, which is well manifested through the operation of many on-line communities and social media. Chapter 1 deals with the use of this huge information; in particular, it addresses the effect of on-line messages on investment behavior and financial market dynamics. Chapter 2 also deals with the use of information from on-line communities, but from a marketing perspective; it demonstrates the agent-based simulation of the interactions among bloggers, advertisers, and blog audience, and then evaluates the effectiveness of various affiliated marketing strategies. Through internet, the e-government attempts to provide citizens better public service. However, very much due to the habitual reasons, the adoption of this new service channel may be very slow, and people are still very much dependent on the conventional counter service. Chapter 3 develops an agent-based model to understand how micro-level individual preferences of public service channel lead to macro-level e-government service adoption phenomenon. Because of their anonymity, many conversations appearing in on-line communities can be malicious and are intended to be in that way. Using an agent-based model, Chapter 4 addresses the impacts of the malicious messages or trolls on the development of an on-line community as well as the effective policies to cope with these malicious agents.

In addition to on-line community, the chapters in Part II study social networks in different forms. Financial networks have financial institutions as important parts of the net. Through the analysis of the flow of financial capital in these networks, one can have a basis to evaluate the security or vulnerability of the financial system. However, networks imply the interdependent relations among creditors and debtors. When networks get large and complex, these interdependent relations can generate cycling troubles that make a sound and unique evaluation of financial security difficult. In the context of payment systems, Chap. 5 gives a thorough analysis of this so-called indeterminacy problem, which has been long largely ignored in the literature.

Both Chaps. 6 and 7 are devotions to a long-standing issue in computational social science, namely, opinion dynamics. In opinion dynamics, the term social interactions means the processes of social influences or persuasiveness. The celebrated Schelling-Axelrod model of cultural dissemination [1, 9] and the political economic model of opinion dynamics proposed by Chen [3] are early examples in this direction. As shown in these pioneering studies, social network can play an important role in these processes since it defines neighborhoods and neighbors as well as the local majority and minority. Various behavioral rules articulating the interactions between the majority and the minority groups can have effects not only on the consensus formation but also on the evolution of social network topologies. In other words, social networks and opinion dynamics are co-evolving in the context of opinion dynamics, and these co-evolution processes are well demonstrated in these two chapters. Chapter 6 demonstrates this co-evolutionary process in the context of voter dynamics. Chapter 7 introduces the context-dependent social networks and demonstrates the co-evolutionary process with this augmentation.

## Economics and Finance

Behavioral finance (Chaps. 8 and 9) has constantly been an interest of research for agent-based modelers, mainly because agent-based models endow us a great flexibility in dealing with a spectrum of behaviors in which the heterogeneity is beyond what the conventional analytical models can handle. Chapter 8 serves as a good example on this issue by addressing the consequences of traders' overconfidence in an agent-based financial market. Chapter 9 also uses an agent-based financial market model to justify the use of passive investment strategies when the assumption of efficient market hypothesis no longer holds.

Two chapters (Chaps. 10 and 11) on the agent-based macroeconomic models demonstrate the recent research ambition of economists to have a holistic picture of the operation of the whole economy from individual firms and households, all the way up to the behavior of the aggregate economy. The development of the agent-based macroeconomic models allows us to conduct policy experiments in which the possible macroeconomic consequences emerge from the downward causation between policy and the populations of heterogeneous firms and households. The agent-based macroeconomic framework allows us to analyze the policy effects on the firms of different sizes (Chap. 10) and the effect of corporate tax rate on GDP under different characteristics (or operation specifications) of firms (Chap. 11).

## Other Social Sciences

Part IV is the use of social simulation in other disciplines, including demographics (Chap. 12), health care and social work (Chap. 13), linguistics (Chap. 14), and social stratification (Chap. 15). Using the agent-based model to simulate marriages, fertility, and mortalities, Chap. 12 projects population demography in the UK from 1950 onward. Chapter 13 addresses an issue relating to health care policies and their collateral health effect. This issue is extremely important because the quality of the health care system and the incurred social costs are vital to modern aging societies. The authors set up an agent-based model to tackle this problem and make preliminary policy appraisals based on their simulation by simultaneously taking into account patients, patients' families, hospitals, social workers, and the government.

In Chap. 14, the linguistic evolution in communities of interacting agents is discussed in the frame work of agent-based social simulation. Linguistic development and the evolution of language are unsolved important problems. In this chapter, it is shown that various interesting phenomena have emerged under different control parameters, such as emergence of linguistic divergence by word mutation as well as transmission of language between generations. Distinct groups of agents that speak initially different languages, which are the sets of correspondence of an object to a word, converge to a common language group. An initially monolingual community splits to two or more groups of different languages. Chapter 15 explores the factors related to the emergence of social stratification structure.

## Participatory Modeling

Participatory modeling generally refers to modeling with the involvement of human subjects. While social simulation in most cases only involves artificial agents (software agents), many cases have shown that the participation of human agents can be critical and valuable. There are different purposes of involving human agents in agent-based modeling, and each of the three chapters in Part V illustrates one possible way to involve human agents in social simulation. First of all, one can use agent-based models to replicate the results of human-subject experiments; in fact, one of the origins of social simulation in economics is the attempt to replicate what was observed in human-subject experiments [5]. Based on that replicability, agent-based modeling goes beyond the limit of human-subject experiments. The agent-based modeling of Swedish Lottery (the lowest unique bid auction) in Chap. 16 is a case in point.

Secondly, one can use the agent-based model as a bridge to facilitate the communication among different stakeholders. In a complex system, each individual stakeholder may have limited capacity to comprehend the consequences of his any possible actions. The chain of the responses to his action can be so long and complex that is beyond what any single person can perceive. However, through agent-based models, very much as in a gaming situation, it is easier to simulate "if I do this and you do that" and see its full effect, including the possibly unintended consequence. Then, on the basis of these simulations, one can decide what could be the feasible solutions acceptable for all stakeholders.

Of course, to do so, one has to first build up an agent-based model that all stakeholders in a real system acknowledge that the model is really "them". This will trigger a close communication between modelers and stakeholders, and through this communication, missing fine details can be brought back and arbitrary behavioral assumptions of stakeholders can be avoided. In other words, participatory modeling provides us with another way to validate the model. Sean Boyle referred to this agent-based modeling approach as the *mirror function* [2, 4], but this novel idea has not been often seen in the practice of agent-based modeling; Chaps. 17 and 18 are two exceptional illustrations of this kind of participatory modeling.

## Methodology

The last part of the book is devoted to the methodological aspect of agent-based modeling. It covers two issues: one is validation, and the other is model comparison. The validation issue has been long discussed in the literature of agent-based modeling. Depending on the data availability and the scale of the model, it can be implemented with different granulations. Calibration and validation have been used quite intensively in agent-based economic and financial models [6]. In this kind of calibration and validation, the agent-based model is considered to be a parametric statistical model. By calibrating or estimating these parameters, the modelers attempt to use the agent-based model to generate the data or observations which are most similar to the real data with respect to one or a few given metrics. In Chap. 19, the authors attempt to calibrate an agent-based model of web news consumption by using genetic algorithms in search of the optimal set of parameters in a large parametric space. It shows that depending on the metric applied to measure the error one may come up with different calibrated models.

Chapter 20 is an agent-based model of agricultural societies in East Africa. It concerns the household decisions on farming, herding, and labor activities in response to the surrounding environment. Chapter 20 presents a different style of calibration from Chap. 19's. It does not formally define the model as a parametric statistical model, neither does it use the aggregate data to fine-tune the behavioral parameters at the very micro level. Instead, the validation is done at the very bottom level of the model using the anthropological data almost at the same micro level, while the emergent aggregate phenomena are further examined with aggregate data. This work shows the use of field study in empirical-based, agent-based modeling [8].

The last chapter of the book deals with the model-to-model analysis. This issue has drawn a lot of attentions among agent-based modelers. There were even special issues edited for this subject [7]. However, because of the difficulties indicated in this chapter, the full-fledged implementation of the model-to-model analysis is rarely seen and has not become a practice by most modelers. For example, there are large sets of agent-based financial markets, macroeconomic models, and even the electricity markets as illustrated in the chapter, but there is almost no model-to-model analysis being done in these areas. Hence, given a full plethora of models, it leaves the robustness of policy recommendations unchecked. This final chapter gives some suggestions to make progresses in this direction possible.

The editors of this book, with great pleasure, now formally announce the presentation of these 21 inspirational high-quality chapters to all interested readers in CSS and invite them to keep their wonders of CSS alive by traveling along its exciting research frontier, drawn collectively by these respectable 51 contributors.

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# Part I
# Online Communities and Social Media

# Chapter 1
# Stock BBS Factor Model Using Principal Component Score

**Hirohiko Suwa, Eiichi Umehara, and Toshizumi Ohta**

**Abstract** Our aim is to develop a new factor for stock bulletin board system (BBS) postings that is different from our bullish-bearish model (BMB) factor. In our previous study, the content of stock BBS postings was classified into two categories, i.e., bullish postings and bearish postings, and our BMB factor is based on these categories. The results of recent studies suggest that the content of stock BBS postings may be represented by employing more than one index. To develop new factors on the basis of the principal component score, we use morphological analysis and principal component analysis to analyze the content of stock BBS postings. As a result, we find candidates for new factors that can explain stock returns.

**Keywords** Content of message • Factor model • Internet BBS • Stock return

## 1.1 Introduction

We aim to discover anomalies caused by stock bulletin board system (BBS) postings in the Japanese stock market and to develop a new factor model to explain stock returns that uses the content of messages on stock BBSs. Studies on financial markets have used factor models with several factors as a way to explain the returns of a portfolio. The most basic model is Sharpe's capital asset pricing model (CAPM [11]). In the CAPM, if the market is in equilibrium, the excess return of the portfolio can be represented by the market return and the market sensitivity ($\beta$).

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Any excess return that the CAPM cannot explain is called an abnormal return. The source of the abnormal return is an anomaly. Many anomalies have been found, such as the small-cap effect and the value stocks effect [12]. However, many of these are based on numerical information such as accounting data.

On the other hand, in investment decisions, many investors use not only numerical information but also non-numeric information such as news. Internet stock BBSs are forums for seeking the opinions of other investors. BBSs may have the potential to be helpful in making investment decisions. However, this idea has barely been researched. Therefore, we have tried to determine whether messages on stock BBSs are sources of anomalies in the Japanese stock market.

Factor models using messages on BBSs have previously been researched. Antweiler and Frank [1] proposed a factor model, called the NMQ model, in which a message number factor is added to the CAPM and Fama and French's three-factor model on the U.S. stock market. Suwa et al. [13] proposed not only the NMQ model but also the bullish-bearish model (BMB) using bullish-bearish analysis of BBS messages on the Japanese market. They found that the content of messages might possibly be used to explain stock returns, though the number of messages could not. However, they pointed out that the BMB cannot explain all residual returns. They classified the content of messages by using only one dimension such as bullish-bearish. Previous studies found that text data can be classified in several dimensions. Similarly, messages on BBSs might be classified in dimensions other than bullish-bearish. The purpose of our research is thus to develop a new factor based on BBSs, instead of the BMB, to explain stock returns.

This chapter is organized as follows. Section 1.2 reviews previous research. Section 1.3 describes our analytical methods. Section 1.4 shows the results of our analysis, and Sect. 1.5 discusses the results. Section 1.6 is the conclusion.

## 1.2 Previous Research

Wysocki [15] examined the cross-sectional and time-series determinants of the volume of messages posted on stock message boards on the Web. Using a sample of more than 3,000 stocks listed on Yahoo! message boards, he found that the cumulative posting volume is highest for firms with high short-seller activity, high market valuations relative to fundamentals, low institutional holdings, high trading volume, extremely high performance, and a large following of analysts. Changes in daily posting volume are associated with earnings announcements and daily changes in stock trading volume and returns. The overnight message-posting volume was found to be able to predict changes in the next day's stock trading volume and returns, but it is difficult to use it to make a profit when commissions are taken into consideration. Tumarkin and Whitelaw [14] examined the causal relationship between the number of messages and the opinions in messages posted on Raging Bull and the return and trading volume by using an event study and multi-auto-regression analysis. They concluded that the messages cannot estimate stock returns or volume, which means that the market works efficiently. Jones [8] examined the stock return behavior for a large subset of firms in the S&P 100 both before and after the opening of the firms' message boards on Yahoo! Finance. She found that daily trading volume significantly increased and that daily return fell significantly after a firm's message board was established. These results hold after controlling for market- and industry-wide events.

Antweiler and Frank [2] analyzed the number and content of more than 1,500,000 messages posted on Yahoo! and Raging Bull concerning 45 companies on the Dow Jones Industrial stock index and the Dow Jones Internet index by using natural language processing (Naive Bayes) and empirically examined the relationship between message boards and the stock market. They found that (1) the message boards do not estimate stock returns, (2) because the difference between bullish and bearish opinions drives stock trading, the message boards forecast the trading volume, and (3) the message boards forecast the volatility of the next day's trading.

Das and Chen [4] used a simple majority of five algorithms to classify messages. This voting approach resulted in a higher signal-to-noise ratio for extracting sentiment. They analyzed 145,110 messages about 24 tech-sector stocks in the Morgan Stanley High-Technology 35 Index (MSH) during July and August 2001. They obtained the same results as Antweiler and Frank [2].

Antweiler and Frank [1] examined factor models such as the CAPM and added the factor of the number of messages in a BBS to Fama and French's three-factor model [5, 6]. They called their model NMQ. They analyzed more than 35 million messages posted on Yahoo! BBS in the USA from 1999 to 2001. Their results suggested that the message-number factor might be statistically significant. However, they did not examine the factor of message content.

Maruyama et al. [9] analyzed the relationships between the stock market and a stock BBS in Japan. Previous studies in the USA found that the characteristics of messages posted on stock BBSs can predict market volatility and trading volume. Maruyama et al. developed hypotheses on the basis of those analyses and statistically analyzed data about companies mentioned in a large number of messages posted on the Yahoo! stock message board in Japan during 2005 and 2006. They analyzed the content of these messages using natural language processing. They found significant correlations between the number of postings and market volatility and trading volume and between the amount of bullish and bearish opinion and stock returns.

Suwa et al. [13] found that Fama and French's three-factor model may not be validated by bullish and bearish messages posted on BBSs. They added two factors to the three-factor model: the difference in the returns of the portfolios with the most and the fewest messages, and the difference in the returns of the portfolios with the most bullish and most bearish messages. The results suggest that the content of messages in BBSs may relate to the return.

Previous research has focused on the analysis using the number of messages and bullishness of messages. However, the content of messages may contain a variety of claims other than bullish or bearish ones, such as claims about interest rates and corporate activities. By performing principal component analysis and morphological analysis on the monthly monetary reports of the Bank of Japan, Izumi et al. [7] tried to determine whether such reports could explain actual financial markets (stocks, bonds, yen-dollar exchange rate). First, they extracted words using morphological analysis. Next, in order to extract the important words, they created a collocation graph based on the Jaccard index, and then ran the principal component analysis on those words. As a result, 30 principal components which had more than 60 % of the cumulative contribution were extracted. Using the 30 principal components as an explanatory variable, they carried out multiple regression analysis to explain Japanese financial markets (two-, five-, and ten-year government bonds, Nikkei Stock Average, and yen-dollar exchange rate). As a result, they reported that (1) it is possible to forecast the trends of two- and five-year Japanese government bonds (JGBs) at 85 % probability and the Nikkei Stock Average at 77 % probability, and (2) these trends last approximately 3 months. Therefore, we believe that there are many principal components in stock BBSs, as well as in the monthly monetary reports. Thus we extracted words in the morphological analysis of the messages in stock BBSs and determined the importance of a word by using the term frequency-inverse document frequency (TF*IDF) [10]. We applied principal component analysis to those words. According to the procedure of Fama and French [5, 6], we developed a new factor to use these principal components and examined the effects of these factors.

## 1.3 Method of Analysis

Here, we describe the method using messages on a stock BBS to examine whether anomalies exist or not. Moreover, we describe how to develop factors using the principal component score and how to examine the effectiveness of these factors. Figure 1.1 shows the flow chart of our analysis.

### *1.3.1 Collection of Messages on Yahoo! BBS*

We developed a program to collect messages from Yahoo! BBS automatically. We collected messages about stocks listed in the Tokyo Stock Exchange 1st Section on Yahoo! BBS from 1 January 2003 to 31 December 2008 (six years). We collected messages about 1,501 stocks. However, for reasons such as new listings and delistings on the TSE, the number of stocks collected changed on a monthly basis. For example, we collected 1,485 stocks in January 2003 and 1,398 stocks in December 2008. The fluctuation rates of the Tokyo Stock Exchange Price Index (TOPIX) were 23.8, 10.2, 43.5, 1.9, −12.2, and −41.8 % in the 6 years from 2003 to 2008. We regard the Japanese stock market as bullish from 2003 to 2005 and as a box market (stock prices moving up and down repeatedly between an upper bound and a lower bound) in 2006. The market was bearish during 2007 and 2008.

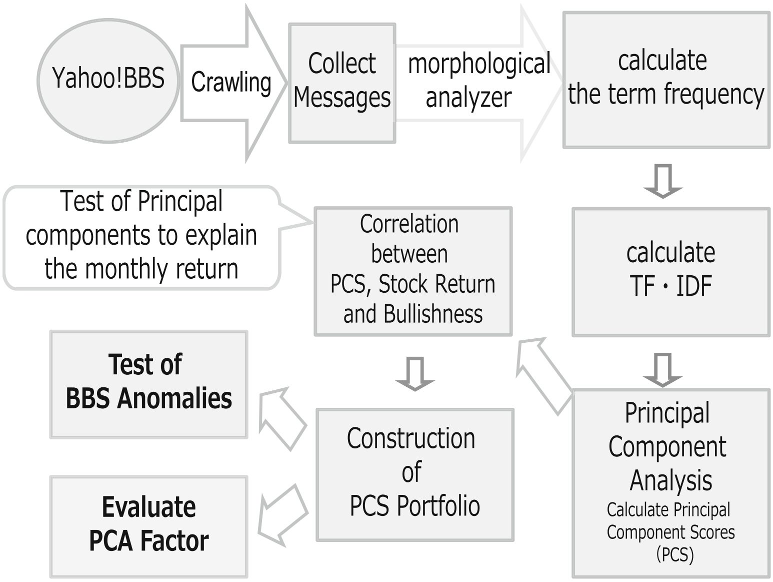


**Fig. 1.1** Flow chart of our analysis

### *1.3.2 Morphological Analyzer*

First, we examined the words in the messages. Sentences in Japanese are not clearly divided into separate words as they are in English. Therefore, to extract words, we divided sentences into morphemes by using a morphological analyzer (MeCab).

### *1.3.3 TF*IDF Calculation*

Next, we calculated the TF*IDF [10] of each word to determine the word's importance. This method determines the importance of the word by its frequency of appearance, but it reduces the importance of a word that appears in many messages because of a common word. The importance is given by Eq. (1.1).

We filtered words used in our analysis, because there were many words in the set of messages and many words appeared only once. We extracted only words that had a frequency of occurrence of more than 1,000. Furthermore, we used the top 700 important words in the principal component analysis.

$$w(d) = \sum_{t=1}^{N} \ln(tf_{t,d}) \cdot \ln(N/df_d) \tag{1.1}$$

- $w(d)$: Importance of word d
- $t$: Message
- $d$: Word
- $N$: The number of messages posted in each period
- $tf_{t,d}$: The appearance frequency of word (d) in message (t)
- $df_d$: The number of messages including word d.

### 1.3.4 Principal Component Analysis

To develop factors based on stock BBSs explaining stock returns, we used principal component analysis using the 700 words as independent variables. To examine the words with a large absolute value of principal component load in each principal component, we determined the characteristics of the principal components.

### 1.3.5 Correlation Between Principal Component Scores, Stock Return, and Bullishness

We defined the monthly principal component score (PCS) of each stock as a monthly average of the PCSs of each month, as follows:

$$PCS_{p,k} = \sum_{j=1}^{n} \frac{X_p(k, j)}{n} \tag{1.2}$$

- $p$: Index of the principal component
- $k$: Index of a stock
- $n$: Number of messages about a stock in a month
- $X_p(k, j)$: Principal component score of a message.

First, we determined whether the PCSs were the same as bullishness or not, by calculating the correlation between these two indexes. Second, by calculating the correlation between the monthly return and PCSs of each stock, we tried to determine whether these PCSs could explain the stock's return or not. As a result, we supposed that the PCSs that correlated with stock returns but not bullishness might be new factors different from bullishness.

If a PCS correlated with a stock return, the principal component analysis might be able to explain the return. Moreover, if the PCS did not correlate with bullishness, it might be a candidate for a new factor, because the BMB is based on bullishness.

**Table 1.1** Definition of portfolio

| Portfolio | Definition |
|---|---|
| PF1 | First quintile of the PCSs |
| PF2 | Second quintile of the PCSs |
| PF3 | Third quintile of the PCSs |
| PF4 | Fourth quintile of the PCSs |
| PF5 | Fifth quintile of the PCSs |
| PFX | None of messages |

According to Maruyama et al. [9], bullishness is defined as the difference between the numbers of bullish and bearish messages each month, as follows:

$$Bullishness = \ln\left(\frac{1 + \text{No. of bullish messages}}{1 + \text{No. of bearish messages}}\right) \tag{1.3}$$

We classified the BBS messages into "bullish", "bearish", and "neither" by using a support vector regression (SVR) program, LibSVM [3]. Yahoo! BBS has a function for disclosing the poster's sentiment to the public. The poster of each message in Yahoo! BBS can select a sentiment from five alternatives: "strong buy", "buy", "hold", "sell", and "strong sell". However, many messages are posted without sentiments. Therefore, we used SVR on all of the messages to estimate whether they were bullish or bearish. The learning data were messages with disclosed sentiments. The input data were the feature vectors of the messages, and the output for each message was "strong buy"=1, "buy"=0.5, "hold"=0, "sell"= −0.5, or "strong sell"= −1. In accordance with the work of Suwa et al. [13], we classified messages that had SVR outputs equal to or larger than 0.744 as "bullish", larger than −0.297 but smaller than 0.744 as "neither", and equal to or smaller than −0.297 as "bearish".

### *1.3.6 Construction of the Portfolio*

To check for the presence of abnormal returns in the CAPM, we constructed portfolios in accordance with the PCSs. First, we denoted a portfolio including stocks that had no messages during a month as portfolio X (thereafter PFX). Next, in accordance with the PCSs of each month, we classified the remaining stocks into five portfolios (PF1 to PF5). PF1 and PF5 were the portfolios that included the stocks that had the highest and lowest PCSs each month. The definition of each portfolio is shown in Table 1.1.

### *1.3.7 Test of Abnormal Returns*

We checked, using the CAPM, whether there were any abnormal returns ($\alpha_i$) by using regression analysis. The CAPM is defined by Eq. (1.4). If there were abnormal returns, the $\alpha$ of a portfolio with a high (low) monthly average principal component score (PCS) would be greater (less) than zero.

$$R_{i,t} - Rf_t = \beta_i(Rm_t - Rf_t) + \alpha_i \tag{1.4}$$

- $R_{i,t} - Rf_t$: Excess return of portfolio i
- $Rm_t - Rf_t$: Excess return of market portfolio
- $R_{i,t}$: Return of portfolio i
- $Rm_t$: Return of market portfolio
- $Rf_t$: Risk-free rate (call rate)
- $\beta_i$: $\beta$ of portfolio i
- $\alpha_i$: Abnormal return of portfolio i.

We used the average return of all stocks as the return of market portfolio for each month.

### 1.3.8 Evaluation of Factors Using PCSs

We developed a multi-factor model by adding a factor found using the principal component scores (PCAp) to the CAPM. We checked whether this multi-factor model had abnormal returns or not. Fama and French [5, 6] proposed a three-factor model that added a size factor (SMB) and book-to-market equity factor (HML) to the CAPM. SMB is the difference in the return between a portfolio of small stocks and a portfolio of large stocks. HML is the difference between the returns on portfolios of high and low book-to-market stocks. To develop a new factor using PCSs, we defined the PCAp factor as follows:

$$PCA_p = \text{Return of portfolio with highest PCS (PF1) - with lowest PCS (PF5)} \tag{1.5}$$

where p is the index of each principal component.

The multi-factor model is defined by Eq. (1.6). In this model, if the factor PCAp can explain any part of the return, the abnormal return ($\alpha$) does not depart from zero.

$$R_{i,t} - Rf_t = \beta_i(Rm_t - Rf_t) + PCA_p + \alpha_i \tag{1.6}$$

- $R_{i,t} - Rf_t$: Excess return of portfolio i
- $Rm_t - Rf_t$: Excess return of market portfolio
- $R_{i,t}$: Return of portfolio i
- $Rm_t$: Return of market portfolio
- $Rf_t$: Risk-free rate (call rate)
- $\beta_i$: $\beta$ of portfolio i
- $\alpha_i$: Abnormal return of portfolio i
- $PCA_p$: Factor using principal component p.

## 1.4 Results

We collected 2,950,002 messages from Yahoo! BBS that were posted from 1 January 2003 to 31 December 2008. Using morphological analysis, we extracted 3,223,578 words, 4,885 of which had a frequency of occurrence of over 1,000. We calculated the TF*IDF values of these 4,885 words. From these, we used the top 700 words in terms of TF*IDF value in the principal component analysis.

We calculated the PCSs for the top ten principal components with high proportions of variance. Table 1.2 lists the correlations between PCSs, monthly returns, and bullishness. These results show that PCSs1, 2, 7, and 8 have statistically significant correlations with the monthly return and that PCSs4, 5, 6, 7, and 10 have statistically significant correlations with bullishness.

Next, we constructed the PCS's portfolios. We examined them by using regression analysis to determine whether they had abnormal returns in terms of the CAPM. Table 1.3 lists the results of the regression analysis of the PCS1 portfolio. PF1, PF2, and PF5 have abnormal returns ($\alpha_i$: $p < 0.01$). The portfolios with higher PCSs have a more positive divergence from zero, and the portfolios with lower PCSs have a more negative divergence from zero. We then constructed portfolios of PCS4, which does not correlate with stock returns but does with bullishness, and performed a similar regression analysis (Table 1.4). The results indicate that the PCS4 portfolios do not have abnormal returns in terms of the CAPM.

**Table 1.2** Correlations between PCSs, monthly returns, and bullishness

| Principal component | Return | Bullishness |
|---|---|---|
| PCS1 | 0.0223** | 0.0025 |
| PCS2 | 0.0175** | −0.0036 |
| PCS3 | 0.0065 | 0.0075 |
| PCS4 | −0.0032 | −0.0362** |
| PCS5 | 0.0061 | −0.0374** |
| PCS6 | −0.0035 | −0.0315** |
| PCS7 | 0.0126* | 0.0208** |
| PCS8 | 0.0194** | −0.0009 |
| PCS9 | −0.0097 | 0.0025 |
| PCS10 | −0.0020 | −0.0223** |

$^{*}p < 0.05$, $^{**}p < 0.01$

**Table 1.3** Regression of PCS1 portfolio

| Portfolio | $\alpha_i$ | $\beta_i$ | P($\alpha_i$) | P($\beta_i$) | $R^2$ |
|---|---|---|---|---|---|
| PF1 | 0.0032** | 1.013 | 0.001 | 0.469 | 0.979** |
| PF2 | 0.0037** | 1.187** | 0.009 | 0.000 | 0.966** |
| PF3 | −0.0006 | 1.079** | 0.585 | 0.001 | 0.970** |
| PF4 | −0.0024* | 0.894** | 0.021 | 0.000 | 0.967** |
| PF5 | −0.0057** | 0.851** | 0.000 | 0.000 | 0.958** |
| PFX | 0.0004 | 0.922** | 0.751 | 0.003 | 0.949** |

$^{*}p < 0.05$, $^{**}p < 0.01$

**Table 1.4** Regression of PCS4 portfolio

| Portfolio | $\alpha_i$ | $\beta_i$ | P($\alpha_i$) | P($\beta_i$) | $R^2$ |
|---|---|---|---|---|---|
| PF1 | −0.0003 | 1.007 | 0.820 | 0.761 | 0.968** |
| PF2 | 0.0010 | 1.065* | 0.460 | 0.011 | 0.964** |
| PF3 | −0.0004 | 1.040 | 0.695 | 0.051 | 0.974** |
| PF4 | −0.0012 | 1.009 | 0.192 | 0.626 | 0.978** |
| PF5 | −0.0009 | 0.902** | 0.353 | 0.000 | 0.971** |
| PFX | 0.0004 | 0.922** | 0.751 | 0.003 | 0.949** |

$^{*}p < 0.05$, $^{**}p < 0.01$

**Table 1.5** Regression of multi-factor model (PCS1 portfolio)

| Portfolio | $\alpha_i$ | $\beta_i$ | PCA1 | P($\alpha_i$) | P($\beta_i$) | P(PCA1) | $R^2$ |
|---|---|---|---|---|---|---|---|
| PF1 | −0.0002 | 0.9499** | 0.3878** | 0.817 | 0.000 | 0.000 | 0.985** |
| PF2 | 0.0032 | 1.1775** | 0.0571 | 0.078 | 0.000 | 0.651 | 0.966** |
| PF3 | 0.0009 | 1.1076** | −0.1775 | 0.533 | 0.000 | 0.097 | 0.971** |
| PF4 | −0.0005 | 0.9283** | −0.2144* | 0.694 | 0.000 | 0.020 | 0.969** |
| PF5 | −0.0002 | 0.9499** | −0.6122** | 0.817 | 0.000 | 0.000 | 0.979** |
| PFX | −0.0012 | 0.8929** | 0.1803 | 0.483 | 0.000 | 0.134 | 0.951** |

$^{*}p < 0.05$, $^{**}p < 0.01$

**Table 1.6** Summary of analysis

| Principal component | CAPM | Multi-factor model |
|---|---|---|
| PCS1 | ○ | × |
| PCS2 | ○ | ○ |
| PCS3 | ○ | ○ |
| PCS4 | × | – |
| PCS5 | × | – |
| PCS6 | × | – |
| PCS7 | × | – |
| PCS8 | ○ | × |
| PCS9 | ○ | × |
| PCS10 | × | – |

○: Portfolio with an abnormal return exists
×: Portfolio with an abnormal return does not exist
–: It was not analyzed, because abnormal returns did not exist in the CAPM

Moreover, because the PCS1 portfolio has an abnormal return, we developed a new PCA factor, defined as Eq. (1.5), and examined this new factor model. Table 1.5 shows the results of the regression analysis for the PCS1 portfolio. It indicates that the $\alpha_i$ of the portfolios do not depart from 0 in a statistically significant way. From this result, we can confirm that our multi-factor model using the PCA1 factor does not have an abnormal return.

Using the same method as in Table 1.5, Table 1.6 summarizes the analysis of the top ten principal components. As in the case of the portfolio constructed using PCS1, we found that the portfolios constructed using PCS2, PCS3, PCS8, and PCS9 had abnormal returns in terms of the CAPM. Therefore, we developed a multi-factor model using PCA1, PCA2, PCA3, PCA8, and PCA9 as new factors. The results of the regression analysis show that there are no abnormal returns in the multi-factor model using PCA1, PCA8, and PCA9.

## 1.5 Discussion

### *1.5.1 Candidate Factors*

As shown in Table 1.2, PCS 1, PCS 2, and PCS 8 correlate with monthly returns but not with bullishness. Therefore, these PCSs might be candidates for a new factor different from bullishness. Next, we constructed a portfolio in accordance with each PCS and confirmed the presence of abnormal returns using the CAPM. As shown in Table 1.3, PF1, PF2, and PF5 in the portfolios of PCS1 have abnormal returns ($\alpha_i$). As a result, PCS1 might be a candidate. In contrast, no portfolio constructed using PCS4 has an abnormal return (Table 1.4), and thus PCS4 is not a candidate. In summary, PCS1, PCS2, PCS3, PCS8, and PCS9 (Table 1.6) might be candidate factors.

### *1.5.2 Developing a New Factor*

Table 1.5 shows the results of the regression analysis in a multi-factor model on the basis of PCA1. Because PCA1 might be able to explain stock returns, PCA1 might be a candidate for a new factor based on stock BBS postings.

The first reason is that the multi-factor model using PCA1 did not have an abnormal return. In the CAPM, portfolios based on PCS1 have abnormal returns. We believe this result suggests that PCA1 might be able to explain stock returns.

The second reason is that PCS1 does not correlate with bullishness. The new factor, PCA1, is based on PCS1, and PCS1 does not correlate with bullishness, on which the BMB is based. Therefore, we believe that PCA1 is a new factor different from the BMB. Moreover, as shown in Table 1.6, PCA9 and PCA8 also might be candidates for a new factor based on stock BBS postings. In contrast, the multi-factor model based on PCA2 and PCA3 does have abnormal returns. Therefore, these factors cannot explain stock returns.

These results indicate that certain PCSs might be new factors. Note that our correlation analysis in Table 1.2 led us to expect that PCS2 would be a candidate and that PCS9 would not. However, the results were contrary to our prediction. Finding a reason for this will be a topic of future research.

### 1.5.3 Principal Component Analysis

We investigated the top ten words with large factor loadings in each of the top ten principal components. PCS1, PCS8, and PCS9 included words about economics and finance, investment strategies such as “contrarian strategy”, or shareholding such as “owners” and “shareholding ratio”. These results are reasonable, because stock prices are determined from investment behaviors. Note that these factors are not related to bullishness.

On the other hand, words that seem to have nothing to do with economics such as “geek”, “old man”, “praise”, “personality”, “pregnancy”, “marriage”, and so on were in PCSs3, 4, 6, and 10, i.e., PCSs that were eliminated from being a new factor. These words can be considered to be noise in terms of explaining stock returns. We believe that words like these caused their factors to be ineffective.

PCS2 contains a lot of words about margin transactions, and PCS7 has words about business conditions such as sales or income. As shown in Table 1.2, PCS2 and PCS7 correlate with stock returns, and we had expected that these would be new factors to explain stock returns. However, this turned out not to be the case. The reason for this failure may have to do with the effect of noise, or it may be that our analysis cannot determine whether the meanings of these words are positive or negative for stock returns. In the future, we will have to (1) develop a new dictionary that contains only words relevant to stock trading in order to remove noise and (2) use syntactic analysis.

## 1.6 Conclusion

We analyzed 2,950,002 messages posted on stock BBSs by using morphological analysis and principal component analysis and constructed portfolios in accordance with the principal component scores. Using the CAPM, we examined the relationship between stock returns and portfolios. As a result, we found that some portfolios formulated using principal components that were not correlated with bullishness could account for abnormal returns in the CAPM. As a result, we confirmed that there are anomalies other than bullishness.

Moreover, multi-factor models using PCA1, PCA8, and PCA9 as factors did not show any abnormal returns. As a result, these factors might be able to help explain stock returns. Therefore, these factors are candidate factors that are different from bullishness.

In the future, we will have to improve our dictionary to extract words that have more effect on stock returns.

**Acknowledgements** This work was supported by JSPS KAKENHI, Grant Number 25380481.

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# Chapter 2
# How Consumer-Generated Advertising Works: An Empirical Agent-Based Simulation

**Makoto Mizuno**

**Abstract** Affiliate advertising is a novel form of Internet advertising that enables bloggers to insert advertising for any product in their blog articles and to gain rewards based on consumers' actual responses. To understand how this form of advertising works, we conducted Web-based questionnaire surveys among bloggers, including affiliates, and readers, including buyers. Moreover, we constructed an agent-based model that is empirically validated by the above data. The results of the simulation using this model showed that (1) link structures between affiliates and readers have a remarkable impact on the average revenues of all affiliates, and (2) the presence of random walkers in searching for a better ad mix may increase total revenues for all affiliates compared to the presence of local imitators. Based on these results, we discuss the managerial implications and suggest future avenues for research.

**Keywords** Affiliate advertising • Agent-based modeling • Blogs • Consumer behavior • Empirical validation

## 2.1 Introduction

Bloggers participating in an affiliate advertising program, often called "affiliates," insert advertising for products they have chosen themselves in their blogs, and gain rewards from advertisers if customers buy the products or click on the advertisements. Advertisers (or their agents) offer a list of products to be advertised and corresponding advertising materials to affiliates, and then pay fees to the affiliates.

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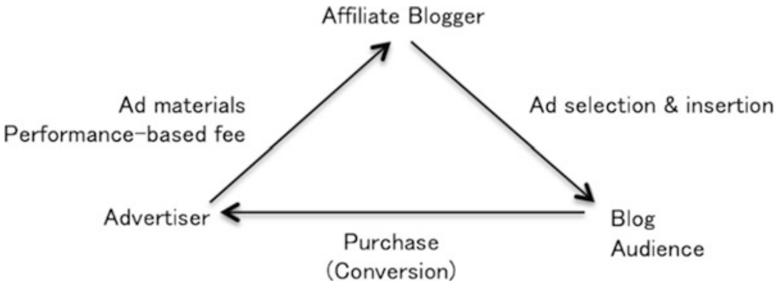


**Fig. 2.1** Relationships between agents in affiliate advertising

This relationship is depicted in Fig. 2.1. The affiliate market in Japan has been growing at a moderate rate [8], although the size is limited relative to the entire Internet advertising market in Japan.

A distinctive feature of affiliate advertising is that consumers, who are neither advertisers nor media companies, control advertising insertion; thus, affiliate advertising can be seen as "consumer-generated advertising media." This type of advertising can be interpreted as part of the shift of power in advertising from companies to consumers [6]. Despite the increasing popularity of affiliate advertising, little research has been done on it, except for a few studies [2, 3, 5].

To grasp the state of the art of affiliate advertising, we conducted Web-based questionnaire surveys among bloggers and blog readers. Moreover, to gain insight into the possible outcomes of the complex interactions among bloggers, blog readers, and advertisers, we adopted an agent-based model. We then used our obtained survey data to characterize each agent's preferences and feasible actions under certain constraints.

The problem is the lack of information about the links between affiliates and readers. To address these "missing links," we draw bipartite graphs of the relationships between bloggers and readers, utilizing the survey data. Such links are thought to be a result of choices of blogs by readers, which could be governed by congruence in interests or preferences of both bloggers and readers. Accordingly, we artificially generate possible links based on the various congruences calculated from the survey data.

Given the link structures from the bipartite graphs, we then model and simulate interactions between affiliates and readers. In doing so, we examine how affiliates should act in order to increase revenues. The choice of advertised products (ad mix) is routinized as a strategy. Thus, we consider the following two strategies: local imitation and random walk strategies. By simulating the model and varying the parameters, we examine which conditions and what kind of strategy could yield larger revenues.

The rest of this chapter is organized as follows. In Sect. 2.2, we show the key findings from the surveys related to our modeling. In Sect. 2.3, we describe the formulation of our model. In Sects. 2.4 and 2.5, we describe the simulation procedure and present the results. Lastly, we discuss the managerial implications and suggest future research avenues.

## 2.2 Empirical Study

First, we show the key results from the Web-based questionnaire surveys. The first survey was conducted on February 2011 among bloggers who posted blog entries at least once a month. The respondents are categorized as either affiliates or non-affiliates based on whether they participate in any affiliate program or not. The subsequent survey was conducted on December 2011 among blog readers who read blogs at least once within the most recent month. The readers are categorized as either buyers or a non-buyers based on whether they bought advertised products or not within the recent half year. These four classes of respondents are sampled independently and at random from a large panel provided by a Web-centric research company in Japan ($N = 361$ for affiliates; $N = 361$ for non-affiliates; $N = 412$ for buyers; and $N = 412$ for non-buyers).

Although the surveys yielded many interesting findings [4], we only show those relevant to our modeling. Table 2.1 presents the findings regarding the reasons why affiliate bloggers participated in any affiliate program (note that the respondents were allowed to choose multiple answers).

This result suggests that affiliates are strongly motivated by monetary rewards, at least when they begin the program. Table 2.2 shows the distribution of monthly affiliate rewards. It shows that more than half of the affiliates earned small or very small monetary rewards despite their initial motivation.

About 70 % of the affiliates adopted some means to increase rewards. As shown in Table 2.3, the three main means are changing the advertising mix, changing the

**Table 2.1** Reasons for participating in affiliate advertising programs (multiple answers)

| Reason | % |
|---|---|
| To gain monetary rewards | 64.0 |
| To start a blog free of charge | 50.0 |
| To recommend favorite products to readers | 29.0 |
| To provide useful information to readers | 13.0 |

**Table 2.2** Distribution of average monthly revenues for affiliates

| Revenue | % |
|---|---|
| Higher than 50,000 yen (about \$500) | 2.3 |
| 10,000–50,000 yen (about \$100–\$500) | 5.0 |
| 5,000–10,000 yen (about \$50–\$100) | 3.0 |
| 1,000–5,000 yen (about \$10–\$50) | 12.5 |
| 100–1,000 yen (about \$1–\$10) | 24.1 |
| Lower than 100–1,000 yen (lower than \$1–\$10) | 51.5 |
| Unknown | 1.7 |

**Table 2.3** Means to increase affiliate rewards (multiple answers)

| Means | % |
|---|---|
| Advertise products that fit the blog | 39.0 |
| Align the content of the blog with the ads | 37.0 |
| Increase traffic to the blog | 36.0 |
| No means in particular | 28.0 |

content or theme of the blog, and increasing the number of blog visitors. Among these options, changing the content of the blog seems the riskiest because doing so might disappoint current readers of the blogs or alter the identity of the blogs. On the other hand, changing the ad mix seems to be the least risky option. Hence, this study focuses on examining the effect of the ad mix in blogs, keeping the content of the blog constant.

## 2.3 Model

In modeling the affiliate advertising process, we model the behaviors of two classes of agents: bloggers who participate in an affiliate program, and thus were classified as affiliates in the blogger survey, and blog readers who bought products by clicking on affiliate ads, and thus were classified as buyers in the reader survey. These agents are linked across classes by a bipartite graph, but they are not directly linked within the same class.

### *2.3.1 Affiliate Bloggers' Behavior*

In our model, affiliates are allowed to choose the ad mix, which is represented by the following $K$-dimensional vector:

$$\mathbf{a}_{it} = (a_{i1t}, a_{i2t}, \ldots, a_{ikt}, \ldots, a_{iKt}) \tag{2.1}$$

where $a_{ijt}$ is a variable that equals 1 if product $k(= 1, 2, \ldots, K)$ is advertised in blog $i(= 1, 2, \ldots, I)$ at time $t(= 1, 2, \ldots, T)$, and 0 otherwise. On the other hand, affiliates have central themes or topics in their blogs, represented by the $J$-dimensional vector

$$\mathbf{b}_i = (b_{i1}, b_{i2}, \ldots, b_{ij}, \ldots, b_{iJ}) \tag{2.2}$$

where $b_{ij}$ is a variable that equals 1 if topic $j(= 1, 2, \ldots, J)$ is covered in blog $i$, and 0 otherwise. Here, it is assumed that the sets of topics never vary over time in each blog. The components of vectors **a** and **b** are determined based on our questionnaire surveys.

The affiliates' choice of an ad mix is affected by many factors, including non-monetary motivations; however, in this chapter, we focus only on the affiliates' monetary motivation, which is not unrealistic given the results from our blogger survey (Table 2.1). In addition, we assume that affiliates search for a better ad mix if they are not satisfied with their monetary rewards.

The most naïve strategy for seeking a better ad mix may be the random walk, which requires little rationality or thought by agents. Another strategy is the local imitation, in which slightly more rational affiliates adopt a strategy in which they imitate the most successful action of their peers, for which the scope for search is bounded. More specifically, these two strategies are formulated as follows:

**Random Walk.** If an agent's revenue at time $t$ is lower than the revenue at time $t-1$, the agent replaces a product in the ad mix with another one, both chosen at random. The number of products advertised simultaneously in each blog is kept at the initial level indicated in the survey data. Of affiliate agents, $g * 100\,\%$ adopt this strategy.

**Local Imitation.** If the revenue at time $t$ is lower than the revenue at time $t-1$, the agent searches for some very similar blogs in terms of topics covered, and then copy the ad mix of the blog that earns the largest revenue. The similarity between blog $i$ and $i'$ is calculated by Eq. (2.3):

$$SIML_{ii'} = 1 - \sum_{j=1}^{J} \left| b_{ij} - b_{i'j} \right| / J \tag{2.3}$$

It may seem unrealistic to assume that affiliates can know each other's revenues; however, they can estimate the revenues by looking at the number of visits for a blog, which is easily available through indicators embedded in the front page of a blog or through ranking sites. Thus, from such traffic data, bloggers can roughly estimate which blogs have a similar number of clicks and conversion rates as theirs. $(1-g) * 100\,\%$ of affiliate agents adopt this strategy.

## *2.3.2 Readers' Behavior*

Blog readers in our model are potential buyers of products advertised in affiliate ads. They have preferences for blog topics and advertised products, which are represented, respectively, as follows:

$$\mathbf{u}_h = (u_{h1}, u_{h2}, \ldots, u_{hj}, \ldots, u_{hJ}) \tag{2.4}$$

$$\mathbf{v}_h = (v_{h1}, v_{h2}, \ldots, v_{hk}, \ldots, v_{hK}) \tag{2.5}$$

where $u_{hj}$ equals 1 if buyer $h$ has a preference for topic $j$, and 0 otherwise, and $v_{hk}$ equals 1 if buyer $h$ has a preference for product $j$, and 0 otherwise. These factors were also determined based on our questionnaire surveys.

Before reading blog entries or purchasing a product, readers have to choose which blogs to visit. Unfortunately, our surveys did not collect information on which affiliate blog each buyer has visited; the reason is that the blogger and reader respondents were independently sampled, and thus, it would be difficult to connect the blogs to the readers and vice versa. Alternatively, we artificially spanned "links" between these two groups, utilizing the empirical data as much as possible. Fortunately, our surveys collected information that we could use to match agents based on preferences in topics and products. We explain this matching process below.

Firstly, we reasonably expected that readers will be inclined to visit blogs where the topics are the most congruent to their preference. The extent of this congruence (topic congruence) is calculated by Eq. (2.6):

$$TOPIC_{ih} = 1 - \sum_{j=1}^{J} \left| b_{ij} - u_{hj} \right| / J \tag{2.6}$$

Likewise, we can consider links based on the congruence between advertised and preferred products (product congruence). The extent of this congruence is calculated by Eq. (2.7):

$$PROD_{ih} = 1 - \sum_{k=1}^{K} |a_{ik} - v_{hk}| / K \tag{2.7}$$

Although it seems unrealistic to assume that readers choose blogs based on the advertising of their favorite products, product congruence could be a good proxy for similarity in taste for consumption. In addition, if affiliates are able to find an ad mix that is most congruent to the target readers' product preferences, the resulting links will maximize this congruence. In that sense, this congruence could measure the "optimality" of the affiliates' actions.

The links maximizing topic congruence and product congruence are, respectively, extremes of a continuum of the possible links between the agents. Since there is an infinite number of factors affecting these links, more realistic links would not converge into such extremes, rather existing somewhere in between them.

We consider that the realistic links between affiliates and readers can be determined by combining all of the above criteria. Hence, we use Eq. (2.8) as a meta-level criterion:

$$C_{ih} = w_1 RAND_{ih} + w_2 TOPIC_{ih} + w_3 PROD_{ih} \tag{2.8}$$

where $RAND_{ih}$ is a random disturbance term uniformly distributed within $(0, 1)$, $w_1 + w_2 + w_3 = 1$, and $w_1$, $w_2$ and $w_3$ are all nonnegative. With the in-degree or out-degree constraints of each node in the bipartite graphs, the affiliate to which each reader is linked is selected so as to maximize Eq. (2.8). The constraints are given by the surveys: the number of favorite blogs is used to determine the out-degree of a reader, and the page view and the frequency of blog visits are used to determine the in-degree of an affiliate.

After visiting and reading a blog, readers decide whether to buy a product advertised on that blog. For simplicity, we assume that readers are exposed to all advertising inserted in the blog and consider buying a product that best fits their preference. We also assume that if there are many great alternatives, they only choose one at random. The readers' purchase volume is determined by the constraints assigned to them, based on the frequencies of blog visits and shopping reported in the survey.

### *2.3.3 Assignment of Agents*

The agents in our model are generated based on the questionnaire surveys: bloggers who participate in any affiliate program are classified as affiliates, and blog readers who have previously purchased a product by clicking on affiliate advertising are classified as buyers.

In assigning agents in the model to respondents in the survey, we find a gap between desirable agent size and actual sample size. To ensure the scalability of the model, we apply a method of bootstrapping [1] in the context of an agent-based modeling. That is, we generate the size of the bootstrap sample by repeated random sampling from a survey data with replacement; correspondingly, we can draw distributions of the sample statistics or the aggregate outcomes emerging from simulation. This approach also provides more reliable information to avoid sample bias.

## 2.4 Simulation

Firstly, we repeatedly generated agents by bootstrapping, resulting in 50 samples involving 100 affiliates and 1,000 readers. Secondly, for each bootstrap sample, we constructed different link structures corresponding to the following sets of parameters in Eq. (2.8): $\mathbf{w} = (w_1, w_2, w_3) = (1, 0, 0)$, $(1/2, 1/2, 0)$, $(0, 1, 0)$, $(1/2, 0, 1/2)$, $(1/3, 1/3, 1/3)$, $(0, 1/2, 1/2)$, or $(0, 0, 1)$, where the first component represents whether to consider the strength of random noise in link formation; the second, topic congruence; and the third, product congruence.

Each of the affiliate characteristics $\mathbf{a}$ and $\mathbf{b}$ (see Eqs. (2.1) and (2.2)) is given by the products (11 categories, e.g., books, foods/beverages) that the respondents of affiliates in our questionnaire survey have advertised and by the topics (29 genres, e.g., cooking, social events, travel) of blog entries that they have posted, respectively. On the other hand, each of the reader characteristics $\mathbf{u}$ and $\mathbf{v}$ (see Eqs. (2.4) and (2.5)) is given by the topics that the respondents of blog readers in the survey prefer to read and by the products that they have bought via any affiliate, respectively.

Thirdly, given the link structure and the bootstrap sample, we performed a simulation, varying the proportion of the random walkers and local imitators: $g = 0.1, 0.3, 0.5, 0.7$, or $0.9$. For a set of these parameters, a simulation is repeated

20 times to cancel out accidental variations. The time horizon is set to $t = [1, 30]$. In imitating others, affiliates following the local imitation strategy choose the five agents whose blogs are most similar to theirs, based on the calculations from Eq. (2.3).

## 2.5 Results

In order to confirm that the outcomes predicted by our simulation are distributed in a unimodal and almost symmetric manner (e.g., unlike a power law), we average out the outcomes using a set of parameters to summarize the results. As Fig. 2.2 indicates, the average cumulative revenue per affiliate at $t = 30$ is remarkably high when $w_3 = 1$, which indicates link structures based on product congruence rather than topic congruence or random noises. Also, the proportion of random walkers, $g$, shows a positive effect on the average revenue of all agents in most cases. We can find the threshold between $g = 0.1$ and 0.3, except for $\mathbf{w} = (1, 0, 0)$, where only random disturbance is dominant. This suggests the effectiveness of the random walk strategy in boosting average revenue for all affiliates. In particular, if random walkers were eliminated from the market beyond a certain line (that is, if $g$ is less than between 0.1 and 0.3), the market would contract drastically.

Figure 2.3 shows the temporal changes in the average revenue of all affiliates by a set of parameters. Below are some of the interesting findings:

1. Average revenue is sufficiently high at the initial period when $w_3 = 1$ (links based on product congruence), and is very low otherwise. This result is understandable since maximizing product congruence is equivalent to maximizing

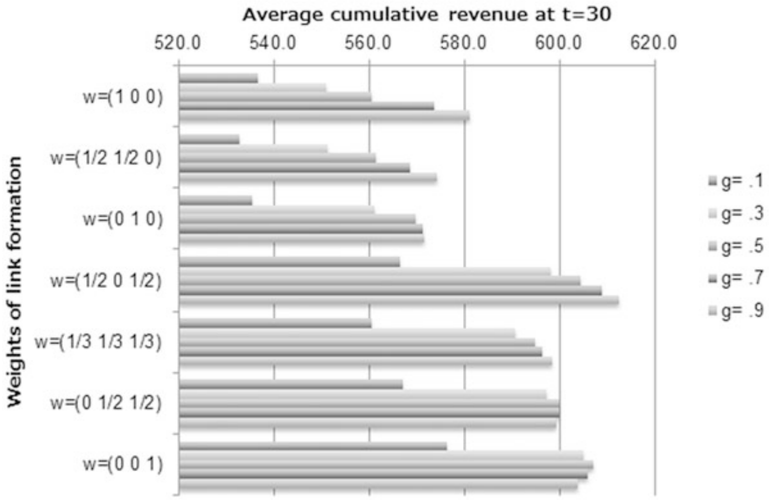


**Fig. 2.2** Average cumulative revenues at $t = 30$

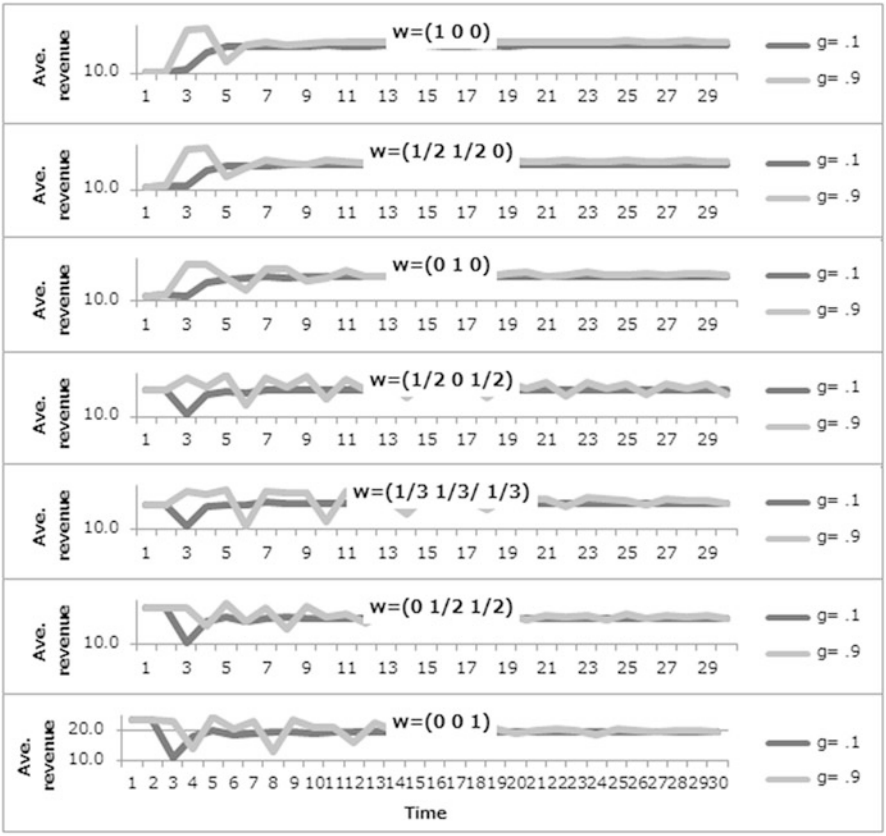


**Fig. 2.3** Time-series trajectory of average revenues

purchase in our model. We expect such a case to be more realistic if the market is at the mature stage, since the affiliates could have enough time to learn their readers' preferences.

2. In earlier periods, just after the initial period, average revenue drastically fluctuates. For instance, at $t = 3$ or 4, it reaches a peak if $g$ is relatively high, that is, when the proportion of random walkers is higher. This result suggests that the presence of agents with "no intelligence," who have put little thought into their ad mix, amplifies short-term fluctuations in the market in earlier periods.
3. In the long term, the average revenues converge regardless of the link structure or proportion of random walkers. Accordingly, the difference in cumulative revenues may depend on the difference in earlier revenues. This dependence becomes more important when calculating the present discounted value with a reasonable discount rate.

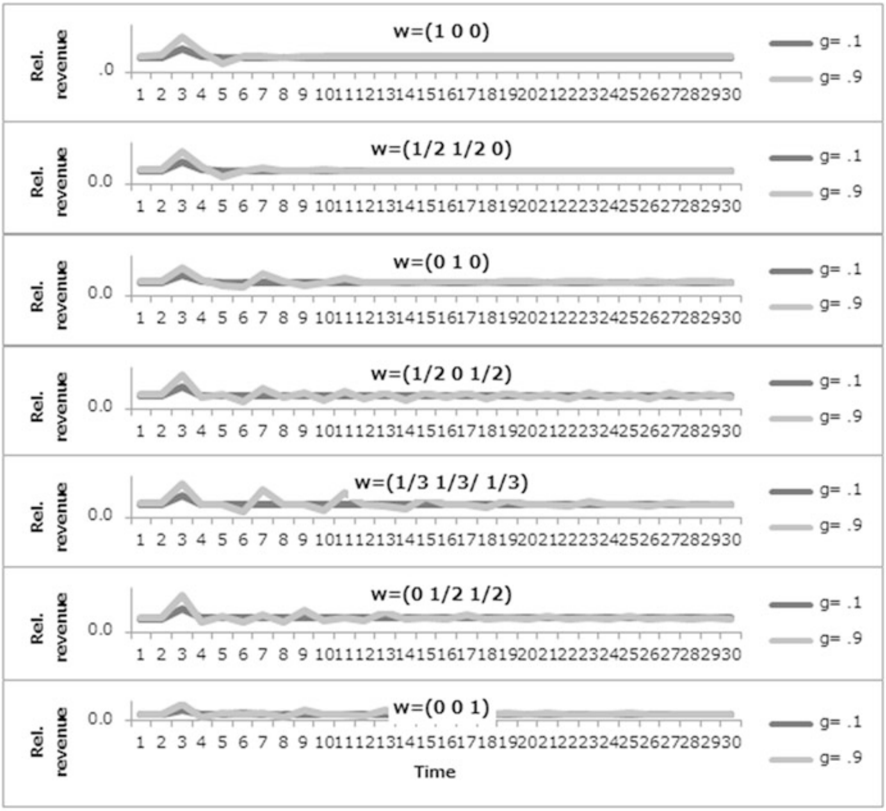


**Fig. 2.4** Relative revenues of random walkers vs. local imitators

We compare the revenues of random walkers with those of local imitators. As shown in Fig. 2.4, the ratio between these two types of revenues quickly converges, that is, both types are almost always at the same level except in the earlier periods. This result suggests that the choice of search strategies may have little impact over the long term. Only when the proportion of random walkers exceeds a threshold ($g > 0.1$) do the average revenues of random walkers become higher than those of local imitators in earlier periods.

In addition, we compare the revenues of affiliate leaders, that is those whose cumulative revenues are in the top 10 % by $t = 30$, with those of the rest of the affiliates (followers). Figure 2.5 shows that the difference in trajectories depends mainly on whether the link structure is product-congruence based ($w_3 = 1$) or not ($w_3 = 0$). For product-congruent link structures, the leaders' revenues surge temporally in earlier periods, particularly if the proportion of random walkers is low. For other link structures, the leaders' revenues are high from the beginning, decreasing over time, particularly if the proportion of random walkers is high. In any case, the differences in revenues between leaders and followers disappear over time as the revenues converge.

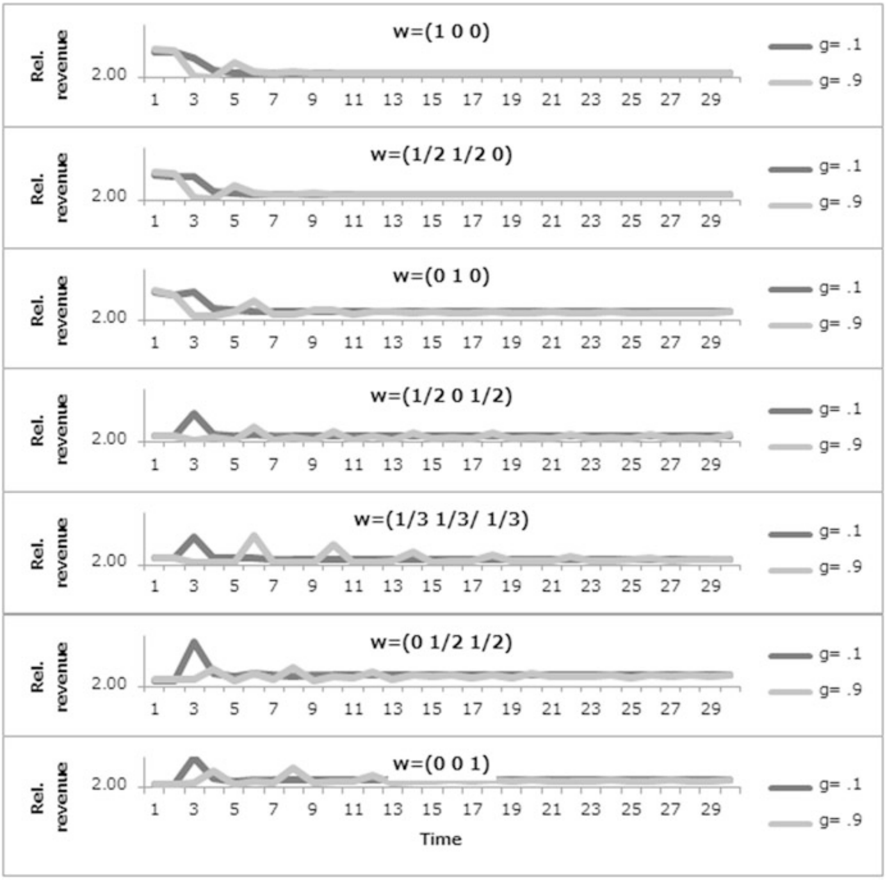


**Fig. 2.5** Relative revenues of leaders vs. followers

## 2.6 Discussion

Although most affiliates participated in affiliate programs with a monetary motivation, their revenues from such programs were very small. One of the possible means for increasing revenues is changing the ad mix in the blogs. In our model, affiliates seek a better ad mix by adopting a more or less bounded-rational strategy, that is, they become either a random walker or a local imitator. On the other hand, readers choose blogs to visit based on their preferences on topics or products with a certain level of noise, and buy a product advertised on blogs based on their preferences for products.

The key results from our simulation are summarized as follows:

1. Average long-term revenues for affiliates are higher if the link structure is more product congruent and the proportion of random walkers exceeds a certain threshold.

2. The effect of the proportion of random walkers on total average revenues fluctuates only in earlier periods; in other words, the presence of random walkers contributes to the increase in total revenues through this fluctuation.
3. There is no difference in the average revenues between random walkers and local imitators; the difference is stable over time except in very early periods. The presence of random walkers has little impact on the competitiveness of each agent.
4. Except for the fluctuation in earlier periods, the difference in average revenues between leaders (top 10 % of affiliates based on earnings) and followers (all other affiliates) is stable over time and does not vary by link structure or the presence of random walkers.

Interestingly, the presence of random walkers, despite the little thought they put into their ad mix, positively affects not only their revenues but also those of all other affiliates in the entire market, resulting in little difference in competitiveness. A possible reason for this outcome is that a random-walk search guarantees a diverse ad mix that sufficiently satisfies readers' heterogeneous preferences. This suggests that a key factor in earning more from an affiliate program is maintaining diversity among the ad mixes of blogs.

Hence, for affiliates who wish to increase revenue, the results suggest not imitating peers who have seemingly effective ad mixes, but rather adopting a distinctive ad mix, as if searching at random. Consequently, if the proportion of random walkers in the market increases, the expected revenues for all affiliates will also increase. This scenario illustrates a positive-sum game with no trade-off among affiliates.

This study also has implications for researchers interested in empirical validation for agent-based modeling [7]. In this study, we calibrated each agent's parameters based on the questionnaire surveys for bloggers and readers. To map the empirical data according to the agents in the model, we extend the method of bootstrapping, which has been developed in statistics [1].

Lastly, we suggest further avenues for research. In this paper, we simplified many factors in order to keep the model parsimonious. However, we could further extend this simplification to deal with more complex or dynamic phenomena. For instance, we can consider other types of strategies for each affiliate for improving the ad mix. Moreover, we could allow affiliates to change the topics or themes of their blogs in order to enter or exit the market. At the same time, we could allow readers to change their preferences for blogs and advertised products. If such changes occur in converging into a steady state reported as above, some longer standing fluctuations might emerge.

As a further extension, we can consider agents who put greater thought into or use emotions to determine their strategy or behavior. When buying something from affiliate advertising, readers' decisions might be influenced somehow by emotions such as sympathy, reciprocity, trust, or anxiety. From a managerial viewpoint, our findings are expected to help integrate affiliate advertising with other advertising media and marketing practices.

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# Chapter 3
# Understanding Citizens' Channel Choice of Public Service Delivery: An Agent-Based Simulation Approach

**Shuang Chang, Manabu Ichikawa, and Hiroshi Deguchi**

**Abstract** E-government has become a rapidly emerging research field in recent decades. An obvious benefit of deploying e-government service is that the quality is improved through integrated services and the services provided can more flexibly satisfy the citizens' needs. However, the adoption rate of e-government is still relatively low, especially for transactional services. We propose a new method, agent-based simulation, to understand how citizens from different social groups choose channels to utilize certain kinds of governmental services over time. In addition, by evaluating different public strategies such as public propaganda and increased technical support, we try to identify what kind of strategy could attract more citizens to utilize e-government services.

**Keywords** Agent-based modeling • E-government system • Policy evaluation

## 3.1 Introduction

Within the realm of service-oriented innovation studying, e-government is a rapidly emerging research field. As defined by the United Nations and the American Society for Public Administration (ASPA), e-government is "utilizing the Internet and the world-wide-web for delivering government information and services to citizens [22]". This electronic means of public service delivery enables the government to promote transparency, convenience, and effectiveness to citizens. Recently the services have evolved from mere static information provision to more value-added services such as transactional services [3].

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An obvious benefit of deploying e-government service is that the quality is improved through integrated services and the services provided can more flexibly satisfy citizens' needs [23]. On the other hand, there are noticeable challenges. There is no clear and well-recognized definition of e-government yet in the literature [7]. Different definitions have been proposed from various angles, trying to grasp different aspects of this phenomenon [2, 10, 13]. Therefore the meaning of e-government might depend on its use in a particular context such as dominant social groups and enacted e-government strategies [24]. Furthermore, different classes of citizens might not all grasp the overall clear image of e-government [20]. The deployment and usage rate of transactional services are also still relatively low [17]. Researchers claim that most of the e-government systems fail to raise citizens' awareness and thus fail to attract them to take advantage of the services [18].

In the literature, few extant empirical research works focus on the citizens' preference of using e-government services over other traditional means such as visiting the government service counter [15]. Service is not a generic and passive notion, rather different service types possess unique features. Citizens from different social groups might require various things from those services, which might further impact their choice of channels for utilizing different governmental services, such as information provision and transactional services [12, 23]. Therefore, understanding how divergent attributes of the service influence citizens' channel choices of public service delivery across different social groups, and how we can explore the differences and similarities of channel choices across different social groups with increased awareness rate and technical support, are meaningful and challenging research questions that have inspired this study. A new way to understand how micro-level individual preferences of public service channels lead to a macro-level e-government service adoption phenomenon is also needed, and an agent-based simulation approach is applied in this work.

In this work, by simulating the dynamic channel selection behaviors of citizens from different social groups, we aim to understand which channels citizens prefer for utilizing certain kinds of governmental services over time. In addition, by evaluating different public strategies such as increasing the awareness rate of e-government services and providing more technical support, we attempt to identify what kinds of strategies could be effective to attract more citizens to use e-government services.

### *3.1.1 Hong Kong E-Government*

E-government research has a focus on Western countries, whereas the Asian e-government systems are still overlooked [6, 11, 21]. In this work, we will study the case of the Hong Kong e-government system, which we introduce briefly as follows.

In 1998, the Hong Kong "Digital 21" IT strategy was formulated, which defined the key issues of the development of the e-government system; it was updated in 2001. More than 130 public services are provided: citizens can change their personal particulars, book public leisure and sports facilities, file tax returns, subscribe to governmental publications, and submit various applications [6]. In addition, a smart identity card is issued to facilitate the usage of various services. Furthermore, a public key infrastructure supported by HK Post as the certification authority guarantees the integration, authentication, confidentiality, and non-repudiation of online transactions. An e-certificate is issued to facilitate the authentication of users and enable various transactional services.

### *3.1.2 Methodology*

A quantitative research method such as a survey is the prevailing method applied in investigating factors that might influence citizens' intention to adopt e-government services [6, 8, 11, 16, 23]. However, this method ignores the dynamic process and interactions among stakeholders. In addition, the particular social context is missed, which is critical for e-government research. Therefore, a new method to examine the e-government phenomenon is needed. Agent-based simulation (ABS) [4] might be more practical to analyze the service diffusion process from a "bottom-up" perspective. It could be utilized to explore the dynamic channel choice behaviors of citizens over time, and to examine the impact of different strategies in the service diffusion process since the whole process is dynamic and heterogeneous stakeholders are involved.

In this work, the agent-based model is developed by the simulation language called the Spot Oriented Agent Role Simulator (SOARS) [19]. SOARS is a type of ABS framework and does not require prior programming experience [9]. Details of SOARS will be discussed in Sect. 3.3.

This chapter is organized as follows. Section 3.2 explains the agent-based model proposed in this work. The simulation work and result analysis are presented in Sect. 3.3. The conclusion and future work are discussed in the last section.

## 3.2 Modeling

### *3.2.1 Overview*

This section introduces the characteristics of each service provision channel and the dynamic behaviors of citizens during the channel selection. In the following, a set of assumptions embedded in this model is presented.

- There are basically two types of public service provision channels: traditional counter service and e-government service. Both transactional services (such as online tax filing) and information provision services in a broad sense, such as the governmental website, consulting service, and online booking/reservation service, are provided.

- The basic service provision procedures are similar for both channels. Technical support for e-government is provided by the government in order to facilitate the service provision process. Different services provided on different channels may differ in terms of time and effort designated to complete the process. For instance, a transactional service (such as online tax filing) requires more time and effort to complete through both traditional counter service and e-government service.
- Citizens are assumed to be rational in choosing the channel for a particular kind of service. Based on their evaluation of each channel in terms of time and effort, they will choose their favorite one. Citizens are categorized into different social groups according to sex *(Male/Female)*, educational level *(Secondary/Secondary above)* and economic status *(Economically active/Student/Homemaker)*, and different social groups may value time and effort differently, which may influence their selection behavior.

## *3.2.2 Formal Modeling of Agents*

### 3.2.2.1 Service Provider Agent

Basically, service channels enabled by the government are defined as static agents that provide transactional and information provision services in terms of time and effort required to complete the process, as well as the provided technical support. The rationale behind this abstraction is that the governmental services normally can be evaluated by three major aspects: easier service, faster service, and better service [5]. Easier service refers to the effort that is consumed to complete the service. Faster service refers to the time needed to obtain the service result. Better service refers to the technical support received during the service provision process. These indicators are rather objective in the sense that they address particular attributes which can be controlled by the service provider.

Therefore, the service provider agent will be abstracted as $Service = \{S_1, S_2\}$, where $S_1$ indicates the traditional counter and $S_2$ represents the e-government. Each of $S_i, i \in \{1, 2\}$ will be defined as $< T_s, E_s >$, where $T_s, E_s \in R^+$. $T_s$ represents the total time of service provision, including the time from locating the service until obtaining the result. $E_s$ represents the total effort required to complete the process, including the effort needed to become familiar with the location, to know where to submit the request, and how to obtain the result. Technical support $TS_s$ which is only provided by e-government is defined as $< T_{TS}, E_{TS}, Cap_{TS} >$, where $T_{TS}, E_{TS} \in R^+$, and $Cap_{TS} \in \mathbb{Z}$. Three kinds of technical support are identified: a Help website (such as FAQ), email contact, and direct communication (such as face-to-face communication or a phone call). $T_{TS}$ indicates the time required for technical support, and $E_{TS}$ refers to the effort saved by receiving technical support. $Cap_{TS}$ indicates the capacity per time unit enabled by the service provider, i.e.

**Table 3.1** Value table of $T_s$ and $E_s$

| $T_s/E_s$ | Transactional service | Information provision service |
|---|---|---|
| Traditional counter | $High/High$ | $High/Low$ |
| E-government | $Low/High$ | $Low/Low$ |

the number of requests that can be handled within a certain time. The values of $T_s$ and $E_s$ are different for the traditional counter $S_1$ and e-government $S_2$, and they also differ for transactional services and information provision services. Intuitively, we sense that the effort required for a transactional service is higher than one for an information provisional service. In addition, the effort required for using a traditional counter is lower than that for using e-government. However, the case for time is just the opposite. Also, for a traditional counter, there are office hours $Time_{open}$ and $Time_{close}$ defined such that the service is only available within this time period. The conceptual value of $S_i$ is shown in Table 3.1.

#### 3.2.2.2 Citizen Agent

A citizen is an active agent who may utilize governmental service (both transactional service and information provision service) through different channels as he prefers. A citizen set is defined as $Citizen = \{C_1, C_2, \ldots, C_n\}$, where $n$ is the number of citizens. Each citizen is abstracted as $C_i =< Util_{S_1}, Util_{S_2}, Pref_T, Pref_E, T_c, E_c, L_{exp} >$, where $Util_{S_1}, Util_{S_2}, T_c, E_c \in R^+$, and $Pref_T$ and $Pref_E$ vary between 0 and 1. In addition, we require $Pref_T + Pref_E = 1$. $L_{exp}$ is a list of 0 and 1 which represents the history of using e-government service; 1 indicates success, and 0 otherwise. $T_c$ is the total time required for citizens to complete the service including the time to complete the process plus the time spent on technical support. $E_c$ is the total effort consumed to complete the service process successfully; received technical support would help decrease the effort. $Pref_T$ and $Pref_E$ indicate how the citizen weights the time and effort required to complete the service process respectively. Citizens from different social groups are assigned different values of the weight. The larger the value, the more citizens emphasize the attribute. For instance, a citizen who thinks time is more important than effort will be assigned a larger value of $Pref_T$ compared with $Pref_E$.

Each citizen will calculate a utility value of either traditional counter or e-government based on time and effort consumed at each iteration, indicated as $Util_{S_i}, S_i \in \{S_1, S_2\}$. The service channel with the lower utility value will be chosen each time the citizen has to use a particular service type. The utility value for traditional counter and e-government service at each time unit $t$ is updated as follows:

$$Util_{S_1}(t) = Pref_T * T_c(t) + Pref_E * E_c(t) + \varepsilon \tag{3.1}$$

$$T_c(t) = T_s \tag{3.2}$$

$$E_c(t) = E_s \tag{3.3}$$

For traditional counter service, we assume that citizens do not need any technical support since they can communicate with the staff directly during the process; thus, the time and effort required are equal to the time and effort defined in the service provider agent. The value of $T_s$ will vary according to different time slots within the office hours. For instance, in the early morning and late afternoon, the value of $T_s$ will be smaller than those of the other time slots.

$$Util_{S_2}(t) = Pref_T * T_c(t) + Pref_E * E_c(t) + \varepsilon \tag{3.4}$$

$$T_c(t) = T_s + \frac{Num_c(t)}{Cap_{TS}} * T_{TS} \tag{3.5}$$

$$E_c(t) = E_s * P_{EST} - \frac{Num_c(t)}{Cap_{TS}} * E_{TS} \tag{3.6}$$

For e-government, technical support will be provided. $\frac{Num_c(t)}{Cap_{TS}}$ is multiplied to adjust the time and effort required by technical support according to the current situation. $Num_c(t)$ is the number of citizens at time $t$ receiving the technical support, and $Cap_{TS}$ is defined as the capacity of technical support within a certain time period. For the Help website and email contact, the value of this ratio is assigned to be 1. For direct communication this value is assigned based on the simulation process. $\varepsilon$ is a random noise uniformly distributed between 0 and 1. From time to time, the time consumed to complete the service process $T_c$ will not change significantly, but the effort of utilizing e-government service will be evolving. $E_c$ will evolve based on citizens' previous channel choice and corresponding experience. The way to update the evolved effort rate $P_{EST}$ for e-government at each iteration is explained as follows [1]. Basically the value depends on whether the previous w tries of e-government are successful or not. Each citizen will keep a list to record the history of using e-government service, denoted as $L_{exp}$. We let Num indicate the length of the list, NoW indicate the number of success of the last w tries, and NoS represent the total number of successful tries, where w, Num, NoW, NoS $\in \mathbb{N}$, and $P_{EST} \in R^+$. Then $P_{EST}$ will be updated at each iteration as follows:

$$P_{EST} = \begin{cases} 1 - Est & \text{if the current try is successful} \\ 1 + Est & \text{otherwise} \end{cases} \tag{3.7}$$

$$Est = \begin{cases} \text{NoW}/\text{w} & \text{if Num} \geq \text{w} \\ (\text{w} - \text{Num} + \text{NoS}/\text{Num})/\text{w} & \text{if Num} < \text{w} \end{cases} \tag{3.8}$$

The dynamic channel selection behavior of citizens at each iteration is shown in Fig. 3.1.

For transactional services provided by e-government, before citizens carry out the procedures for the first time, they must go to HK Post to obtain an e-certificate

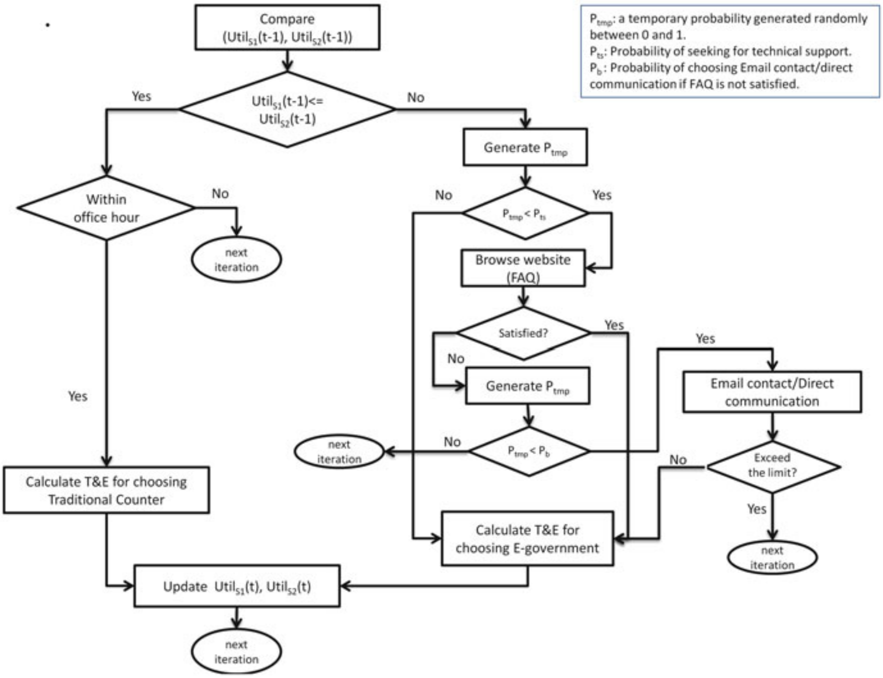


**Fig. 3.1** Selection behavior of citizens at each iteration

for conducting the transactional services. This process is only performed once and is thus omitted in Fig. 3.1. The time and effort for this one-time step will be updated as $T_c(t) = T_s + T_{cert} + \frac{Num_c}{Cap} * T_{TS}$, and $E_c(t) = E_s * P_{EST} + E_{cert} - \frac{Num_c}{Cap} * E_{TS}$. Here $T_{cert}$ and $E_{cert}$ indicate the time and effort consumed to obtain this e-certification respectively.

## 3.3 Simulation Model

In SOARS [19], the behaviors of a citizen agent are defined in agent roles. In each role, a set of rules are defined, and agents will behave according to these rules. The rules are defined according to the dynamic selection behavior of citizens as shown in Fig. 3.1. In this work seven types of roles are defined according to sex (Male/Female), educational level (Secondary/Secondary above) and economic status (Economically active/Student/Homemaker). These roles possess the same rules but differ in the value of parameters, i.e. $Pref_T$ and $Pref_E$.

The service channels as well as the technical support and HK Post in SOARS are defined as spot. Each simulation iteration represents an hour and within every 24 simulation iterations citizens will go to either the traditional counter spot or e-government spot based on their channel choice. In other words, citizens are allowed to make only one channel choice within 24 h (per day). Since e-government is available all day, citizens will not be restricted to use it with respect to time. In contrast, for traditional counter, citizens can only use it during office hours. If a citizen's decision is traditional counter but the iteration time is out of the office hour, then he will wait until the traditional counter is open within the day. With probability $P_{ts}$ citizens will go to technical support spot for help. Firstly they will browse the website (FAQ), and only go for email contact and direct communication support if they cannot find answers on the website with probability $P_b$. Each spot will record the number of citizens who have visited on a daily basis.

### 3.3.1 Simulation and Parameter Setting

For each social group, there will be 500 citizen agents. For each simulation run, $40 * 24$ iterations which represent 40 days (24 h per day) will be carried out. Citizens will randomly choose one and only 1 h to make the decision within each day. Office hours are defined from 9 A.M. to 5 P.M. According to SOARS's characteristics, all simulation results shown in the following subsections are the average value of 40 runs, which could guarantee a reasonable output. Social groups are divided with respect to their preference of time and effort required to complete the process, i.e. $Pref_T$ and $Pref_E$. Social groups with relatively larger values of $Pref_T$ are treated as groups favored by e-government, whereas the ones with relatively larger value of $Pref_E$ are treated as groups not favored by e-government, such as citizens with less education. In this work, we set the value $(Pref_T, Pref_E)$ for male as $(0.55, 0.45)$, female as $(0.5, 0.5)$, citizens with secondary and above education as $(0.6, 0.4)$, citizens with secondary education as $(0.45, 0.55)$, economically active citizens as $(0.6, 0.4)$, students as $(0.55, 0, 45)$, and homemakers as $(0.4, 0.6)$. $T_s$ and $E_s$ for different services based on different channels are scaled as real numbers ranging in $(0, 5]$. We assume that technical support will mitigate the effort of using e-government ($E_s$) by $1/3$, and the effort of acquiring the e-certificate $E_{cert}$ is set as half of $E_s$ for transactional services. The initial value of $Util_{S_1}$ is set smaller than $Util_{S_2}$ to indicate a favor of traditional counter at the outset. Probability $P_{ts}$ is set as 10% in scenario 1 and 2, while $P_b$ is set as 50%. All the parameters could be set independently to approximate a particular circumstance; thus in this work the simulation results are only restricted to the above parameter setting.

### 3.3.2 Scenarios

We evaluate this model from two aspects: (1) the daily take-up rate of both traditional counter and e-government for 40 days and (2) the impact of awareness rate and technical support on the adoption rate of e-government for transactional service.

#### 3.3.2.1 Scenario 1

This scenario represents the base scenario. The input data and parameters are not based on empirical data, but estimated ones. In this scenario, at the initial step citizens from different social groups will opt for either traditional counter or e-government randomly (i.e. 50% probability of each channel) for a particular service type. Two simulations are carried out, one for transactional service and one for information provision service. This scenario aims to capture the "AS-IS" phenomenon which might indicate the basic e-government adoption situation without any strategy enacted.

In all the following figures, the $x$ axis represents the time unit (daily base), and the $y$ axis represents the number of citizens choosing a particular channel per day over time. From Fig. 3.2 we can see that for transactional service, the adoption rate of e-government is relatively low for all social groups, especially for social groups not favored by e-government. Here social groups not favored by e-government refers to the groups with higher values of $Pref_E$, i.e. citizens with only secondary school education and homemakers. This result is very similar to reality according to the No. 43 Hong Kong Thematic Household survey (2009), published by the Census and Statistics Department of HKSAR [14], which shows that the usage rate of e-government for social groups such as male, citizens with secondary-above education, students, and economically active citizens is higher than that for other social groups. On the other hand, as shown in Fig. 3.3, for information provision services with relatively low effort required ($1/2$ of $E_s$ for transactional service) and without the extra effort of obtaining the e-certificate $E_{cert}$, the adoption rate of e-government could increase rapidly and finally become stable. The difference is that for social groups which are not favored by e-government, the rate will increase relatively slowly. For this reason, in the following scenarios only transactional service is considered to evaluate different policies.

#### 3.3.2.2 Scenario 2

This scenario aims to evaluate the effectiveness of awareness rate on channel choice for transactional service. At the initial step, the citizens will go for e-government based on their awareness rate of it, rather than as a random choice. This result is compared with the base case in which the initial choice is random. In addition, we increase the probability of acquiring the e-certificate, which is compulsory for transactional services, by 30% as the awareness rate of e-government is increased. The data in Table 3.2 on the awareness rate have been obtained from the No. 43 Hong Kong Thematic Household survey (2009) as well [14].

In Fig. 3.4, the base case in scenario 1 is compared to the case with the awareness rate considered; for simplicity, only the take-up rate of e-government is represented. It is interesting to see that the increased awareness rate does not necessarily improve the take-up rate of e-government but may rather do the opposite. An explanation could be that as even more citizens are aware of the transactional service provided

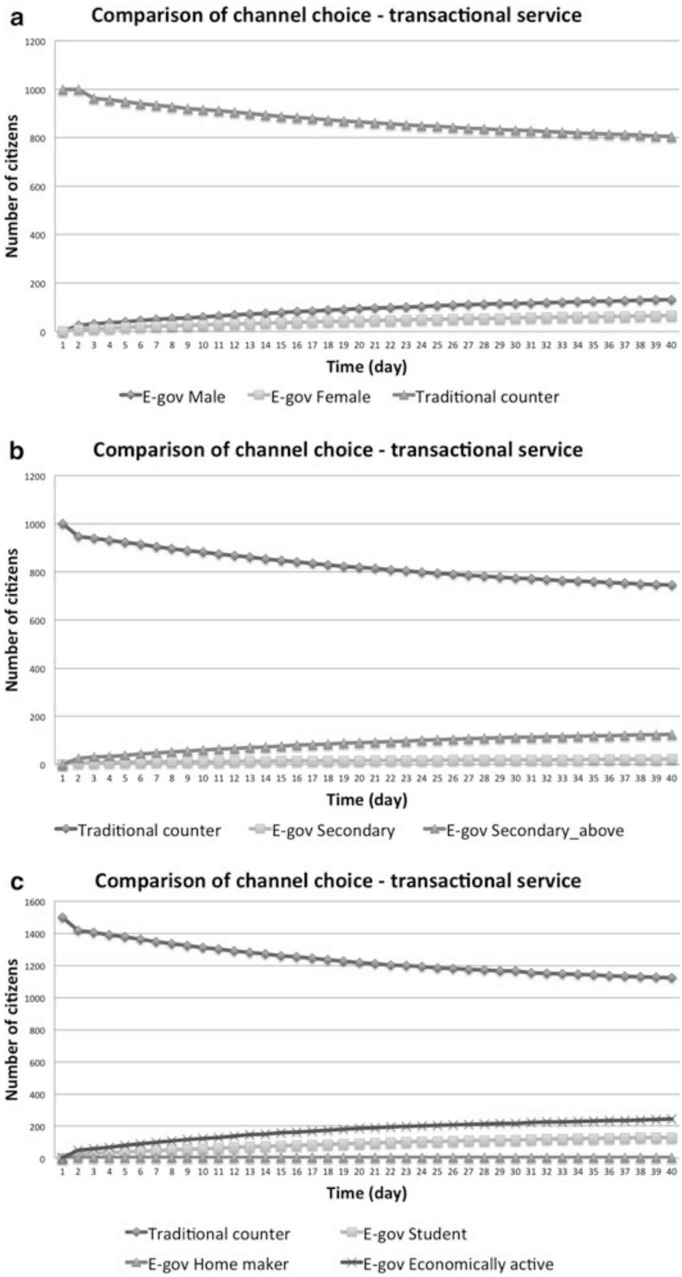


**Fig. 3.2** Channel choice of different social groups for transactional service. (**a**) Sex, (**b**) education, (**c**) economic status

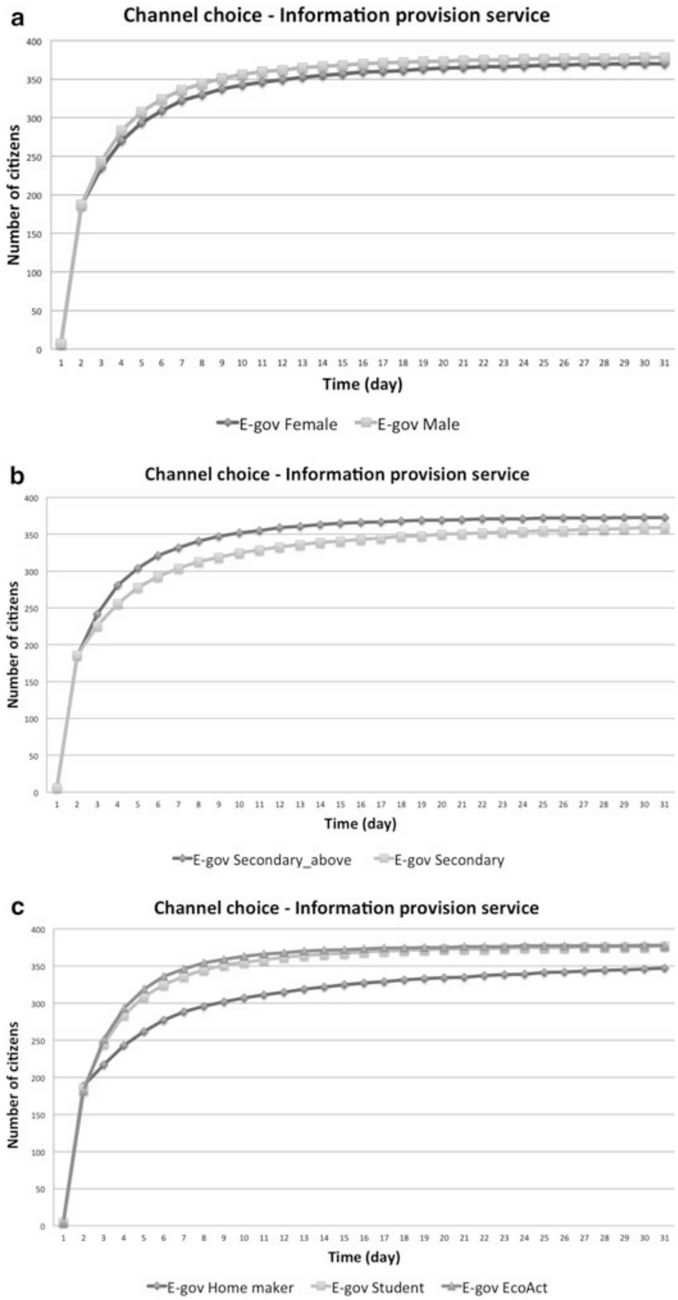


**Fig. 3.3** Channel choice of different social groups for information provision service. (**a**) Sex, (**b**) education, (**c**) economic status

**Table 3.2** Value of awareness rate

| Social group | Awareness rate (%) | Social group | Awareness rate (%) |
|---|---|---|---|
| Male | 56 | Economically active | 63 |
| Female | 52 | Student | 68 |
| Secondary education | 58 | Home maker | 35 |
| Above secondary education | 81 | | |

by e-government, the involved complexity, especially the necessity of $E_{cert}$ for transactional service, hinders them further from taking up the service. As a result, the take-up rate of e-government does not increase proportionally to the increased awareness rate as expected. In this sense, public propaganda for e-government transactional service might not be very effective in increasing the adoption rate.

#### 3.3.2.3 Scenario 3

This scenario aims to evaluate the effectiveness of providing more technical support. In this scenario, for e-government transactional service, the citizens' willingness rate to request technical support $P_{ts}$ will be increased from 10 to 20% evenly for all kinds of technical support. In addition, the effort of acquiring the e-certificate $E_{cert}$ will be decreased by $1/3$. The legend "Male-base" in Fig. 3.5 represents the base case, whereas "Male-TS" represents the case with a higher rate of technical support requested by males. Other social groups are represented in the same way.

From Fig. 3.5 we can see that, for transactional service, with increased technical support the usage of e-government is increased accordingly, though the increased rate is different across various social groups. For social groups who are favored by e-government, i.e. those with a smaller value of $Pref_E = 0.45$, such as males, students, and citizens with secondary-above education, the increased rate is larger (around 16%) than that for social groups who are not favored by e-government, i.e. those with a larger value of $Pref_E = 0.6$, such as homemakers (around 5%). In other words, with the above setting the technical support is more effective for the group of citizens who prefer e-government from the very beginning. In this sense this scenario indicates the possibility of digital divide in utilizing e-government service, even with more technical support provided in a broad sense.

In summary, under the parameter setting presented above, compared with the policy of increasing awareness such as public propaganda, increasing technical support is more effective in helping to improve the e-government transactional service take-up rate. However, this strategy tends to be more beneficial with social groups who already have a higher usage rate of e-government. New policies targeting social groups with lower usage rates of e-government should be developed in the future.

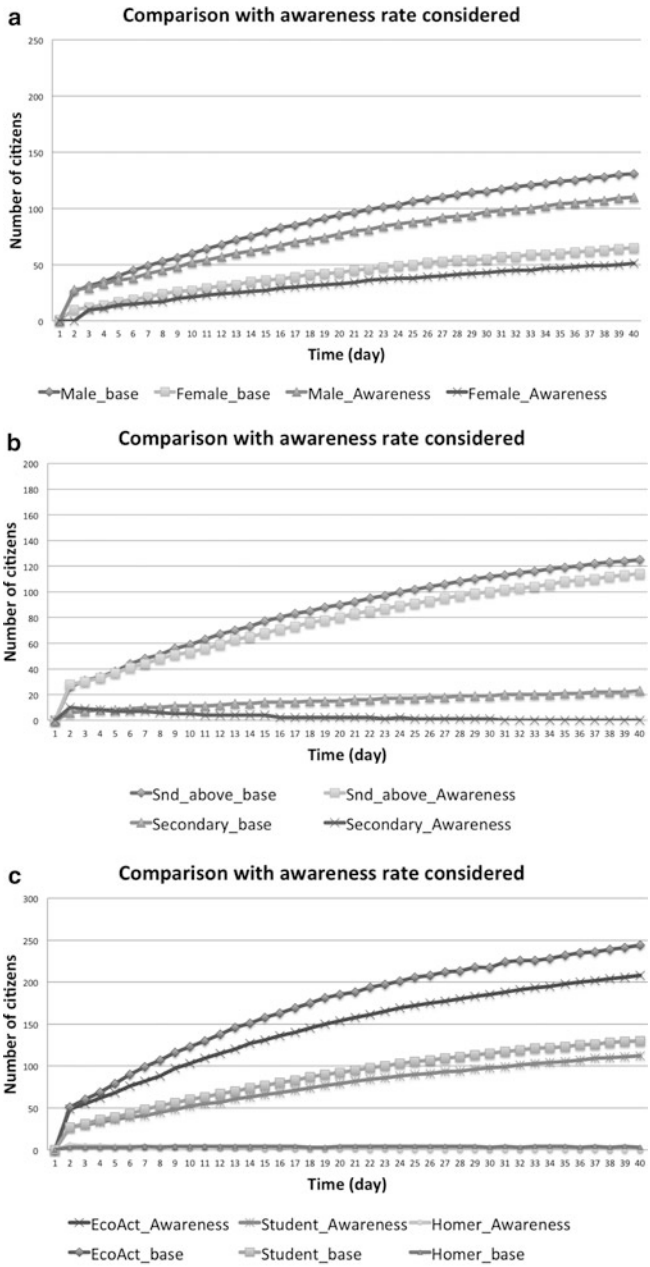


**Fig. 3.4** Channel choice with awareness rate for transactional service. (**a**) Sex, (**b**) education, (**c**) economic status

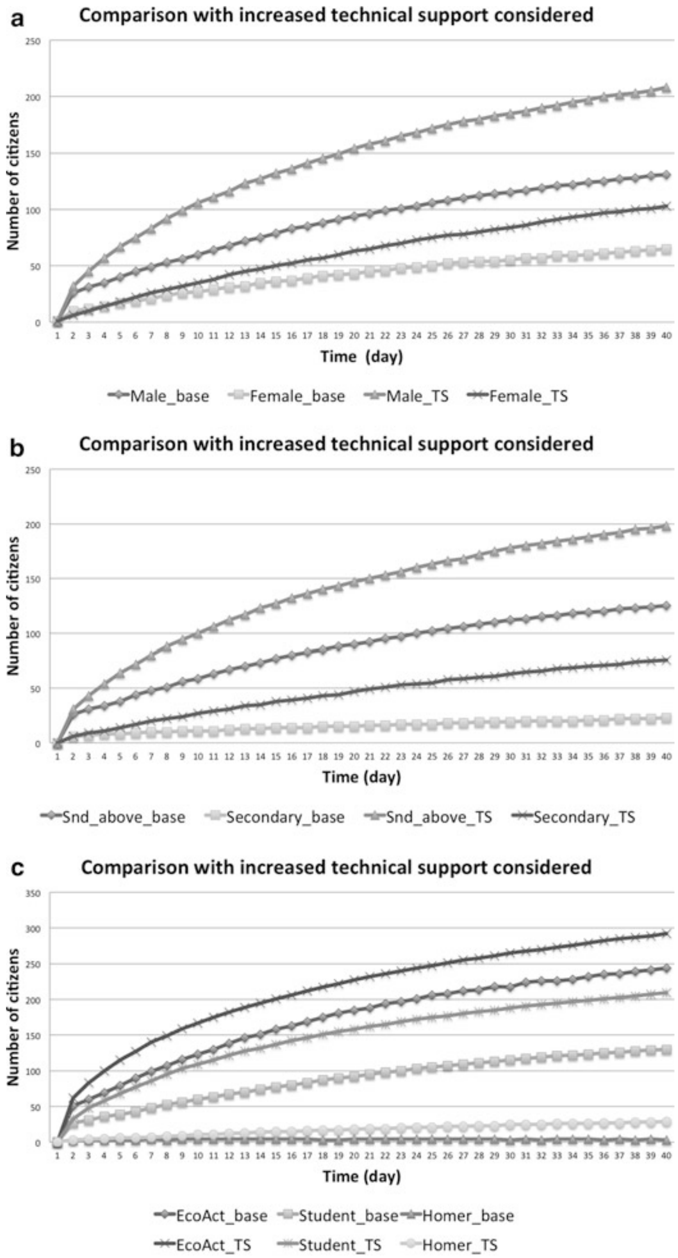


**Fig. 3.5** Channel choice with increased technical support for transactional service. (**a**) Sex, (**b**) education, (**c**) economic status

## 3.4 Conclusion

In this work we have proposed a new method, agent-based simulation, to study and understand the channel choice of citizens from different social groups when they want to take up certain types of governmental services. We have used three scenarios, first to obtain a better understanding of the basic situation of e-government adoption across different social groups for a particular kind of service, and then to predict the take-up rate of the e-government service with policies of increasing the awareness rate and providing more technical support. It is interesting to see that increased awareness of e-government transactional service doesn't obviously help improve its take-up rate, while increased technical support does. In addition, for different social groups the effectiveness of technical support varies. For social groups who have chosen e-government for transactional service frequently, the increased technical support is more effective, which implies that other policies should be considered to improve the e-government adoption rate of social groups who have not yet utilized it frequently. This work could serve as the first attempt to capture citizens' channel choice of public services by applying agent-based simulation, and future models could be based on it to understand the underlying dynamics better and to examine the effectiveness of potential policies. One advantage of applying agent-based simulation rather than other methodologies is that interactions among citizens, such as social learning, could be integrated into this base model easily for further investigation. On the other hand, the parameter setting of agents is not based on empirical data, and thus the simulation results are restricted to the parameter setting in this work only. Survey work should be conducted in order to obtain empirical data for future modeling and validation.

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# Chapter 4
# Cyclical Pattern of the Rise and Fall of an Online Community Due to a Troll

**Yutaka Nakai**

**Abstract** A deviant behavior against an online community such as a troll sometimes forces a community to close. A troll's action is regarded as a crime of pleasure: a selfish, anonymous individual feels delight in inflaming others and in seeing their confusion, knowing that there is no effective sanction for such behavior in an online community. The most effective countermove, by popular opinion, is to completely ignore the troll: "Do not feed the troll." There also exists the unintentional troll, who is unaware that he or she is in fact trolling. If a troll is motivated by evil-minded pleasure and a secure feeling because there are no effective countermoves, it is not surprising that an intentional troll occurs. However, an unintentional troll is also not trivial. To understand a troll thoroughly, we formulated an anti-community strategy and a pro-community strategy, to express a troll's behavior and a community member's behavior, respectively, and we also assumed a third strategy: a de-community strategy. We executed evolutionary simulations with the three strategies, and then examined their outcomes. We found that we could replicate the situation where an excessive response against a troll leads to the closure of an online community and that an unintentional troll can have the same result. We also found the cyclical pattern of a dominant strategy such as rock-paper-scissors.

**Keywords** Anti-community strategy • Cyclicality • Evolutionary simulation • Online community • Rock-paper-scissors • Troll

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## 4.1 A Troll in an Online Community

A troll is a typical deviant behavior in an online community. A troll is defined as a hostile behavior that causes trouble to community members and reduces the value of the online community. Typical examples include provocation with an offensive comment, inflaming others with an intentionally selfish comment, negation of an identity of a community, a discriminating remark, and mental abuse [7]. A troll elicits counterarguments by making very unreasonable comments. Such behavior, if frequently duplicated, induces some to react against it with alarm, and other members to join the troll's bandwagon. It causes the community's atmosphere to become savage and sometimes forces the community to close [3, 7]. Typical characteristics of a troll are as follows [3].

1. Crime for pleasure as a motivation: to feel delight at others' confusion by caviling and "getting on their nerves." Strong and paradoxical dependence on a community.
2. Closed and exclusive sense of value: narrow acceptable range for a different value.
3. Selfish and uncooperative behavior: excessive self-assertiveness and a lack of communications ability.

One reason a troll develops is the anonymity of an online community. Sproull and Kiesler [8] say that a decrease in social clues induces a troll. Kiesler [4] says that anonymity in an online community can easily induce hostile communication. Morioka [5, 6] says that people with an inferiority complex in their daily lives can feel liberated by playing a fragmentary character with a secure feeling caused by that anonymity. While deviant behavior is usually sanctioned in a real society, there is no effective sanction in an online community. Sanctions are limited to a warning from a provider or a restriction of access. There is a tacit understanding that the most effective countermove against a troll is to completely ignore the troll ("Do not feed the troll"), and the one regarded as least likely to succeed is an emotional counterargument. To summarize, a troll is a selfish behavior by an individual who takes pleasure in seeing others troubled under the protection of anonymity and no effective sanction, and trolling results in the closure of many online communities.

Another popular belief is that there are two types of trolls, an intentional troll and an unintentional troll. The latter is not aware that he or she trolls others [2]. If a troll is motivated by evil-minded pleasure and a secure feeling because there are no effective countermoves, it is not surprising that an intentional troll occurs. However, the occurrence of an unintentional troll is not trivial. To understand a troll thoroughly, we have formulated a troll to express the behavior of a selfish agent delighted to see others' embarrassment while aware that there was no risk of a sanction. Using this, we replicate the fact that an intentional troll leads to the closure of an online community, and that ignoring a troll is an effective defense. We also show that an unintentional troll can cause the closure of an online community as well. (Hereafter we call an online community a community.)

## 4.2 Anti-community, Pro-community, and De-community Strategies

We assume that online users sometimes form a community which collectively produces intellectual value and exchanges it among members (Fig. 4.1). (We call such a behavior a pro-community strategy or PC strategy.) On the other hand, it is assumed that, among the online users, there will appear individuals who receive mental satisfaction by inflaming and abusing community members. (We call this behavior an anti-community strategy or AC strategy.) In addition, online users are assumed to enter into or exit from a community freely. (We call this behavior a de-community strategy or DC strategy.)

First, we formulate a PC agent's behavior and an AC agent's response in detail as follows (Fig. 4.2).

1. PC agents form a community to enjoy a collective intellectual activity.
2. Each member in the community contributes to the community at a production cost ($C_p$) (e.g., time). The total amount of contributions is equal to $\sum C_p = C_p \times N_p$, where $N_p$ is the population of PC agents.
3. The community produces a value equivalent to $K_p \sum C_p = K_p \times C_p \times N_p$, corresponding to the total contribution multiplied by its production efficiency ($K_p$).
4. This value represents, for example, the amount of time saved due to a collective intellectual activity compared to the time required to solve a problem alone.

Because the value is publically available, everyone can use it with no cost. However, AC agents do not use it because they don't accept a different value from their value. Of course, DC agents by definition cannot use it. Thus, only PC agents share and use the value.

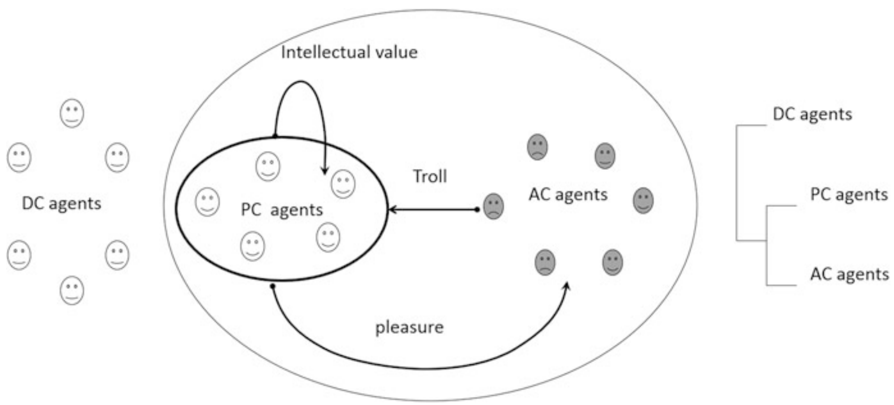


**Fig. 4.1** Relationships among AC agents, PC agents, and DC agents

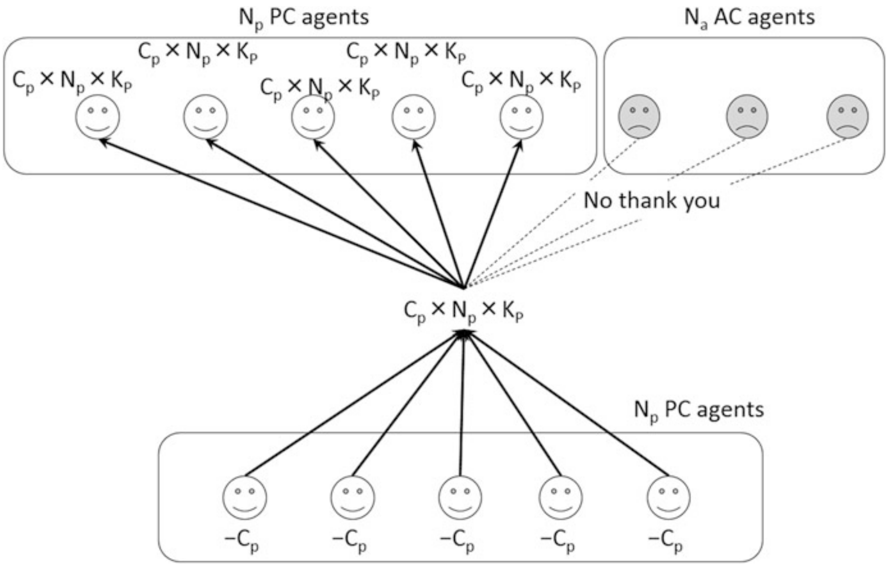


**Fig. 4.2** PC agents' behavior and AC agents' response

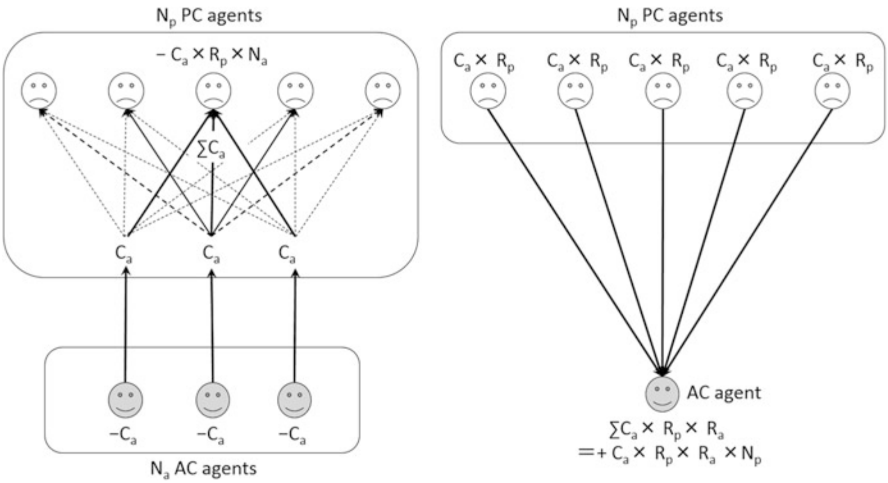


**Fig. 4.3** AC agents' behavior and PC agents' response

Conversely, we formulate an AC agent's behavior and a PC agent's response in detail as follows (Fig. 4.3).

1. An AC agent is engaged in a crime for pleasure, experiencing satisfaction from trolling a community. Also, having uncooperative characteristics, he or she trolls alone.

2. Each agent spends a trolling cost ($C_a$) to troll (e.g., time). He or she inflames and mentally abuses community members.
3. To restore a community, each member expends an effort of $R_p \times C_a$, corresponding to the trolling cost ($C_a$) multiplied by the member's response to the troll ($R_p$). The member's response to the troll ($R_p$) expresses the degree of a member's effort to restore the situation. Such efforts could include a mutual information exchange, a confirmation of authenticity, or a mutual mental cure.
4. The effort expresses a PC agent's damage. All members in the community suffer damage from the troll. The damage could be, for example, time inevitably spent to restore the community's activity. Even if the troll aims at an individual, it causes some sort of damage to every community member.
5. If there is more than one AC agent, then each PC agent's damage extends to $\sum R_p \times C_a = R_p \times C_a \times N_a$, where $N_a$ is the population of AC agents.
6. The member's response to the troll ($R_p$) can be seen as a parameter related to the member's character. A high value of $R_p$ implies the member's excessive response against the troll.
7. An AC agent obtains a benefit by seeing the damages to PC agents.
8. This benefit could be, for example, a time to enjoy observing PC agents' embarrassment caused by the AC agent.
9. The AC agent is not interested in the confusion caused by other AC agents because AC agents have a closed and exclusive sense of value, and his or her acceptable range for a different value is narrow.
10. Corresponding to the member's effort to restore the community's activity ($R_p \times C_a$), each AC agent gets the benefit of $R_a \times R_p \times C_a$, corresponding to the effort ($R_p \times C_a$) multiplied by the troll's pleasure ($R_a$).
11. Because AC agents are exhibitionistic, the greater the confusion, the more pleased the agent is. Therefore, if there is more than one PC agent (as victims), the AC agent's benefit grows in proportion to the population of victims ($N_p$). The benefit finally becomes equal to $\sum R_a \times R_p \times C_a = R_a \times R_p \times C_a \times N_p$.
12. The troll's pleasure ($R_a$) expresses the degree to which the troll is pleased at the members' confusion and can be seen as a parameter related to the troll's character. An AC agent with a higher value of $R_a$ is more satisfied with others' troubles.
13. In addition, note that $R_a$ indicates whether a troll is intentional or unintentional. A troll with a positive $R_a$ can be perceived as an intentional one because the troubles of others make him or her happy. On the contrary, a troll with a negative $R_a$ can be perceived as an unintentional troll because the trouble makes him or her feel unpleasant.

The above formulations can be summarized as each strategy's payoff as follows.

$$\Phi_p = -R_p C_a N_a - C_p + K_p C_p N_p \tag{4.1}$$

$$\Phi_a = -C_a + R_a R_p C_a N_p \tag{4.2}$$

$$\Phi_d = 0 \tag{4.3}$$

## 4.3 Evolutionary Simulation of a Troll

We conducted evolutionary simulations among the three strategies and examined which strategy becomes dominant, and under what conditions it does so, with particular interest in what causes AC agents. The following explains the procedure of the simulation (Fig. 4.4).

1. An artificial society is composed of $N$ agents (a population).
2. One run comprises a series of iterations.
3. Each iteration comprises three phases: action, reflection, and mutation.
4. Each agent adopts one of three strategies: an AC strategy, a PC strategy, or a DC strategy. He or she can change the strategy in reflection or mutation.
5. In the action phase, each agent acts according to his or her strategy. PC agents are engaged in a collective intellectual activity. AC agents troll. In response, PC agents restore a community.
6. In the reflection phase, agents with lower payoffs ($R$ % of population $N$) abandon their strategies and adopt the strategy of the agent with the highest payoff. (We call $R$ the reflection ratio.)

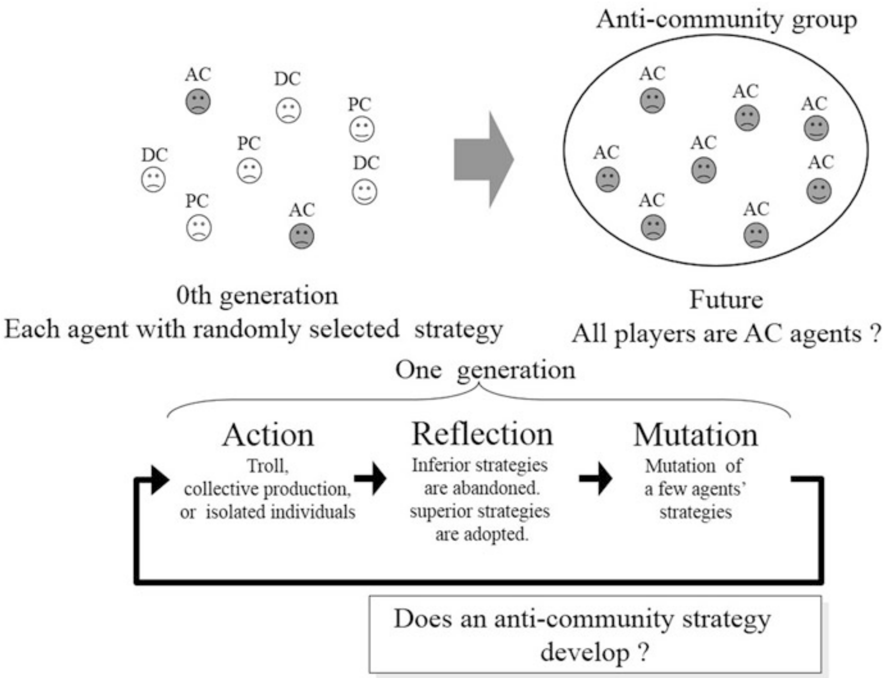


**Fig. 4.4** Evolutionary simulation of a troll as an anti-community strategy

7. In the mutation phase, a few agents are assigned at random by the strategy's mutation rate ($\mu_s$) to abandon their strategies and adopt randomly selected strategies.
8. At the 0th iteration, each agent adopts a strategy that is randomly selected.

## 4.4 Cyclical Pattern of Dominant Strategy

We conducted a variety of simulations with a common setting: total population ($N$) = 20, production cost ($C_p$) = 1.0, production efficiency ($K_p$) = 2.0, a troll's pleasure ($R_a$) = 0.1, reflection ratio ($R$) = 5 %, and mutation rate ($\mu_s$) = 1 %. (A $K_p$ value of more than 1.0 means that a community works more efficiently than an individual. A low $R_a$ (∼0.1) means that a destructive action is easy to do compared to a creative action.) In the simulations, a trolling cost ($C_a$) and a member's response to a troll ($R_p$) vary from 0.0 to 5.0 in increments of 0.05. One run consists of 3,000 iterations. Ten runs were executed for each setting of $C_a$ and $R_p$, which is equivalent to a total of 600,000 players (=10 runs ×3,000 iterations ×20 players). We observed what percentage of the total players adopted each strategy, as shown in the three graphs of Fig. 4.5.

They show that a PC strategy is dominant in a range except with a higher trolling cost ($C_a$) and a higher member's response ($R_p$), and in the range three strategies coexist. Also, the range of PC's dominance consists of two states, one of which is a complete occupation of the PC while the other is a quasi occupation of the PC. The left graph in Fig. 4.6 summarizes these findings. Points A ($C_a = 2.0/R_p = 2.0$), B ($C_a = 3.4/R_p = 3.4$), and C ($C_a = 4.5/R_p = 4.5$) in the graph represent these states. Corresponding to each point, we have a typical iterative series of a component ratio of each strategy, as shown in Fig. 4.7.

The upper graph in Fig. 4.7, corresponding to point A, shows that a PC agent accounts for almost 100 % of a total population, and the other two strategies cannot invade into the state. From the middle graph corresponding to point B, we see that a PC strategy remains almost dominant, but an AC strategy can invade the state and lead to a collapse of the community. (A collapse means that no PC agent exists in a community.) After that, a DC strategy develops to replace an AC strategy. Next, DC agents change into PC agents and a new community appears. (In reality, the last community is quite different from the new one.) In the lower graph corresponding to point C, we can see the frequent emergence and collapse of a community, which is similar to the middle graph.

Here, note a cyclical turnover of a dominant strategy such as a PC strategy → an AC strategy → a DC strategy → a PC strategy, as a common characteristic of the middle and lower graphs in Fig. 4.7. This pattern resembles a kind of rock-paper-scissors scenario. The difference between the two graphs is the frequency of emergence and collapse of a community. Note that there is no state with a frequency different from these two. In other words, the system has only two discrete states; two patterns of a collapse of a community exist.

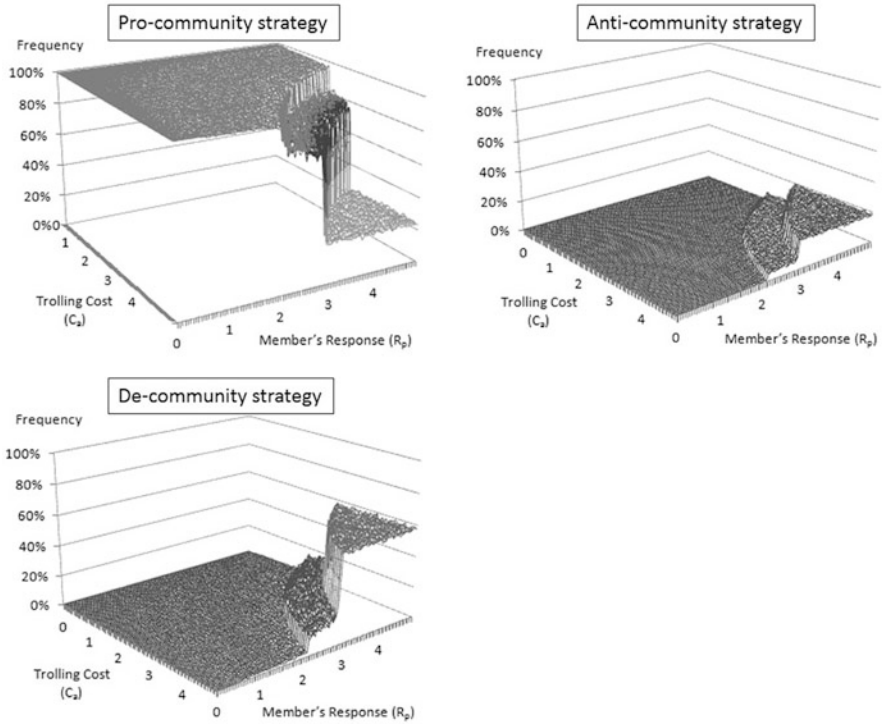


**Fig. 4.5** Frequency of each strategy. Total population $(N) = 20$, production cost $(C_p) = 1.0$, production efficiency $(K_p) = 2.0$, troll's pleasure $(R_a) = 0.1$, reflection ratio $(R) = 5\,\%$, mutation rate $(\mu_s) = 1\,\%$, number of iterations per one run = 5,000 iterations

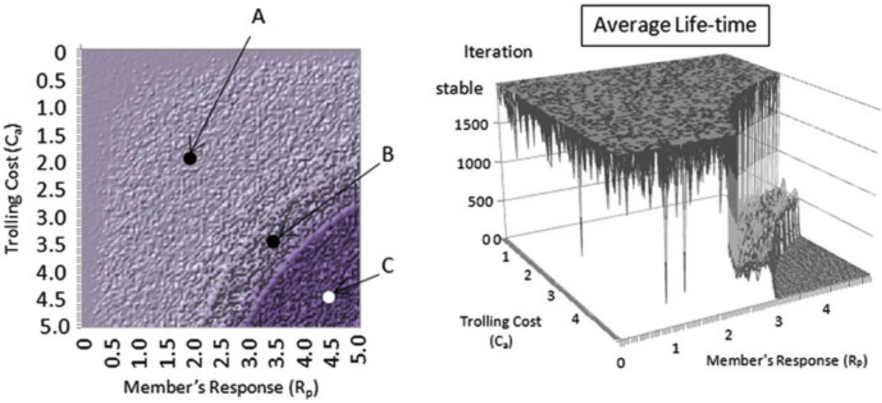


**Fig. 4.6** Three states (*left*) and average lifetime (*right*) with various trolling costs $(C_a)$ and members' responses $(R_p)$

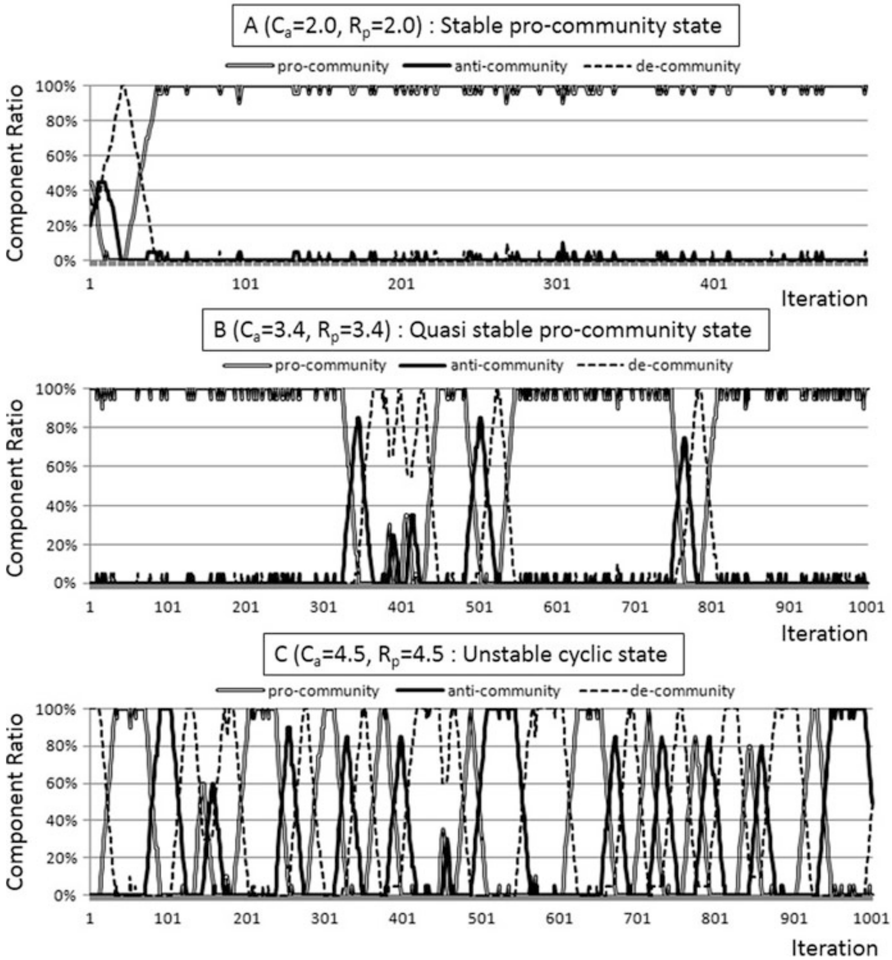


**Fig. 4.7** Three typical component ratios of each strategy vs. iteration (snapshot)

We also are interested in how quickly a community collapses. To do this, we have to define emergence and collapse of a community exactly. If we find an iteration of full occupation by PC agents just after three consecutive iterations through which PC agents increase, we regard a community as beginning to emerge. If we find an iteration of full occupation by PC agents just before three consecutive iterations through which PC agents decrease, we regard a community as beginning to collapse. With these definitions, we examine an average lifetime of a community, resulting in the right graph in Fig. 4.6. From this, we see that point A's state is quite stable and point C's state has a very short lifetime. We call point A's state a stable pro-community state, point B's a quasi-stable pro-community state, and point C's an unstable cyclical state.

## 4.5 Completely Ignoring the Troll and the Unintentional Troll

Next, we conducted simulations with a variety of settings of a troll's pleasure ($R_a$) and a member's response to a troll ($R_p$). In the simulations, we fix a trolling cost ($C_a$) to 2.0 and let the troll's pleasure ($R_a$) and the member's response ($R_a$) vary from 0.0 to 5.0 in increments of 0.05. The other settings are the same as in Fig. 4.5. The result is depicted in the left graph in Fig. 4.8.

The graph shows that the higher a troll's pleasure ($R_a$) and member's response ($R_p$), the more likely AC agents are to appear—and a collapse of the community is likely to happen. That is, the graph shows that the more excessive the response against the troll, the easier is the troll's development. (Further, if an excessive response makes a troll happy and makes a troll's pleasure ($R_a$) higher, a troll appears much more easily.) Therefore, the model could justify the popular belief that the most effective countermove is to completely ignore the troll.

Finally, we examine the case of a negative troll's pleasure ($R_a$). Because the negative value makes a troll unpleasant, as mentioned earlier, an AC agent with a negative value corresponds to an unintentional troll. In the case of the negative troll's pleasure ($R_a$) $= -0.1$, we conducted simulations with a total population ($N$) $= 20$, production cost ($C_p$) $= 1.0$, production efficiency ($K_p$) $= 1.2$, reflection ratio ($R$) $= 5\,\%$, and mutation rate ($\mu_s$) $= 1\,\%$, while the trolling cost ($C_a$) and the member's response to the troll ($R_p$) varied broadly from 0.0 to 60.0 in increments of 0.5. The result is depicted in the right graph in Fig. 4.8.

In addition, we observed an iterative series of component ratios for each strategy, corresponding to the representative point D, as shown in Fig. 4.9. From both figures, we see that a troll develops in the case of a high trolling cost or a high member's

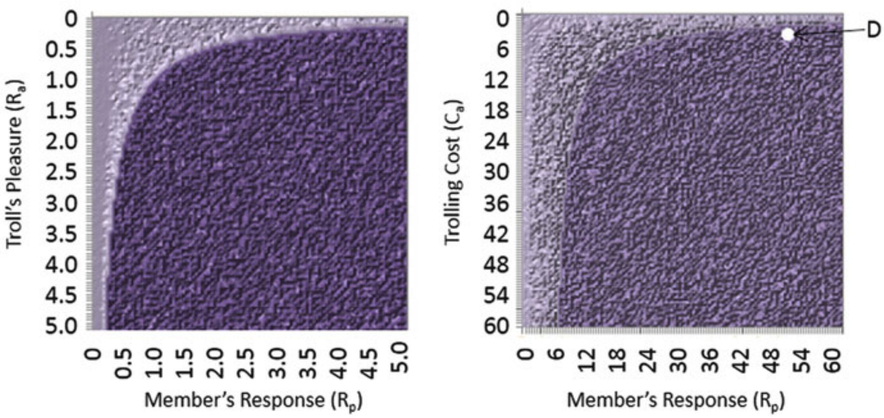


**Fig. 4.8** Effects of various $R_a$ and $R_p$ (*left*) and effects of various $C_a$ and $R_p$ in negative $R_a$ (*right*)

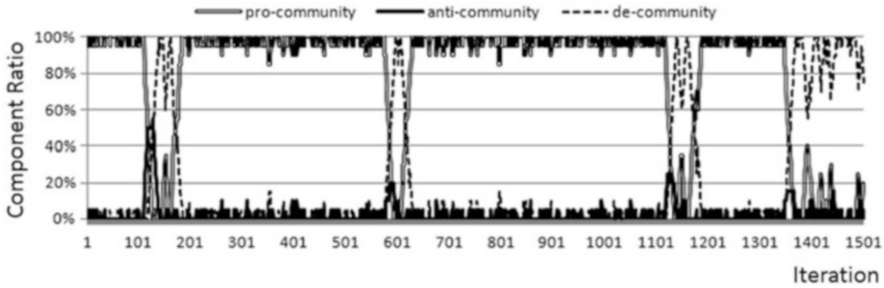


**Fig. 4.9** Typical component ratios of each strategy vs. iteration in minus $R_a$ (snapshot). Total population $(N) = 20$, production cost $(C_p) = 1.0$, production efficiency $(K_p) = 1.2$, a troll's pleasure $(R_a) = -0.1$, reflection ratio $(R) = 5\,\%$, mutation rate $(\mu_s) = 2\,\%$

response. Intuitively, an unintentional troll will not develop because it makes the troll unpleasant; however, we found that such a troll can happen, although rarely. As mentioned earlier, a collapse due to an unintentional troll can exist in a real online community. Our model can also replicate such a counterintuitive fact.

## 4.6 Discussion

We formulated an AC strategy and a PC strategy to express a troll's behavior and a community member's behavior respectively, and assumed a third de-community strategy. Through these three strategies, we executed evolutionary simulations and examined the outcomes. As a result, we could replicate the fact that an excessive response against a troll can lead to the collapse of a community and that an unintentional troll could have the same result. We also found the cyclical pattern of a dominant strategy such as rock-paper-scissors. The dominance of an AC strategy cannot last long, and a shift from an AC agent to a DC agent develops. After that, a community of PC agents emerges again among DC agents. It is interesting that mutually isolated agents can only trigger re-formation of a community. Note that the shift from being an AC agent to a PC agent is difficult. Once AC agents begin to develop, a peaceful community will never be restored, and is forced to close as if infected by a fatal disease.

Arenas et al. [1] introduced the "joker" performing destructive actions on other agents, which is almost equivalent to our AC agent. They showed a result that looked similar to ours. The joker promotes a rock-paper-scissors dynamics, corresponding to the cyclic turnover of a dominant strategy such as cooperator → free rider → joker → cooperator. On the other hand, our cycle was a PC agent (cooperator) → an AC agent (joker) → a DC agent (isolated agent) → a PC agent. Because we pay attention to an isolated agent (a DC agent) instead of a free rider, both models are quite different. (In addition, the "PC agent (cooperator) → an AC agent (joker)" in our result shows a strong contrast to the "joker → cooperator" in their result.)

A community formed with a PC strategy can be perceived as producing a public good in the sense that it indiscriminately produces and distributes an intellectual value. On the other hand, AC agents do not want to receive that public good. Instead, AC agents obtain benefits from the troubles in the community. The community serves AC agents as well as PC agents, although in a different way. Thus, we can interpret the community as a kind of commons. The existence of a community inevitably presents a chance for a troll to emerge. Remember that an AC agent is strongly dependent on a community. A troll finds his or her life worth living only after the community shows confusion.

As typically seen in the tragedy of the commons, an academic concern has been the problem of free rider who uses the commons without any contribution; however, our model is assumed not to suffer from such a free rider. (We assume that the problem of a free rider has already been solved in our community.) Therefore, in this research, we present a new scenario that a community collapses due to an irrational offense committed from the outside, which is different from the well-known scenario of a collapse due to a free rider inside the community.

Finally, we suggest that a troll-to-troll behavior (some PC agents might inflame the AC agents as a sanction) and a mixture of intentional and unintentional troll should be examined as future studies.

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# Part II
# Economic and Social Networks

# Chapter 5
# On the Indeterminacy of the Clearing Payment Vectors in Numerical Simulations on Financial Networks

**Mario Eboli**

**Abstract** This paper points out a methodological lacuna in the recent stream of numerical analyses of contagion in financial networks, and presents a solution to amend it. Under some conditions, the intercyclical obligations that connect the agents in a financial network cause the indeterminacy of the vector of payments that clears such obligations. This problem, first pointed out by Eisenberg and Noe (Manage Sci 47:236–249, 2001), has received little or no attention by authors who investigate payment flows and domino effects in networks using numerical simulations. Here we present an original result that establishes necessary and sufficient conditions for the uniqueness of the clearing payment vector for any financial network, and we demonstrate this result to control for the occurrence of the above-mentioned indeterminacy while performing numerical exercises on financial networks.

**Keywords** Interbank network • Numerical simulation • Payment systems • Social networks

**JEL Classification:** D85, G21

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## 5.1 Introduction

The motivation of this chapter is to draw attention to a methodological lacuna that affects numerous papers which have recently investigated systemic risk and contagion in financial networks by means of numerical simulations. Generally, these simulations consist of the recursive computation of a function that maps a given exogenous vector of cash flows and/or asset values, of the agents in a network, onto the links of that network, assigning to these links values that are either flows of payments or flows of losses, according to the analytical context. As explained below, under some conditions this function is subject to an indeterminacy that arises from the intercyclicity of obligations. Almost all the numerical analyses cited below pay no attention to the problem of the possible indeterminacy of the functions that they run on empirical or randomly generated networks. This implies that their results may be meaningless, in as much as they are obtained by numerically computing instantiations of a function that is not always uniquely defined. This issue is discussed in the following section, along with the state of the literature. In Sect. 5.3 we present a novel resuly that addresses this problem, establishing necessary and sufficient conditions for the uniqueness of the payment vector that clears the obligations that form a financial network. In Sect. 5.4 we suggest embedding this result in the algorithm used for numerical simulations in financial networks. Our conclusions are presented in Sect. 5.5.

## 5.2 The Indeterminacy of the Clearing Payment Vector in Financial Networks

Financial networks are composed of agents who are connected to one another by financial obligations. Formally, a financial network is usually modelled as a directed and weighted graph $G = (\mathscr{N}, L)$, where $\mathscr{N}$ is a set of nodes, or vertices, that represent financial operators, and $L \subset \mathscr{N}^2$ is the set of weighted links, or edges, that represent the obligations that connect the operators. These networks arise in several contexts: payment systems, interbank cross-holding of liquidity, over-the-counter trading in derivative markets, trade credit relations in supply chains, etc. In such networks, where somebody's assets are somebody's else liabilities, various types of financial turbulences (liquidity shortages, funding crunches, default contagion) can be transmitted by an agent to her neighbours and across the system. In other words, these networks create the grounds for systemic phenomena of financial contagion. These phenomena are exacerbated by the feedbacks generated by the presence of cycles in a network: the financial distress propagated by a node to its descendants comes back, and becomes reinforced, if the node lies on a directed cycle of agents.

Directed cycles are also the culprits of the possible indeterminacy that can arise in financial networks. The problem of non-uniqueness of payment flows in a financial network was first pointed out by Eisenberg and Noe [7] (henceforth EN). These authors explain the possible indeterminacy of the vector of payments that clears a network of interdependent financial claims with the following example: "Suppose the system contains two nodes, 1 and 2, both without any operating cash flows. Moreover, each node has nominal liabilities of 1.00 to the other node.[...] In this example, any vector [of payments] $p_t = t(1, 1)$, $t \in [0, 1]$, is a clearing vector of the system" [7, p. 249]. In this case, the flow of payments that goes from node 1 towards node 2 depends only on the payments that node 1 receives from node 2, and vice versa; therefore they can reimburse each other with any payment ranging between zero and unity.

The origin of this indeterminacy lies in the joint and simultaneous determination of the payments made by the agents that belong to a *cycle* of defaulting agents or, more precisely, to a *strongly connected component* (henceforth SCC) of defaulting agents. A directed graph is said to be *strongly connected* if there exists a directed path[1] going from each node to every other node in the graph. A subgraph $S \subset G$ that is strongly connected is called a *strongly connected component*. In other words, two nodes, $i$ and $j$, are in the same SCC if and only if there exists a directed path from $i$ to $j$ and there exists a directed path from $j$ to $i$.

If a set of defaulting nodes is strongly connected, the payments that these nodes make to one another are cyclically interdependent and simultaneously determined, as in the above example of a cycle of two defaulting agents. This simultaneity can generate indeterminacy: under the conditions that we identify below, the value taken on by the inter-agent payments in an SCC of defaulting agents is not uniquely defined.

As mentioned above, this indeterminacy has a bearing on the large and growing literature that studies contagion in financial networks by means of numerical simulations. In the last two decades a growing number of authors have investigated the systemic properties of financial networks. These studies started in the 1990s with the micro-banking literature that analysed systemic risk in the interbank networks. Authors such as Rochet and Tirole [14], Allen and Gale [1, 2] and Freixas et al. [9] focused on some stylised network structures—namely the complete, the cycle and the star networks—to evaluate the effect that the shape of a network has on its resiliency. The formal analysis of systemic risk in more general and complex financial networks proved to be difficult and, as a consequence, many authors resorted to numerical simulations to investigate this and other issues related to contagion. Several authors—such as Sheldon and Maurer [16], Furfine [10], Wells [20], Van Lelyveld and Liedorp [19], Elsinger et al. [8], Upper [17], Upper and Worms [18], Degryse and Nguyen [5], Blavarg and Nimander [3], Cifuentes [4], Mistrulli [11]—who are mostly central bankers, have studied national interbank networks, stress testing them with counterfactual simulations, generally performed making one or more banks fail because of an external shock. Other authors—e.g. Nier et al. [12] and Shin [15]—have run numerical simulations on randomly generated financial networks. Out of all these authors, only Shin [15] is aware of

[1] A *directed path* is a sequence of nodes, with a start node and an end node, such that for any two consecutive nodes, $i$ and $i + 1$, there is a link going from $i$ to $i + 1$. A *cycle* in a directed graph is a directed path where the start node and the end node are the same.

the indeterminacy problem discussed here and deals with it by assuming that at least one unit of each liability issued by each agent in a network is held by a non-indebted agent (the "non-levered sector"). Building on EN's sufficiency result, Shin demonstrates that this condition (which is stronger than the one characterised by EN, see below) is sufficient to ensure the uniqueness of the clearing payment vector. Finally, Pokutta et al. [13] also discuss the indeterminacy issue in putting forward a sensitivity analysis for the evaluation of systemic risk on the basis of EN's model, even though they do not perform numerical simulations. These authors do not try to refine the result of EN but rather propose to overcome the indeterminacy at hand by taking the largest possible vector of losses (hence the smallest vector of payments) as the clearing one, and provide informal arguments in support of this methodological choice.

## 5.3 Necessary and Sufficient Conditions for the Uniqueness of a Payment Vector

In Eboli [6] we model a financial network as a *flow network* and a contagion process as a flow of losses that crosses the network. In that paper we establish the necessary and sufficient conditions required for the uniqueness of the contagion function defined over a financial network. We now proceed to extend this result to a payment system *a' la* Eisenberg and Noe,[2] with the relevant difference that we use a graph-theoretic representation of such a system, rather than the lattice theory approach used by those authors.

Let a payment system composed by $n$ agents, connected among themselves by a set of financial obligations $L$, be represented as a directed and weighted graph $G = (\mathcal{N}, L)$, where $\mathcal{N}$ is a set of $n$ nodes, the agents in the network, and $L = \{L_{ij}\} \subset \mathcal{N}^2$ is the set of weighted links (ordered pairs of $\mathcal{N}$) representing the claims that agents in $\mathcal{N}$ have on other agents in $\mathcal{N}$. There is a link $L_{ij}$ in $L$ if node $i$ is indebted with node $j$, and the weight of this link is equal to the amount that node $i$ owes to node $j$; thus all existing $L_{ij}$ are strictly positive. It is assumed that all these intra-network claims have the same priority. Each node $i$ in $\mathcal{N}$ receives an *operating cash flow* $e_i \in \mathbb{R}^+$ from its own economic activity, and we let $e = (e_1, e_2, \ldots, e_n)$ be the vector of these cash inflows. Let $\overline{p}_i$ be the total nominal obligations of node $i$:

$$\overline{p}_i = \sum_{j=1}^{n} L_{ij}$$

and let $p_i$ be the total payments effectively made by node $i$ to the other nodes in the system. Let $\Pi_{ij} = L_{ij}/\overline{p}_i$ and let $\Pi$ be the corresponding *relative liabilities matrix*.

[2]For ease of comparison, we use the same terminology and notation used by Eisenberg and Noe [7].

The total cash inflow of a node $i$ in $\mathscr{N}$ is equal to the sum of its operating cash flow plus the sums received from other nodes in the system:

$$\sum_{j=1}^{n} \Pi_{ji} p_j + e_i$$

and the *equity* of a node $i$, i.e. the residual value of agent $i$, is equal to

$$\sum_{j=1}^{n} \Pi_{ji} p_j + e_i - p_i.$$

The state of the above-defined financial system, i.e. its structure and the payments made by the agents in it, is then expressed by triple $(\Pi, \overline{p}, e)$: the payments $p_i$ are determined by the network of liabilities, $\Pi$ and $\overline{p}$, and the inflow of cash coming from outside the network, $e$. In this setting, and as defined by Eisenberg and Noe [7], a clearing payment vector of the payment system $(\Pi, \overline{p}, e)$ is a vector $p^* \in [\mathbf{0}, \overline{p}]$ that satisfies the legal requirements of limited liability

$$p_i^* \leq \sum_{j=1}^{n} \Pi_{ji} p_j^* + e_i, \forall i \in \mathscr{N},$$

and debt priority

$$p_i^* = \sum_{j=1}^{n} \Pi_{ji} p_j^* + e_i, \forall i \in \mathscr{N}.$$

Under these conditions, $p^* \in [\mathbf{0}, \overline{p}]$ is a clearing payment vector iff

$$p_i^* = \min\left[\sum_{j=1}^{n} \Pi_{ji} p_j^* + e_i, \overline{p}_i\right], \forall i \in \mathscr{N}. \tag{5.1}$$

Using Tarski's fixed point theorem, EN demonstrate that, for a given triple $(\Pi, \overline{p}, e)$, (1) the clearing vector $p^*$ exists and has an upper and a lower bound, and (2) the equity of each node in $\mathscr{N}$ is the same for all clearing payment vectors.[3] Then the authors establish a condition that is sufficient to guarantee the uniqueness of the clearing payment vector. They demonstrate that, as long as there is at least

[3] See Eisenberg and Noe [7, Theorem 1, p. 240].

one node with strictly positive operating cash flow in the *risk orbit*—i.e. the set of descendants[4]—of each node in $\mathcal{N}$, then the upper and the lower bounds of $p^*$ coincide.

We have refined this result of EN and established the sufficient and necessary conditions for the uniqueness of a clearing payment vector of a financial system $(\Pi, \overline{p}, e)$. Before proceeding, we need to introduce the notions of *closed* and *open* SCCs.

**Definition 5.1.** Let $\mathbf{S} = (S, L(S))$, where $S \subseteq \mathcal{N}$ and $L(S) \subseteq L$, be a strongly connected component of a network $(\mathcal{N}, L)$. We say that $\mathbf{S}$ is **open** if there exists at least one link in $L$ starting from a node in $S$ and ending in $\mathcal{N} \backslash S$. Conversely, we say that $\mathbf{S}$ is **closed** if there is no link in $L$ starting from a node in $S$ and ending at a node in $\mathcal{N} \backslash S$.

In other words, the members of a closed SCC are indebted only among themselves. Conversely, in an open SCC, at least one member of such a component is indebted towards nodes in $\mathcal{N}$ that do not belong to the SCC. We now proceed to show that (a) the clearing payment vector $p^*$ is not uniquely defined if and only if the system $(\Pi, \overline{p}, e)$ entails closed SCCs of insolvent nodes, (b) the indeterminacy is confined to such closed SCCs and (c) the emergence of closed SCCs of defaulting nodes in a system $(\Pi, \overline{p}, e)$ can be unambiguously detected.

**Theorem 5.1.** *Let* $\mathbf{S} = (S, L(S))$ *be an SCC in* $G$*. The value of the clearing payments* $p_i^*$ *of the nodes* $i \in S$ *for a financial system* $(\Pi, \overline{p}, e)$ *is not uniquely defined if and only if (a)* $\mathbf{S}$ *is closed, and (b) all nodes in* $S$ *default.*

*Proof.* To show that conditions (a) and (b) are individually necessary and jointly sufficient to generate the indeterminacy of a propagation in an SCC, we first assume that all nodes in $S$ default and discuss the implications of $\mathbf{S}$ being closed or open. Then we assume that $\mathbf{S}$ is closed and show that all nodes in $S$ must default for the indeterminacy to arise.

(1) Let us assume that all nodes in $S$ default. For each node $i$ in $S$, the total payments made by a node equal its total inflow of cash, which comes from operating cash flows, from payments made by nodes in the same SCC and from payments made by nodes that lie outside $S$:

$$p_i^* = \sum_{j \in S \backslash i} \Pi_{ji} p_j^* + \sum_{j \notin S} \Pi_{ji} p_j^* + e_i$$

For the time being, let us assume that $\mathbf{S}$ is the only SCC in $G$. In this case, the payments $p_i^*$ are uniquely defined for all $i \notin \mathbf{S}$, because none of these nodes belongs to a cycle of agents. To establish this preliminary result formally, let $P^1(i) = \{j | l_{ji} \in L\}$ be the set of parent nodes of node $i$, let $P^2(i)$ be the set

[4]The set of descendants of a node $i \in \mathcal{N}$ consists of all nodes $j \in \mathcal{N}$ such that there exists a directed path starting at $i$ and ending at $j$.

of the parent nodes of $i$ and so forth for $P^3(i)$, $P^4(i), \ldots, P^n(i)$. The union of these sets, $P(i) = \cup_{j=1}^{n} P^j(i)$, forms the set of the *ancestors* of $i$, i.e. the set of nodes $j$ in $G$ such that there exists a directed path from $j$ to $i$. For each $i \in G\backslash\mathbf{S}$, $p_i^*$ is a uniquely defined function of the payments arriving to $i$ from its parent nodes in $P^1(i)$ which, in turn, are uniquely defined functions of the values taken by the payments coming from the nodes in $P^2(i)$, and so forth. In the absence of cycles in $G\backslash\mathbf{S}$, we have that no node $i$ in $G\backslash\mathbf{S}$ belongs to the set of its own ancestors $P(i)$. This implies that $p_i^*$, for all $i \in G\backslash\mathbf{S}$, is obtained through the non-recursive iteration of uniquely defined functions, and thus it is uniquely defined as well.

Now rewrite the above equation as

$$p_i^* - \sum_{j \in S\backslash i} \Pi_{ji} p_j^* = \sum_{j \notin S} \Pi_{ji} p_j^* + e_i$$

The terms on the right-hand side of this equation are known, while the unknowns are the payments of the nodes in $S$. For an SCC $S$ composed of $m$ nodes, we have a system composed of $m$ such linear equations:

$$\begin{bmatrix} 1 & -\Pi_{21} & \cdots & \cdots & \cdots & -\Pi_{m1} \\ -\Pi_{12} & 1 & -\Pi_{32} & \cdots & \cdots & \vdots \\ \vdots & -\Pi_{23} & 1 & \cdots & \cdots & \vdots \\ \vdots & \vdots & \vdots & \ddots & \cdots & \vdots \\ -\Pi_{1(m-1)} & \vdots & \vdots & \vdots & \ddots & -\Pi_{m(m-1)} \\ -\Pi_{1m} & \cdots & \cdots & \cdots & -\Pi_{(m-1)m} & 1 \end{bmatrix} \begin{bmatrix} p_1^* \\ p_2^* \\ \cdot \\ \cdot \\ \cdot \\ p_m^* \end{bmatrix}$$

$$= \begin{bmatrix} \sum_{j \notin S} \Pi_{j1} p_j^* + e_1 \\ \sum_{j \notin S} \Pi_{j2} p_j^* + e_2 \\ \cdot \\ \cdot \\ \cdot \\ \sum_{j \notin S} \Pi_{jm} p_j^* + e_m \end{bmatrix}$$

The solution of this system, i.e. the vector of unknowns $[p_1^*, p_2^*, \ldots, p_m^*]$, is indeterminate if and only if the matrix of the coefficients of the system is singular.[5] The components of this matrix have the following properties:

[5] I am indebted to Paola Cellini for her generous help in characterising the singularity conditions of this matrix.

(1) $\sum_{j \in S} \Pi_{ij} \leq 1$, for every $i \in \{1, 2, \ldots, m\}$;
(2) for every $i, j \in \{1, 2, \ldots, m\}$, if $i \neq j$, then there exists a sequence of indexes $i_1, i_2, \ldots, i_k$, where $i = i_1$ and $j = i_k$, such that $\Pi_{i_1 i_2} \cdot \Pi_{i_2 i_3} \cdot \cdots \cdot \Pi_{i_{k-1} i_k} \neq 0$.

Property (1) holds with the equality sign for the nodes in $S$ that are indebted only to other nodes in $S$. Thus, in a closed SCC we have that $\sum_{j \in S} \Pi_{ij} = 1$ for every $i \in \{1, 2, \ldots, m\}$. Conversely, in an open SCC we have that $\sum_{j \in S} \Pi_{ij} < 1$ for at least one $i \in \{1, 2, \ldots, m\}$. Property (2) is a formal expression of strong connectivity: for every ordered pair $(i, j) \in S$ there exists a directed path that starts at $i$ and ends at $j$.

Now demonstrating the *if* part of the theorem is straightforward. If **S** is a closed SCC, then $\sum_{j \in S} \Pi_{ij} = 1$ for every $i \in \{1, 2, \ldots, m\}$. In this case the sum of the rows of the coefficient matrix is null and so is its determinant.

In order to establish the *only if* part of the theorem, we suppose that the determinant of the matrix is null and show that, in such a case, $\sum_{j \in S} \Pi_{ij} = 1$ for every $i \in \{1, 2, \ldots, m\}$, which means that **S** is closed. We use the fact that the determinant of a matrix is null if and only if its rows are linearly dependent. Thus we suppose that there exist $m$ real numbers $\gamma_1, \gamma_2, \ldots, \gamma_m$ not all null and such that, for every $i, j \in \{1, 2, \ldots, m\}$,

$$\gamma_i = \sum_{j \neq i} \gamma_j \Pi_{ij}.$$

We can suppose, reordering the indexes if necessary, that $|\gamma_m| \geq |\gamma_i|$ for all $i < m$, thus $\gamma_m \neq 0$, and therefore

$$1 = \sum_{j \neq m} \frac{\gamma_j}{\gamma_m} \Pi_{mj}$$

where $\frac{\gamma_j}{\gamma_m} \leq \left| \frac{\gamma_j}{\gamma_m} \right| \leq 1$. Then condition (1) implies that $\gamma_m = \gamma_j$ for every $j$ such that $\Pi_{mj} \neq 0$, thus it implies that $\sum_{j \neq m} \Pi_{mj} = 1$.

Consider now the set

$$E = \left\{ j \in \{1, 2, \ldots, m\} \,|\, \gamma_j = \gamma_m \right\}$$

If $E$ coincides with $\{1, 2, \ldots, m\}$, we obtain that condition (1) holds with the equality sign for all $i \in \{1, 2, \ldots, m\}$, which is our thesis. Seeking a contradiction, let us suppose that $E$ does not coincide with $\{1, 2, \ldots, m\}$. Then we can suppose, reordering the indexes if necessary, that there exists an index $h > 1$ such that $E = \{h, \ldots, m\}$, i.e. such that $\gamma_i = \gamma_m$ if and only if $i \geq h$. The strong connectivity of **S**, as expressed by condition (2), implies that, for at least one index $i \in \{h, \ldots, m\}$, there exists an index $k < h$ such that $\Pi_{ik} > 0$. Let there be

$\Pi_{ik} > 0$—with $i \in \{h, \ldots, m\}$ and $k < h$—and repeat the above reasoning with the index $i$ in place of $m$ : the relation

$$\sum_{j \neq i} \frac{\gamma_j}{\gamma_i} \Pi_{ij} = 1$$

together with condition (1) and with the fact that $|\gamma_i|$ is maximal, implies that $\gamma_i = \gamma_j$ for every $j$ such that $\Pi_{ij} \neq 0$ and, therefore, that $\gamma_i = \gamma_m = \gamma_k$, contradicting the hypothesis that $k < h$. This proves that, if the determinant of the above coefficient matrix is null, then all $\gamma_i$ are equal among themselves and, therefore, $\sum_{j \neq i} \Pi_{ij} = 1$, for every $i, j \in \{1, 2, \ldots, m\}$. Finally, we can remove the preceding simplifying assumption that **S** is the only SCC in $G$: even if there are other SCCs in $G$, these SCCs are either closed or open. The SCCs that are closed do not affect, by definition, the flows of payments that reach the nodes in $S$. The SCCs that are open do not create any indeterminacy, as proved above.

(2) Suppose that **S** is closed and that only some of the nodes in $S$ default. Let $\tilde{S} \subset S$ be the set of defaulting nodes in $S$ and let $L(\tilde{S})$ be the set of the links that connect these failing agents among themselves. Then the subgraph $(\tilde{S}, L(\tilde{S})) \subset \mathbf{S}$ may or may not be an SCC. If it is not an SCC, no indeterminacy arises, as implied by Lemma 8. If $(\tilde{S}, L(\tilde{S}))$ is strongly connected, such an SCC of defaulting agents is open because $(\tilde{S}, L(\tilde{S})) \subset \mathbf{S}$ and **S** is strongly connected. Hence, also in this case the propagation is uniquely defined on the links in $L(\tilde{S})$. □

Note that this possible indeterminacy is confined to closed SCCs of defaulting nodes; it does not affect the values taken by the clearing payments $p_i^*$ in the rest of the network. This is due to the fact that a closed SCC is a *cul-de-sac*: the nodes in such an SCC make payments only to nodes that belong to the same SCC.

**Theorem 5.2.** *Let $\Theta = \{\mathbf{S}\}$ be the (possibly empty) set of* ***closed*** *SCCs of nodes in $G$. Then, in a financial system $(\Pi, \overline{p}, e)$: (1) the clearing payments $p_i^*$ are uniquely defined for all nodes in $\mathcal{N} \backslash \Theta$, and (2) $p_i^*$ is indeterminate for the nodes in a closed SCC* **S** *if and only if all nodes in* **S** *default.*

*Proof.* (1) From Theorem 5.1, the indeterminacy of the values of the clearing payments arises only in closed SCCs of defaulting agents. By the very definition of a closed SCC, we have that such possible indeterminacies have no effects on the payments received by the nodes in $\mathcal{N} \backslash \mathbf{S}$. (2) It follows from Theorem 5.1. □

This theorem refines the analogous result put forward by EN. As mentioned above, these authors demonstrate that, for a clearing payment vector to be uniquely defined, it is sufficient that all *risk orbits* in the network—i.e. the set of descendants of each node in $\mathcal{N}$—are *surplus sets*, where a surplus set is a set of nodes such that "no node in the set has any obligation to any node outside the set and the set has positive operating cash flows"[6] [7, p. 241]. A first refinement lies in the fact that our conditions for uniqueness show that the problem of indeterminacy is confined to closed SCCs, not to entire sets of descendants (i.e. risk orbits), as appears from the conditions set by EN. This can be seen with the help of a simple example.

*Example 5.1.* Consider a network composed of four nodes: nodes 1, 2, 3 and 4, and suppose that they are linked as follows:

$$1 \to 2 \rightleftarrows 3 \to 4.$$

The subgraph $(2, 3, 4)$ is the risk orbit of node 1. According to the sufficient conditions proposed by EN, the clearing payment vector in this network is unique if $e_2 + e_3 + e_4 > 0$. We demonstrate, with the above theorem, that this condition is not required because the subgraph $(2, 3)$ is not a closed SCC.

EN also show that, for any clearing vector of payments, it is impossible for all nodes in a surplus set to have zero equity value; i.e. at least one node in the set does not default. In the light of the above theorem, we can replace this condition with a less restrictive one and state that, in order to have a clearing payment vector $p^*$ of a financial system $(\Pi, \overline{p}, e)$ which is uniquely defined, it is necessary and sufficient that all closed SCCs in $G$, if any, have positive cash inflows, either coming from operating cash flows or from payments arriving from agents who do not belong to the SCC.[7] Indeed, the above theorem 5.2 is complemented by the following corollary.

**Corollary 5.1.** *Let* $\mathbf{S} \in \Theta$ *be a closed SCC in* $G$. *All nodes in* $\mathbf{S}$ *default if and only if the total cash inflow that reaches* $\mathbf{S}$ *from the rest of the network and from the operating cash flows of the agents in* $\mathbf{S}$ *is null.*

This refinement of the uniqueness conditions is best shown with an example.

*Example 5.2.* Consider a network composed of three nodes: nodes 1, 2 and 3, and suppose that they are linked as follows:

$$1 \to 2 \rightleftarrows 3$$

Note that the subgraph $(2, 3)$ is the risk orbit of all nodes in the graph. The sufficient conditions for uniqueness of the clearing payment vector, proposed by EN, require that $e_2 + e_3 > 0$. The necessary and sufficient conditions that we established require that $e_1 + e_2 + e_3 > 0$, i.e. both 1 and 2 may have zero operating cash flow and the clearing payment vector is still unique as long as $e_1 > 0$.

[6] This means that, for every risk orbit, there is at least one agent $i$ with strictly positive operating cash flows: $e_i > 0$.

[7] Note that all closed SCCs with positive operating cash flows are surplus sets, whereas the converse is not true because surplus sets need not be strongly connected.

This result has a bearing on the algorithms used to perform numerical simulations in financial networks, as argued in the following section.

## 5.4 Controlling for Indeterminacies of the Value Function in Numerical Simulations on Networks

A useful consequence of the above theorem and corollary is that the occurrence of closed SCCs of defaulting agents in $(\Pi, \overline{p}, e)$ is unequivocally revealed by the value taken by $p_i^*$ for the nodes in $\mathscr{N} \setminus \Theta$. Recall that to cause the failure of all the agents that form a closed SCC, the total cash flows (payments plus operating cash flows) that reach this SCC must be equal to zero. As demonstrated above,[8] the clearing payments $p_i^*$ of the nodes that do not belong to an SCC of defaulting agents are uniquely defined for any system $(\Pi, \overline{p}, e)$. Therefore, our corollary implies that, in computing a clearing payment vector, the occurrence of the conditions that cause the above described indeterminacy can be detected unambiguously by monitoring the flows of cash that reach the closed SCCs of agents, if any. As long as this cash flow is strictly positive, no indeterminacy arises.

It is straightforward to embed this condition in an algorithm that computes the clearing payment vector of a financial system. Usually such algorithms[9] compute the payments recursively, starting from the initial set of inflows, using the adjacency matrix of the network to capture the cash transfers that occur among the agents. At each round of the computation, the algorithm also computes the set of defaulting agents. It is then sufficient to check whether (1) such a set contains an SCC and (2) if this SCC has null cash inflow, in order to determine whether the payments of the nodes in the SCC are uniquely defined or not. This procedure to control for the occurrences of non-uniqueness of the clearing inter-agent payments has been implemented in the algorithm that computes a contagion process in Eboli [6], and can be implemented on any similar algorithm (such as the one of EN).

## 5.5 Conclusion

Financial networks are attracting growing attention in the fields of economics and finance, partly because of the fears of contagion that have accompanied the current financial crisis. Many authors have investigated the systemic implications of financial systems using numerical simulations of the contagion process, but this stream of literature has paid very little attention to the problem of indeterminacy that can affect the contagion functions that the authors compute numerically. Here

[8] See the proof of Theorem 5.2.

[9] See, inter alia, the *fictitious default* algorithm in EN and the algorithm proposed in Eboli [6].

we have refined the sufficiency result of Eisenberg and Noe [7] and characterised the necessary and sufficient conditions that guarantee the uniqueness of the clearing payment vector of a financial network. We show that the indeterminacy at hand only arises in *strongly connected components* of defaulting agents, where none of the members of such a network component has any obligation towards agents that do not belong to the component. We also argue that this result can be easily embedded in the algorithms used to numerically compute the contagion processes, enabling the analyser to control for the emergence of possible indeterminacies.

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# Chapter 6
# Three-State Opinion Formation Model on Adaptive Networks and Time to Consensus

**Degang Wu and Kwok Yip Szeto**

**Abstract** We investigate the three-state majority rule model in a coevolving network with intensive average degree using Monte Carlo simulations. The key parameter investigated is the degree of homophily (heterophily), which is the probability $p$ ($q = 1 - p$) of a given person being affected by others with the same (different) opinion. For a system with a uniformly random initial state, so that each person has an equal chance of selecting one of the three opinions, based on extensive Monte Carlo simulations, we found that there are three distinct phases: (1) When the population has an intermediate homophilic tendency, it reaches the consensus state very fast. (2) When the system has a moderate to large heterophilic tendency (a small value of $p$), the time to consensus (or convergence time) can be significantly longer. (3) When the system has a high homophilic tendency (a large value of $p$), the population can remain in a polarization state for a long time. We defined the convergence time for the system of voters to reach consensus operationally, and obtained a distribution function for the convergence time through Monte Carlo simulations. We observed that the average convergence time in a three-state opinion formation process is generally faster than in the same model of voting dynamics when only two states are available to voters, given that in the beginning of the simulations, different opinions are uniformly spread in the population. The implications in diversity are discussed.

**Keywords** Adaptive network • Consensus • Diversity • Opinion dynamics • Opinion formation

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## 6.1 Introduction

Statistical physicists have recently made important contributions to complex systems using the language of networks. Among these systems the issue of opinion formation in social dynamics is particularly interesting, since it involves both dynamics defined on the social network and the geometry that evolves as a result of the dynamics [3, 4, 14, 15]. The interplay of dynamics and geometry has been a fundamental problem in physics, and the simple models of competing options provide a rather simple and neat arena for this investigation. The results of this study in physics will be of great interest to social sciences, as the models provide a rigorous framework for understanding the dynamics of opinion formation, especially in political elections.

The dynamics of opinion formation is based on interactions between individuals connected in a social network; the interactions will modify the links in the network as people become friends or drift apart with time [8]. Recently, this problem of coevolving opinion formation networks was considered for discrete opinion dynamics [11]. Among the models of opinion formation in coevolving networks, the simplest one is the voter model [7, 9] with a binary opinion variable influenced by the neighbors of the voter. In statistical physics, this corresponds to the study of the dynamics of the Ising model in a coevolving network, which is generally not regular and can be quite random [5, 10, 13]. Here we investigate a model with three choices of opinion. It defines the simplest generalization of the binary option model to have either one dominant party with two minority parties, or two dominant parties and one minority [16].

In this chapter, we investigate a majority rule model on a coevolving network, based on a modification of the recent papers by Benczik et al. [1,2] and Schmittmann and Mukhopadhyay [12]. In these models, only two opinions can be chosen by the voters, but the social networks evolve along with the voters' opinions. We generalize this binary opinion model to a society with voters holding three different opinions. Each voter can be influenced by and can also exert influence on other voters. Temporary connections between voters allow them to change their opinions using a simple majority rule: a particular voter can change his opinion if the majority of his neighbors hold an opinion different from his own. In this process where the voters interact, the crucial step involves establishing a connection between a pair of voters. Whether this connection is established is probabilistic, reflecting whether the pair prefers to interact when they hold the same opinion, or to interact when their opinions differ. Since we have three choices of opinions (such as three parties competing in an election), the dynamics is more complex than the dynamics in an Ising-type opinion formation.

We find evidence that the convergence time scale of the three-state model exhibits unique features that are absent in an Ising-type model. This finding could have implications in the central question of how cultural and political diversity is maintained.

## 6.2 Model

Our model consists of $N$ nodes (individuals), each carrying a spin variable (opinion) $\sigma_j = 1, 2$ or 3, with $j = 1, 2, \ldots, N$. Nodes and links coevolve according to the following dynamics. In each time step, we randomly choose a node $i$ to be updated. Temporary links will be formed between $i$ and some other nodes in the population, according to probabilities $p$ and $q$, which are constants among the whole population. We go through all possible edges between $i$ and $j$, where $j = 1, 2, \ldots N$ and $j \neq i$. If $\sigma_i = \sigma_j$, then a link will be formed between the two nodes with a probability $p$. If $\sigma_i \neq \sigma_j$, a link will be formed with a probability $q$. In some earlier studies[1,2], $p$ and $q$ were fixed parameters of the model, independent of the number of nodes. It was pointed out that, if $p$ and $q$ are independent of the number of nodes, the typical degree of a given spin scales with $N$[12]. Here, we rescale $p$ and $q$ such that the average degree remains independent of $N$. This is achieved by replacing $p$ by $\tilde{p} \equiv \eta p/N$ and $q$ by $\tilde{q} \equiv \eta q/N$, where $q + p = 1$. The positive parameter $\eta$ controls the average degree such that for a voter having opinion 1, the expected degree is $\dfrac{\eta}{N}\left(pN_1 + q(N - N_1)\right)$, where $N_1$ is the number of voters having the same opinion. The second moment of the degree distribution can be easily calculated using a moment generating function. Large $\eta$ indicates that people will consider the opinions of a large number of other people before deciding on their own opinion, reflecting their strong social ability. The case of $\eta$ independent of $N$ is called intensive and is relevant to opinion formation in a rather large population. In this chapter, we only consider the intensive case of small $\eta$. This parameter setting describes voters who live in a large community but discuss their opinions only with a rather small circle of friends.

Once we have determined all the temporary links between node $i$ and all other nodes, we update $i$ using the following rule: we count the number of the three spins in $i$'s temporary neighborhood. If a majority of the temporary neighbors have spin value $v$, then we update the value $\sigma_i = v$; otherwise, we keep the value of $\sigma_i$ unchanged. This update rule is very similar to the majority rule model [6]. After the update, all temporary links are eliminated. The temporary nature of the link formation process renders our model amenable to a mean-field-like mathematical treatment. The overall structure of the model is very similar to the one investigated in [12] such that the effect of having more than two opinions can be shown clearly.

In our model, large $p$ or small $q$ could indicate that individuals are more likely to hear from people holding the same opinion (homophily) or supporting the same political party. Small $p$ or large $q$ may represent the situation where individuals are more likely to interact with people with different and diverse backgrounds (heterophily) or are not satisfied with their original opinion or party and are seeking a different opinion. However, our model does not assume that the voters are homophilic or heterophilic by nature. We can have other interpretations; for example, we can anticipate a situation where the voters are in an environment that encourages a certain type of interaction (homophilic or heterophilic). This flexibility in interpretation renders the model relevant in the context of cultural or political diversity.

We study the system using Monte Carlo simulations, focusing on the long-time behavior of the system and the distribution of the time to consensus of opinion. We want to know if there exist stable states and, if so, their nature and their distribution of opinions. We also want to know the various features of the long-time behavior of the system as a function of the parameters $p, q, N, \eta$ of our model.

To answer these questions, we first introduce the following measure of opinion distribution in a population. We define $m_1, m_2, m_3$ to be the fraction of opinion $1, 2, 3$ in the system, respectively. Moreover, we define $x_1 = m_1 - 1/3$, $x_2 = m_2 - 1/3$, $x_3 = m_3 - 1/3$, which measures the deviation from the uniform opinion distribution. An order parameter, commonly used in statistical physics, is then introduced as $m$, defined by

$$m = \sqrt{\frac{3}{2}\left(x_1^2 + x_2^2 + x_3^2\right)}.$$

When the system is in a total disordered state, i.e., $x_1 = x_2 = x_3 = 0$, $m$ will reach its minimum value, 0. When the system is in the consensus state, i.e., only one opinion survives (e.g., $m_1 = 1, m_2 = m_3 = 0$), $m$ will have its maximum value, 1. We see that $m$ is the order parameter commonly used in the study of magnetic phase transitions in physics. Here we interpret $m$ as a measure of homogeneity in the three-state opinion formation model.

In our model, the consensus state is an absorbing state. Therefore, in the simulation, when the population reaches the consensus state, the simulation ends because from then on the population would not change. In principle, every simulation will end in the consensus state (or convergence), but the time it takes could be very long. The time it takes for the population to evolve to a consensus state (with only one opinion in the population), from an initial condition where different opinions are uniformly distributed across the population (or other different initial conditions, depending on the context), is defined as the convergence time (or time to consensus). Convergence time is a random variable for a particular opinion formation model with respect to a particular set of parameters, and the mean, the variance, and the type of the convergence time random distribution are of great interest and could have significant implications in the behavior of the system being modeled. For a real election, which has a deadline for voting, the convergence time is of great practical importance, as it will determine which party will win the election.

## 6.3 Simulation Results

The Monte Carlo simulation makes use of a random sequential update scheme. Initially, every node in the system is randomly assigned one of the three spins with equal probability such that $m_1(t = 0) = m_2(0) = m_3(0) = 1/3$, corresponding to $x_1(t = 0) = x_2(0) = x_3(0) = 0$ and $m = 0$. In one Monte Carlo step, a node $i$ is randomly selected. We consider all pairs, $(i, j)$, with $j \neq i$, and decide whether to establish a link between each pair, according to the following rules: if $\sigma_i = \sigma_j$, the two nodes are linked with probability $\tilde{p}$; if $\sigma_i \neq \sigma_j$, they are linked with probability $\tilde{q}$. Once all choices are made with the temporary links, $\sigma_i$ is updated following a simple majority rule: if there exists an opinion $\alpha^*$ such that

$$N_{\alpha^*} > N_\beta \quad \forall \beta \neq \alpha^*,$$

we assign $\sigma_i = \alpha^*$. Here $N_\alpha$ is the number of opinion $\alpha$ in the neighborhood. Otherwise we will not update the state of node $i$. The temporary linking information will be discarded after the updating procedure. In one Monte Carlo sweep, we perform $N$ Monte Carlo steps. In our analysis, the unit of time is one Monte Carlo sweep, or one MC step per site. As a first step, every simulation stops after a fixed number of MC sweeps ($t = 500$). For each set of parameters $(N, \eta, p)$, at least 1,000 independent simulations are performed.

First we set $\eta = 10$ and $N = 900$. Since we observe that the relaxation time is approximately 20 MC sweeps, we consider 500 MC sweeps sufficiently long for the system to reach the absorbing state (consensus state) or metastable state. We perform the simulations for various values of $p$ from 0 to 1 and record the value of $m$ at the end of the simulation. We observe that when $p$ is larger than a critical value $p_{c2} < 1$, $m$ will always reach 1, indicating a total consensus state. However, there exists another critical value $0 < p_{c1} < p_{c2}$ such that when $p_{c1} < p < p_{c2}$, some runs of our simulation enter into a state where $m$ is fluctuating around 0.5, while other runs end up in a total consensus state. The detailed investigation of the final states shows that in those runs with $m \approx 0.5$, when the final state is not a consensus state, only two of the three possible spin values (opinions) survive. Thus, we might say that this phase of the system corresponds to the polarization state, following the nomenclature in [3]. Therefore, for $p_{c1} < p < p_{c2}$, we actually have a mixed state situation, where in some cases but not always, our simulation will end in a consensus state. When $p < p_{c1}$, none of our runs of the simulation end in the total consensus state, and the steady state corresponds to a polarization state. In Fig. 6.1, we show the distribution of the final state, measured by the order parameter $m$, for $N = 900, \eta = 10, p = 0.29$. There is a large gap between the two peaks, implying the existence of the polarization state ($m \approx 0.5$). Furthermore, the polarization state persists, though the distribution shows fluctuation. We expect this state to be a metastable state as it persists over a long time (as long as 500 MC sweeps), which is much longer than the relaxation time.

In order to study the characteristics of the transition and locate approximately the critical values $p_{c1}, p_{c2}$, we introduce a new measure $p_{\text{order}}$ for the ordering probability. We define $p_{\text{order}}$ to be the probability that the system will end up in the consensus state at the end of the simulation for a given parameter set $(N, \eta, p)$. We measure $p_{\text{order}}$ by performing a large number of runs of the simulation with the given set of parameters $(N, \eta, p)$, and then compute the fraction of times that the order parameter $m$ is 1. The number of runs is at least 1,000. The results are shown in Fig. 6.2 for $p_{\text{order}}$ as a function of $p$ for $N = 900, \eta = 10, 20, 30$ and $N = 1200, \eta = 10$. We see a sharp increase in $p_{\text{order}}$ at some critical values. This

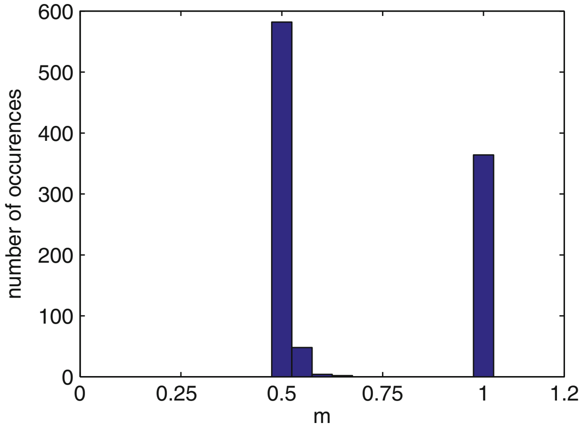


**Fig. 6.1** Distribution of the final state after 500 MC sweeps, measured by the order parameter $m$, for $N = 900, \eta = 10, p = 0.29$. The data is collected from 1,000 independent simulations. The large gap between $m = 1$ and $m = 0.5$ suggests that $m \approx 0.5$ is a metastable state. Note the high probability of occurrence for the $m = 0.5$ state

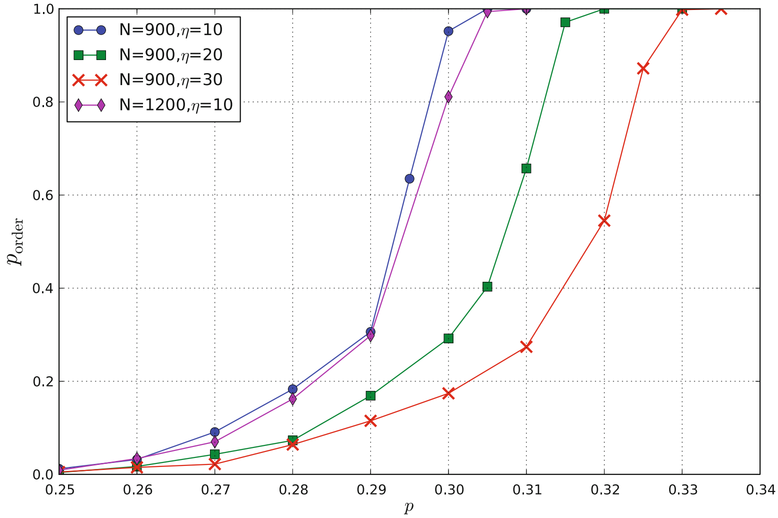


**Fig. 6.2** $p_{\text{order}}$ as a function of $p$ for $N = 900, \eta = 10, 20, 30$ and $N = 1200, \eta = 10$. Every data point is an average of 1,000 independent simulations. The stopping time is 500 MC sweeps. Note that the curve for $N = 900, \eta = 10$ almost overlaps with that for $N = 1200, \eta = 10$

phenomenon is robust and is indicative of a phase transition in statistical physics. The transition is asymmetric in that the increase in $p_{\text{order}}$ is slow when $p$ is near $p_{c1}$, but sharp near $p_{c2}$. From the graph, we see that $p_{c2}$ is around 0.3, and $p_{c1}$ is around 0.25 for $N = 900, \eta = 10$. From our simulations, we also identify the nature of the three phases: a consensus phase for $p > p_{c2}$, a polarization phase for $p < p_{c1}$, and an interesting mixed phase for $p_{c1} < p < p_{c2}$.

Figure 6.2 suggests that the values of $\eta$ significantly affect on the location of the transition. Larger $\eta$ will shift the mixed region to the right, as larger $\eta$ will result in larger $p_{c2}$. Note that the critical $p$ values could change for different stopping

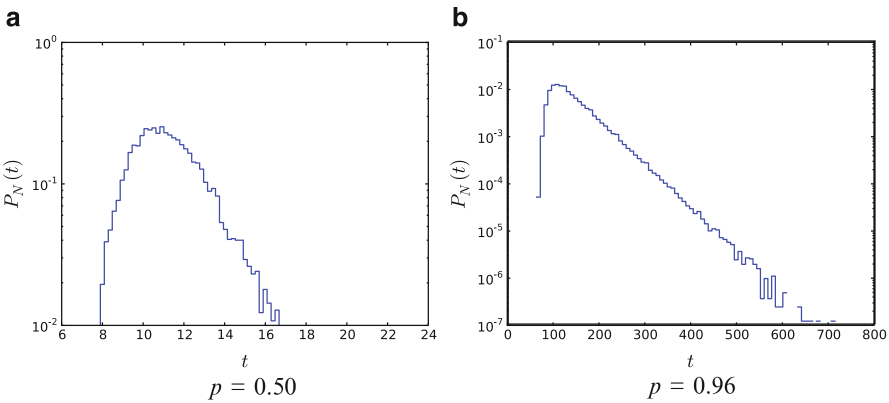


**Fig. 6.3** Convergence time distribution. Here $N = 900$, $\eta = 10$. (**a**) $p = 0.50$. (**b**) $p = 0.96$

times (measured as the number of MC sweeps), which in our simulation we set to be 500. Since we have introduced the order parameter $p_{\text{order}}$, we can define a convergence time for the system of voters to reach consensus operationally, and thereby obtain a distribution function for the convergence time. When discussing the time to convergence, Fig. 6.2 is particularly useful for indicating the state of the system under investigation.

Figures 6.3a, b show the convergence time distribution for $p = 0.5$ and $p = 0.96$. Here, $N = 900$ and $\eta = 10$. The distribution $P_N(t)$ is calculated from $10^6$ independent simulations for each value of $p$. The y-axis is in log scale. In Fig. 6.3a, we see that there is a peak in the probability distribution of the convergence time. The average convergence time for $p = 0.50$ is very fast: the convergence time is never longer than 30 MC sweeps, and the most probable convergence time is around 10 MC sweeps. For $p = 0.96$, the average convergence time is much longer. The most probable convergence time is around 100 MC sweeps. After the peak in the convergence time distribution, which in Fig. 6.3a is around t=10 MC sweeps and in Fig. 6.3b is around 100 MC sweeps, the distribution in log scale is linear, implying that the probability of finding a convergence time larger than the peak value decays exponentially.

The convergence time distribution for the case when $p = 0.30$ is quite different. See Fig. 6.4. Comparing Fig. 6.3a and 6.4, we can infer that the average convergence time for $p = 0.30$ is longer than that for $p = 0.50$, but the data collected from $10^6$ independent simulations reveals that the most probable convergence time for $p = 0.30$ is also around 10 MC sweeps, which is very close to the most probable convergence time when $p = 0.50$. The difference is that after the maximum, the density function for $p = 0.30$ decays very fast before settling into an exponential decay tail. The whole convergence time density profile resembles the superposition of two different convergence time scales. Note that the most probable convergence time (around 10 MC sweeps) is almost one order of magnitude more likely than the time at the beginning of the exponential tail (around 60 MC sweeps). This

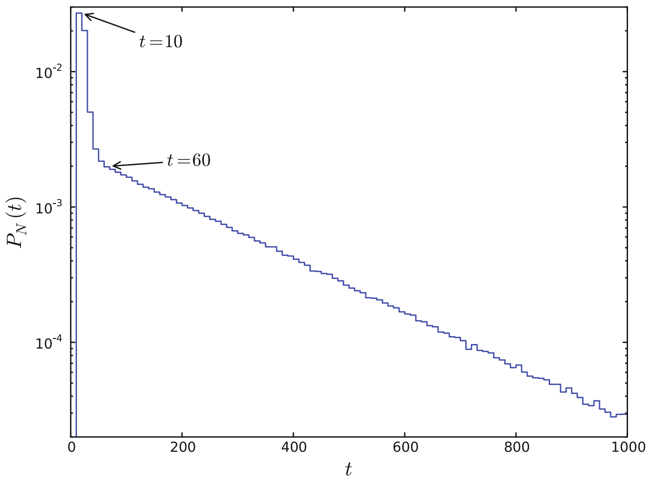


**Fig. 6.4** Convergence time distribution for $p = 0.30$. Here $N = 900$, $\eta = 10$. The approximate locations of the most probable convergence time and the start of the exponential tail are indicated on the figure

result strongly suggests that when the value of $p$ is 0.3, the distribution of time to convergence indicates the possible mixture of two sets of outcomes from the $10^6$ independent simulations.

We obtain an interesting finding by comparing the three-state model and the two-state model used in [12]. Both models start with uniform initial opinion distributions, one with two states and the other with three states. We compare $p_{\text{order}}$ for the three-state model and the two-state model in Fig. 6.5. Similar to the three-state model, the two-state model also exhibits a continuous transition in $p_{\text{order}}$, but the latter has an almost symmetric transition and the transition is sharper. From the analysis of the distribution of convergence time, we conclude that in the small $p$ region (less than 0.31 for $\eta = 10$ and less than 0.32 for $\eta = 20$) the average convergence time for the two-state model is even longer than that for the three-state model. This goes against our intuition. We would expect that when there are more choices, we may need a longer time to reach consensus. Figure 6.6 shows the empirical cumulative distribution function (ECDF) for various parameter settings. When $p = 0.3$, the ECDF curve for the three-state model is always larger than that for the two-state model. This confirms our earlier observation that, given the initial uniform opinion distribution, for $p = 0.3$, the dynamics of the three-state model is faster than that of the two-state model. For $p = 0.5$. the dynamics of the two-state model is comparable in speed with the three-state model. When $p$ is large, for example, for $p = 0.96$, again the three-state model is faster than the two-state model.

This finding suggests that the addition of the third opinion has a highly nonlinear effect on the dynamics, which could have important implications in cultural and political diversity.

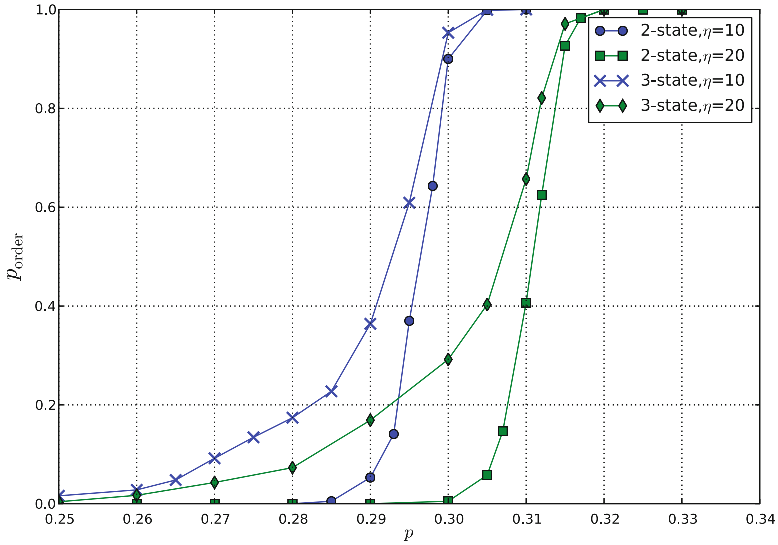


**Fig. 6.5** $p_{\text{order}}$ as a function of $p$ for $N = 900$, $\eta = 10, 20, 30$. Every data point is an average of 1,000 independent simulations

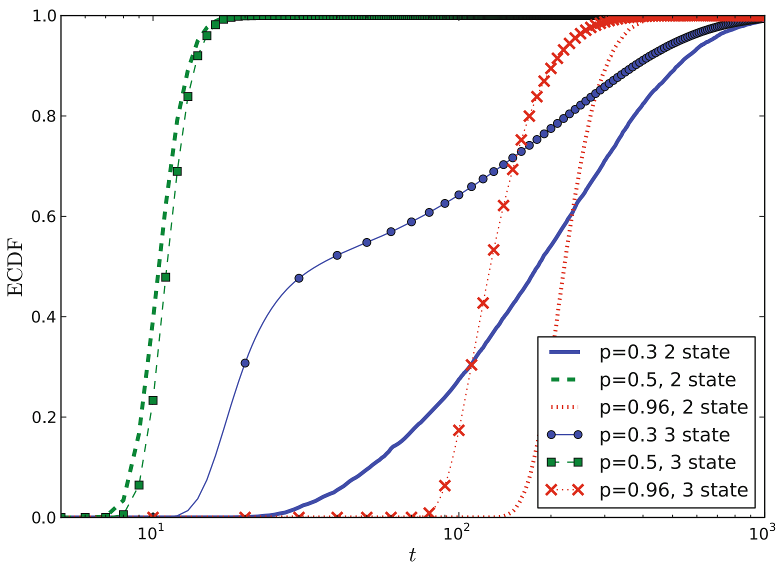


**Fig. 6.6** The empirical cumulative distribution function for the convergence time with $p = 0.30$, $0.5, 0.96$ for the two-state and the three-state models

## 6.4 Discussion

In our model, large $p$ or small $q$ indicates that individuals are more likely to hear from people holding the same opinion (homophily) or supporting the same political party. Small $p$ or large $q$ may represent the situation where individuals are more likely to interact with people with different and diverse backgrounds (heterophily) or are not satisfied with their original opinion or party and are seeking a different one. Other interpretations are possible, and the flexibility in interpreting our model makes it useful for a large range of applications.

We have investigated the three-state majority rule model in a coevolving network with intensive average degree by using Monte Carlo simulations. We have identified three different regions of the degree of homophily $p$ (heterophily $q$). The major difference of homophily and heterophily is in the difference in the convergence time scales. We obtained the following results, given that the system starts in a uniformly random state:

1. When the system has an intermediate homophilic tendency, the population reaches the consensus state very fast. In the context of cultural and political diversity, this means that diversity vanishes very quickly.
2. When the system has a moderate to large degree of heterophilic tendency, corresponding to a small value of $p$, the convergence time can be significantly longer. The willingness to listen to and entertain different ideas can maintain diversity for a longer time, which is consistent with our intuition.
3. When the system has a high degree of homophilic tendency, the population can remain in a polarization state for a long time. People holding different opinions yet only communicating with their own kind splits the population into isolated groups, and people will not be able to benefit from the existence of different opinions. This is similar to a society in deadlock.

The parameter $\eta$ can be interpreted as a measure of the sociability of the voters. This parameter will affect the boundary value $p_{c2}$ between the mixed phase and the total consensus phase. A high degree of sociability (large $\eta$) lengthens the convergence time on average. The above results are obtained using the initial conditions that the three spins are randomly and uniformly distributed among the whole population. It is necessary to investigate how robust these results are in the presence of small perturbations in the initial conditions. Here we set $p = 0.29$, which is near the middle of the transition. Our numerical results show that $p_{\text{order}}$ in the middle of the transition region is robust in the presence of small perturbations.

A comparison of convergence time scales between the two-state model and the three-state model leads to an interesting finding. When people in the population have a heterophilic tendency, the convergence time is faster than that of the two-state model, which goes against our intuition. There exists a social setting where this phenomenon will be significant. Let us consider an example where an organization encourages its members with diverse attitudes towards some public issues to interact with each other. Our model suggests that the more diverse the initial attitudes of the members, the faster they will reach a consensus. It would also be interesting to think about generalizing our three-state model to even more states. We will investigate the mathematics of the voting dynamics to answer the question on the relationship between the number of different initial opinions and the convergence time scales. This could also have implications in an effort to actively maintain cultural and political diversity.

The relation between our analysis of the time to convergence and its values in a real-life scenario is a difficult issue. Our choice of time unit is one Monte Carlo sweep, which is an artificial time. In order to compare the results of our model to real-life scenarios, we need to define the time unit in our simulation in accordance with the intrinsic time scale of the real-life scenario. In general, this mapping of the time unit of simulation to the actual time unit in real voting is a complicated issue. However, we may still extract a useful interpretation from the results of our model in the following manner. We can first identify a real-life scenario that is describable by our model, which implies that the real-life scenario should be one that has a relatively short time to convergence. Let's call this real-life scenario case A. Next we can use this scenario (case A) and estimate the parameters used in the simulation, namely, the degree of homophily $p$ and the social ability measured by $\eta$. From this mapping, we can extend our analysis to another similar real-life scenario (case B) describable by our model with different parameters. We can then use our model to predict the results of case B by performing a simulation of the model. If the simulation results suggests a time to consensus much different than the time to consensus in case A, we can make an informed prediction about the real-life scenario (case B) that we are going to analyse in the future.

The three-state model for opinion formation poses interesting questions on the dynamics as well as the social network evolution. Here we only discuss the statics, in the sense that we focus on the long-time behavior of the system. In a future paper we will discuss the various time scales associated with the formation of phases, and the network evolution which may show an interesting formation process of a social community that holds certain opinions. An interesting extension of our present work will be the consideration of the case of $\eta \rightarrow N$ and $N \rightarrow \infty$. In future work, we also want to consider the community structure of the social network of voters and how the structure affects the present analysis. We recognize that the homogeneity of the degree of homophily in our model is a strong assumption, and hence we will address the validity of this assumption with a random distribution of the homophily degree in future work.

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# Chapter 7
# Achieving Consensus with Segregation in Multiple Social Contexts

**Davide Nunes and Luis Antunes**

**Abstract** In social simulation, not only are the structures of the social relations fundamental for the construction of plausible scenarios, but also the interaction processes are shaped by these structures. Each actor interacts in multiple social contexts located within multiple social relations that constitute his social space. We build on previous work about context switching to study the notion of context segregation. The agents not only switch between social contexts, carrying with them their unique social identities, but also choose the contexts according to personal reasons. We apply the notion of context segregation to a simple game of consensus in which agents try to collectively achieve an essentially arbitrary consensus. We make a first analysis of our set of experiments towards understanding the influence of the segregation mechanism in the speed of convergence to global consensus and compare the results with those of the context switching model.

**Keywords** Agent-based modelling • Social networks • Social simulation and modelling

## 7.1 Introduction

The structure of social spaces is fundamental for the construction of plausible scenarios in social simulation. This structure not only provides a filter to what kind of interactions social actors can engage in, but also has a deep influence on the way emergent diffusion processes are achieved. In real social world scenarios, agents interact in multiple complex social relations with other agents and/or institutions. Each one of these relations may be of different kind and quality, possessing different

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topologies and social dynamics. Moreover, given the highly contextual qualities of real social spaces, approaches like the ones proposed in [1–3] are adequate to model such complex structures and study the interaction dynamics that they impose.

Multi-context models [3] introduce a framework to test social context dynamics. We are particularly interested in making observations on how different social relation topologies influence emergent auto-organization processes like the achievement of arbitrary consensus in a society of agents.

In this chapter, we explore the hypothesis presented in [3], which states that a society of agents converges to consensus more rapidly due to local consensus group formation. We explore this hypothesis by introducing a segregation behaviour in the context switching model that leads the agents to avoid undesirable states of available social contexts. We conducted a set of experiments focussed not only on the understanding of the segregation phenomenon, but also on the usage of different complex social networks to model abstract social relations and how they influence segregation. This chapter presents the first analysis of these experiments and focusses on the usage of scale-free and regular networks.

The difference between context switching and context switching with segregation is in the change from one context to another. The segregation process introduces reasons to change, whereas the context switching model [3] only considers the probability of changing.

Social segregation phenomena refer to the separation of social actors into different social interaction groups. Examples of such phenomena include the work of Schelling on racial segregation [11, 12]. Moreover, these approaches were some of the first attempts to apply, in effect, agent-based computer modelling to social science. Similar work also includes the adaptation of the *Schelling* model to complex social networks [7]. Although the essence of segregation is similar, our work is focussed on the usage of multiple coexisting social networks to represent the social space. The structures used to represent social relations are extremely important in multiple-context dynamics [1–3]. The importance of network topologies along with segregation phenomena has been reported in [13], where a model of equality in a labour market is explored.

The chapter is organized as follows. In Sect. 7.2, we describe the methodology used to construct the social simulation model, modelling social contexts as social networks. We then describe the basic mechanism behind the context segregation model and its usefulness to social simulation. In Sect. 7.3, we briefly describe the model of our experiments and what is expected to be observable. Finally, we analyse and discuss the results on the context segregation model exploration and compare them to previous results of context switching.

## 7.2 Context Segregation Model

In this section we describe the multi-agent-based model of context segregation. We start by giving an overview on how we model social spaces with multiple social contexts using social networks. We then briefly present the context switching model [3] that we have built on. Finally, we describe the context segregation model, introducing the model parameters to be explored.

### 7.2.1 Modelling Social Contexts with Social Networks

We focus on the study of dynamic consequences of the topological structures underlying social simulations. To manage the complexity, we take actors and relations between them as given and keep our relations as abstract as possible, so that we can concentrate on the dynamics they induce. We can think of the relations in our simulation as reasonably stable, such as family, work colleagues or our contacts in an online social network. We then construct a social space with multiple coexisting social network structures in which agents are involved.

To represent real-world social networks we use network models to generatively produce these structures. Here we focus on k-regular and scale-free networks and their induced dynamics on the context segregation model.

Barabási and colleagues proposed a model to procedurally create scale-free networks [4]. This model builds upon the perception of a common property of many large networks, a scale-free power law distribution of node connectivity. This feature was found to be a consequence of two generic mechanisms: networks expand continuously by the addition of new vertices, and new vertices attach preferentially to sites that are already well connected, this mechanism being more commonly known as "preferential attachment". In these networks, the probability $P(k)$ of two nodes being connected to each other decays as a power law, following $P(k) \sim k^{-\gamma}$.

This social network model is well fitted with the reality of many real-world social networks and has interesting properties such as a certain "fault-tolerant" behaviour (problems affecting random nodes will hardly fall on the critical hub nodes).

It has been established in [3] that the structure of connections the agents engage in simultaneously has an important role in the shape of convergence towards a global consensus. Here we aim to investigate how these structures influence the new segregation mechanism.

### 7.2.2 Context Switching Model and Consensus

This section briefly describes the context switching model [3], used as a basis to develop our model of context segregation. We also describe the simple consensus game used in both switching and segregation models.

In the context switching model [3], a society of agents engages in a simple abstract game: the consensus game. Each agent has to choose from one of two possible opinion values. The objective of the game is to reach a global consensus, but the particular choice that is collectively selected is irrelevant. What is important is that overall agreement is achieved.

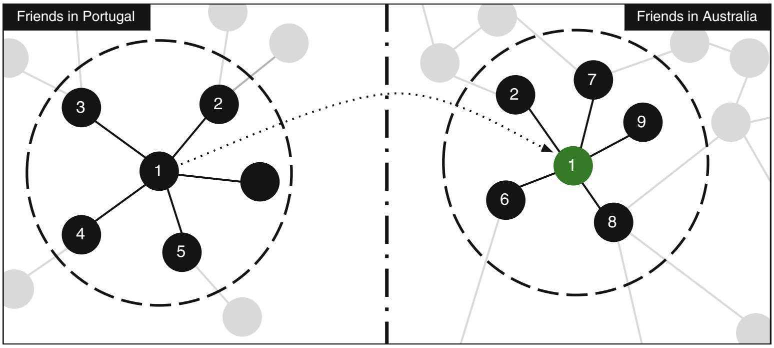


**Fig. 7.1** Example of context switching [3] considering two contexts for the social agent denoted by the number 1. In this case, these contexts are created by two distinct physical spaces. Common nodes in both neighbourhoods (like agent 2) represent the same social actor being able to travel between both distinct contexts, representing an acquaintance of actor 1 in both of them. The *dashed circle* represents the scope of each context

Agents can change their choice. In the approach presented herein, agents have a chance to change their choice when they have an interaction with another agent in its neighbourhood (context), by playing the majority game: agents keep track of their previous interactions and select the choice that they have seen most often in the past. This game resembles a simple binary voter model and can thus be easily related to the existing literature [5, 8].

The agents are embedded in multiple relations represented as static social networks and they switch contexts (see Fig. 7.1) with some probability $\zeta_{C_i}$ associated with each context $C_i$. The agents are only active in one context at a time and can only perform encounters with available neighbours of the current context. We can think of context switching as a temporary deployment in another place, such as what happens with temporary immigration.

The behaviour of the agents in this simple model can be described as follows:

1. Choose an available neighbour from the current context (neighbourhood of the network structure where the agent is currently located);
2. Check the selected interaction partner current choice and increment the memory for the number of individuals "seen" with that choice;
3. Check for the choice that has the majority and switch to it if the current opinion differs;
4. Switch to a random distinct context $C_j$ (located in another network) with a probability $\zeta_{C_i}$, which is a parameter of the model related to each social context $C$.

### 7.2.3 Context Switching with Segregation

In [3] it was suggested that the switching mechanism increases the speed of convergence to the global consensus, due to the formation of local consensus groups that, once formed, continually reinforce their members. Building on the previous model, we explore a mechanism that serves as an accelerator for this hypothesis. This is done by introducing a segregation mechanism [11, 12].

Whereas the previous context switching mechanism has only one parameter $\zeta_{C_i}$, which is the probability of switching from a context $C_i$ to another, the new mechanism encompasses a new parameter $\mu_{C_i}$, which we call social tolerance of the context $C_i$. The social tolerance $\mu_{C_i}$ depicts the ratio of different opinions that a social agent tolerates in the context $C_i$. The mechanism can then be described in the following manner.

Let $C_i$ be the social context in which a selected social agent exists at the moment. Consider also $\mu_{C_i}$ as the social tolerance for the context $C_i$, and $\zeta_{C_i}$ the probability of switching from the context $C_i$ to another selected relation.

1. Compute the ratio $r$ of agents present in $C_i$ with a choice opposite from the current agent's choice.
2. If $r > \mu_{C_i}$ (if the ratio is not within the social tolerance of the current context):
   switch to a randomly selected social context $C_j$;
3. Otherwise
   switch to context $C_j$ with a probability $\zeta_{C_i}$ (the probability of switching from the context $C_i$ to the selected context $C_j$ when the social tolerance requirements fail);

In summary, low levels of tolerance in a social context make agents avoid that context if the neighbourhood is not in conformity with the agent current choice. High values of tolerance promote the interaction with contexts even if the majority of the agents in a neighbourhood are not in agreement.

Context switching still plays a role in the dynamics of this model and contributes to the adjustment of the overall time spent in a social context. If an agent has a high tolerance level and chooses to stay in a neighbourhood, that agent may still be forced to switch out by the switching probability.

## 7.3 Model of the Experiments

The experiments were developed in MASON [9] and executed in a grid environment described in [10]. Each experiment consists of 30 runs in which 300 agents interact until 3,000 cycles pass or until total consensus is reached. In this set of experiments, our goal is to analyse the influence of the new parameter (the context tolerance $\mu_{C_i}$) in the speed of convergence to global consensus.

We spanned the tolerance parameter between two contexts ($\mu_{C_i}, \mu_{C_j}$) from 0 to 1 in intervals of 0.05. We also varied the context switching parameter $\zeta_{C_i}$ between three values that were found to be interesting for the context switching mechanism [3]. Another source of variability is the network topology configuration for the two contexts.

In a first set of experiments, we focussed on the usage of scale-free networks in both contexts, exploring the influence of the context tolerance parameter on the speed of convergence to global consensus. We then observed how different context switching probabilities affect the outcome of these experiments.

In a second series of experiments, we analysed the usage of *k-regular* networks and how they affect the segregation mechanism. We conceived this scenario because the structure is the same for all the nodes in the network, allowing us to analyse the contribution of neighbourhood size for the segregation mechanism.

In another series of experiments, we used two different network topologies (*scale-free* networks and *regular* networks) in the construction of our scenario. We then explored not only the previously referred parameter variability, but also the consequences of the interplay between these distinct network shapes in the achievement of consensus.

Finally, we analysed the influence of adding more social contexts to our scenarios and compared the results with the previous model of context switching [3]. The next section focusses on the details of the results.

## 7.4 Discussion and Experimental Results

In the following experimental results, we show how the different values for context tolerance affect the speed of convergence to consensus. We explore the interplay between the switching and segregation mechanisms and the influence of different network topologies on the achievement of consensus.

### *7.4.1 Homogeneous Social Contexts with Scale-Free Networks*

In our first set of experiments, we focus on a scenario with two social contexts, each one with a scale-free network. Figure 7.2 depicts the landscape for the span of tolerance parameter $\mu_{C_i}$ for both social contexts, maintaining homogeneous values of the switching probability $\zeta_{C_i}$ in both contexts $\zeta_{C_i} = \{0.25, 0.5, 0.75\}$. The landscape represents the average number of encounters necessary to achieve global consensus (100 %).

Focussing on the values of tolerance for which the number of encounters is smaller, we can immediately extract a domain for which the tolerance parameter leads the speed of convergence to be faster. This happens for $\mu_{C_i} \in [0.2, 0.6]$.

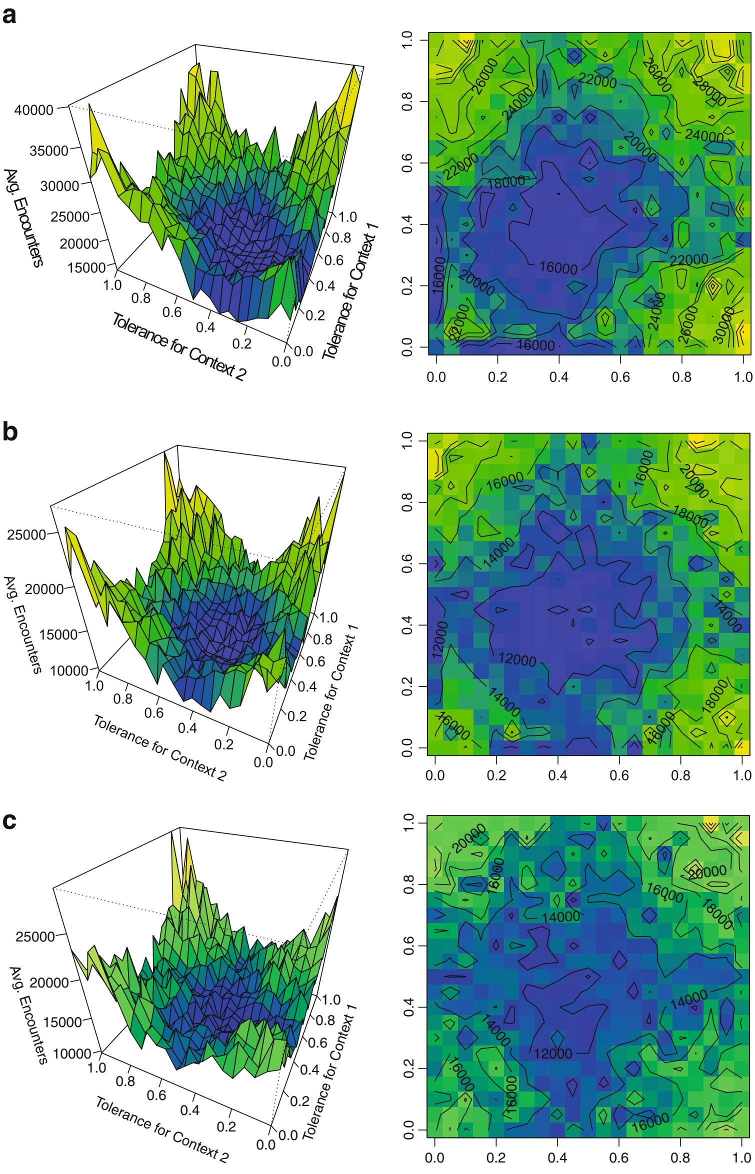


**Fig. 7.2** Average number of encounters to achieve global consensus with a context tolerance ($\mu_C$) span of [0..1] for two social contexts and uniform context switching values for each social context ($\zeta_{C_1} = \zeta_{C_2}$). (**a**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.25, 0.25)$. (**b**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.5, 0.5)$. (**c**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.75, 0.75)$

Another interesting result is that for smaller context switching values [for example, $(\zeta_{C_1}, \zeta_{C_2}) = (0.25, 0.25)$], although globally the convergence is slowed, the described values of moderate tolerance maintain an area of faster convergence. Even when the tolerance is 0 in one context, the convergence to consensus is still fast if the other context maintains a value of tolerance between 0.2 and 0.6. The context tolerance is actually preserving the speed of convergence, not only by raising the overall switching ratio, but also by making the agents switch when needed.

Comparing these results with a model that has only context switching, we can see that the context segregation model actually leads the society of agents to consensus faster. We see this by observing the number of encounters for the maximum tolerance in both contexts. According to the segregation mechanism defined in Sect. 7.2.3, when the tolerance is at its maximum value, only the switching mechanism is used, as "bad neighbourhoods" are not considered to exist.

In the next set of experiments we vary the context switching parameter and make it heterogeneous between contexts. Basically we adopt a high value of switching for one context and a low value of switching for the second. If agents only considered the context switching mechanism, this would imply that they would switch from the context with the high switching probability more frequently (spending less time in that context) and spending more time in the context with a low switching value. Figure 7.3 presents the results for the described heterogeneous configuration. We obverse from Fig. 7.3 that maintaining a moderate tolerance value is extremely important in the context from which the agents switch less frequently. In this case if an agent spends more time in context $C_1$ and switches more frequently from context $C_2$, the convergence to local consensus achieved in $C_1$ can be delayed if the agent chooses to stay there with an adverse neighbourhood. This happens because the switching probability ensures that an agent spends more time at that context. In Fig. 7.3a, we also see that very low tolerance values in context $C_1$ do not improve the speed of convergence if this has a moderate switching ratio.

It is interesting to observe that on the limit of the heterogeneity $[(\zeta_{C_1}, \zeta_{C_2}) = (0.25, 0.75)]$ (see Fig. 7.3b) the lowest values of tolerance for context $C_1$ also help to maintain an optimal speed of convergence. This is coherent with our explanation for the phenomenon. As the agents switch more frequently from context 2 due to the switching probability ($\zeta_{C_2} = 0.75$), they establish local consensus groups within context 1 as long as the tolerance value for that context remains proximately within $\mu_{C_i} \leq 0.6$.

To summarize, from these results we see that a context with low tolerance and low switching allows for the agents to stay on that context more frequently when this presents more stable neighbourhoods. We hypothesize that this allows for dissemination of local consensus groups, as it ensures that agents switch more frequently from undesirable neighbourhoods at first. When these neighbourhoods stabilize, the normal context switching mechanism allows for the consensus groups to be reinforced.

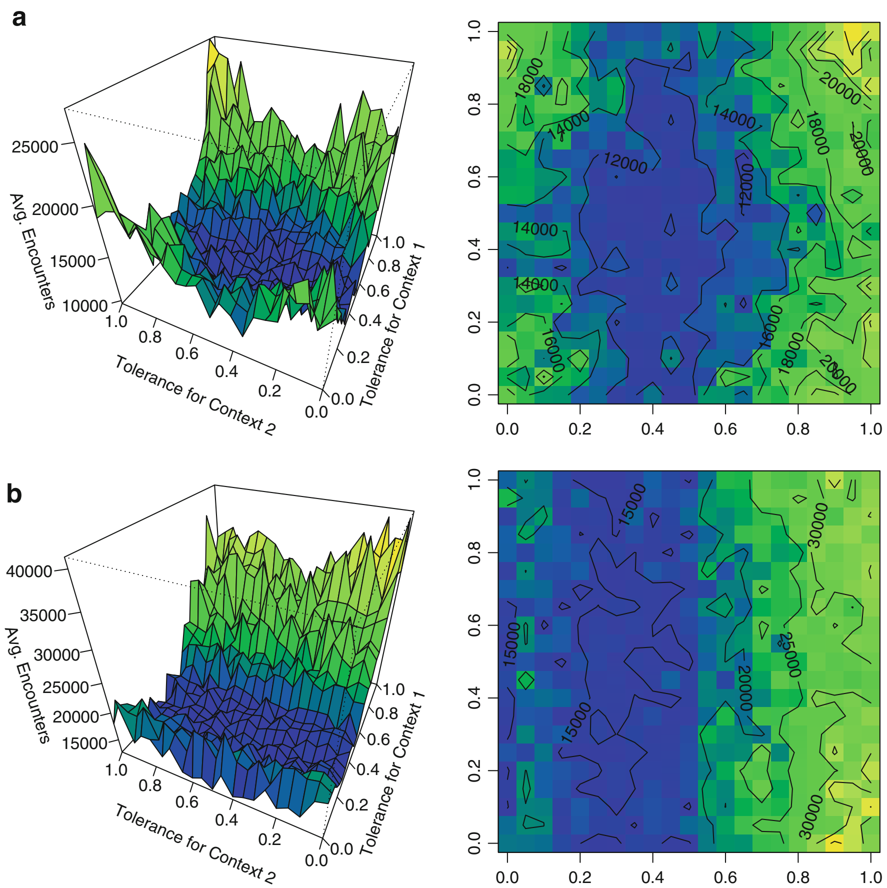


**Fig. 7.3** Average number of encounters to achieve global consensus with a context tolerance ($\mu_C$) span of [0..1] for two social contexts and non uniform context switching values. One of the social contexts has a lower value of switching than the other. We only present this configuration for one context because the results are symmetrical in this case. (**a**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.25, 0.5)$. (**b**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.25, 0.75)$

## *7.4.2 Homogeneous Social Contexts with Regular Networks*

In this set of experiments, we analysed the usage of *k-regular* networks and how they affect the segregation mechanism. Although k-regular networks are not very good representations of real social networks, they provide a good baseline for the evaluation of our model of multiple social contexts. We think this is the case because the structure is the same for all the nodes in the network. In these networks, each node has the same number of connections ($2k$), which creates a highly clustered entity. This structure allows us to analyse the contribution of neighbourhood size for the segregation mechanism.

We first observe the influence of switching in the segregation tolerance response surface (see Fig. 7.4).

In Fig. 7.4 we see that for small values of $k$ (in this case, each one of the 300 agents having 20 neighbours), the values of moderate context tolerance ($\mu_C \in [0.2, 0.4]$) are fundamental for achieving faster consensus with low values of switching probability $\zeta_C = 0.25$. When we raise the switching probabilities, the optimal tolerance region spans from 0.2 to 0.6, similarly to what happened in the homogeneous scale-free networks previously discussed. The number of encounters necessary to reach global consensus in the optimal tolerance region also increases with the switching probability but not drastically; this was also seen in the previous results for the scale-free networks (Fig. 7.2). These results indicate that the segregation mechanism actuates with similar outcomes independently of the topologies being used. Scale-free networks require more encounters for consensus, as they do not possess the high clustering features of these regular structures.

Our next experiment consisted in observing what would happen when bigger neighbourhoods were considered. In this case, Fig. 7.5 shows the results of this experiment. Here we can see that with larger neighbourhoods ($k = 30$ and $k = 50$) the tolerance parameter does not exert a substantial impact on the convergence to consensus. However, it is fundamental to keep the tolerance parameter roughly above the 0.2 threshold, because large neighbourhoods present a structure in which low tolerances produce constant switching. This happens because there is a high probability of an agent encountering a neighbourhood in which more than 20 % of its neighbours have different choices at the beginning of a simulation. This does not help the creation of local consensus at an early stage of a simulation, as agents are constantly switching. This phenomenon was observed throughout all our experiments with homogeneous contexts (same topologies), allowing us to infer that, under certain conditions, there is a minimum tolerance that agents must respect so that the segregation process will actually be beneficial for the convergence to global consensus. Consequently, for the optimal consensus regions, the segregation mechanism operates as a regulatory mechanism transversal to the network topologies being used.

Analysing the results of homogeneous *k-regular* networks with heterogeneous switching (see Fig. 7.6), that is, $\zeta_{C_1} \neq \zeta_{C_2}$, we can confirm a previously observed phenomenon. In Fig. 7.6 we can see that similarly to what happened in the *scale-free* networks (see Fig. 7.3), to ensure faster convergence to consensus, we must ensure that the tolerance for the context from which the agent switches less frequently has moderate values.

In this case, the tolerance values (as we observed in the previous experiment results depicted in Fig. 7.4) must be superior to a certain value (0.2) to allow for faster consensus. This is the aspect that differs from the scale-free topologies in what concerns the segregation phenomenon. In scale-free networks, context tolerance is less influencial if we have a scenario where one of the contexts has a high switching probability while the other one allows for the creation of local consensus groups (by enabling the agents to stay there long enough).

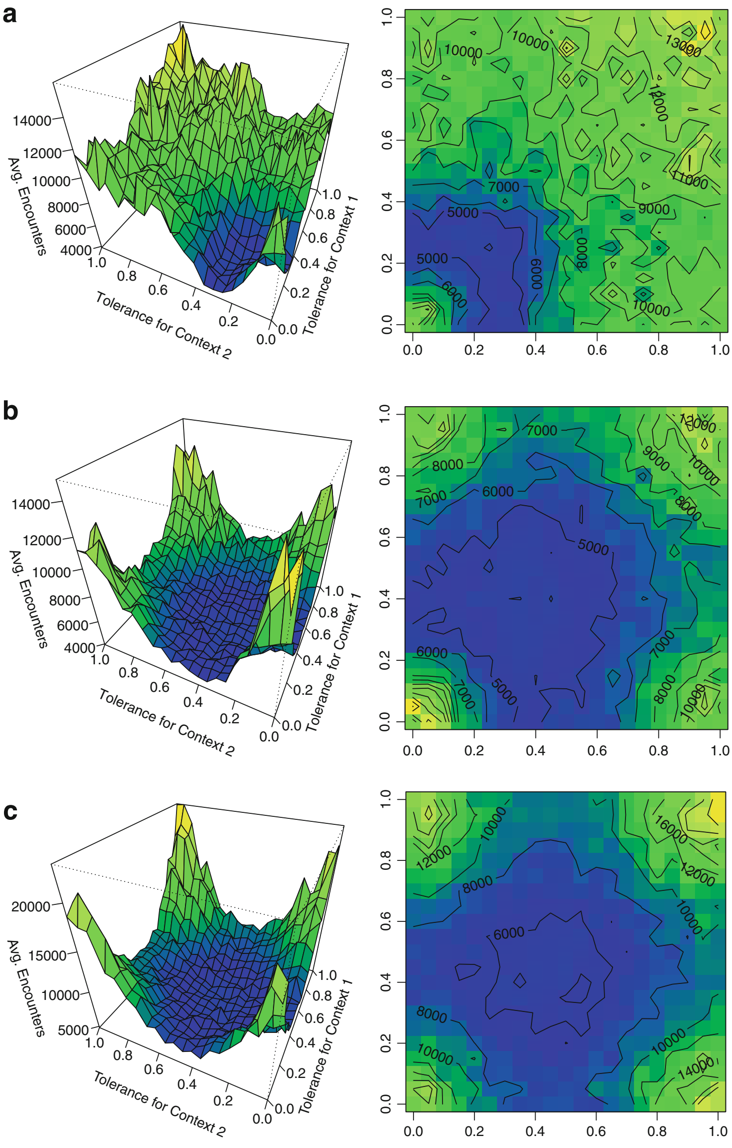


**Fig. 7.4** Average number of encounters to achieve global consensus with a context tolerance ($\mu_C$) span of [0..1] for two social contexts with k-regular networks having a small k value and uniform context switching values for each social context ($\zeta_{C_1} = \zeta_{C_2}$). (**a**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.25, 0.25)$ and $k = 10$. (**b**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.5, 0.5)$ and $k = 10$. (**c**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.75, 0.75)$ and $k = 10$

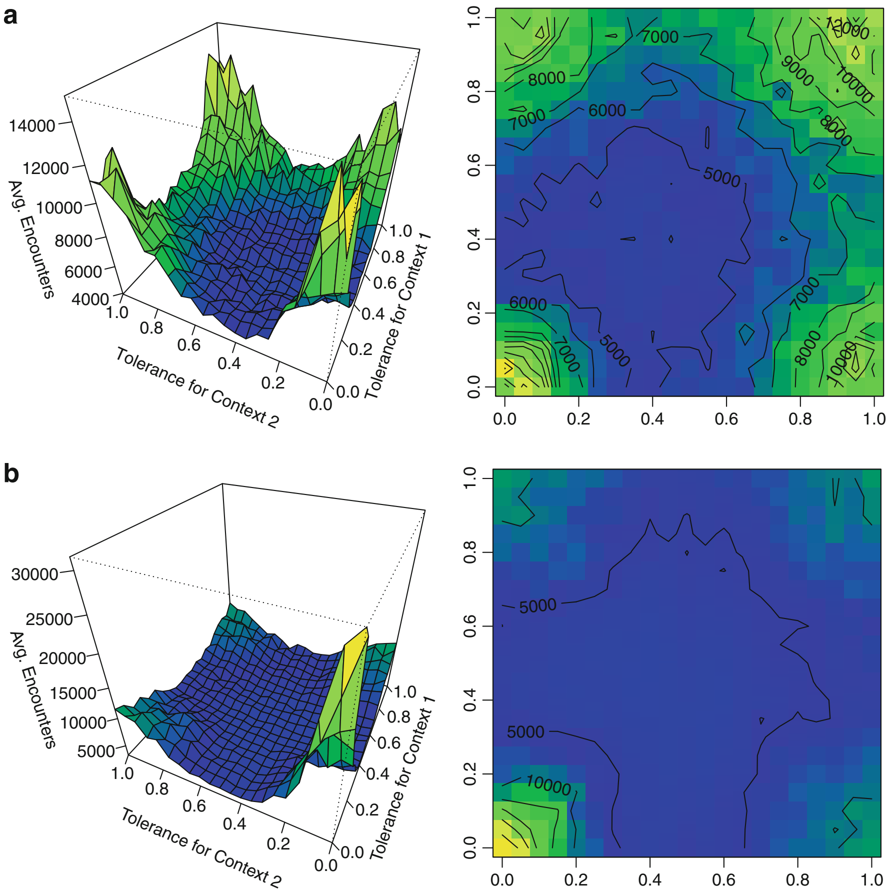


**Fig. 7.5** Average number of encounters to achieve global consensus with a context tolerance ($\mu_C$) span of [0..1] for two social contexts with regular networks and uniform context switching values for each social context ($\zeta_{C_1} = \zeta_{C_2} = 0.5$). In this experiment, we vary the value of k to observe the influence of bigger neighbourhoods in the segregation mechanism. The results for $k = 50$ are practically identical to the results for $k = 30$. (**a**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.50, 0.50)$ and $k = 10$. (**b**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.50, 0.50)$ and $k = 30$

### *7.4.3 Heterogeneous Social Contexts*

This set of experiments involved a configuration of the two social contexts with heterogeneous networks; that is, each context had a different network topology. We focussed on the interplay between k-regular networks and scale-free networks. As in the previous section, we experimented with $k \in \{10, 30, 50\}$ these being reasonably small, medium, and large neighbourhood sizes.

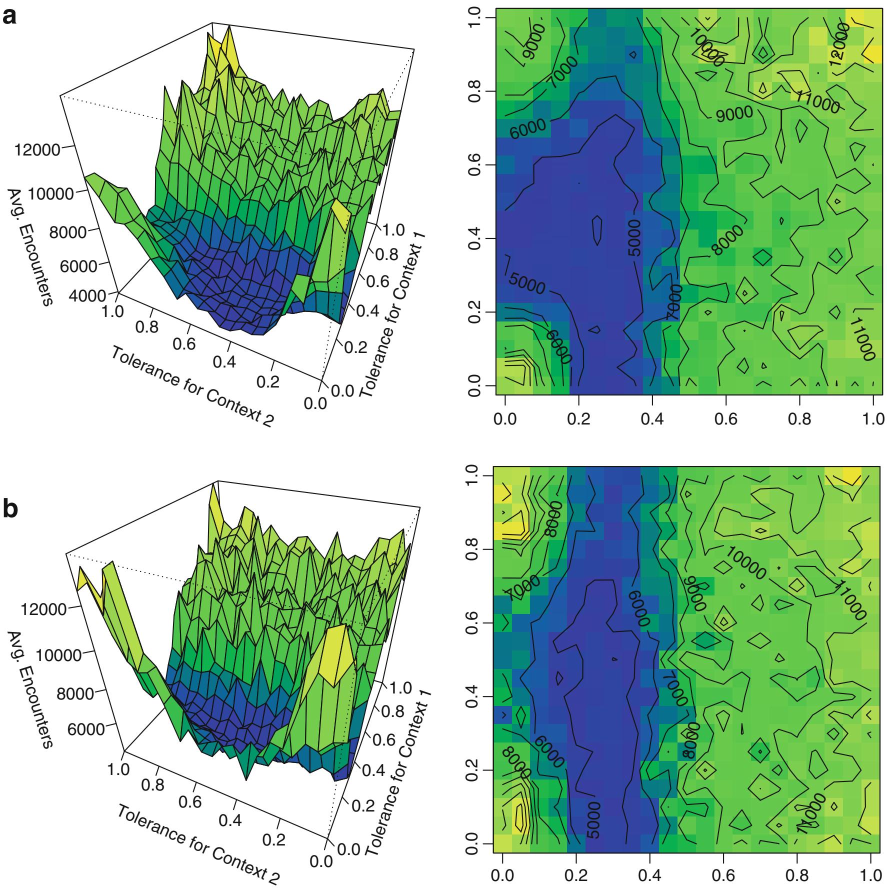


**Fig. 7.6** Average number of encounters to achieve global consensus with a context tolerance ($\mu_C$) span of [0..1] for two social contexts with k-regular networks having a small k value and heterogeneous context switching values for each social context ($\zeta_{C_1} \neq \zeta_{C_2}$). (**a**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.25, 0.50)$ and $k = 10$. (**b**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.25, 0.75)$ and $k = 10$

Figure 7.7 depicts the effect of having a heterogeneous setup for the social context networks. A social relation with a k-regular network displays interesting results when combined with a scale-free network. We see that it is worse to have high tolerance in regular networks for a small value of k than for a large one. Note that for smaller values of k, the neighbourhoods are smaller. Having higher tolerance in small-sized social contexts implies that an agent has a higher probability of interacting with a bad neighbourhood according to its personal choices in a given moment. For large values of k there is no need to have such a low tolerance value.

The final interesting results on the combination of scale networks with k-regular networks are depicted in Fig. 7.8. The scale-free network has a context switching

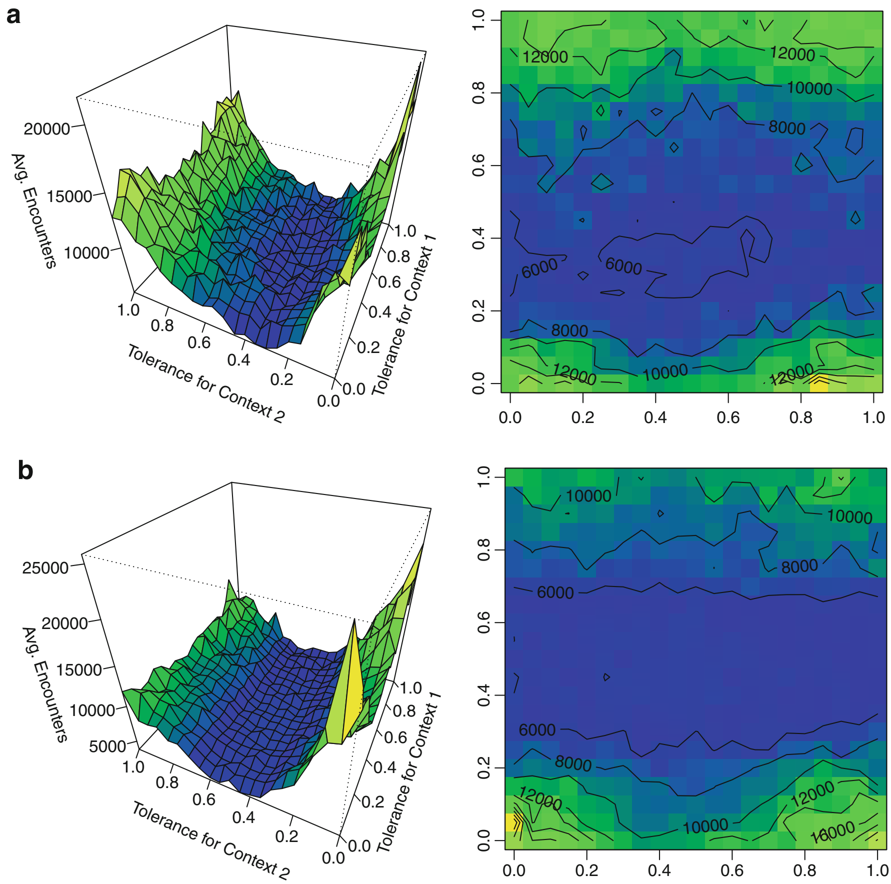


**Fig. 7.7** Average number of encounters to achieve global consensus with a context tolerance ($\mu_C$) span of [0..1] for two social contexts, uniform context switching values $(\zeta_{C_1}, \zeta_{C_2}) = (0.5, 0.5)$ and heterogeneous networks (scale-free and regular, for context 1 and 2 respectively). (**a**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.5, 0.5)$ and $k = 10$ for the k-regular network. (**b**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.5, 0.5)$ and $k = 50$ for the k-regular network

value of 0.75 and the k-regular, 0.25. This means that agents will switch more from the scale-free network and switch less frequently from the regular network.

We can see that low values of k promote the same effect we described in Fig. 7.7, but the imbalance in the switching makes the phenomenon more evident. Another surprising result is that the landscape presented in Fig. 7.8 is very close to the shape of the landscape for homogeneous switching set to $(\zeta_{C_1}, \zeta_{C_2}) = (0.25, 0.25)$. What this means is that when combining a regular network with a scale-free network, for medium or low levels of switching, very low to moderate values of tolerance are

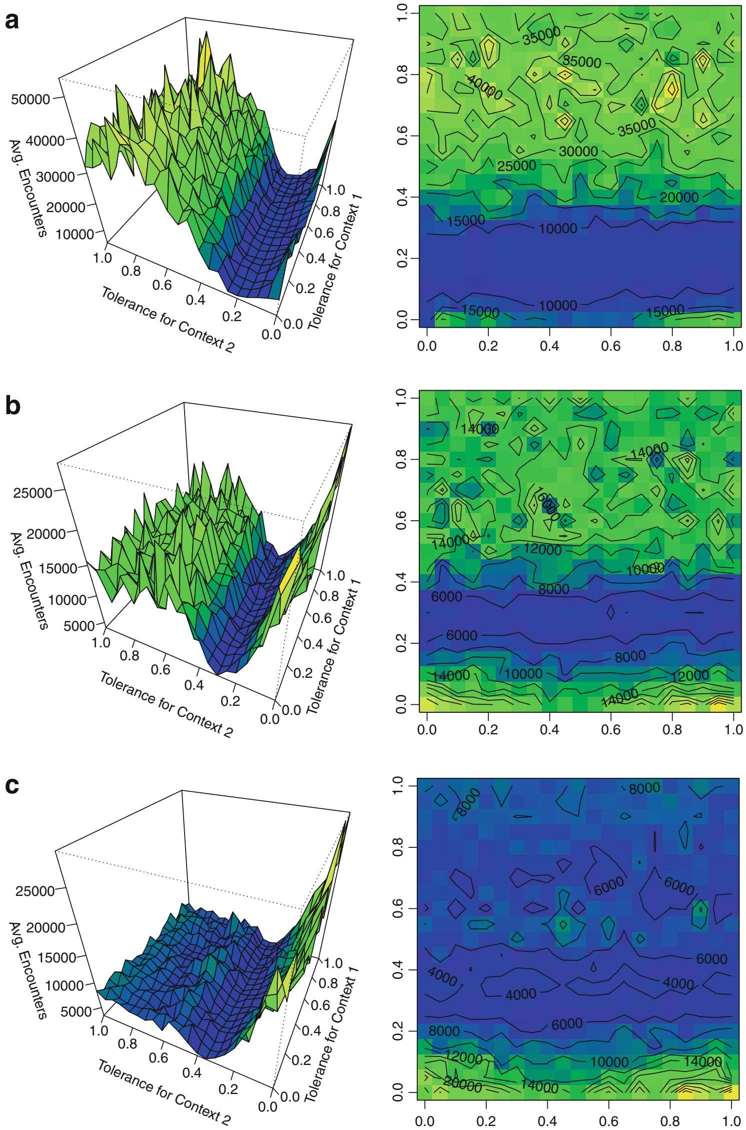


**Fig. 7.8** Average number of encounters to achieve global consensus with a context tolerance ($\mu_C$) span of [0..1] for two social contexts, heterogeneous context switching values $(\zeta_{C_1}, \zeta_{C_2}) = (0.75, 0.25)$ and heterogeneous networks (scale-free and regular, for context 1 and 2 respectively). (**a**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.75, 0.25)$ and $k = 10$ for the k-regular network. (**b**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.75, 0.25)$ and $k = 30$ for the k-regular network. (**c**) Context switching with the values $(\zeta_{C_1}, \zeta_{C_2}) = (0.75, 0.25)$ and $k = 50$ for the k-regular network

desirable to foster neighbourhood stability in the regular networks. For high levels of k, as we have seen before in Fig. 7.7, higher levels of tolerance also promote faster convergence.

Comparing the context segregation model with the context switching model [3], for moderated values of tolerance, this model outperforms the former. We have also seen that the interplay between social network structures plays an important role in context dynamics. This is one of the key points discussed in the work of Antunes et al. [2, 3], but it is shown to be more evident in this exploration of the context segregation mechanism.

Although we only chose to analyse the context segregation model with scale-free and regular networks as the core structure for the abstract social relations, we have experimented with other topologies, which have also given us interesting insight into the dynamics of this model and the influence of segregation processes on the achievement of global agreement. As an example, when using random networks, [6] it is fundamental to model the social space with other concurrent social network topologies to avoid the social isolation that occurs in these kinds of networks. Nevertheless, the topologies and configurations that were not discussed in this chapter open up an interesting path for future work.

### *7.4.4 The Influence of Multiple Social Contexts*

In this section we discuss a new experiment consisting in adding more social relation planes to the social space of our model. While we have seen that adding multiple concomitant social networks promotes faster and more frequent convergence to consensus, in the previous context switching model [3] we have observed that the speed of convergence is considerably worse when we add more than two networks. These relational planes can be compared to real-world social networks or relationships maintained by an actor. Consider as an example that a person can interact in multiple network structures, such as online social networks. At the same time, the structures of these different networks can differ in type and quality. What this means is that different network topologies can have distinct impacts on the process consensus formation. Moreover, our model can be seen as an abstraction for a population of actors dedicating their time to interactions in multiple relational planes: the segregation mechanism ensures that they avoid relations they do not tolerate and seek out neighbourhoods with similar opinions to their own.

Our aim is to explore what happens when we consider more than two social networks as well as the effect of the increasing number of simultaneous networks. We use the results to make a comparison with our previous model of context switching [3]. We analyse the results for the *scale-free* networks. In the context switching model, these networks show the worst results in terms of speed of convergence. These models are especially interesting to us, as most of the well-known real-world complex network structures display scale-free properties [4].

**Table 7.1** Comparison of the number of encounters necessary to achieve consensus between the *context switching* [3] and the *context segregation* models with *scale-free* networks

| | | Switching prob. | | | | | |
|---|---|---|---|---|---|---|---|
| | | $\zeta_C = 0.25$ | | $\zeta_C = 0.5$ | | $\zeta_C = 0.75$ | |
| Num. planes | Model | Avg | St dev | Avg | St dev | Avg | St dev |
| 1 | Segregation | – | – | – | – | – | – |
| | Switching | – | – | – | – | – | – |
| 2 | Segregation | 3,322 | 1,657 | 2,401 | 1,159 | 2,317 | 1,276 |
| | Switching | 10,341 | 6,386 | 5,600 | 3,844 | 4,660 | 3,547 |
| 3 | Segregation | 3,514 | 1,722 | 2,812 | 1,557 | 2,966 | 1,845 |
| | Switching | 15,163 | 8,666 | 8,805 | 5,785 | 7,729 | 5,604 |
| 4 | Segregation | 3,783 | 1,730 | 3,477 | 1,622 | 3,516 | 1,912 |
| | Switching | 18,775 | 10,807 | 13,224 | 8,192 | 14,309 | 10,901 |

In these experiments, 100 agents interact to a maximum of 3,000 cycles. The tolerance parameter for the segregation model is set to a value of $\mu_C = 0.4$

In this experiment, we consider the usage of multiple *scale-free* networks fixing the tolerance parameters within the optimal region (see Fig. 7.2). The tolerance parameter is fixed with the value $\mu_C = 0.4$. We vary the switching values homogeneously across the various contexts to compare our results with the context switching model.

As we can see in Table 7.1, our initial conjecture that some tolerance values create an optimal zone for consensus achievement was confirmed. Adding more social relation planes to the social space means that we need more encounters to reach global consensus, but this increment is not significant. Also, when we only have a single network in which the agents interact, consensus is never reached. This was also verified in our previous work [2, 3].

The comparison between the results of simple context switching versus the model with the segregation mechanisms (see Table 7.1) confirms some previously observed facts and provides some insight. In this case, with more social relation planes available, the segregation mechanism always presents better results than the simple switching mechanism. This is due to the fact that the switching is no longer uninformed and the agents switch according to their personal preferences. Switching from undesirable neighbourhoods, creating a segregation between multiple social contexts, promotes an early formation of local consensus groups.

We can see that adding more relational planes not only does not interfere significantly in the convergence to consensus, but also presents another curious insight: the fact that the number of encounters observed for the segregation model (although this model requires much fewer encounters) follows a similar trend to the results for the context switching model, meaning that the original switching mechanism influence is preserved.

## 7.5 Conclusion and Future Work

These results show that not only do contexts play an important role in the dissemination of social concepts in structured societies, but also that social segregation allows for the speeding up of convergence of this dissemination. Considering that scale-free networks seem to be present in a significant amount of real social relations, the mechanism of context switching with segregation with several concurrent networks can have a decisive role in enhancing the conditions for achieving overall dissemination of a given phenomenon, as well as significantly increasing the speed of the convergence.

We also discovered some leads that corroborate the hypothesis made in [3]. First, the formation of local consensus groups fosters faster convergence to a global consensus, especially if those consensus groups are given the right conditions to be created. One interesting idea that follows is that in the right conditions, the dynamics of the formation of consensus groups can be tracked down and correlated to social topologies. This is especially interesting for applications regarding dissemination of information in relatively well-known structures, for instance, the organization of political or marketing campaigns using online social networks.

Future work includes the analysis of the evolution of local consensus groups throughout an experiment, while tracking the dynamics of the creation of these groups. To do this, we will investigate the usage of different segregation measures adequate for measuring segregation on complex social networks, similar to what is done to analyse the model presented in [7]. This ongoing work also focusses on the analysis of different network topologies and on adding more concurrent social relation planes to the experiments. With this, we will be able to compare the performance of this model with the context switching model more extensively by using the speed of convergence to consensus as a criterion.

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# Part III
# Behavioral Finance and Macroeconomics

# Chapter 8
# How Does Overconfidence Affect Asset Pricing, Volatility, and Volume?

**Chia-Hsuan Yeh and Chun-Yi Yang**

**Abstract** Overconfidence is one of the most important characteristics of traders. In the past decade, theoretical approaches have paid much attention to this topic and obtained significant results. However, they heavily rely on specific assumptions regarding the characteristics of traders as well as the market environments. Most importantly, they only consider the market with a few types of traders. None of them is built upon a truly heterogeneous-agent framework. This paper develops an agent-based financial market. Each trader adopts a genetic programming learning method to form his expectations regarding the future. The overconfidence level of each trader is modeled as the degree of underestimation of the conditional variance. Based on this framework, we examine how traders' overconfidence affects the market by analyzing the results regarding market volatility, price distortion, and trading volume.

**Keywords** Agent-based modeling • Artificial stock market • Behavioral finance • Genetic programming • Overconfidence • Rationality

**JEL Classification:** D83, D84, G11, G12

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## 8.1 Introduction

In the past two decades, examining how traders' overconfidence affects financial markets has been an important issue in the fields of financial economics and behavioral finance. Overconfidence is one of the most salient characteristics of traders' psychological activities. Basically, research that takes traders' psychological factors into account originates from the motive of questioning the validity of the efficient market hypothesis (EMH), which is mainly constructed under the framework where the representative agent has rational expectations. Theoretical results as well as empirical studies have provided the possibilities and evidence that financial markets could or may be inefficient; see, e.g., [6, 7, 12, 20, 26, 28]. Therefore, it is quite natural for researchers to consider another approach which argues imperfect rationality for market traders. This reasoning is supported by theoretical and empirical foundations. In [32], the author claims that a more appropriate and reasonable way to describe traders' behavior is bounded rationality because traders have neither unlimited computational power nor perfect or complete information regarding the environment. Tversky and Kahneman [37] point out that humans do not behave rationally and that their decision making under uncertainty can be described by three heuristics which will result in systematic errors. Benos [4] also indicates the importance of bounded rationality:

> Bounded rationality, alias behavioral research, in finance and economics can be promising if it can provide an exposition of the exact way in which economic agents err and if it accounts in detail for possible implications of these deviations from full rationality. (pp. 377–378)

Actually, a large body of the empirical evidence from cognitive psychology has shown that individuals exhibit overconfidence in the sense that they overestimate their own abilities. Therefore, they underestimate their forecasting errors or the risk they encounter. Kyle and Wang [22] argue that overconfidence may be due to an anchoring and adjustment process. This process has been mentioned in [37]. People's estimates regarding the problem of interest rely heavily on the initial point. Adjustments regarding these estimates are usually insufficient. Different initial points result in different estimates, which are then biased toward these initial points. This phenomenon is called "anchoring." The anchoring effect comes into play with the result that people have tight subjective probability distributions.

One decade ago, most of the literature regarding the effects of traders' overconfidence on financial markets followed theoretical approaches. Several models have been proposed to study the related topics with different focuses, and the differences between these studies can be roughly classified into two different aspects. One is the modeling of overconfidence, and the other concerns the topics of interest. Overconfidence is usually modeled as overestimating the precision of the information (or underestimating the risk). Basically, most of the related papers, such as [4, 12, 18, 22, 29], adopt a framework where the overconfident traders have constant but lower, compared with the true fundamental risk, estimation regarding the risk. They do not consider the situation where the degree of investors' overconfidence may adjust over time as the outcome changes. By contrast, Daniel et al.

[11] and Gervais and Odean [14] propose models with time-varying overconfidence. Each trader updates his overconfidence level based on whether or not his earlier private signal confirms the realization of the public signal.

From the perspective of the topics of interest, researchers have noted the effects of overconfidence on asset pricing, volatility, or volume. Based on the model of [21], Benos [4] considers a one-shot call auction market where some of the informed traders are overconfident. Comparing the markets with and without the overconfident traders where all the other traders are rational, Benos [4] finds that price informativeness, volatility, and trading volume increase when the market maker is risk neutral. In [11], the authors show that overconfidence causes higher price distortion and increases price volatility around private signals. Odean [29] obtains similar results. Overconfident traders increase both price volatility and volume and decrease the expected utility. In addition, overconfident price takers make price quality lower. Scheinkman and Xiong [31] propose a continuous-time equilibrium model where overconfidence results in traders' heterogeneous beliefs. In their study, volume and price volatility are high when bubbles occur.

References [4, 12, 22], and [18] focus on the issue regarding the survivability of overconfident traders. Under the assumption that overconfident (noise) traders are unable to affect prices, De Long et al. [12] show that overconfident traders as a group can make a higher expected profit than rational traders. Moreover, they not only survive but also dominate the market in the long run. References [4,22], and [18] derive the same results in different frameworks. In [29], the influence of overconfidence is further analyzed from the perspective of who is overconfident. The results indicate that the existence of overconfident insiders may improve rather than worsen price quality, while overconfident market makers may decrease price volatility. Based on the modelings of investors' overconfidence and biased self-attribution, Daniel et al. [11] point out that overconfident traders overestimate the precision of private signals and underestimate the importance of public signals. This behavior generates short-lag positive autocorrelation and long-lag negative autocorrelation of returns. In a framework where traders' overconfidence is determined endogenously, Gervais and Odean [14] find that volatility and trading volume increase with the level of the trader's overconfidence. Overconfident traders obtain lower rather than higher profits, which is inconsistent with the results of [12]. In addition, Gervais and Odean [14] show that overconfidence may emerge when traders exhibit self-serving attribution bias.

In contrast with the theoretical works, the empirical studies were not conducted until the past few years because there is no testable and well-defined implication regarding overconfidence [34]. To date, the empirical literature mainly focuses on measuring the existence of overconfidence or its effects on volatility and trading volume; see, e.g., [1,9,15,16,34]. Allen and Evans [1] employ experimental bidding data to determine the level of traders' overconfidence as well as its determinant variables. Using monthly turnover data of the NYSE/AMEX market, Statman et al. [34] examine the predictions of trading volume on the basis of formal overconfidence models. They find that the trading volume of the stock is more related to the shocks of market returns than to the shocks of the stock. In [9], the influence of overconfidence on trading performance is investigated with student participation in a simulated trading environment. Overconfidence is measured by its psychological traits, which include miscalibration, market confidence, the better than average effect, and risk attitudes. The results show that higher levels of overconfidence result in poorer trading performance. Using similar measures regarding overconfidence, Glaser and Weber [15] test the relationship between overconfidence and trading volume by requesting online broker investors to complete an Internet questionnaire. Their findings indicate that overconfident investors, whose investment skills or past performance are higher or better, trade more. However, miscalibration, which is also an important index of overconfidence, is not related to trading volume. This result is contrary to those obtained in most theoretical models. Grinblatt and Keloharju [16] also analyze the impacts of overconfidence on trading activity. Their data used to measure overconfidence are obtained from a scientifically designed and validated psychological assessment. People who are overconfident are found to trade more frequently. According to the *ZEW-Finanzmarkttest*, which is a monthly survey of the market practitioners in Germany, Deaves et al. [13] examine the forecasters' overconfidence in terms of its statics and dynamics. Overconfidence is shown to be persistent, while market practitioners do exhibit some degree of learning behavior in that their confidence intervals are narrower (wider) after success (failure). In addition, market experience raises the degree of overconfidence.

Theoretical studies regarding overconfidence have rested on an imperfect rationality, and they have not been conducted based on a full heterogeneous-agent framework. In addition, overconfident traders in their models are usually assumed to know the underlying distribution of the signals, but falsely perceive the precision (volatility) of the signals. Without these assumptions, analytical results are difficult to derive because the complexity in such an environment would be too high. However, the framework of agent-based modeling provides us a way to tackle this difficulty by means of a computational approach. Since the development of agent-based modeling, its applications to economics and finance have been widely recognized. The major benefit of this approach is that it relaxes the assumptions of the rational expectations hypothesis and the representative agent.[1] Therefore, nowadays, it is quite natural to investigate the effects of overconfidence under a heterogeneous-agent framework.

To the best of our knowledge, the literature has very few studies that adopt the agent-based approach; however, see [27, 35]. Following a typical heterogeneous-agent model, Takahashi and Terano [35] build a financial market consisting of two types of traders: fundamentalists and trend predictors. Traders' behavior is represented by the Bayes correction model. In this model, the stock price deviates from the fundamental values when trend predictors are overconfident. In addition, overconfident traders may earn excess returns. Lovric et al. [27] employ the artificial stock market based on the model of [25]. The effects of both traders' sentiment measured by the level of optimism and traders' overconfidence are examined. In this

[1]The benefits of agent-based modeling in economics and finance are described in [23, 36] in depth.

model, there are two assets for traders to invest. One is a risky stock, the other is a risk-free bond. Traders are classified into two types: rational informed investors and efficient market believers. The rational informed investors are aware of the dividend process and can correctly estimate the fundamental values of the stock. By contrast, the efficient market believers are those who believe that stock prices will reflect all currently available information without any information regarding the dividend process. Therefore, their estimations are subject to their optimism and confidence. The results indicate that both investors' sentiment and confidence will affect price dynamics, volatility, and trading volume. Optimism and pessimism have different effects on price dynamics. The former results in higher volatility, whereas the latter stabilizes price dynamics. The presence of overconfidence strengthens the effect of sentiment. Contrary to the results obtained in the previous studies, overconfidence tends to decrease rather than increase trading volume.

Following the framework of [42], we propose an agent-based model to examine the effects of investors' overconfidence on the market. What distinguishes this work from the previous studies are the following. First, it is very important for traders to form expectations regarding the first moment as well as the second moment of the signals in financial markets. The formation of these expectations plays an important role in determining market behavior when traders have no information regarding the signals or the fundamental values of the asset, and is characterized by bounded rationality.[2] However, previous studies regarding overconfidence seldom take this factor into account. Traders in those models are assumed to either understand the distribution of the signals except for overestimating their precision, or to be able to infer the distribution through Bayes' rule. Both approaches do not essentially address the formation of expectations. By contrast, traders in our model are equipped with the learning methods to form these expectations.

Second, our model is a more general agent-based model compared with those of [27, 35]. For boundedly rational traders, the types or forms of their forecasting models (or strategies) are the outcomes of evolution. We thus have no reason to specify either of them in advance. Kirman [19] and LeBaron [23] have also pointed out the importance of these characteristics. Moreover, predetermining the types or forms of forecasting models may seriously harm the traders' heterogeneity, which is recognized as the driving force behind the evolution of the economic systems and the rationales of many stylized facts observed in financial markets, e.g., [19]. In this chapter, traders are not preclassified into a set of specific types of traders who employ predetermined forms of forecasting models. Each of them is allowed to form various types of forecasting models by means of a genetic programming (GP) learning algorithm. This design would be able to resolve the drawbacks of the previous studies.

Finally, in the literature, transaction prices are usually determined by a market maker who announces the equilibrium prices according to the excess demand. However, the market behavior would be very different when different price mechanisms

[2] Simon [33] points out that the definition of rationality should consider prediction and the formation of expectations under uncertainty if the assumptions of perfect foresight are discarded.

are employed; see, e.g., [2, 30]. Therefore, it is worthwhile to examine whether or not analytical results are still valid for different price mechanisms. We employ a simplified double auction (DA) mechanism as the trading system, which allows us to gain access to the features of continuous trading observed in financial markets, including market and limit orders. With this framework, we are able to analyze the intraday trading behavior.[3]

The remainder of this chapter is organized as follows. The framework of the artificial stock market, traders' learning behavior, and the mechanism of price determination are described in Sect. 8.2. Section 8.3 presents the designs of traders' overconfidence and the classification of markets under investigation. The simulation results and their analysis are given in Sect. 8.4. Section 8.5 concludes the chapter.

## 8.2 The Model

### *8.2.1 Market Structure*

The economy that we construct here is populated by traders whose preferences are characterized by the same constant absolute risk aversion (CARA) utility function, i.e., $U(W_{i,t}) = -\exp(-\lambda W_{i,t})$, where $W_{i,t}$ is trader $i$'s wealth at period $t$, and $\lambda$ is the degree of absolute risk aversion. Each trader's wealth consists of two types of assets, one is risky and the other is risk-free. The risky asset is the stock that pays dividends at the end of each period. The dividend payment follows a stochastic process ($D_t$) unknown to traders. The rest of a trader's portfolio is the risk-free asset, money, which is perfectly elastically supplied with a constant interest rate per annum, $r$. Following the design of [17], the daily rate is thus $r_d = r/K$ (where $K$ stands for the trading frequency spanning 1 year[4]), which guarantees a gross return equal to $R = 1 + r_d$. Therefore, we may describe trader $i$'s wealth at the next period as

$$W_{i,t+1} = RW_{i,t} + (P_{t+1} + D_{t+1} - RP_t)h_{i,t}, \tag{8.1}$$

where $P_t$ is the price (here the closing price) per share of the stock and $h_{i,t}$ denotes the stockholdings, i.e., the number of stock shares, held by this trader at time $t$. The second term in Eq. (8.1) is the excess revenue from the stock at $t + 1$ with the excess return, $R_{t+1} = P_{t+1} + D_{t+1} - RP_t$.

Subject to their wealth constraints given by Eq. (8.1), these CARA utility traders myopically maximize their one-period expected utilities

[3]Research such as that of [10, 39–42] adopts this approach.

[4]For example, K=1,12,52,250 represent the number of trading periods measured by the units of a year, month, week, and day, respectively.

$$\max_h \{E_{i,t}(W_{t+1}) - \frac{\lambda}{2} V_{i,t}(W_{t+1})\}, \tag{8.2}$$

where $E_{i,t}(\cdot)$ and $V_{i,t}(\cdot)$ are their one-period ahead forecasts regarding the conditional expectation and variance at $t+1$, respectively, given their information set, $I_{i,t}$, updated up to $t$. Here we have the details:

$$E_{i,t}(W_{t+1}) = RW_{i,t} + E_{i,t}(P_{t+1} + D_{t+1} - RP_t)h_{i,t} = RW_{i,t} + E_{i,t}(R_{t+1})h_{i,t}, \tag{8.3}$$

$$V_{i,t}(W_{t+1}) = h_{i,t}^2 V_{i,t}(P_{t+1} + D_{t+1} - RP_t) = h_{i,t}^2 V_{i,t}(R_{t+1}), \tag{8.4}$$

By solving Eq. (8.2), traders individually determine their optimal stock shares, $h_{i,t}^*$, at the outset of each period:

$$h_{i,t}^* = \frac{E_{i,t}(R_{t+1})}{\lambda V_{i,t}(R_{t+1})} = \frac{E_{i,t}(P_{t+1} + D_{t+1}) - RP_t}{\lambda V_{i,t}(R_{t+1})}. \tag{8.5}$$

Suppose that traders' current stockholdings have already reached their optimal levels, i.e., $h_{i,t}^* = h_{i,t}$. We may thus derive their reservation prices by reorganizing the third term of Eq. (8.5). The reservation price describes what the value of the stock should be if a trader has no intention of changing his stockholding situation:

$$P_i^R = \frac{E_{i,t}(P_{t+1} + D_{t+1}) - \lambda h_{i,t} V_{i,t}(R_{t+1})}{R}. \tag{8.6}$$

### *8.2.2 Traders' Learning Behavior*

To introduce the traders' learning behavior, we have to first define how they form their beliefs regarding the future returns and risks. As [19] points out, heterogeneity of traders' expectations is the driving force that fuels the market dynamics. Because of the GP generative strategy representation, traders in our market are able to evolve heterogeneous strategies not restricted to the dichotomy between a fundamental analysis or a technical trading rule.

#### 8.2.2.1 Belief Formation

As Eq. (8.6) shows, traders' reservation prices hinge on their conditional expectations and variances. Therefore, the way we represent these two factors plays a determinant role in how traders learn their baselines for the stock prices. The functional form we adopt for traders' expectations $E_{i,t}(\cdot)$ is

$$E_{i,t}(P_{t+1} + D_{t+1}) = \begin{cases} (P_t + D_t)[1 + \theta_0 \tanh(\frac{\ln(1+f_{i,t})}{\omega})] & \text{if } f_{i,t} \geq 0.0, \\ (P_t + D_t)[1 - \theta_0 \tanh(\frac{\ln(|-1+f_{i,t}|)}{\omega})] & \text{if } f_{i,t} < 0.0, \end{cases} \tag{8.7}$$

where $f_{i,t}$[5] is the value derived from the GP evolution based on $I_{i,t}$.[6]

Note that traders update their active rules' estimated conditional variances at the end of each period. Now let $\sigma^2_{i,t}$ denote $V_{i,t}(R_{t+1})$. We assume that a trader's conditional variance takes the following form:

$$\sigma^2_{i,t} = (1-\theta_1-\theta_2)\sigma^2_{i,t-1} + \theta_1(P_t+D_t-u_{t-1})^2 + \theta_2[(P_t+D_t)-E_{i,t-1}(P_t+D_t)]^2, \tag{8.8}$$

where

$$u_t = (1-\theta_1)u_{t-1} + \theta_1(P_t + D_t). \tag{8.9}$$

The above is a variant of the conditional variance used in [24], synthesized with the property of decaying historical volatility that appears in the version of [17]. The latter argues that part of the autocorrelation features and the power law pattern observed in financial data may come from the geometric decay processes of the sample mean and variance.

#### 8.2.2.2 Learning

In order to maximize their one-period expected utility, traders strive to maximize their excess revenues by searching for better forecasts of the next period's sum of the price and dividend, while at the same time minimizing their perceived uncertainties of the excess return. Each trader maintains a pool of forecasting models ($N_I$) in mind that are represented by the GP. Some of these models may act as technical trading rules, while others may function like fundamental analyses. Which one will stand out as the next period's forecasting model in use crucially depends on their relative performances in the current period. The performance (or strength) of each model is then measured by its forecast accuracy, i.e., the conditional variance,[7]

$$s_{i,j,t} = -\sigma^2_{i,j,t}, \tag{8.10}$$

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[5]With this kind of functional form, the traders are still able to take a chance on the martingale hypothesis when $f_{i,t} = 0$. The form employed in [8] shares the same merit. Although we agree that it is reasonable to also allow the traders to separately form their expectations about prices and dividends, a multi-objective GP design that aims to accommodate this bipartite learning may be, at the current stage, too complicated to establish an intuitive causal link between price dynamics and individual expectations. Even the models which assume more classic frameworks, like those proposed by Brock and Hommes [5] or the SF-ASM, still somehow simplify the formations of traders' expectations.

[6]For more details about applying the GP to the evolution of function formation, the readers are recommended to refer to Appendix A in [42].

[7]A similar design was used in [3, 24].

where $j$ ranges from 1 to $N_I$ and $s_{i,j,t}$ is the strength of trader $i$'s $j$th model in period $t$.

On the basis of the strengths driven by the GP fitness criterion, traders adapt to learn better forecasts by abandoning the poorest model while generating a new one. Each trader asynchronously iterates this evolutionary process to update his own prediction pool every $N_{EC}$ periods (an evolutionary cycle). At the beginning of each evolutionary cycle's first period, each trader randomly chooses $N_T$ out of $N_I$ models. Among these initial candidates, a trader selects the one with the highest strength to make his prediction in each period of this cycle. At the end of each cycle's last period, traders evaluate their own strategy pools in terms of the model's performance. Each trader then replaces the model that scores the lowest strength with a new entry that is generated by one of the three operators: crossover, mutation, and immigration.

### *8.2.3 Market Mechanism*

It is well known that the trading mechanism significantly impacts the price dynamics. Anufriev and Panchenko [2] find that the distribution of traders' heterogeneous beliefs may vary under different market mechanisms, such as a Walrasian scenario and an order-book mechanism. Some price determination mechanisms, e.g., a price adjustment function with predetermined upper and lower bounds in each period, may seriously inhibit the potential dynamics of price movements and thus the heterogeneity of traders' beliefs. It is very important to choose an appropriate market clearing mechanism whereby the evolution of price dynamics depends not only on what traders expect but also on how their beliefs interact.

We adopt a simplified continuous DA as the market mechanism for price determination. Each trading period consists of $N_R$ rounds that separately serve as pseudo-devices for shuffling agents' queuing orders. All traders' orders in which they take turns to engage in trade are randomly permutated before the start of each round. In the absence of parallel computing that allows traders to propose their bids and asks simultaneously, these rounds together reduce the biases induced by fixing on an arbitrary trading order.

Traders post their bids or asks (one at a time) in accordance with the following rules. Although the order book keeps the whole record of all bids and asks, traders are restricted to observing only the best bid ($B_b$) and the best ask ($B_a$), i.e., the highest price for buying and the lowest price for selling, respectively, revealed on the billboard. Traders' subsequent bids (asks) must be higher (lower) than the existing one as long as the billboard is not empty. Before deciding whether or not to post a new offer or accept a deal, a trader must take into account both the reservation prices and the current best ask and best bid as follows.

- If $B_b$ and $B_a$ exist ($B_a > B_b$),
  - If $P_i^R > B_a$, he will post a market order, and buy at $B_a$.
  - If $P_i^R < B_b$, he will post a market order, and sell at $B_b$.
  - If $B_b \leq P_i^R \leq B_a$ and $P_i^R < (B_a + B_b)/2$, he will post a sell order at a price uniformly distributed in $(P_i^R, P_i^R + S_i)$, where $S_i = (\frac{\lambda \sigma_{i,t}^2}{1+r})\Delta h$. $S_i$ is the maximum spread from the reservation price.
  - If $B_b \leq P_i^R \leq B_a$ and $P_i^R \geq (B_a + B_b)/2$, he will post a buy order at a price uniformly distributed in $(P_i^R - S_i, P_i^R)$.
- If only $B_a$ exists,
  - If $P_i^R > B_a$, he will post a market order, and buy at $B_a$.
  - If $P_i^R \leq B_a$, he will post a buy order at a price uniformly distributed in $(P_i^R - S_i, P_i^R)$.
- If only $B_b$ exists,
  - If $P_i^R < B_b$, he will post a market order, and sell at $B_b$.
  - If $P_i^R \geq B_b$, he will post a sell order at a price uniformly distributed in $(P_i^R, P_i^R + S_i)$.
- If no bid and ask exist,
  - he will have an equal chance to post a buy or a sell order at a price uniformly distributed in $(P_i^R - S_i, P_i^R)$ or $(P_i^R, P_i^R + S_i)$, respectively.

Once the existing best bid or ask is accepted or a bid and ask pair cross, a transaction is done. To sidestep the effect of determining the amount of the stock in each transaction, each deal is assumed to be a fixed amount of stock shares ($\Delta h$). A trading round ends when all traders have taken their turns. The unfulfilled orders of the traders are removed when they post their new orders in the subsequent rounds. An order reshuffle then takes place at the beginning of the coming round. Therefore, traders may execute a series of deals during a period while taking different positions, i.e., buyer or seller, across rounds. The last transaction price in the final round is registered as the market price (the closing price) for this period.

## 8.3 Simulation Design

We consider the case where all traders hold the same constant level of overconfidence. In other words, traders are always overconfident and their overconfidence is outcome-independent. In this chapter, overconfidence implies that traders underestimate their forecasting errors or the risk, i.e., the conditional variance. Therefore, the conditional variance shown in Eq. (8.8), $\sigma_{i,t}^2$, is replaced by $\Omega_{i,t}^2$ when each trader calculates his own reservation price according to Eq. (8.6):

$$\Omega_{i,t}^2 = \gamma \sigma_{i,t}^2, \tag{8.11}$$

where $\gamma$ is the level of overconfidence.[8] It ranges between 0 and 1. The lower its value, the more overconfident the trader. However, our market situation is different from that of [11]. In [11], all informed traders underestimate the true risk, i.e., $\sigma_\epsilon^2$, which is constant over time. By contrast, in our model, each trader has his own expectation regarding the risk, which is time-varying. Therefore, overconfidence is presented in the manner that a trader underestimates the risk he ought to perceive without overconfidence.

Following the design of [42], the parameters for conducting simulations, which include the parameters regarding traders' learning behavior as well as those for the execution of the GP algorithm, are calibrated to mimic several stylized facts of the daily data in financial markets. Table 8.1 summarizes the basic parameters used to conduct our simulations.

## 8.4 Results

This chapter studies the effects of traders' overconfidence on asset pricing, volatility, and trading volume. We follow the method proposed in [38] to analyze these influences. The measures of price distortion, volatility, and volume are used to evaluate the impacts of different levels of traders' overconfidence on the market. To evaluate the degree of price distortion, we have to know the fundamental value of the asset. In this model, the homogeneous rational expectations equilibrium (REE) price is as follows[9]:

$$P_f = \frac{1}{R-1}(\overline{D} - \lambda\sigma_D^2 h), \tag{8.12}$$

where $h$ represents the average shares of the stock per trader. According to the parameters given in Table 8.1, the fundamental price of the stock is 90.0. The price distortion ($P_D$) is defined as the average deviation from the fundamental price:

$$P_D = \frac{100}{N_P}\sum_{t=1}^{N_P}\left|\frac{P_t - P_f}{P_f}\right|. \tag{8.13}$$

The market volatility ($P_V$) is measured as the average absolute return:

$$P_V = \frac{100}{N_P - 1}\sum_{t=1}^{N_P}\left|\frac{P_t - P_{t-1}}{P_{t-1}}\right|. \tag{8.14}$$

[8]Technically speaking, we may adjust the value of the parameter to achieve the same effects of the parameter shown in Eq. (8.6); however, $\lambda$ and $\gamma$ have their own implications. $\lambda$ describes a trader's risk preference, while $\gamma$ measures the level of a trader's overconfidence, which is not related to his risk preference.

[9]Refer to [3], pp. 40–41.

**Table 8.1** Parameters for simulations

| | |
|---|---|
| *The stock market* | |
| Shares of the stock ($h$) for each trader | 1 |
| Initial money supply ($M_0$) for each trader | \$100 |
| Interest rate ($r$, $r_d$) | (0.05, 0.0002) |
| Stochastic process ($D_t$) | $N(\overline{D}, \sigma_D^2)$=N(0.02, 0.004) |
| Amount for each trade ($\Delta h$) | 1 |
| Maximum shares of stock holding ($\overline{h}$) | 10 |
| Number of rounds for each period ($N_R$) | 50 |
| Number of periods ($N_P$) | 20,000 |
| *Traders* | |
| Number of traders ($N$) | 100 |
| Number of strategies for each trader ($N_I$) | 20 |
| Tournament size ($N_T$) | 5 |
| Evolutionary cycle ($N_{EC}$) | 5 |
| $\lambda$ | 0.5 |
| $\theta_0$ | 0.5 |
| $\omega$ | 15 |
| $\theta_1$ | 0.01 |
| $\theta_2$ | 0.005 |
| *Parameters of genetic programming* | |
| Function set | {if-then-else;and,or,not;≥,≤, =,+,−,×,%,sin,cos,abs,sqrt} |
| Terminal set | $\{P_{t-1}, ..., P_{t-5}, D_{t-1}, ..., D_{t-5}, R\}$ |
| Selection scheme | Tournament selection |
| Tournament size | 2 |
| Probability of creating a tree by immigration ($P_I$) | 0.1 |
| Probability of creating a tree by crossover ($P_C$) | 0.7 |
| Probability of creating a tree by mutation ($P_M$) | 0.2 |

R denotes the ephemeral random constant

We consider nine different overconfidence levels which range from 0.9 to 0.1 with a step size of 0.1. The market where traders are not overconfident serves as the benchmark. Figure 8.1 shows the information regarding how market volatility and price distortion change as traders become more overconfident. The values of volatility and distortion for each simulation are indicated by dots displayed in the plots. The solid and dashed lines represent the tracks of the average and standard deviation for all 30 runs, respectively. The corresponding results obtained in the benchmark market, marked as B, are indicated by the symbol * on the leftmost of the plots. It is shown that market volatility decreases as traders become

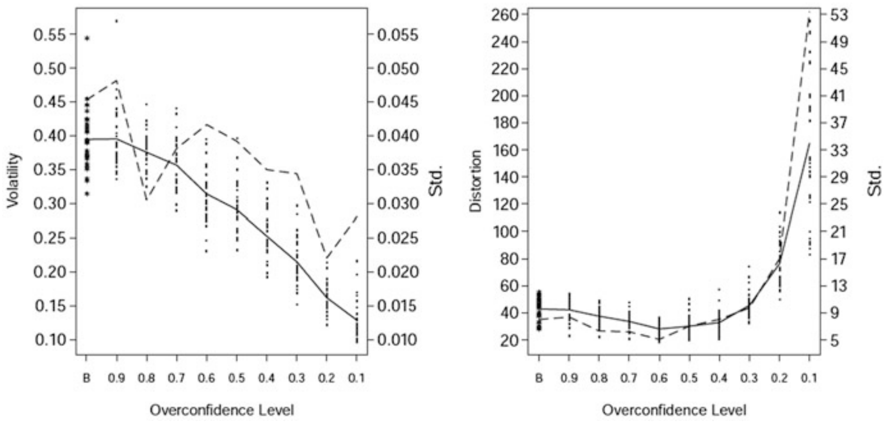


**Fig. 8.1** Volatility and distortion

more overconfident, i.e., the value of $\gamma$ is smaller. This result is inconsistent with the conclusions obtained in many theoretical frameworks which argue that the more overconfident the traders are, the more volatile the market is.

However, this inconsistency may result from several unrealistic layouts adopted by previous studies. For example, traders are not truly heterogeneous and/or the types of traders are prespecified, or they have too much information regarding the fundamental values and/or the fundamental risk of the asset (i.e., they are overconfident informed traders), so that their overconfidence is modeled based on a common reference point. This type of design regarding the risk implicitly argues that the source of the risk comes mainly from the objectively observed risk. The overconfident traders simply underestimate it. This feature is also found in [27, 35], both of which employ an agent-based modeling approach. However, in practice, the risk that traders encounter should include their own subjective risk resulting from their forecasting errors, and this is what distinguishes this work from the literature. In our framework, the traders who are boundedly rational are heterogeneous in their beliefs. They have no information regarding the fundamental values of the stock (i.e., they are uninformed traders), and so they have to learn about not only the trend of the price and dividend but also the estimated volatility (risk) which takes into account traders' objective and subject risk. This design is rather important because, during the interaction between the traders and the market, the traders' subject risk will affect their expectations regarding the trend of the price and dividend, and vice versa. This feature, which is the main characteristic of our model, is totally missing in the literature.

In the right panel of Fig. 8.1, the price distortion exhibits a different pattern. When $\gamma$ ranges between 1 (i.e., traders are not overconfident) and 0.6, price distortion slightly decreases, while it increases quickly when the value of $\gamma$ is further reduced. This phenomenon is not surprising. Traders' estimated risk is on average smaller when they become more overconfident. In this situation, they tend

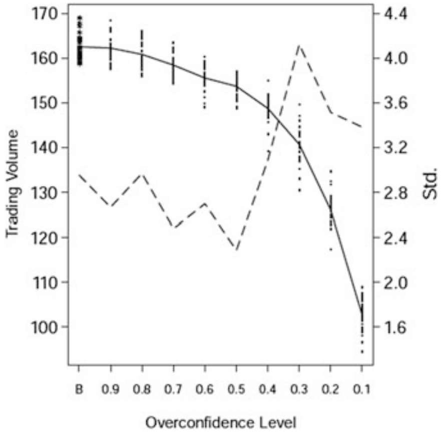


**Fig. 8.2** Trading volume

to overestimate the intrinsic values of the asset. This type of overestimation exists for most of the traders, because traders in our model have the same overconfidence level. Therefore, prices largely deviate from the fundamental value.

Figure 8.2 displays how trading volume changes as the traders become more overconfident. We obtain a similar feature to that found in the market volatility. Volume decreases as the value of $\gamma$ is reduced. In other words, overconfident traders do not enhance market liquidity. This result is also contrary to those obtained in [4] and [14], where overconfident traders trade more aggressively, so that it leads to higher volume. However, this conclusion is based on the framework where some rather than all traders are overconfident. When the market is composed of all overconfident traders on the bottom, they have to compete with each other, rather than trade with informed and/or rational traders who are not overconfident. In addition, both of the previous studies were conducted in an environment where a market maker sets the price and the stock supply is infinitely elastic. However, in our model, the supply of the stock is constant and the DA mechanism is used as the trading system. Therefore, trading volume is determined by the traders' heterogeneity, i.e., the distribution of traders' reservation prices. In this case, overconfidence does not necessarily result in higher trading volume on the top.

## 8.5 Conclusion

In contrast to the models analyzed in the literature consisting of rational and/or informed traders who are overconfident, we proposed a framework using all boundedly rational uninformed heterogeneous traders. They have to learn not only the forecasts regarding the trend of the price and dividend but also the estimated risk comprising both subjective and objective components. Overconfidence is represented as a trader underestimating the risk he ought to perceive without biases from overconfidence. In addition, we adopt the DA mechanism to determine the market prices. We find that market volatility and trading volume decrease and price distortion increases, when traders become more overconfident. Our next step would extend this framework to the situation where traders' overconfidence level is outcome-dependent, e.g., taking into account traders' biased self-attribution. This kind of approach is quite important because, in this situation, overconfidence is endogenously generated rather than exogenously given as done in this chapter. Therefore, we are able to examine when and how overconfidence may emerge as well as its implications. We can also incorporate different types of traders, such as informed traders, into the model, in order to understand the effects resulting from different types of overconfident traders.

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# Chapter 9
# Analyzing the Validity of Passive Investment Strategies Under Financial Constraints

**Hiroshi Takahashi**

**Abstract** This chapter describes the validity of a passive investment strategy through agent-based simulation. As a result of intensive experimentation, I have concluded that a passive investment strategy is valid under conditions where market prices deviate widely from fundamental values. However, my agent-based simulation also shows that the increase in the rate of passive investment slows as financial restrictions become more severe. The results are of both academic interest and practical use.

**Keywords** Agent-based modeling • Asset management • Finance • Passive investment strategy

## 9.1 Introduction

Financial markets contribute to efficient capital allocation, and much research regarding the efficiency of markets has been carried out. Theories of asset pricing have developed mainly in the area of finance, and the efficiency of the market is one of the most significant concerns in the world of traditional financial theory. For example, in the Capital Asset Pricing Model (CAPM)—one of the most popular asset pricing theories—equilibrium asset prices are derived on the assumption that markets are efficient and investors rational [24]. The CAPM indicates that the optimal investment strategy is to hold a market portfolio. Since it is very difficult for investors to get an excess return in an efficient market, it is assumed to be difficult to beat a market portfolio even if the investment strategy is firmly based on public information. A passive investment strategy—which tries to maintain

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an average return using benchmarks based on market indices—is consistent with traditional asset pricing theories and is considered to be an effective method in efficient markets.

The mainstream view argues that markets operate efficiently. However, there is also a great deal of research that takes the opposite view, suggesting that markets are actually inefficient. For example, the field of behavioral finance has raised some doubts about the efficient market assumption, by arguing that (a) an irrational trader could have an influence on asset prices, and (b) there is a limit to arbitrage trading. Moreover, there are many analyses which point out the drawbacks of traditional financial theory from the viewpoint of information structures, financial restrictions, and so on [13, 27, 33]. There is a growing need for analyses which take realistic aspects of financial markets into account.

There has been much research into the validity of passive investment strategies in efficient markets. With these arguments, passive investment has spread and become one of the most popular investment methods in the asset management business. On the other hand, there have been insufficient analyses of the validity or otherwise of a passive investment strategy in an inefficient market. Passive investment strategies play an important role in the asset management business, so it is significant to clarify their characteristics from both practical and academic points of view. By considering these factors, this research analyzes the validity of a passive investment strategy under inefficient market conditions.

To address this problem, I have employed agent-based modeling in this analysis. Agent-based modeling is proposed as an effective method to analyze the relation between micro-rules and macro-behavior [2, 3, 8]. Agent-based modeling is an attempt to explain the macro-behavior of systems by local rules. As a result of applying this model to social science, it has been found that a variety of different macro-behaviors emerge bottom-up from local micro-rules. Agent-based modeling has many applications, and none more suitable than for the creation of an artificial market. For example, Arthur et al. [1] analyzed the market under conditions where heterogeneous investors trade and concluded that complex conditions emerge. Takahashi and Terano [30] modeled investor behavior based on behavioral finance and concluded that irrational traders could survive in the market throughout the analyses with agent-based modeling. Takahashi [28] suggests that the combination of behavioral biases and financial constraints causes significant deviation from fundamental values. Analyses which attempt to replicate realistic market conditions and dynamics present a greater challenge to the researcher than traditional forms of research. Due to the efficacy of this type of advanced analysis, there is a greater demand for research conducted employing these kinds of models. Therefore, the necessity of analysis using a new approach in addition to the original one has been increasing. Agent-based modeling could contribute to financial research.

With this background in mind, the purpose of this research is to analyze the validity of passive investment strategies under financial constraints. The next section describes the model used in this analysis. Section 9.3 shows the results of the analysis. Section 9.4 summarizes this chapter.

## 9.2 Model

A computer simulation of the financial market involving 1,000 investors was used as the model for this research. Shares and risk-free assets were the two types of assets used, along with the possible transaction methods. Several types of investors exist in the market, each undertaking transactions based on their own stock evaluations [1, 14, 32]. This market was composed in three major stages: (1) generation of corporate earnings, (2) formation of investor forecasts, and (3) setting of transaction prices. The market advances through repetition of these stages. The following sections describe negotiable transaction assets, modeling of investor behavior, transaction price setting, and rules of natural selection in the market.

### *9.2.1 Negotiable Assets in the Market*

This market has both risk-free and risk-associated assets. There are risk-associated assets in which all profits gained during each term are distributed to shareholders. Corporate earnings $(y_t)$ are expressed as $y_t = y_{t-1} \cdot (1 + \varepsilon_t)$. However, they are generated according to the process of $\varepsilon_t \sim N(0, \sigma_y^2)$ with share trading being undertaken after the public announcement of profits for the term [5, 23]. Each investor is given common asset holdings at the start of the term with no limit placed on debit and credit transactions (1,000 in risk-free assets and 1,000 in stocks). Investors adopt the buy-and-hold method for the relevant portfolio as a benchmark[1] to conduct decision making by using a one-term model.

### *9.2.2 Modeling Investor Behavior*

Each type of investor handled in this analysis is organized in Table 9.1. This analysis covers most major types of investors [6, 27]. The investors can be classified into two categories: active investors (types 1–4) and a single passive investor type (type 5). Active investors in this market evaluate transaction prices based on their own forecasts of market movements, taking into consideration both risk and return rates when making decisions. Passive investors employ a buy-and-hold strategy[2] [16]. Each active investor determines the investment ratio $(w_t^i)$ based on the maximum objective function $(f(w^i t))$, as shown below [11, 17].

[1]The buy-and-hold method is an investment method to hold shares for medium to long term.

[2]The passive investment strategy is one of the most popular investment strategies in the asset management business.

**Table 9.1** List of investor types

| No. | Investor type |
|---|---|
| 1 | Fundamentalist |
| 2 | Forecasting by past average (most recent 10 days) |
| 3 | Forecasting by trend (most recent 10 day) |
| 4 | Latest price |
| 5 | Passive investor |

$$f(w_t^i) = r_{t+1}^{int,i} \cdot w_t^i + r_f \cdot (1 - w_t^i) - \lambda(\sigma_{t-1}^i)^2 \cdot (w_t^i)^2.$$

Here, $r_{t+1}^{int,i}$ and $\sigma_{t-1}^i$ express the expected rate of return and risk for stocks as estimated by each investor $i$. $r_f$ indicates the risk-free rate. $w_t^i$ represents the stock investment ratio of the investor $i$ for term $t$. The value of the objective function $f(w_t^i)$ depends on the investment ratio $(w_t^i)$. The investor decision-making model here is based on the Black-Litterman model that is used in the practice of securities investment [4, 18, 20, 21].

The expected rate of return for shares is calculated as follows [4]:

$$r_{t+1}^{int,i} = (1 \cdot c^{-1}(\sigma_{t-1}^i)^{-2} \cdot r_{t+1}^{f,i} + 1 \cdot (\sigma_{t-1}^i)^{-2} \cdot r_t^{im})/(1 \cdot c^{-1}(\sigma_{t-1}^i)^{-2} + 1 \cdot (\sigma_{t-1}^i)^{-2}).$$

Here, $r_{t+1}^{f,i} r_t^{im}$ expresses the expected rate of return, calculated from the short-term expected rate of return, and the risk and gross current price ratio of stocks respectively. $c$ is a coefficient that adjusts the dispersion level of the expected rate of return calculated from the risk and gross current price ratio of stocks [4].

The short-term expected rate of return $(r_t^{f,i})$ is obtained where $(P_{t+1}^{f,i}, y_{t+1}^{f,i})$ is the equity price and profit forecast for term $t + 1$ estimated by the investor, as follows: $r_{t+1}^{f,i} = ((P_{t+1}^{f,i} + y_{t+1}^{f,i})/P_t - 1)$.

The price and profit forecast $(P_{t+1}^{f,i}, y_{t+1}^{f,i})$ includes the error term $(P_{t+1}^{f,i} = P_{t+1}^{f,typej} \cdot (1 + \eta_t^i), y_{t+1}^{f,i} = y_{t+1}^{f,typej} \cdot (1 + \eta_t^i)$, where $\eta_t^i \sim N(0, \sigma_n^2))$, reflecting that even investors using the same forecast model vary slightly in their detailed outlook. This paper analyzes the two cases where the dispersion of valuations is normal $(\sigma_n = 5\,\%)$ and large $(\sigma_n = 10\,\%)$. The stock price $(P_{t+1}^{f,i})$, profit forecast $(y_{t+1}^{f,i})$, and risk estimation methods are described in the following subsections.

The expected rate of return obtained from stock risk and so forth is calculated from the stock risk $(\sigma_{t-1}^i)$, benchmark equity stake $(W_{t-1})$, investors' degree of risk avoidance $(\lambda)$, and risk-free rate $(r_f)$, as follows [25]: $r_t^{im} = 2 \cdot \lambda \cdot (\sigma_{t-1}^i)^2 \cdot W_{t-1} + r_f$.

#### 9.2.2.1 Stock Price Forecasting Method

The fundamental value is estimated by using the discounted cash flow (DCF) model, which is a well-known model in the field of finance. Fundamentalists estimate the forecasted stock price and forecasted profit from the profit for the term ($y_t$) and the discount rate ($\delta$) as $P_{t+1}^{f,typej} = y_t/\delta, y_{t+1}^{f,typej} = y_t$.

Forecasting based on trends involves forecasting the next term's stock prices and profit through extrapolation of the most recent stock value fluctuation trends. The next term's stock price and profit are estimated from the most recent trends of stock price fluctuation ($a_{t-1}$) from time point $t-1$ as $P_{t+1}^{f,typej} = P_{t-1} \cdot (1 + a_{t-1})^2, y_{t+1}^{f,typej} = y_t \cdot (1 + a_{t-1})$.

Forecasting based on past averages involves estimating the next term stock prices and profit based on the most recent average stock value.

#### 9.2.2.2 Risk Estimation Method

In this analysis, each investor estimates risk from past price fluctuations. Specifically, stock risk is estimated as $\sigma_{t-1}^i = \sigma_{t-1}^h$ (common to each investor). Here, $\sigma_{t-1}^h$ represents the stock volatility that is calculated from price fluctuation from the most recent 100 terms.

### *9.2.3 Determination of Transaction Prices*

Transaction prices are determined as the price where stock supply and demand converge ($\sum_{i=1}^{M}(F_t^i w_t^i)/P_t = N$). In this case, the total asset ($F_t^i$) of investor $i$ is calculated from transaction price ($P_t$) for term $t$, profit ($y_t$) and total assets from the term $t-1$, stock investment ratio ($w_{t-1}^i$), and risk-free rate ($r_f$), as $F_t^i = F_{t-1}^i \cdot (w_{t-1}^i \cdot (P_t + y_t)/P_{t-1} + \left(1 - w_{t-1}^i\right) \cdot (1 + r_f))$.

### *9.2.4 Natural Selection in the Market*

Investors who are able to adapt to and, hence, profit from the market as it fluctuates will remain in the market and their positions will grow strongly. Conversely, investors who are unable to do this will drop out of the market. This pattern is very suggestive of what might be termed "natural selection in the market." The driving force behind this "natural selection" is the desire for cumulative excess profit [9]. Two aspects of this pattern are of particular interest: (1) the identification of investors who alter their investment strategy and (2) the actual alteration of investment strategy [30].

Each investor must decide whether they should change investment strategies based on the most recent performance of each five-term period (after 25 terms have passed since the beginning of market transactions). The higher the profit rate that has been obtained most recently, the lower the possibility of strategy alteration becomes. The lower the profit, the higher the possibility becomes. Specifically, when an investor cannot obtain a positive excess profit for the benchmark portfolio profitability, he is likely to alter his investment strategy with the following probability:[3]

$$p_i = \min(1, \max(-100 \cdot r^{cum}, 0)).$$

Here, however, $r_i^{cum}$ is the cumulative excess profit for the most recent benchmark of investor $i$. The measurement was conducted for 1, 5, and 25 terms, and the cumulative excess profit was calculated as a one-term conversion.[4]

In terms of deciding on a new investment strategy, an investment strategy that has a high cumulative excess profit for the most recent five terms (forecasting type) is "naturally" more likely to be selected. Where the strategy of the investor $i$ is $z_i$ and the cumulative excess profit for the most recent five terms is $r_i^{cum}$, the probability $p_i$ that $z_i$ is selected as a new investment strategy is given as $p_i = e^{(a \cdot r_i^{cum})} / \sum_{j=1}^{M} e^{(a \cdot r_j^{cum})}$.[5] Those investors who altered their strategies make investments based on the new strategies after the next step.

## 9.3 Results

I first look at the validity of a passive investment strategy, as well as the influence of financial constraints on asset prices. (The analyses of the validity of the passive investment strategy and the influence of financial constraints are conducted as a reference to compare with the later detailed analyses.) Then, the validity of the passive investment strategy under these financial constraints is analyzed.

### *9.3.1 The Validity of a Passive Investment Strategy and the Influence of Financial Constraints*

This section analyzes the validity of a passive investment strategy and the influence of financial constraints.

[3] In the actual market, evaluation tends to be conducted according to baseline profit and loss.

[4] For example, if excess profit over a five-term period is 5 %, a one-term conversion would show this as a 1 % excess for each term period.

[5] Selection pressures on an investment strategy become higher as the coefficients' value increases.

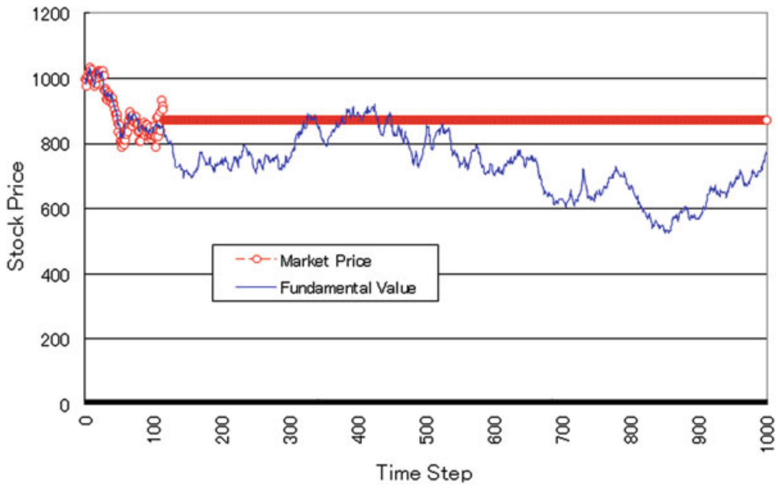


**Fig. 9.1** Price transitions (without financial constraints)

#### 9.3.1.1 The Validity of Price Indexing

First, a situation where there is the same number of fundamentalist and passive investors in the market is analyzed. Figures 9.1 and 9.2 show the transitions of stock prices and the number of investors. At the initial stage, the number of fundamentalist and passive investors is equal. (The number of each investor is 500 at t = 0.) The horizontal axis in the graph shows time steps, and the vertical axis shows stock prices. Two transitions are shown: fundamental values and transaction prices. It can be seen that the number of passive investors increases over time steps. Generally, the behavior of fundamentalists and passive investors is the same. However, the forecast of the fundamentalists has an error term, and therefore the number of passive investors increases. These results suggest that a passive investment strategy is a valid one.[6] Investors who employ a passive investment strategy adopt a buy-and-hold strategy, and therefore do not affect market prices. When all investors in the market become passive investors, market prices no longer reflect fundamental values. For a detailed analysis of passive investors, refer to Takahashi et al. [31].

Figure 9.3 shows the transition of numbers of investors where the same numbers of five types of investors exist in the market[7] (Table 9.1, types 1–5). The results demonstrate that passive investors can survive in a market where various kinds of investors trade, as in Fig. 9.2. Under these conditions, market prices will not reflect fundamental values when all investors become passive investors.

[6]On average, passive investors have obtained a better performance than fundamentalists.

[7]This model consists of an equal number of fundamentalists, passive investors, trend chasers, investors based on historical price average, and investors who estimate stock prices based on the latest price.

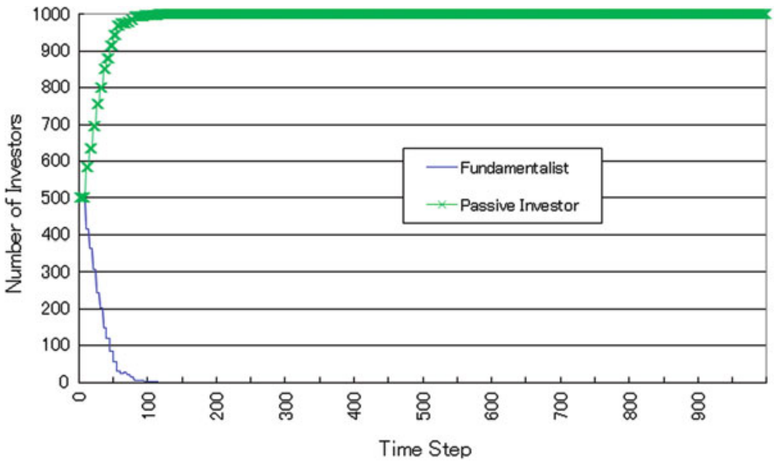


**Fig. 9.2** Transition of number of investors (without financial constraints)

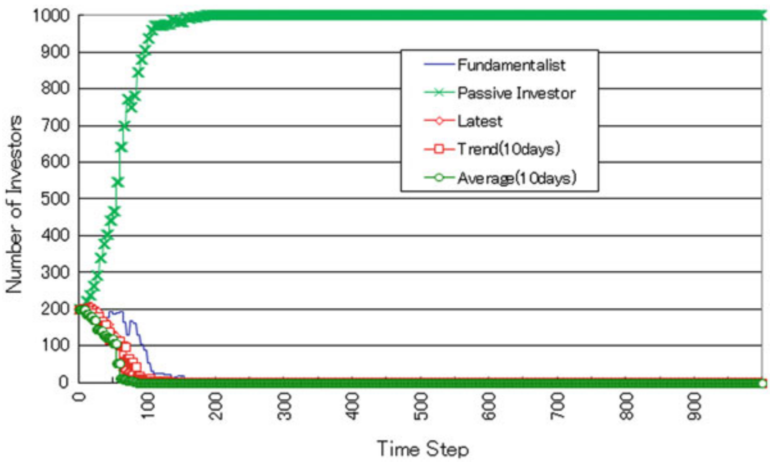


**Fig. 9.3** Transitions of number of investors (five types of investors, without financial constraints)

#### 9.3.1.2 The Influence of Financial Constraints on Asset Prices

This section analyzes the influence of financial constraints on financial markets where fundamentalists trade—many kinds of financial constraints could be considered. In this section, I focus on tilting limits (the deviation from benchmark weight). In many cases, institutional investors, e.g., pension funds, make investment decisions by referring to the benchmark weight. For example, if an investor estimates asset "A" as attractive, she will invest in asset "A" by more than the benchmark weight.

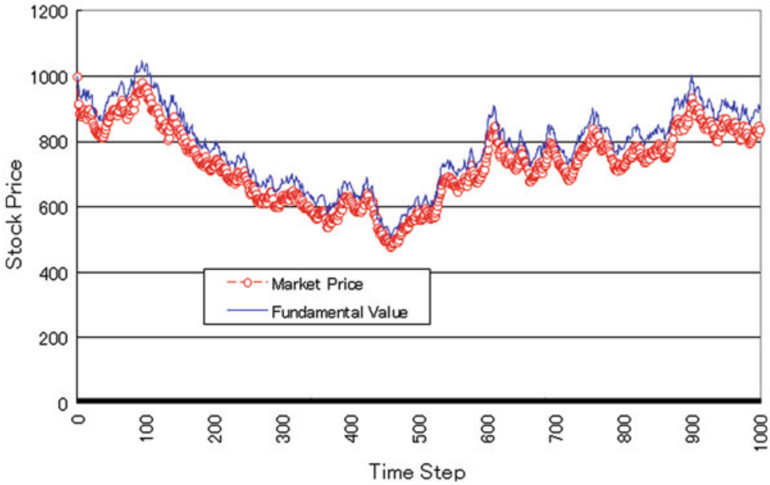


**Fig. 9.4** Price transition (upper limit on tilting: 5 %)

Figure 9.4 shows the price transition where upper limits on tilting are put on investors. In practice, investors are restrained from tilting more than 5 % against the benchmark weight. In this case, investors who hold negative information can go underweight against benchmark. However, investors who hold positive information cannot go sufficiently overweight, due to the upper limit on tilting. As shown in Fig. 9.4, transaction prices are lower than the fundamental value, because it is difficult for investors who hold positive information to affect asset prices while operating under financial constraints. These results are in accord with traditional financial theory [12, 22]. Although this chapter deals only with limits on tilting, similar results are seen with the introduction of other constraints (e.g., limit on leverage, short-selling) [31].

Figure 9.5 shows the case where the limit is tighter.[8] As the financial constraints become stricter, the deviation between transaction prices and the fundamental values becomes wider. Figure 9.6 shows the result when minimum tilt requirements are introduced. (The case where the lower limit on tilting is −1 % is shown.) In this case, the market price deviation is a mirror image of that seen with the introduction of upper limits. When lower limits are introduced, investors who hold negative information do not affect stock prices due to the existence of constraints, and therefore market prices become higher than the fundamental value [12, 22, 31].

[8]Figure 9.5 shows the case where investors cannot go overweight more than 1 %. As the upper limit becomes stricter from 5 to 1 %, the portfolio's risk decreases.

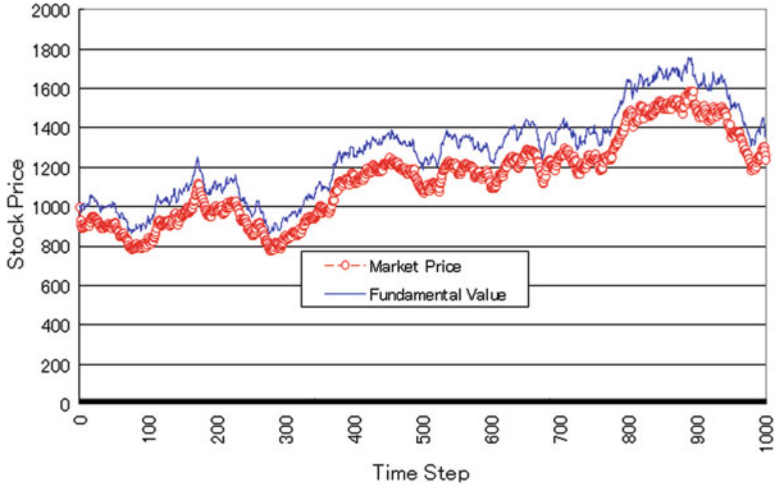


**Fig. 9.5** Price transition (upper limit on tilting: 1 %)

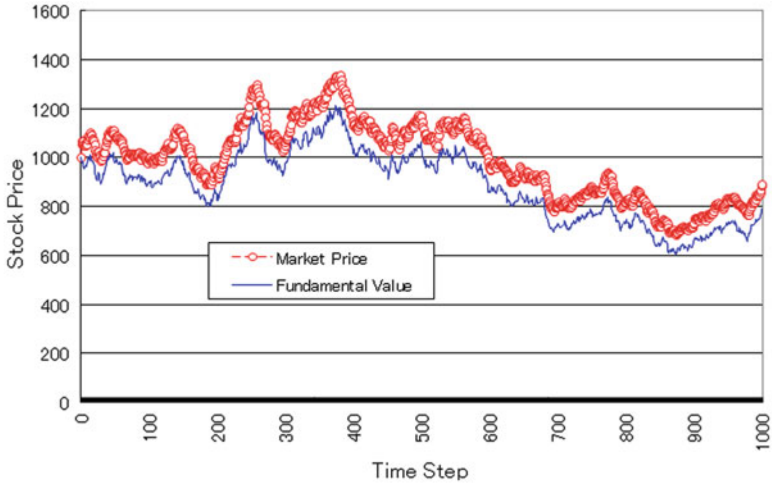


**Fig. 9.6** Price transition (lower limit on tilting: 1 %)

## *9.3.2 Influence of Financial Constraints on Passive Investors*

This section analyzes the validity of passive investing under financial constraints. In the market model, there are the same numbers of fundamentalists and passive investors.

Figure 9.7 shows the price transition when there are fundamentalists and passive investors in the market. In this case, investors are not allowed to go overweight more than +5 % against the benchmark weight. Figure 9.7 shows that market prices

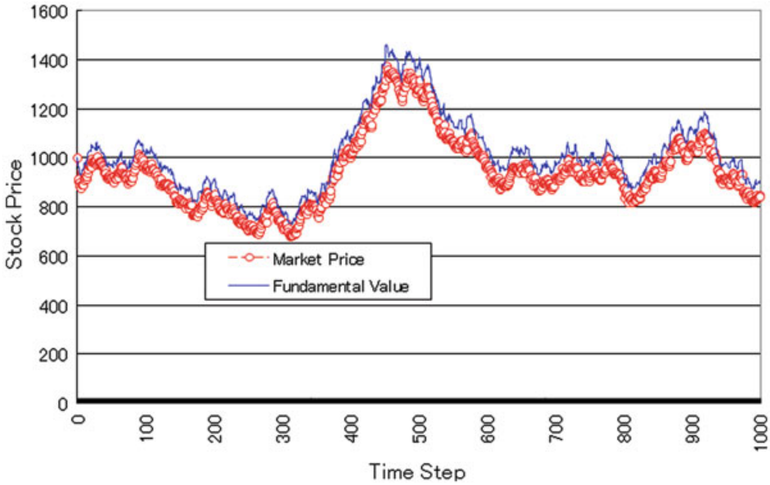


**Fig. 9.7** Price transition (passive investor, upper limit on tilting 5 %)

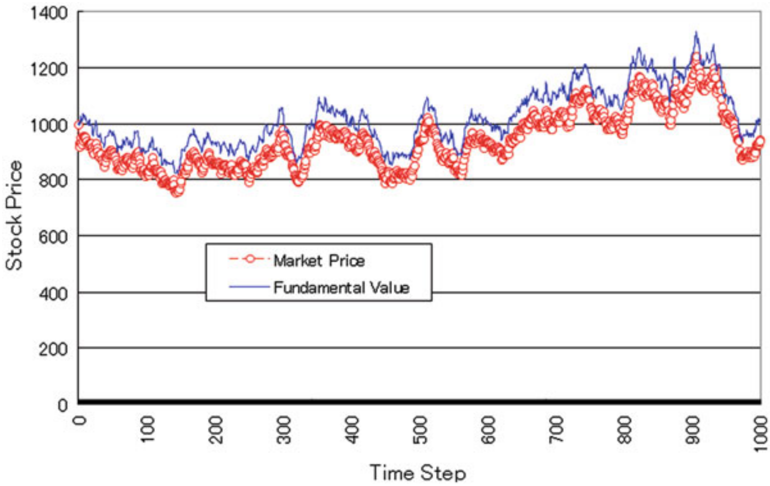


**Fig. 9.8** Price transition (passive investor, upper limit on tilting 3 %)

deviate from the fundamental value in a similar way to results produced when only fundamentalists exist in the market. Passive investors do not affect stock prices, so similar results may be seen. Figures 9.8 and 9.9 show price transitions when financial restrictions become more severe. Figure 9.8 shows the result when the upper limit on tilting is 3 %, and Fig. 9.9 shows the case of 1 %. Figures 9.8 and 9.9 suggest that as restrictions become more severe, the deviation of market prices from fundamental values becomes wider.

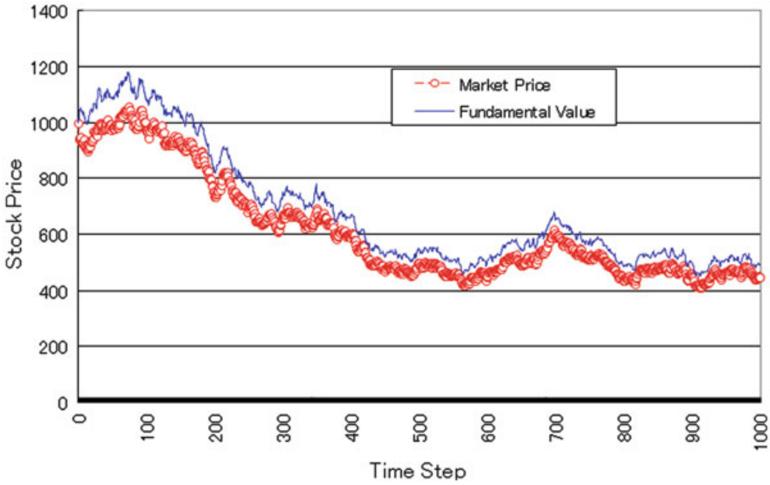


**Fig. 9.9** Price transition (passive investor, upper limit on tilting 1 %)

Figure 9.10 shows the transition of the number of investors when investors change their strategies according to past performance.[9] As time steps pass, the number of passive investors increases.[10] Figures 9.11 and 9.12 show transitions of the number of investors when financial restrictions become more severe. These transitions show that the number of passive investors increases under conditions of financial restriction. In traditional asset pricing theory, a passive investment strategy is regarded to be the most effective investment strategy under efficient market conditions. However, the results presented here suggest that a passive investment strategy is effective even when inefficient market conditions cause market prices to deviate from fundamental values. From both practical and academic viewpoints, this is an interesting development. A detailed analysis taking into account various kinds of investors is planned for the future.

### *9.3.3 Discussion*

A closer look at the transition of number of investors could find that as the financial restriction becomes more severe, the rate at which passive investors increases

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[9]Conditions where investors cannot go overweight more than 5 % against the benchmark weight are analyzed.

[10]At the 300th time step in Fig. 9.10, most investors in the market employ a passive investment strategy.

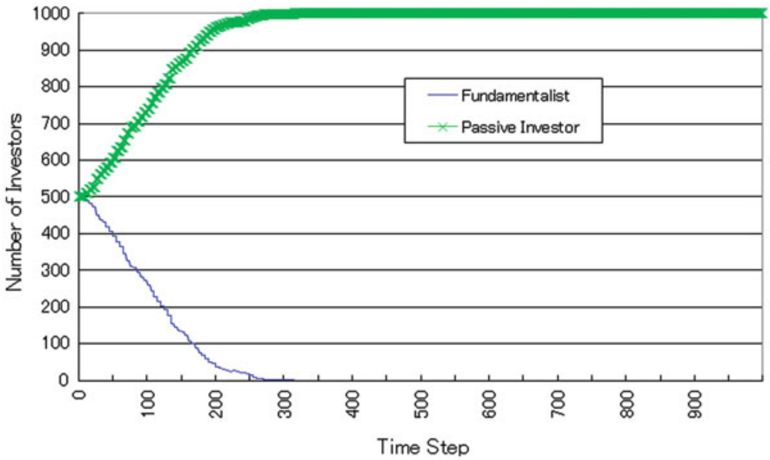


**Fig. 9.10** Transitions of number of investors (passive investor, upper limit on tilting 5 %)

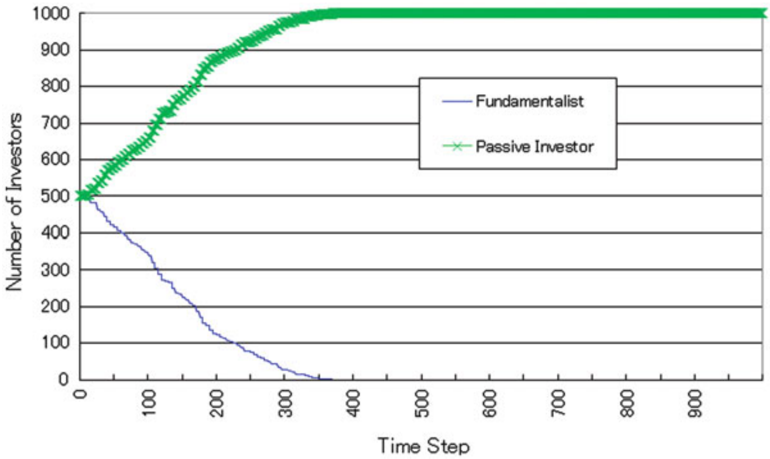


**Fig. 9.11** Transitions of number of investors (passive investor, upper limit on tilting 3 %)

becomes slower[11] (see Figs. 9.10, 9.11, and 9.12). Severe financial constraints contribute to the larger deviation of market prices from fundamental values. These results suggest that there could be a close relationship between the speed of the increase in the number of passive investors and the extent of the deviation of the market from fundamental values. A detailed analysis of this point is planned for

[11] Reduction of dispersion in investment behavior caused by the investment restrictions might be one factor. For an analysis of the influence of dispersion of fundamentalists' valuations, refer to Takahashi [29].

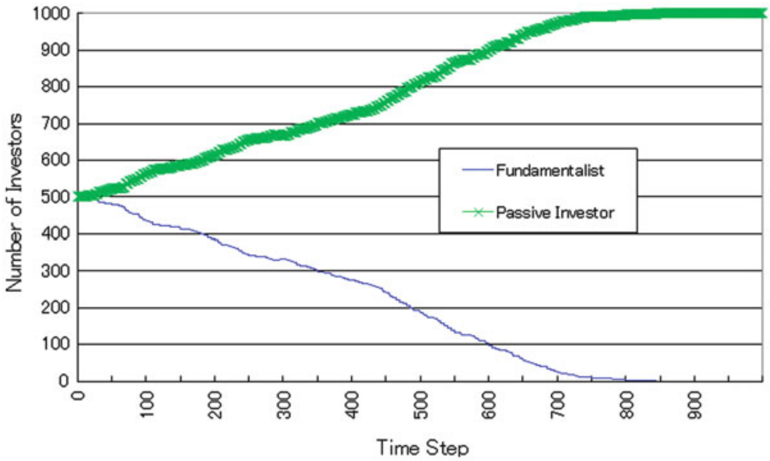


**Fig. 9.12** Transitions of number of investors (passive investor, upper limit on tilting 1 %)

a future paper. Agent-based modeling allows analyses to be conducted which can also take speed into account, and this could be an advantage. This chapter analyzes the market under conditions where financial restrictions don't change over time. However, in practical markets, market conditions will change over time. Future studies should focus on the impact of such changes.

## 9.4 Summary

This chapter examines the validity of passive investment strategies under financial constraints, utilizing agent-based modeling. As a result of intensive experimentation, I confirmed that a passive investment strategy is valid under conditions where market prices deviate widely from fundamental values. However, the rate at which passive investors increases becomes slower as the financial restriction becomes more severe. This conclusion is of interest in itself and merits further study. Future analyses will focus on examining the effect on markets of practical changes.

## Appendix: List of Parameters

This section lists the major parameters of the financial market designed for this chapter. The explanation and value for each parameter are given.

M: Number of investors (1,000)
N: Number of shares (1,000)

$F_t^i$: Total asset value of investor i for term t ($F_0^i = 2\,000$: common)
$W_t$: Ratio of stock in benchmark for term t ($W_0 = 0.5$)
$w_t^i$: Stock investment rate of investor i for term t ($w_0^i = 0.5$: common)
$y_t$: Profits generated during term t ($y_0 = 0.5$)
$\sigma_y$: Standard deviation of profit fluctuation ($0.2/\sqrt{200}$)
$\delta$: Discount rate for stock ($0.1/200$)
$\lambda$: Degree of investor risk aversion (1.25)
$\sigma_n$: Standard deviation of dispersion from short-term expected rate of return on shares (0.05)
$c$: Adjustment coefficient (0.01)

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# Chapter 10
# Macroeconomic Forecasting with Agent-Based Models: Prediction and Simulation of the Impact of Public Policies on SMEs

**Federico Pablo-Marti, Antonio Garcia-Tabuenca, Juan Luis Santos, Maria Teresa Gallo, Maria Teresa del Val, and Tomas Mancha**

**Abstract** The aim of this chapter is to show and discuss an integrated scheme of the MOSIPS project. This project, using an agent-based model methodology, focuses on simulating and evaluating policies for small and medium enterprises within a local environment. Its purpose is to conduct experiments on the implementation of policies according to different socio-economic scenarios. The results of these experiments allow stakeholders and citizens to know how the measures proposed by governments affect them and enable them to interact in the decision-making process. This perspective allows the analysis and implementation of the actions, interactions, and results between agents. At the micro-level, the model provides two main kinds of agents: individuals and firms, and some other entities: the public sector, the financial system, and the external sector. It also determines rules for actions and interactions. Simulations of variables and parameters lead to the analysis of the evolution and the forecast of the system at the macroeconomic level. The trajectories of the agents offer a dynamic standpoint that overcomes the standard equilibrium models.

**Keywords** Agent-based modeling • Policy evaluation • Prediction and simulation

## 10.1 Introduction

The traditional forecasting models assume that a representative agent—by maximizing its utility—solves a social problem with which it is faced. However, this neglects the fact that the economy is a complex and evolving system made up of diverse interacting agents [12]. Consequently, these models present major

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shortcomings and they fail to provide an overview of the phenomenon studied, as they are concerned with analyzing specific aspects of reality without factoring in the actions and interactions between the participating agents. Thus, these non-general models often include many endogenous aspects as fixed variables. Even those models provide an overview, such as the dynamic stochastic general equilibrium (DSGE) models, which refer to global rather than local areas and reveal further important constraints such as the non-inclusion of the heterogeneity of agents. These models include various types of individuals, but they do not capture individual differences [1]. Other limitations are the controversial assumptions of rationality and perfect information [8] or, from a macroeconomic point of view, difficulties in incorporating the endogenous emergence of crises into the analysis (Committee on Science and Technology [2]).

Additionally, the implementation of policies generally produces an impact that goes beyond the area of analysis considered (e.g., spillovers, side effects), and such impacts are not usually considered in the models or are only partially included.

These reasons justify the need to find a different approach that makes possible to study in detail and forecast the effects that economic policies have on the business sector [10].

Consequently, agent-based models (ABMs) have increased their importance in economics. In particular, the latest financial crisis was not predicted by standard macroeconomic models. Due to several of their assumptions, they were not able to represent the prediction of the significant deviation from the equilibrium growth path. By contrast, if the approach is bottom-up, starting with the specification of the agents involved in the economy, an emergent behavior of the system appears, one which cannot be explained from the behavior of the representative agent. This allows the appearance of "bubbles" followed by a sharp reduction in prices and a lowering of expectations. Multi-agent models have been used to study economic systems in several ways: there are examples of conceptual works on agent-based economic models, such as [11], while a variety of agent-based models focus on a part of the economy, for example, leverage effects in financial markets [6]. Multi-agent models of the economy as a whole are infrequent; examples are the models by Gintis [7], Dosi et al. [4], Mandel et al. [9], and the EURACE model [3].

The Modeling and Simulation of the Impact of Public Policies on SMEs (MOSIPS) project includes a number of features of the models previously referred to, but it represents the economy by placing the emphasis on the actions and interactions of two basic types of agents: individuals and firms (basically small and medium enterprises, SMEs), and also some other entities (the public sector, the financial system, and the external sector) participate in the process. Therefore, at the micro-level, the model provides these agents and entities. It also determines rules for actions and interactions. Simulation of the variables and parameters used leads to the analysis of the evolution and forecasting of the system at the macroeconomic level. The trajectories of the agents offer a dynamic standpoint that overcomes the standard equilibrium models.

The aim of this chapter then is to show and discuss an integrated scheme of the MOSIPS project. Using an ABM methodology, MOSIPS focuses on simulating and evaluating policies for SMEs within a local environment. It tries to conduct experiments on the implementation of policies according to different socio-economic scenarios. The results of these experiments allow stakeholders and citizens to know how the measures proposed by governments affect them and enable them to interact in the decision-making process by relying on first-hand information.

The structure of the chapter takes as a methodological guide the multi-agent Lagom regiO model [12] and includes a number of features of the multi-agent models, such as those of the Lagom family multi-agent model developed within the World Climate Forum. The second section provides an overview that includes the rationale of the model and the type of relationships that determine the interactions and activities developed by the agents. The third and fourth sections concern policy design in the MOSIPS model. Starting with the Small Business Act of the European Commission, we arrive at policy domains, which are implemented in every module of the model.The final section outlines the main conclusions.

## 10.2 Overview of the MOSIPS Model: An Agent-Based Model Able to Forecast Macroeconomic Behavior with Real Microfoundations

The aim of the model is to forecast the impact of public policies. It then depicts the economic reality of a region by focusing on how agents perform their activities, how they interrelate, and how policies have an impact on their decisions.

The MOSIPS system has four main kinds of agents and objects (see Fig. 10.1):

1. Establishments and firms are the key agents in MOSIPS systems. In fact, the model has been created to understand the effect of public policies, which take place in several ways, directly or indirectly, on individuals and firms. MOSIPS uses information related to the activity level of the agents, their surpluses, the location of their establishments, research and development investment, ownership, workers and competitors, and whether they cooperate with other firms.
2. Individuals and families. The aim of the MOSIPS system is not to simulate and predict the effects of public policies on these agents, although they are also computable. They are taken into account as a kind of agent as significant as firms, since they are the owners of the firms. These agents also play the role of workers, as well as final purchasers of goods and services produced by enterprises. They are located in the territory, both in their residence and their workplace, and they are interacting most of the time with a number of firms close to their location, and with some other individuals, such as their families or their work colleagues. The model uses information about how many there are, where they are located, where they work, who their relatives are, their level of education, their mobility patterns, and their income and expenses.

   In addition to these two basic types of agents, there appear other complementary entities for their activities, involved to a greater or lesser extent in the modeling process but which are pivotal in the composition of agents. These

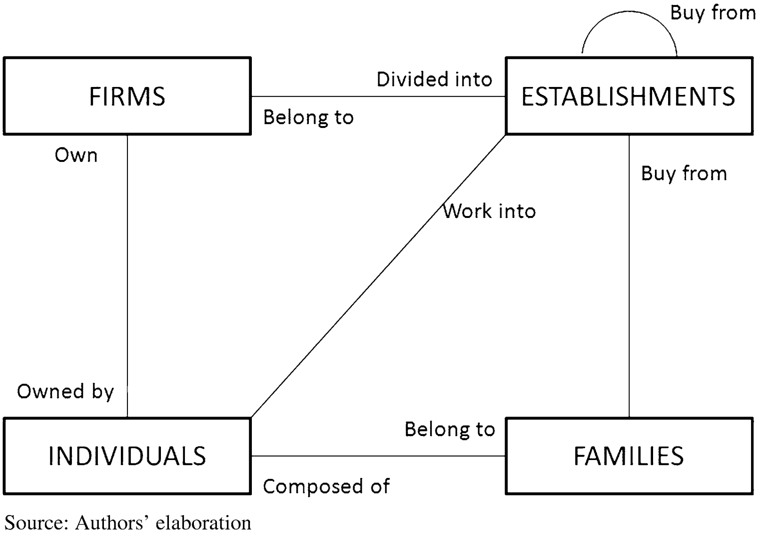


**Fig. 10.1** Main relations between agents. *Source*: authors' elaboration

entities do not make decisions directly in the process, but the evolution of their behaviors in time clearly impacts the creation of the expectations and decisions of firms and individuals. Specifically, these entities are the public sector, the financial system, and the external sector.

3. The macroeconomic environment and public policies have a lot of influence over the decisions of the individuals and enterprises. The model uses a large amount of macroeconomic information in order to create agents' expectations.
4. The raster of locations allows every agent to be located, and supports establishing the links between them in a more realistic way, compared to other possibilities that do not take location into account. Thus, families only demand goods and services near their residences and their workplaces; however, they often buy in other areas such as downtown. Individuals working far from their residences will tend to move either from their houses or from their jobs, as they tend to be dissatisfied. The degree of competition in an area and the density, among other factors, are determinants of price levels. The more items on location we consider in the model, the more faithful is the representation of a region.

The MOSIPS model represents the dynamics of behavior and decisions of agents, and their interactions. It forecasts the evolution of an economic system over a time horizon of one quarter to several years. It is based on a multi-agent approach at the microeconomic level. It can be used to model macroeconomic features of a system and permits economists to focus on a specific part of the economy, at the sector and spatial levels. Taking into account firms' and individuals' characteristics, the model evaluates the effects of policies at a local level over them. The main components included in the MOSIPS model are the following (see Fig. 10.2):

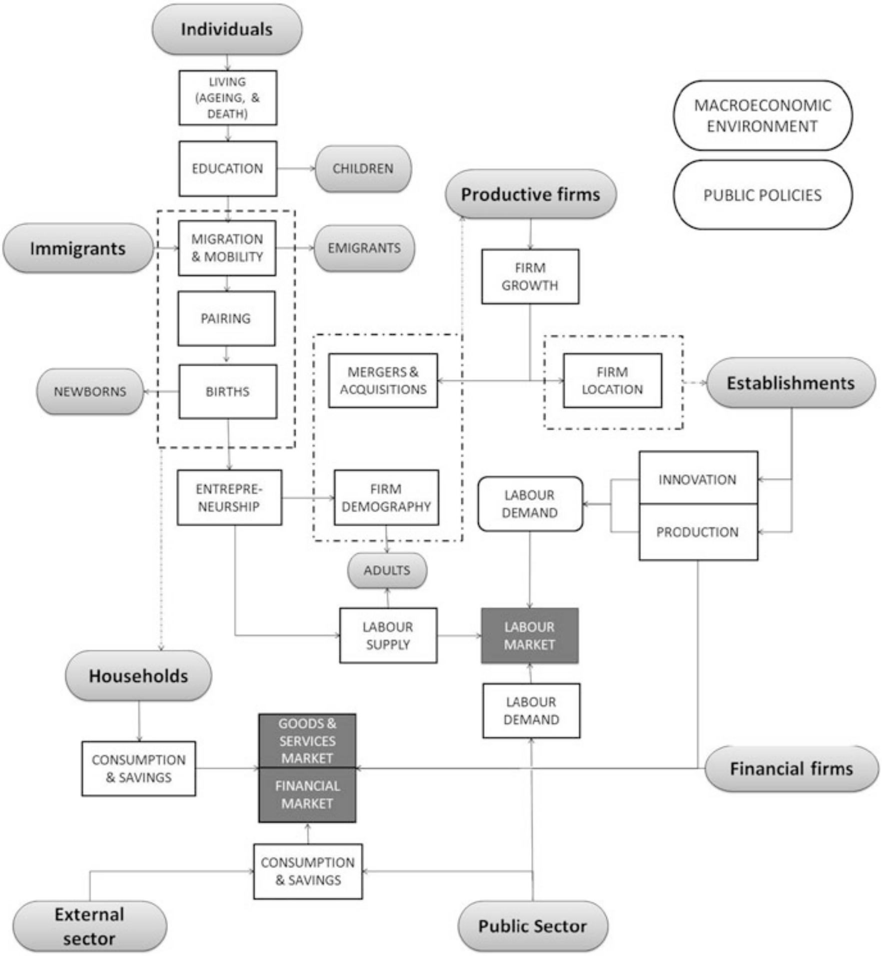


**Fig. 10.2** Main components included in the MOSIPS model. *Source*: authors' elaboration

(1) AGENTS have these properties: reactivity, proactivity, social skills, and autonomy. They are: (a) INDIVIDUALS: people in the place under study. (b) IMMIGRANTS: people arriving in period t, to the place under study. Both agents form (c) HOUSEHOLDS: groups of individuals of the same family living together. (d) PRODUCTIVE FIRMS, which are owned by individuals. (e) ESTABLISHMENTS are the places where firms develop their activity. (2) OTHER ENTITIES are present in the model: (a) FINANCIAL FIRMS play the principal role in facilitating funding to whichever agents require it. (b) The PUBLIC SECTOR represents the set of different authorities. (c) The EXTERNAL SECTOR is the aggregation of firms and individuals not located in the place under study.

Several actions taken by agents in period t have effects over other kinds of agents in the following period (indicated in the figure by a striped line)

There are three MARKETS where agents and other entities relate to each other: the labor, financial, and goods and services markets. Agents, other entities, and markets are affected by the MACROECONOMIC ENVIRONMENT and PUBLIC POLICIES.

## 10.3 Small Business Act and MOSIPS Policy Domains

The MOSIPS project takes the Small Business Act (SBA) (European Commission [5]) as the core area for policy investigation, analysis, and modeling. The SBA forms the "enabling framework" of the EU for improved SME performance and policy quality. It is the EU flagship SME policy initiative comprising ten principles that should guide the design and implementation of policies in the EU and its Member States. These principles, listed below, are central to the conceptual, theoretical, and empirical scope of MOSIPS. The SBA "aims to improve the overall policy approach to entrepreneurship, to irreversibly anchor the 'Think Small First' principle in policymaking from regulation to public service, and to promote SMEs' growth by helping them tackle the remaining problems which hamper their development" [5].

1. Create an environment in which entrepreneurs and family businesses can thrive and entrepreneurship is rewarded.
2. Ensure that honest entrepreneurs who have faced bankruptcy quickly get a second chance.
3. Design rules according to the "Think Small First" principle.
4. Make public administrations responsive to SMEs' needs.
5. Adapt public policy tools to SME needs: facilitate SMEs' participation in public procurement and better use State Aid possibilities for SMEs.
6. Facilitate SMEs' access to finance and develop a legal and business environment supportive to timely payments in commercial transactions.
7. Help SMEs to benefit more from the opportunities offered by the Single Market.
8. Promote the upgrading of skills in SMEs and all forms of innovation.
9. Enable SMEs to turn environmental challenges into opportunities.
10. Encourage and support SMEs to benefit from the growth of markets.

Figure 10.3 provides a diagrammatic view of the principles presented as an SME "Policy Radar". The "Radar" represents the composite performance assessment of all EU Member States, according to the ten principles. We can see an example based on the real evolution of two European countries. On the basis of this analysis we can assess issues of scalability and contribution to European standards. In the context of analysis that moves from the "specific" to the "generic" we can illustrate the final impact of the project SME policy simulation that allows forecasting and visualization of the socio-economic impact of public policies.

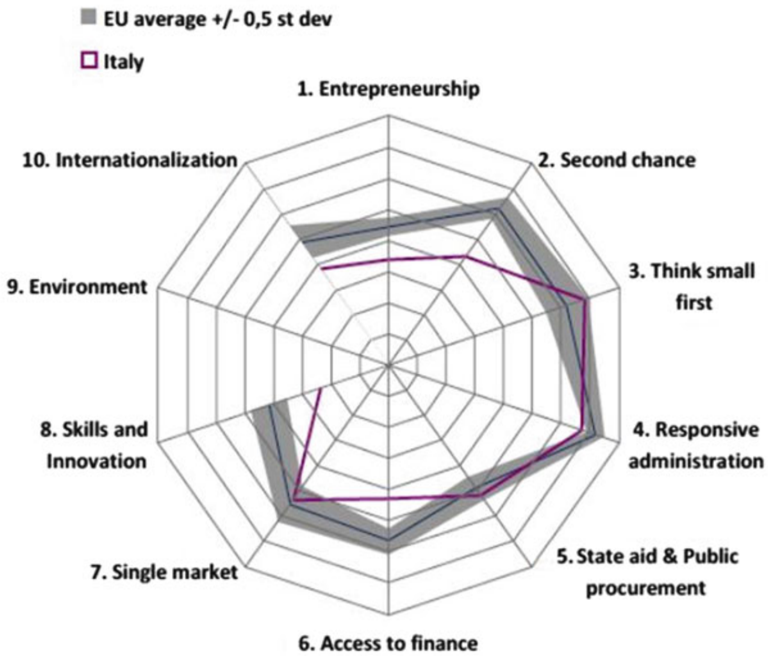


**Fig. 10.3** Policy radar for Italy. *Source*: European Commission [5]

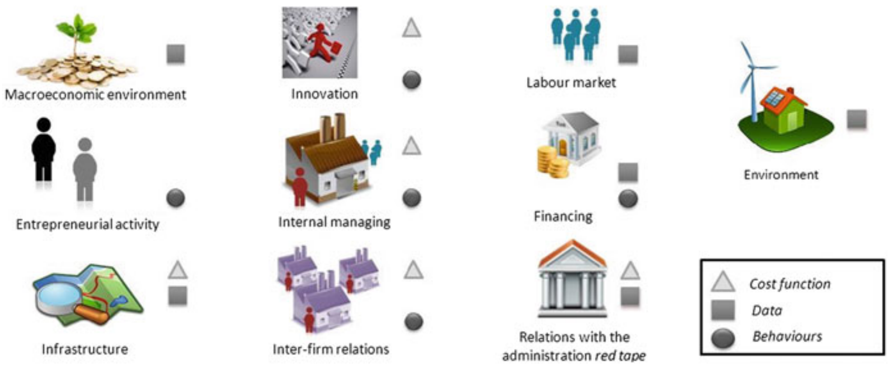


**Fig. 10.4** MOSIPS policy domains

The ten principles outlined in the policy radar have their counterparts in the principles of the model. However, these principles cannot be directly implemented in the model as input policies. Thus, there is a need to map selected SBA policies to policy domains.

We identify the following ten policy domains according to the rationale of the MOSIPS model (see Fig. 10.4). The purpose of this categorization is to include all the possible different areas in which policies on SMEs can be undertaken.

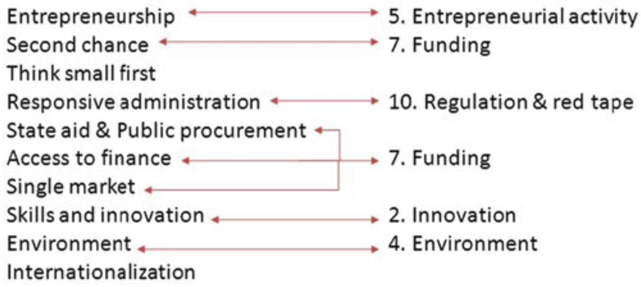


**Fig. 10.5** Conversion of the SBA principles into functional domains

Moreover, this can be translated to the principles presented by the SBA developed by the European Commission, strengthening the project by demonstrating a strong "rationale" behind the presented categorization.

This approach makes it possible to provide aggregate results easily understandable by policymakers, public administrators, and citizens. In addition, every policy can be integrated in the system only in a specific manner, thereby avoiding errors in the inclusion. It is possible to identify many public policies that directly or indirectly affect SMEs. This fact makes it almost impossible to develop a model that allows each policy to be specified individually. To solve this problem we classify public policies into several groups that cover all the possibilities, but not so many that one would tend to include a policy in several groups.

The model permits the study of almost any policy implemented by the public administration which has effects on SMEs, not only those designed specifically to encourage business activity. All the principles included in the SBA have been taken into account and turned into a concrete set of policy domains. The model then allows the inclusion of any policy related to entrepreneurial activity, infrastructure, innovation, internal managing, inter-firm relations, labor market, funding, and relations with the administration and macroeconomic environment such as changes in taxation or trade restrictions.

These policy domains can affect agents in three different ways: They can change their cost function, their characteristics (data), or their behavior. They affect the performance, development, and decay of every industrial district present in the economy, as well as the processes undertaken among the components of the district such as cooperation, competition, innovation, and knowledge dissemination.

Every policy domain can affect agents in many ways. Thus, the effect of a policy included in the model can affect several of the modules indicated in Fig. 10.2. Every policy included can have a dispersive effect on many agents, or focus on a small number with specific characteristics. The effects of policies are extended throughout the system over time, and even policies that are in principle outside the industrial districts may have a far-reaching impact on them.

Thus, the effect of public policies on SMEs, in accordance with the ten principles of the European SBA, is included in the previously presented categorization (Fig. 10.5). Those principles are connected to MOSIPS policy fields as follows:

However, two of the principles are not directly connected to each other. Firstly, the single market is a principle more closely related to rules of standardization. It is then linked somehow, but not exclusively, to innovation. Indirectly, it will also be part of financing (financial support to standardization) because the public sector has to expend financial resources for its correct implementation. Secondly, internationalization is included in two different domains: inter-firm relations and internal management. The first of these encompasses the importance of business relationships (e.g., temporary joint ventures, chamber of commerce memberships). The second takes into account the importance of the decision to internationalize the enterprise undertaken by the entrepreneur.

## 10.4 Policy Design in the MOSIPS Model

To show how these ten policy domains are included in the model, we present one of the modules of the MOSIPS model: firm demography (see Fig. 10.2 to view the position in the model). After adults decide to become entrepreneurs, or they continue being entrepreneurs, they are asked whether they have any firms, or if they want to open or close one, and if the answer is affirmative, the system determines whether the firms finally open, that is, whether licenses and funding are obtained. The answers to these questions determine the firm's demographics, as all the main decisions taken by firms are made by the owners or the managers. In the firm demographics module four policy domains are included: The macroeconomic environment affects the decision to start a new firm through expectations about its success, and if the entrepreneur wants to create a firm, has effects on the determination of its characteristics (sector, size, location, etc.). The labor market has effects on the decision to open a new business. Strong labor regulation could discourage the entrepreneur, whereas if there are public subsidies for contracting new employees or becoming self-employed the entrepreneur will decide to open a new firm. Funding is present in the determination of funding possibilities for new potential firms and in the evaluation of the performance of current firms (Fig. 10.6). Regulation and red tape have three different effects on company demographics:

1. They are the principal obstacle to overcome to open a new firm.
2. They affect the characteristics of new firms, as public administrations discourage or even forbid some sectors and locations.
3. Red tape and regulation also affect the current operation of firms, having effects on their profitability in many ways.

The algorithmic implementation of this module is the following:

**1. Does the entrepreneur have a firm?**

Business people skip steps 2–4. If they decide to create another firm they go back to step 2. By contrast, every entrepreneur goes directly to step 2.

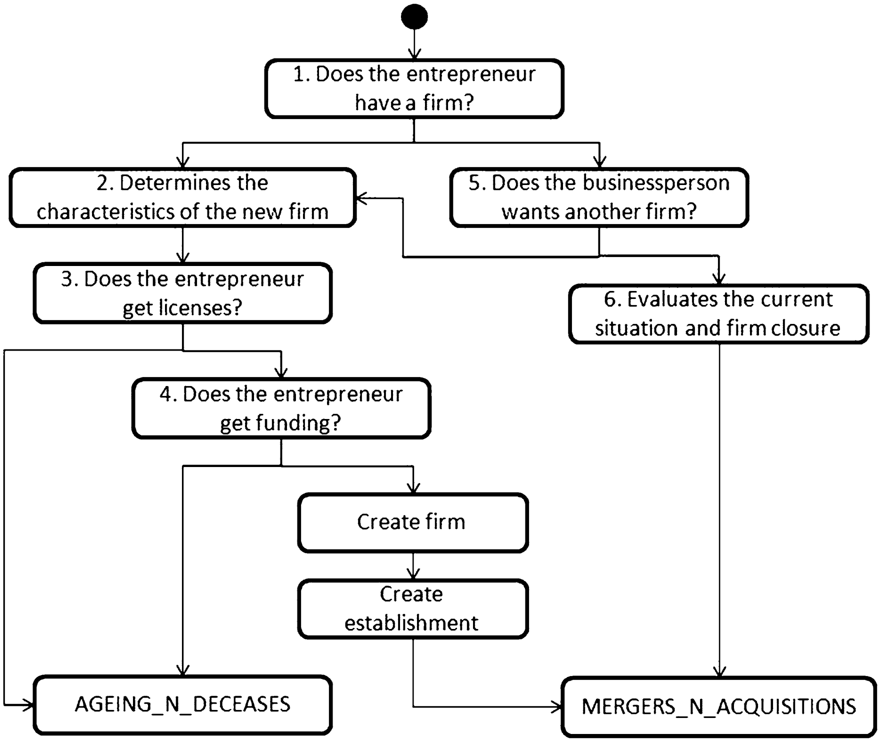


**Fig. 10.6** Firm demographics. *Source*: authors' elaboration

If $ENTREPRENEUR = 2$ and the individual is linked to at least one firm, then go to step 5. Otherwise go to step 2.

**2. Determine the characteristics of the new firm**

All entrepreneurs without a firm want to create a new one. If they don't do so it is because they are not able to, for several reasons. Thus, entrepreneurs are defined by the fact that they want to have a firm, if they do not yet have one. In order to be able to create one they have to define their project by determining the size, the sector, and net capital requirements.
Firstly, the entrepreneur chooses the sector. At the regional level there is computed
For all sectors
For all firms

$$SECTOR.EXPECT = \sum \frac{FIRM.PROFIT/TOTAL.ASSETS}{SECTOR.FIRMS} \quad (10.1)$$

Every individual assigns expected utility values to every sector according to:

$$SECTOR.OPT = \beta_{75} \times SECTOR.EXPECT + \beta_{76} \times SECT.RATE.CREAT \quad (10.2)$$

However, individuals have fuzzy rationality, and they will not always choose the best choice. $\beta_{77}$ times they choose the best one, i.e., the one with the highest *SECTOR.OPT*, $\beta_{78}$ times they choose the second best one, and $1 - \beta_{77} - \beta_{78}$ times they choose a random option, where

$$\beta_{77} = \frac{\beta_{79} \times ENTREP.FAM + \beta_{80} \times ENTREP.PAST}{\beta_{81} \times EDUC.LEV.2 + \beta_{82} \times (AGE - \beta_{83})} \quad (10.3)$$

$$\beta_{78} = \frac{\beta_{84} \times ENTREP.FAM + \beta_{85} \times ENTREP.PAST}{\beta_{86} \times EDUC.LEV.2 + \beta_{87} \times (AGE - \beta_{88})} \quad (10.4)$$

After choosing the sector the entrepreneur chooses the desired size of the new company according to successful firms created in the sector in the preceding period. The entrepreneur knows a higher initial size means a greater probability of success once the firm is created, but a lower chance of creating it; thus he tries to create slightly bigger companies than those created in the preceding period, on average terms following a normal distribution.

$$WF.FIRM = N(\beta_{89} \times SECTOR.AVE.SIZE, \beta_{90} \times SECTOR.SD.SIZE) \quad (10.5)$$

$$\text{If} \quad WF.FIRM < \min(\beta_{91} SECTOR.AVE.SIZE, 1) \quad (10.6)$$

Extract a new value of the normal distribution. According to the extracted value for the establishment size, the entrepreneur asks for licenses. Go to step 3.

**3. Does the entrepreneur get licenses?**

The importance of the red tape costs is made explicit by including a cost, which is monetary but also includes terms of time and effort, which is an important aspect of the policies directed at SMEs. This lag depends on the sector and size of the company.

$$\text{If} \quad (\beta_{92} \times LICENSE.EAS \times WORKFORCE.FIRM) < RNDM(0, 1) \quad (10.7)$$

The process ends. Otherwise go to step 4.

**4. Does the entrepreneur get funding? The entrepreneur creates the firm**

When entrepreneurs' financing capacity is lower than the capital requirements, they try to obtain funding. Thus, entrepreneurs are linked to the finance market. If they do not obtain the required funds, the process ends. After computing the size of the firm the entrepreneur chooses which part of the funding should proceed from his or her personal wealth and which should be obtained in the financial market.

$$INIT.LOAN = \max(WF.FIRM \times (AVE.WAGE.SECT - \beta_{93} \times WEALTH), 0) \quad (10.8)$$

$$LOAN.NEC = INIT.LOAN - \beta 93 PUBLIC.GRANTS \quad (10.9)$$

$$\text{If} \quad FIN.RISK = \frac{\beta_{94} \times WF.FIRM}{\beta_{95} \times LOAN.NEC} > \beta_{96} \times AVE.FIN.RISK.SECT \quad (10.10)$$

The end for this individual
Else

$$DEBT.FIRM = LOAN.NEC \quad (10.11)$$

$$TOTAL.ASSETS = INIT.LOAN \quad (10.12)$$

Create a firm and assign the property to the owner. Delete labor relation if any. Create an establishment.

**5. Evaluate whether the business person wants another firm**

The business person wants to create other firms if she observes that the entrepreneurial activity is profitable, although her firms are not obtaining adequate results, basically because they are not located in the correct sector. If the *PROFIT.SECTOR* of at least one sector is higher than the one defined by the expression $FIRM.PROFIT/TOTAL.ASSETS$ in every one of the entrepreneur's firms, then with Probability $= RNDM(0, 1)^2$ return to step 2.

**6. Evaluate the current situation and firm closure**

The entrepreneur assesses the current situation of each and every one of his firms and closes the firms with no employees (the $WF.FIRM = 0$ in all of the establishments) and those that appear to be non-viable in the future.
If $FIRM.PERFORM = 0$ and if $FIRM.AGE > 4$ and $WF.FIRM = 1$
Increase *NSDN.FIN.SUP* by $TOTAL.ASSETS - DEBT.FIRM$
Delete the establishment
The firm is closed.
Erase ownership and labor relation between the owner and the firm and establishment, respectively.
If the entrepreneur has no firms left after the last closing:
$ENTREPRENEUR = 1$
$LABOR.PERIODS = 0$
$FAILURE = 1$
$LABOR = 2$

## 10.5 Conclusions

The MOSIPS model is an agent-based model (ABM) which consists of a set of agents (firms/establishment and individual/households) with their own attributes which interact with each other according to a set of broadly defined appropriate rules. Although the scope of application of this model is wide, the main simulation object is the impact of public policies on small and medium enterprises (SMEs) from a bottom-up approach.

This kind of model makes it possible to tackle the analysis of complex phenomena, capturing complex processes not fully described by traditional techniques. The nucleus is the agent, instead of the whole system. The model also explicitly considers and models the heterogeneity of agents, and their social interactions and decision-making processes. The interaction between agents is nonlinear, and they can adapt, learn, evolve, and even develop some self-organization mechanisms that allow them to collectively acquire properties or characteristics that they do not have individually. Consequently, there will be outcomes arising from the interactions among agents and between agents and the environment in which they operate. In other words, aggregate macroeconomic results will emerge from the behavior of individuals who take part in these complex environments.

The MOSIPS building blocks include the agents' population and other entities, the interaction paradigm among agents, the activities the agents develop as well as their adaptive capability (i.e., the degree of reactivity and proactivity), and finally the object of the simulation, namely the impact of public policies on SMEs. A number of advantages may be highlighted from the application of the proposed ABM.

- Traditional approaches give a partial view of economic reality and are broadly used to evaluate and predict the effects of policies, which, even though they offer a global sphere of analysis, scarcely take into account the heterogeneity of agents. In contrast, the model offers the possibility of analyzing in depth the effects of public policies on SMEs from a bottom-up approach. Thus there is the possibility of dealing with "what if" questions that allow focusing on those aspects in which policies may produce the most important impacts.
- The model permits a virtual reality to be implemented with its features to simulate and forecast different scenarios. The users define the values of a set of variables to evaluate the effects of the alternative decisions.
- The highly detail information derived from the agents' behavior, their interactions, their decision rules, and the impact of the environment allow the characteristics of a more complex system to be dealt with. Heterogeneous, autonomous, reactive, and proactive agents with bounded rationality are at the base of the logical operation of the model.
- The MOSIPS project takes the Small Business Act (SBA) (European Commission [5]) as the core area for policy investigation, analysis, and modeling. A list of ten policy domains is consequently defined, including all the different possible areas in which policies on SMEs can be performed.

- These policy domains can be translated to the principles presented by the SBA and developed by the European Commission, demonstrating a strong "rationale" behind the categorization presented. The nature of these policy domains also allows one to deal appropriately with specific interventions as they focus on changes in the cost functions, data, and behaviors of the agents.

## Appendix: Parameters and Variables in Firm Demographics

See Tables 10.1 and 10.2.

**Table 10.1** Estimated value of parameters

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| 75 | 0.668 | 86 | 1.018 |
| 76 | 0.372 | 87 | 1.06 |
| 77 | n/a | 88 | 34.8 |
| 78 | n/a | 89 | 0.85 |
| 79 | 1.013 | 90 | 0.234 |
| 80 | 36.3 | 91 | 0.609 |
| 81 | 0.172 | 92 | 1.275 |
| 82 | 1.003 | 93 | 3.026 |
| 83 | 36.3 | 94 | 1.024 |
| 84 | 1.03 | 95 | 2.985 |
| 85 | 1.088 | 96 | 1.85 |

Estimations for Madrid (Spain)

**Table 10.2** Description of variables

| Variable | Definition | Type | Object | Original data |
|---|---|---|---|---|
| Educ.level.2 | 1 if higher education | B (i,t) | Individual | Census |
| Entrep.past | 1 if the individual was entrepreneur in the past | B (i,t) | Individual | GEM |
| Entrepreneur | 1 if the individual does not have firms, but wants to create one. 2 if the individual owns firms. | N (i,t) | Individual | GEM |
| Failure | 1 if one of the firms of the entrepreneur failed in the past | B (i,t) | Individual | GEM |
| Labor | Labor status of the individual: 1 if age less than 16, 2 if unemployed, 3 if employed, 4 if inactive | N (i,t) | Individual | LFS |
| Labor.periods | Number of periods since the last change in labor value | N (i,t) | Individual | LFS |
| Wealth | Total net wealth of the individual | N (i,t) | Individual | ITP |
| Entrep.fam | At least one individual of the family is entrepreneur | B (i,t) | Family | GEM |
| Debt.firm | Firm debt | N (f,t) | Firm | Amadeus |
| Fin.risk | A higher number shows a lower probability of repaying the debt | R+ (f,t) | Firm | Funding Stats |
| Firm.age | Number of periods in which the firm is active | N (f,t) | Firm | Amadeus |
| Firm.perform | 2 if the firm is one of the first decile, 0 if the firm has losses and 1 otherwise | N (f,t) | Firm | Amadeus |
| Firm.profit | Amount of money earned by the firm | N (f,t) | Firm | Amadeus |
| Init.loan | Initial loan of the firm | N (f) | Firm | Free parameter |

(continued)

**Table 10.2** (continued)

| Variable | Definition | Type | Object | Original data |
|---|---|---|---|---|
| Loan.nec | Loan needed to start a new firm | N (f) | Firm | Free parameter |
| Public.grants | Public grants for the creation of new firms | N (f,t) | Firm | Free parameter |
| Total.assets | Total assets of the establishment | N (f,t) | Firm | Amadeus |
| Wf.firm | Number of employees of the establishments in the current period | N(f,t) | Firm | Amadeus |
| Ave.fin.risk.sect | Average financial risk | R (s,t) | Sector | Free parameter |
| Ave.wage.sect | Average wage for workers | N (s,t) | Sector | Free parameter |
| License.eas | Ease of opening a new firm | Cod (s) | Sector | Free parameter |
| Profit.sector | Average profit in the sector | R (s,t) | Sector | Free parameter |
| Sector.ave.size | Average workforce of the establishments in the sector | R (s,t) | Sector | Free parameter |
| Sector.expect | Average profit of the firms in the sector | R (b,t) | Sector | Free parameter |
| Sector.firms | Number of firms | N (s,t) | Sector | Amadeus |
| Sector.opt | Sector attractiveness | R (s,t) | Sector | Free parameter |
| Sect.rate.creat | Sector rate creation | R (s,t) | Sector | Free parameter |
| Sector.sd.size | New firms' distribution standard deviation size | R (s,t) | Sector | Free parameter |
| Nsdn.fin.sup | Total financial supply | N (v,t) | Environ. | Free parameter |

*GEM* Global Entrepreneurship Monitor, *LFS* Labour Force Survey, *ITP* Income Tax Panel

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# Chapter 11
# Influence of the Corporation Tax Rate on GDP in an Agent-Based Artificial Economic System

**Shigeaki Ogibayashi and Kousei Takashima**

**Abstract** An agent-based model of an artificial economic system, including the government, was developed on the basis of the authors' previous model. This model was used to analyze the factors influencing the relationship between GDP and the corporation tax rate and its mechanism. The findings show that executive compensation and the use of producers' own cash for investment are both indispensable factors for reproducing the negative correlation between GDP and the corporation tax rate, because these actions help redistribute the firm's surplus money to the market. Inefficiency in government expenditure is another indispensable condition. The calculated average multipliers for the reduction of both income tax and corporation tax are in good agreement with real data based on the macroeconometric model.

**Keywords** Agent-based computational economics • Corporation tax • Expenditure policy • GDP • Government • Income tax • Tax rate

## 11.1 Introduction

Agent-based modeling (ABM), used to explain or understand social phenomena via a bottom-up approach, is widely used in social simulations [1, 2]. An important feature of ABM is that, once you have designed a computer program that mimics the desired characteristics of the system in question, you can use it to perform controlled experiments, varying one factor at a time while keeping the others constant [3, 4]. Therefore, ABM provides a new way to understand the behavioral mechanisms of

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complex macroeconomic systems. A potential area for the application of ABM in the real world is government policy formulation in areas such as tax reduction, public spending, and quantitative monetary relaxation [5, 6].

From a practical application perspective, a model developer should ensure that the model is as simple as possible [1] while still considering all important factors required to reproduce the desired phenomena. The factors that need to be incorporated into the model differ according to the phenomena to be reproduced in the real system. In other words, macroeconomic mechanisms can be explained and interpreted by a series of computer experiments in which one constituent factor of the model is changed at a time, with other factors being held constant.

A number of ABM-based research studies have focused on various macroeconomic aspects, such as business cycles, innovation, economic growth, the role of banks, monetary policies, industrial dynamics, and wealth inequality [5–10]. Most of these studies reported some new findings, but the way in which they constructed their models was different in each case. This made it difficult to identify the crucial assumptions of the models, and to what extent these assumptions were important in reproducing the concerned phenomena. Many researchers have also developed practical models that aim to simulate multiple-market economic structures as elaborately as possible [11, 12]. However, given the nature of these economic phenomena, these studies have often not fully clarified the structural factors of the model that are important for their reproducibility.

Considering this limitation, we have constructed a simple, artificial economic model consisting of consumers, three types of producers, and a bank. This simple model was able to reproduce fundamental economic behavior, such as a loose equilibrium in price, a business cycle affected by capital investment, and the influence of money supply on gross domestic product (GDP) [13]. We also extended this model to include government policy to analyze the influence of the tax rate on GDP [14]. While the basic model failed to reproduce the positive influence of a corporate tax reduction on GDP, the extended model clearly reproduced the positive influence of an income tax reduction on GDP. The fact that some factors essential to the corporate tax effect on GDP were not considered in the basic model probably accounts for this result. We also conducted a preliminary comparison of our results with the econometric model estimates of the Japanese government. This comparison suggested that the positive tax reduction effect was most likely reproduced because of the following factors: the unemployment rate, executive compensation, use of internal funds for investment, and purchase of both consumption and durable goods by retailers.

In the present study, the revised model is employed to consider the preceding factors and to examine their influence on the tax rate-GDP relationship. We analyzed each factor individually to identify those most responsible for the reproducibility of the negative tax rate-GDP relationship. According to our results, the redistribution of a firm's surplus money to the market and inefficiency in government expenditure are both indispensable conditions to the reproducibility of actual phenomena under a balanced-budget condition.

## 11.2 Simulation Model

### *11.2.1 Outline of Model*

The ABM of an artificial economic system in this study comprises consumers, producers, a bank, and a government as autonomous decision-making agents. It is assumed that consumers are divided into three types of agents: workers, executives, and public workers. They work for one of the other agent types, receive wages, pay taxes, and buy consumption goods at the cheapest price available in the market. Moreover, producers are assumed to hire consumers, produce and sell products, and pay wages and taxes. They are divided into three types of agents: retailers, who produce and supply consumption goods for consumers; raw material makers, who produce and supply raw materials for retailers; and an equipment maker, who supplies equipment for production for other types of producers. The bank keeps the surplus money of other agents in their respective bank accounts and lends money to producers. The government collects taxes from other agents, pays wages to public workers, and spends the remaining money on public expenditure. They are heterogeneous agents, who interact with others in the economic activities. Heterogeneities of agents are characterized by state variables and other parameters included in their action rules.

### *11.2.2 Sequence of Actions*

The set of actions for each agent comprises period-based units, where one period is assumed to correspond to 1 month in the real system. During each period, agents act and interact with each other according to a sequence of seven steps. At the end of the seventh step, a GDP value is calculated for each period. This value is based on an input-output table in the artificial system, which is calculated by summing the account data for all agents obtained at the beginning of the seventh step. The sequence of the agents' actions is as follows:

1. Agents pay unpaid tax for the previous period at the beginning of the current period. After paying tax, agents create a budget for consumption, paying wages, or public spending.
2. Raw material makers decide the amount and price of products to be produced, produce several types of raw materials, and supply them to the material goods market.
3. Retailers decide the amount and price of products to be produced, purchase raw materials in the material goods market, produce several types of consumption goods, and supply those products to the consumption goods market.
4. Consumers and the government purchase products in the consumption goods market.

5. Retailers and raw material makers decide the necessity of increasing production capacity on the basis of total sales in previous periods and, if necessary, invest in equipment or employ new workers.
6. Each firm pays wages to employees and executive compensation for executives, and the government pays wages to public workers.
7. Each agent settles its accounts using the double-entry bookkeeping method, where the income or profits for the current term are calculated, based on which the amount of tax to be paid is determined as an unpaid tax. In addition, if necessary, each retailer dismisses a worker, or decides to stop production.

The next section describes the rules each agent follows when making a decision.

## *11.2.3 Outline of Agents' Decision-Making Rules*

### 11.2.3.1 Rules for Consumers

Consumers create a budget for consumption $E_b^t$. This budget is defined as the sum of part of their income $I^t$, defined according to the Keynesian consumption function [15] and a withdrawal ratio of $r_{wd}$ times the bank deposit $D^t$ at each fiscal period $t$. The formula for the budget is shown in Eq. (11.1), where $r_{i\_tax}$ is the income tax rate, $a$ is the consumer's basic consumption, and $b$ is the marginal propensity to consume according to the Keynesian consumption function. The withdrawal ratio $r_{wd}$ is set as a random value for each agent.

$$E_b^t = a + bI^t(1 - r_{i-tax}) + r_{wd}^t D^t \ , \tag{11.1}$$

When purchasing products in the consumption market, consumers select and purchase products within the limit of their consumption budget according to the utility function for each class of products given by Eq. (11.2). In Eq. (11.2), $\xi_i$ is the number of products purchased for product class $i$, and $\delta_i$ is the weight of the utility. The latter weight is randomly assigned for each agent and each product class $i$. When there are goods of the same class available in the market at different prices, consumers select and purchase the cheapest available. The value of $\xi$ is reset and returns to 0 at the beginning of the next period.

$$\begin{aligned} utility_i &= \delta_i \times u(\xi) \\ u(\xi) &= 1, 0.5, 0.2, 0 \ldots if\ \xi_i = 0, 1, 2, 3, \ldots \end{aligned} \tag{11.2}$$

### 11.2.3.2 Rules for Producers

The retailers and raw material makers decide on the amount and price of the products they will produce. The price of a product of product class $i$ for period

$t$, $p_i^t$, is determined on the basis of the amount of goods in stock at the end of the previous period, $s^{t-1}$, as shown in Eq. (11.4). Here, $p_{ave}$ is the average price of the products sold during the previous period, and $\gamma_i$ and $\gamma_d$ are the ratios of increasing or decreasing price. When the estimated price is lower than the running cost per product, the minimum price is set to be the running cost.

$$p_i^t = \begin{cases} (1+\gamma_i)p_i^{t-1} & if \quad s_i^{t-1} = 0 \\ p_{avei}^{t-1} & if \quad s_i^{t-1} > 0 \;\; and \;\; p_i^{t-1} > p_{avei}^{t-1} \\ (1-\gamma_d)p_i^{t-1} & if \quad s_i^{t-1} > 0 \;\; and \;\; p_i^{t-1} < p_{avei}^{t-1} \end{cases} \tag{11.3}$$

The amount of production is decided in such a way that the probability of being out of stock is less than 5%. This is estimated on the basis of the total sales during the most recent ten periods. If the estimated amount of production is less than 70% of the production capacity, this latter value is set as the minimum amount of production. The production capacity $Y$ is defined by a Cobb-Douglas-type production function [15], as shown in Eq. (11.5). Here, $K$ is the number of units of equipment for production, $L$ is the number of employees, and $\alpha$ is assumed to be 0.25. In addition, $A$ is a proportionality constant randomly assigned to each producer between a lower and an upper limit. It is assumed that this value is peculiar to each producer and represents that producer's technical capability.

$$Y_i(K, L) = A_i K^{\alpha} L^{1-\alpha} \tag{11.4}$$

Retailers and raw material makers initially have one unit of equipment and a specified number of employees. They can decide to invest to increase their production capacity by increasing either the number of units of equipment or the number of employees. First, they check whether full capacity production has continued for more than a critical number of periods. Full capacity production is fulfilled when all products produced at maximum production capacity are sold within a period. Assuming full production capacity has continued beyond the critical number of periods, they calculate their expected profit using both Eqs. (11.6) and (11.8). When the profit calculated from Eq. (11.6) is greater than that of Eq. (11.8), they decide to increase the number of units of equipment. If the profit from Eq. (11.8) is the greater of the two, they decide to increase the number of employees. In addition, in Eq. (11.6), it is assumed that the depreciation period of the equipment is the same as the repayment period. Here, $p$ is the price of the product, $c$ is the variable cost per product, $r_0$ is the borrowing interest rate, $F$ is the total amount required to buy one unit of equipment, $N$ is the repayment period, and $w$ is the fixed wage per employee.

$$\Delta\pi_K = \max_i[(p_i^t - c_i^t)\{Y_i(K+1, L) - Y_i(K, L)\} - (r_0 + 1/N)F] \tag{11.5}$$

$$\Delta\pi_L = \max_i[(p_i^t - c_i^t)\{Y_i(K, L+1) - Y_i(K, L)\} - w] \tag{11.6}$$

In the case of investing in equipment, half of the necessary funding is financed by the bank and half is financed by the firm's internal funds. The funds borrowed from the bank are repaid as a fixed amount in each period and for a constant number of consecutive repayment periods. During the repayment periods, additional investment is not allowed when the total number of investments exceeds a certain upper limit. In the case of investment in equipment, half of necessary fund is financed by the bank and half is financed by the firm's internal funds. The funds for investment financed by the bank are constantly repaid in each period for a constant number of consecutive repayment periods. During the repayment periods, additional investment is no longer allowed when the total number of investments exceeds a certain upper limit. In the case of hiring additional employees, the producer advertises the vacant position and announces the fixed wage details in the labor market. The unemployed apply for a job with the company that offers the highest fixed wage in the labor market. Then, the producer randomly selects one of the applicants. The equipment maker produces equipment, within its production capacity limit, as required by the retailers and raw material makers. In this study, the price of equipment is assumed to be constant.

One executive and several workers are assigned to each of the producer agents. The producers pay a wage to workers and executive compensation to the executive in each period. Wages comprise a fixed salary, randomly assigned to each employee between a lower and an upper limit, and a bonus given when the producer's profit is positive. The total expenditure on wages for each producer $E_w^t$ is described by Eq. (11.9), where $W_f$ is the total amount paid as fixed salaries, $W_b^t$ is the total amount paid as bonuses, $EC^t$ is the amount paid as executive compensation, $\pi^t$ is the profit before tax, and $AC^t$ is accumulated earnings. In addition, $W_b^t$ is defined as $r_b\pi^t$, where $r_b$ is the bonus ratio, and $EC^t$ is defined as $\pi^t(1-r_b)(1-r_{c-tax}r_e)$, where $r_{c\_tax}$ is the corporation tax rate and $r_e$ is the executive compensation ratio.

$$E_w^t = \begin{cases} W_f & if \quad \pi^t < 0 \\ W_f + W_b^t & if \quad \pi^t > 0 \;\; and \;\; Ac^t < 0 \\ W_f + W_b^t + EC^t & if \quad \pi^t > 0 \;\; and \;\; Ac^t > 0 \end{cases} \tag{11.7}$$

Retailers also have a dismissal rule. If a period of negative profit continues for more than a certain critical time, one of the employees is dismissed and receives unemployment compensation from the government while searching for a new job. The unemployment compensation ceases after the unemployed person becomes an employee of a new company. In addition, there is a bankruptcy rule. When a given class of product remains unsold for longer than a critical period limit, the producer stops its production. The producer goes bankrupt when the production of all classes of its products stops. The employees belonging to a producer who goes bankrupt are dismissed and become unemployed.

#### 11.2.3.3 Rules for the Bank

The bank retains the surplus money of other agents in their respective bank accounts, earns interest on long-term and short-term loans, and pays wages to its employees and taxes to the government in line with its interest income. The bank lends money as a long-term loan to producers in line with their demands for investment, charging a 3% interest rate. The bank also lends money as a short-term loan to producers when their working capital for paying fixed wages and/or purchasing raw material becomes sufficiently small. In the present study, the initial amount of funds in the bank is set to be very large so that there is no limitation on lending to producers, except in the case when long-term loans are not fulfilled during the repayment periods.

#### 11.2.3.4 Rule of Government

The government collects corporation tax and income tax from producers and consumers, respectively, pays wages to public employees, pays social security payments to the unemployed, and uses the remaining money in a given fiscal period for public spending, according to its expenditure policy. Corporation tax is only collected when a producer's profit is positive, and the tax rate is assumed to be constant. Income tax is collected according to the consumer's income, and this tax rate is also assumed to be constant. The public employees' wages are determined for each fiscal period and are equal to the average value of a private employee's combined fixed wage and bonus.

Regarding expenditure policies, market purchasing and firm subsidy, and combinations of the two, are tested. Market purchasing is an extreme case of efficient public spending in which the government directly purchases goods in the market at the market price. This policy corresponds to the extreme case of public works expenditure where the government places job orders with firms in a completely competitive situation at the same price level expected in the market. Firm subsidy is an extreme case of inefficient public spending in which the government evenly distributes funds to producers without any limitations on their use. This policy corresponds to the extreme case of inefficient public works expenditure where the government places job orders at a much higher price level than expected in the market, or pays money for jobs that have no economic value.

## 11.3 Simulation Conditions

A simulation program was constructed using C++ using the object-oriented methodology. The simulation conditions are given in Table 11.1. Table 11.1(a) shows the fixed parameters with values that remain constant during the simulation. Table 11.1(b) shows the initial conditions. Here, the values are initially given

**Table 11.1** Simulation conditions

(a) Parameter values of the base run

| | | | |
|---|---|---|---|
| Maximum fiscal periods $t$ | 360 | Number of consumers | 150 |
| Number of retailers | 30 | Number of material makers | 4 |
| Number of equipment makers | 1 | Number of banks | 1 |
| Withdrawal ratio $r_{wd}$ | 0–0.5 | Weight of utility $\delta$ | 0.3–01.1 |
| Fixed salary | 7,000–7,500 | Basic consumption $a$ | 3,000 |
| Marginal propensity to consume $b$ | 0.7 | Executive compensation ratio $r_e$ | 95 % |
| Bonus ratio $r_b$ | 75 % | Investment price | 500,000 |
| Critical flag number to quit production | 20 | Critical flag number for dismissal | 5 |
| Ratio of increasing price $\gamma_i$ | 0.15 | Ratio of decreasing price $\gamma_d$ | 0.1 |
| Deposit interest rates $r_{int}$ | 0.5 % | Loan Interest $r_0$ | 3 % |
| Repayment period $N$ | 120 | | |

(b) Initial conditions whose values may change during each run of simulation

| | | | |
|---|---|---|---|
| Capital of consumer | 30–50×$10^3$ | Capital of retailer and raw material maker | 80–160×$10^3$ |
| Capital of equipment maker | 200–220×$10^3$ | Capital of bank | 96–104×$10^6$ |
| Price of material products | 130–160 | Price of consumption products | 2,850–3,150 |
| $A$ in Eq. (11.4) for raw material maker | 200–300 | $A$ in Eq. (11.4) for retailer | 8–18 |

(c) Simulation conditions as experimental levels

| | Standard condition | Executive compensation | Internal funds | Upper limit of investment | Labor market |
|---|---|---|---|---|---|
| Executive compensation rule | Without | With/without | With | With | With |
| Internal funds rule | Without | With | With/without | With | With |
| Upper limit of the number of investments rule | 1 | 3 | 3 | 1/3 | 1 |
| Labor market | Without | Without | Without | Without | With/without |
| Income tax rate $r_{i-tax}$ | 10–30 % (5 % intervals)/20 % | | | | |
| Corporation tax rate $r_{c-tax}$ | 20 %/10–30 % (5 % intervals) | | | | |
| Ratio of firm subsidy | 40–80 % (10 % intervals) | | | | |
| Ratio of market purchasing | 60–20 % (10 % intervals) | | | | |

by a uniform random number, but may change during each simulation run. Table 11.1(c) shows the simulation parameters as experimental levels. These are constant, but change in each simulation run to clarify their influence on macroeconomic behavior in the artificial economic system.

As shown in Table 11.1(a), each simulation run includes 360 periods, and the producers' repayment period is assumed to be 120 periods. The simulation parameters as experimental levels are divided into five categories, as shown in Table 11.1(c): a standard condition, and analyses of the executive compensation, internal funds, upper limit of investment, and the labor market.

The analysis of executive compensation aims to analyze the influence of the executive compensation rule on the relationship between corporation tax rate and GDP. Without the executive compensation rule, the producer's profit all goes to its bank account. The analysis of internal funds aims to analyze the influence of using internal funds for investment. Without the internal funds rule, the producer finances all its investment through the bank. The analysis of the upper limit of investment aims to analyze the influence of the number of investments during the repayment period. The analysis of the labor market analyzes the influence of the labor market rule when consumers are dismissed and apply for new jobs. Without the labor market rule, the dismissed consumer is automatically employed by the producer with the largest accumulated profit. The standard condition is the basic condition in which none of the rules mentioned above are employed.

## 11.4 Simulation Results

### *11.4.1 Influence of Executive Compensation Rule*

The influence of executive compensation on the relationship between the corporation tax rate and GDP is shown in Fig. 11.1a, b under the standard condition and under the condition of the internal funds rule and the increased upper limit rule for the number of investments, respectively. In both cases, the labor market is not taken into account.

As shown in Fig. 11.1b, a reduction in the corporation tax rate results in an increase in GDP only when the executive compensation rule and the increased upper limit rule are employed. Thus, the executive compensation rule is considered to be one of the factors responsible for the negative correlation between the corporation tax rate and GDP. In addition, the GDP level is larger in the case with executive compensation, as shown in Fig. 11.1. The reason is that the total amount of consumers' income increases when executive compensation is included.

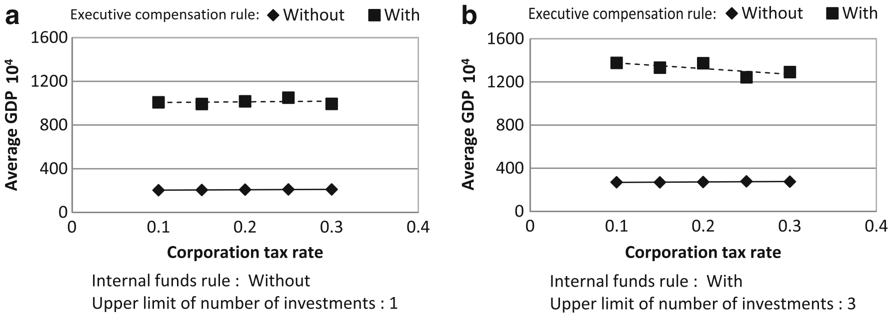


**Fig. 11.1** Influence of executive compensation on the relationship between the corporation tax rate and GDP (**a**) under the standard condition and (**b**) with the internal funds rule and increased upper limit rule for the number of investments applied

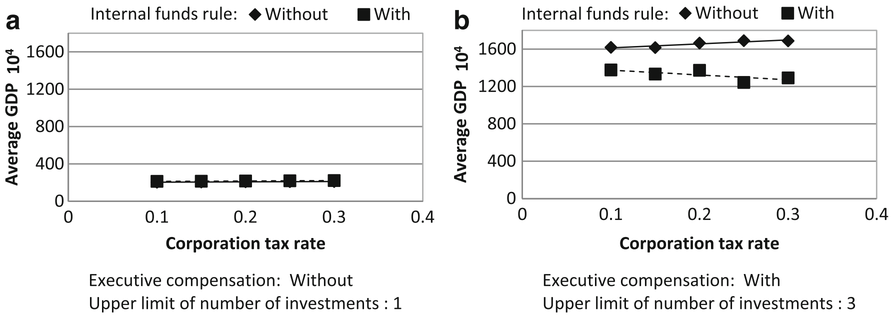


**Fig. 11.2** Influence of the internal funds rule on the relationship between the number of investments and the corporation tax rate under (**a**) the standard condition and (**b**) the condition with the executive compensation rule and an upper limit of the number of investments of three

## *11.4.2 Influence of Internal Funds Rule*

The influence of using internal funds for investment on the relationship between the corporation tax rate and GDP is shown in Fig. 11.2 under the standard condition (Fig. 11.2a) and under the condition with the same two rules applied: the executive compensation rule and increased upper limit rule for the number of investments (Fig. 11.2b). In both cases, the labor market is not taken into account.

As shown in Fig. 11.2, a reduction in the corporation tax rate results in an increase in GDP only when the internal funds are used for investment and the increased upper limit rule for investment is employed. In other words, the negative correlation between the corporate tax rate and GDP is not reproduced under the condition without the internal funds rule, even though the other two rules are employed. Thus, the internal funds rule is considered to be one of the factors responsible for the negative correlation between the corporation tax rate and GDP.

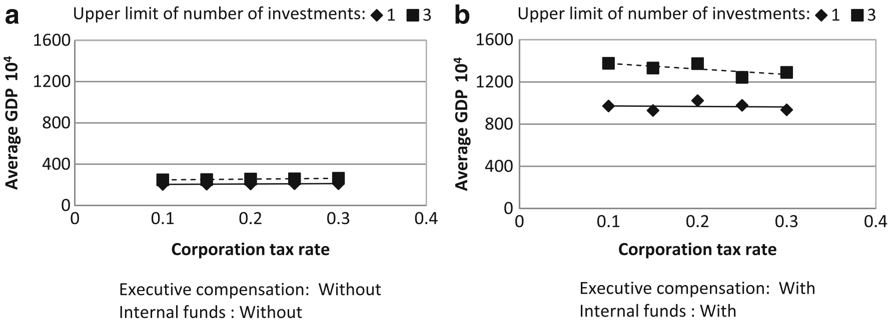


**Fig. 11.3** Influence of the upper limit of number of investments on the relationship between GDP and the corporation tax rate under (**a**) the standard condition and (**b**) under the condition with the internal funds rule and the executive compensation rule applied

### *11.4.3 Influence of Increased Upper Limit Rule for the Number of Investments*

The influence of the increased upper limit rule for the number of investments on the relationship between the corporation tax rate and GDP is shown in Fig. 11.3 under the standard condition (Fig. 11.3a) and under the condition with the executive compensation rule and the internal funds rule applied (Fig. 11.3b). In both cases, the labor market is not taken into account. As shown in Fig. 11.3, the negative correlation between the corporate tax rate and GDP is clearly obtained when the upper limit of the number of investments is three. However, even in the case where the upper limit of the number of investments is one, the correlation seems to be weakly negative rather than positive. Thus, the factors that are essentially responsible for the negative correlation between the corporate tax rate and GDP are considered to be the executive compensation rule and the internal funds rule. In addition, the upper limit of the number of investments strengthens the tendency of the negative correlation between the corporation tax rate and GDP.

### *11.4.4 Influence of Labor Market Rule*

Under the condition with the executive compensation rule and the internal funds rule, it was found that the negative correlation between the corporate tax rate and GDP is reproduced regardless of whether or not the labor market is taken into account, as shown in Fig. 11.4. This indicates that the unemployment rate is not an essential factor for the negative relationship between the corporation tax rate and GDP. The reason for this is considered to be that the contribution by the unemployed to the total demand is not large when compared to that of the other factors.

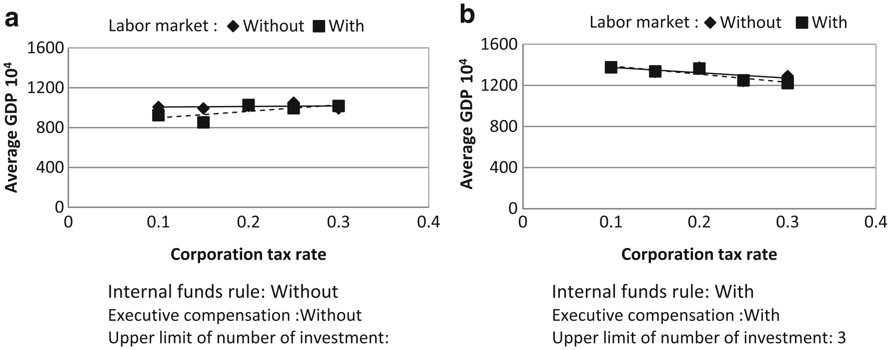


**Fig. 11.4** Influence of labor market rule on the relationship between GDP and corporation tax rate (**a**) under the standard condition and (**b**) with the other rules and elements

## 11.5 Discussion

### *11.5.1 Comparison of the Calculated Result and the Real System*

Summarizing the simulation results on the influence of the rules described above, it was concluded that the clear negative correlation of GDP with the corporation tax rate is only reproduced when three of the rules, namely, the executive compensation rule, the internal funds rule, and the increased upper limit rule, are simultaneously employed. The negative correlation of GDP with the income tax rate is also reproduced under this condition, as shown in Fig. 11.5. It was also found that the labor market is not a responsible factor for the relationship between the corporation tax rate and GDP.

Under the condition where three of the rules are simultaneously employed, the multipliers related to income tax reduction and corporation tax reduction are calculated and compared against the reported data, based on the macroeconometric model presented by the Japanese government [16], under the assumption that this reflects the behavior of the real economic system. The calculated multipliers in the present model, averaged for market purchasing ratios between 40 and 80%, are 0.78 for the income tax reduction and 1.39 for the corporation tax reduction. These values are consistent with the real data in the macroeconometric model, which range between 0.45 and 1.10 for the income tax reduction, and 0.24 and 1.17 for the corporation tax reduction (see Table 11.2).

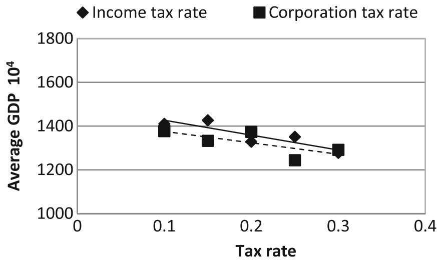


**Fig. 11.5** Influence of income tax rate and corporation tax rate on average GDP

**Table 11.2** Estimated multipliers of GDP and tax revenue when the corporation tax rate is reduced: (a) in the present model and (b) in the real system

| Multiplier due to corporation tax reduction (1 % of GDP) | | | | | |
|---|---|---|---|---|---|
| (a) Simulation results | | | (b) Data in the real system | | |
| Market purchasing ratio | GDP | Tax revenue | Year | GDP | Tax revenue |
| 40 % | −0.25 | −2.70 | 2005 | 0.45 | −5.71 |
| 50 % | 3.00 | −4.23 | 2006 | 0.97 | −4.93 |
| 60 % | 7.69 | −2.70 | 2007 | 1.10 | −4.60 |
| 70 % | −2.01 | −4.01 | Average | 0.84 | −5.08 |
| 80 % | −1.50 | −2.87 | | | |
| Average | 1.39 | −3.30 | | | |
| Multiplier due to income tax reduction (1 % of GDP) | | | | | |
| (c) Simulation results | | | (d) Data in the real system | | |
| Market purchasing ratio | GDP | Tax revenue | Year | GDP | Tax revenue |
| 40 % | 1.35 | −2.38 | 2005 | 0.24 | −5.71 |
| 50 % | 1.67 | −2.39 | 2006 | 0.85 | −4.28 |
| 60 % | 1.05 | −2.49 | 2007 | 1.17 | −3.80 |
| 70 % | 0.30 | −3.05 | Average | 0.75 | −4.60 |
| 80 % | −0.45 | −3.59 | | | |
| Average | 0.78 | −2.78 | | | |

### *11.5.2 Mechanism of the Influence of the Three Rules on the Relationship Between Corporation Tax Rate and GDP*

The chronological changes in the financial assets of consumers and retailers are presented in Fig. 11.6a, b for the cases without and with the executive compensation rule, respectively. In both cases, the internal funds rule and the increased upper limit rule for the number of investments are simultaneously applied. As shown in Fig. 11.6, considering the executive compensation means an increase in financial assets for consumers, but a decrease in financial assets for retailers. The reason for this tendency is that the executive compensation transfers part of the assets of firms to consumers, since executives are a subset of consumers. The executive compensation is thus considered to be one of the factors responsible for the negative

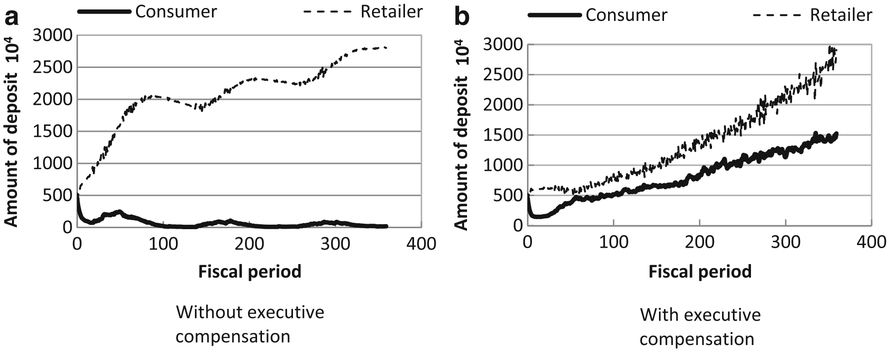


**Fig. 11.6** Influence of the executive compensation rule on the deposit of consumers and retailers under the conditions (**a**) without compensation and (**b**) with compensation

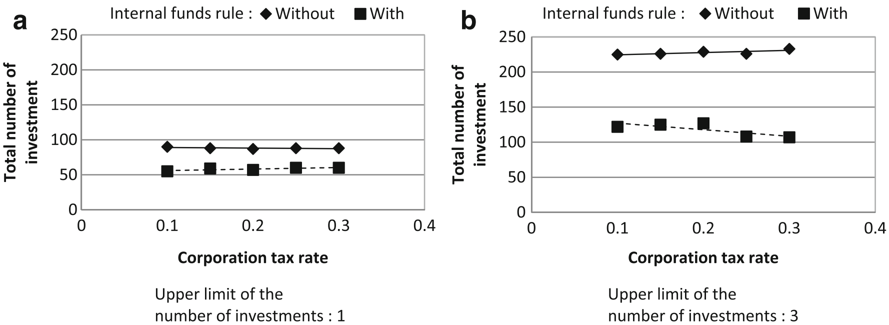


**Fig. 11.7** Influence of the internal funds rule on the relationship between the total number of investments and the corporation tax rate under the condition that the upper limit of number of investments is (**a**) one and (**b**) three

correlation between GDP and the corporation tax rate. Here, the reduction in the corporation tax rate increases the net profit of firms, some percentage of which is transferred to the consumer through executive compensation, thus increasing consumers' demand and GDP. In addition, the tendency for the financial assets of consumers to increase with time is in good agreement with the real data of household deposits presented by the Japanese government [17].

Figure 11.7 shows the influence of the internal funds rule and increased upper limit rule on the total number of investments under the condition of the executive compensation rule. As shown in Fig. 11.7b, the total number of investments shows a negative correlation with the corporation tax rate only when the internal funds rule and increased upper limit rule are both employed. Hence, the internal funds rule and increased upper limit rule are also factors responsible for the negative correlation of GDP with the corporation tax rate, because both rules cause firms' deposits to circulate in the market and increase consumers' income.

In addition, the inefficiency of government expenditure is also a factor responsible for the negative correlation of GDP with the corporation tax rate. Note that all the results mentioned above are obtained under the condition that the market purchasing ratio is 0.6, as shown in Table 11.2(a). If government expenditure is completely efficient, that is, the market purchasing ratio is 100%, no negative correlation between GDP and the corporation tax rate is reproduced in the model. The reason is that, with 100% market purchasing, increasing the corporation tax rate promotes the transfer of internal funds to the market.

This mechanism is qualitatively understood with the following argument. Consider a company that represents the aggregate of all retailers and raw material makers. Similarly, consider a consumer representing the aggregate of all consumers. For simplicity, we assume there are no public consumers and that tax revenue is used entirely for government expenditure. In addition, we denote the total sales of the company in a certain period as T, the consumption ratio of the consumer as $\mu$, and the efficiency of government expenditure as $eta$. It is also assumed that the fixed wage, bonus, and executive compensation are all included in the "bonus" category.

With the above assumptions, total sales T becomes the income of the consumer, the tax revenue of the government, and the company's deposit. Some part of the income and tax revenue will, in turn, be spent on consumption in the market, and so will become the total sales of the company. Once this process is repeated indefinitely, we obtain the total demand for the consumer CC and the total demand of the government CG. In this case, the consumer demand is given by Eq. (11.8) if government expenditure is neglected, and the government demand is given by Eq. (11.9) if consumer demand is neglected.

$$C_C = \sum_{k=1}^{\infty} T r_b^k \mu^k = T/(1 - r_b \mu) \tag{11.8}$$

$$C_G = \sum_{k=1}^{\infty} T(1 - r_b)^k r_{c-tax}^k \eta^k = T/\{1 - (1 - r_b) r_{c-tax} \eta\} \tag{11.9}$$

According to Eq. (11.8), the consumer demand is an implicit function of the corporation tax rate and increases with an increase in the total sales of the company. Therefore, if the company spends the surplus money obtained from the tax reduction on investments, increasing consumer income, or both, but without increasing deposits in the bank, then the tax reduction increases consumer demand and the total sales of the company, thus increasing GDP.

Further, according to Eq. (11.9), the government demand is an explicit function of corporation tax rate and the efficiency of government expenditure. Hence, if government expenditure is more or less efficient, the total demand and GDP increase with the corporation tax rate. Therefore, if GDP increases with a decrease in corporation tax rate, it is due to an increase in consumer demand. When we consider the consumer demand and the demand caused by government expenditure, and we assume government expenditure to be, to some extent, inefficient, a reduction in the corporation tax rate results in an increase in the total demand and GDP. However, this only occurs if the company spends the surplus money obtained from the tax reduction on investments or on increasing consumer income, or both. In other words, the negative correlation between the corporate tax rate and GDP will result if the company redistributes the surplus money to the market. The three rules, namely executive compensation, the use of internal funds for investment, and increasing the upper limit of the number of investments during the repayment period, promote the redistribution of funds from the company's deposits to the market.

Therefore, we conclude that inefficiency in government expenditure and the redistribution of the company's surplus money to the consumer are indispensable conditions for the model to reproduce a negative correlation between GDP and the corporation tax rate. This suggests that, if companies are not willing to use their internal funds for investment, a reduction in the corporation tax rate could result in a decrease in GDP.

## 11.6 Conclusion

An agent-based model of an artificial economic system, including the government, was developed on the basis of the authors' previous model. Using this model, we analyzed the conditions required to reproduce the negative correlation between GDP and the corporation tax rate. The findings were as follows:

1. A clear negative correlation of GDP with the corporation tax rate is reproduced only when executive compensation is paid and producers invest in equipment using internal funds and loans from the bank, and under the condition that the upper limit of the number of investments during the repayment period is greater than one. The unemployment rate was found not to be a factor required to reproduce the negative correlation between GDP and the corporation tax rate.
2. Under this condition, the influence of an income tax and corporation tax reduction on GDP was in agreement with the real data. In addition, the consumers' financial assets increase with time, the qualitative tendency of which also agrees with the real data.
3. This result indicates that the redistribution of the company's surplus money to the consumer and inefficiency in government expenditure are both indispensable conditions for the model to reproduce the negative correlation between GDP and the corporation tax rate. This suggests that, if companies are not willing to use the surplus money from a tax reduction for investment, a reduction in the corporation tax rate could result in a decrease in GDP.

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# Part IV
# Demographics, Health Care, Linguistics, and Sociology

# Chapter 12
# Semi-Artificial Models of Populations: Connecting Demography with Agent-Based Modelling

**Eric Silverman, Jakub Bijak, Jason Noble, Viet Cao, and Jason Hilton**

**Abstract** In this paper we present an agent-based model of the dynamics of mortality, fertility, and partnership formation in a closed population. Our goal is to bridge the methodological and conceptual gaps that remain between demography and agent-based social simulation approaches. The model construction incorporates elements of both perspectives, with demography contributing empirical data on population dynamics, subsequently embedded in an agent-based model situated on a 2D grid space. While taking inspiration from previous work applying agent-based simulation methodologies to demography, we extend this basic concept to a complete model of population change, which includes spatial elements as well as additional agent properties. Given the connection to empirical work based on demographic data for the United Kingdom, this model allows us to analyse population dynamics on several levels, from the individual, to the household, and to the whole simulated population. We propose that such an approach bolsters the strength of demographic analysis, adding additional explanatory power.

**Keywords** Agent-based modelling • Demography • Social simulation

## 12.1 Motivations: Bringing Together the Statistical and the Simulated Individual

Silverman and Bryden [25] divided current work in agent-based models (ABMs) in social science into two main streams: systems sociology and social simulation. The former focuses on the use of ABMs in an explanatory role, with few predefined

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interactions or structures; the models exist to probe elements of social theory, rather than to examine the functionality of specific social systems (e.g., investigations of the behaviour of nation-states, as in [8], or the social effects of different kin systems [23]). Social simulation approaches instead focus on a particular class of behaviour or a particular social system, and may have some link to empirical data (e.g., the reconstruction of the Anasazi population in [1], or the work in [11] on the movement of early Polynesian peoples).

In general, ABMs have become increasingly popular in the social sciences as the methodology has become more established. These models have produced useful insights even when no empirical data was used at all (see, e.g., [24]), and therefore seem to have demonstrated a certain capacity for explanatory power. Meanwhile, some researchers have proposed that ABMs will allow social scientists to more directly integrate their data with simulation approaches [20]. Given the remarkable flexibility the ABMs display, these models can be used for numerous purposes beyond simply explanation and prediction [12].

The methodological challenges facing demography currently (see [26]) have led some demographers to investigate the methodology of agent-based modelling as a potentially valuable addition to the toolkit of the field [4, 5]. In the context of demography, the challenges facing multilevel microsimulation models have alerted some authors to the need to address the issue of the combinatorial explosion of the parameter space in these models [26]. It has also been argued that traditional demographic models cannot fully capture the complexities of micro-level agent behaviour and heterogeneity [26]. ABMs can provide these possibilities [14], as well as a possible platform for understanding social interactions, social networks, and other processes lying at the root of demographic change [5].

Recent work in demography has described the fundamental goals of demographic research—or indeed any field of social science applying statistical methods—as the use of statistical models based on observations (e.g., surveys and censuses) to predict and describe the behaviour of *statistical individuals* [10]. Demography has therefore progressed through a number of different paradigms, ranging from the cross-sectional view, in which events are viewed as separate from individuals, to the event-history perspective, in which demographic events are interdependent on individual life courses. In recent years, the most prominent view has been the *multilevel* paradigm, in which behaviour at the societal level can only be understood by investigating multiple levels of the social world simultaneously [9, 10].

A similar process can be seen within the systems sociology and social simulation communities: in these arenas we focus on *simulated individuals* equipped with some simple behavioural rules, through which we hope to see the emergence of interesting behaviours at the macro level. At the same time, some of these models incorporate feedback loops, social networks, and other related concepts—all of which serve to bring these multiple levels of the social world into play within the simulation.

Thus, we argue that while social science ABMs and demography clearly differ in some respects—for example, in having either theoretical or empirical focus, or using mainly computational or statistical models—the recent history of demographic theory shows synergies developing between the agent-based simulation approach and the multilevel demographic approach. On the technical side, we already see some of these links: some multistate models in demography already assume simple behavioural rules in individuals, while some ABMs of social systems already use substantial empirical information in the model-building process.

Moreover, demographic methods also have significant strengths in the empirical arena, not least the capacity for higher predictive accuracy in many cases, as well as the direct connection to the rich information already embedded in the age structure of populations. Efforts thus far in developing agent-based demography have attempted to incorporate agent-based methods while simultaneously retaining these particular strengths of demography (e.g., [4–6, 16, 29]). Thus, demographic methods can contribute significant additional expertise and allow us to better align models with the real world of empirical observations.

Taking this process further, we propose that directly linking demographic methods with ABM frameworks will allow us to produce models which increase our understanding of population change, while simultaneously helping us to avoid the pitfalls of an *overdependence* on empirical data [26]. ABMs allow us to produce models which have a greater explanatory capacity, while the demographic components allow us to use the inherent flexibility of the ABM approach to generate plausible scenarios within a given parameter space, informed by well-established demographic methods of analysis.

In this framework, such augmented ABMs will allow demographers to examine scenarios over longer time horizons, rather than being heavily limited by data-dependent statistical models. The general consensus is that the predictive horizon of demographic models is about one generation in length [18], but some have argued that scenario-based methods can offer an opportunity to explore a larger space of possible futures (e.g., [3, 30]). Thus, we propose that this new framework can produce a shift within the demographic community: from a focus on prediction and description alone, to an approach which allows for exploration of scenarios of population change, while also providing some insight into the underlying processes.

Hence, we suggest that the social simulation stream of agent-based modelling is of great relevance to demography. The model presented here aims to make progress at this interface, and bring ABMs of population to the fore as a means to both enhance demographic methods, and to tie ABMs more closely to real social systems (an approach we have advocated previously [26]). We refer to this approach as a semi-artificial model of a population to capture the mixture between empirical data and randomly generated agent populations with simple behavioural rules. An example of such a model—inspired by and drawing from the Wedding Ring model seen in [6]—is described in detail in the next section.

## 12.2 From the Wedding Ring to the Wedding Doughnut

### *12.2.1 Wedding Ring: Background*

In order to illustrate the potential benefits of combining demographic and complexity science approaches, we replicated and expanded upon the model of partnership formation implemented by [6], known as the Wedding Ring model. This model attempts to explain the age-at-marriage patterns seen in modern European states by representing the process of partnership formation as a consequence of social pressure. This pressure arises from contact between married and unmarried individuals within a given social network. This conceptual framework serves to formalise some recent research in social influence and social learning, which has shown that these processes are highly relevant in individuals' decisions to get married (see, e.g., [2, 6, 7]).

Thus, the model represents the spread of marriage through a population as a diffusion process. However, marriage differs from other diffusion processes in that even those experiencing a very high level of social pressure towards marriage cannot get married without finding a suitable unmarried partner [6].

The Wedding Ring is so named because agents live in a one-dimensional ring-shaped world, which changes over time [6]. The agents are thus effectively situated in a cylindrical space, with the circular dimension (arc length) representing space, and the linear dimension time. Each agent's network of relevant others is then defined as a two-dimensional neighbourhood on that cylinder [6].

Within that neighbourhood, the proportion of married agents determines the social pressure felt by an individual agent, which influences that agent's decision to seek out a partner. The overall level of social pressure and the agents' age influence parameter determine the range in which agents search for a suitable partner. As social pressure increases, agents widen their search range, and thus have a greater chance of successfully finding a partner [6]. However, the search is mutual; if one unmarried agent finds another within its acceptable range, marriage may only occur if the suitable partner has the searching agent within its acceptable range as well. Once married, agents may bear children; these children are then placed into the ring-world at a random spot in their parents neighbourhood.

In order to define the network of relevant others in which the agent searches for a partner, each agent is first classified into one of five possible types, according to the age ranges of agents by whom they are most influenced (i.e., similarly by younger and older agents, either mostly or only by older agents, or either mostly or only by younger agents—for further details, see [6]). The size of the spatial interval for the agents' network of relevant others is symmetric around their location, and varies according to the size of the initial population.

### 12.2.2 Extending the Model: The Wedding Doughnut

In order to better align our model with the demographic processes under study, we altered the Wedding Ring model in several major ways. First, we situated the agents in a toroidal space, as this would allow for a more complete consideration of the impact of spatiality on partnership formation processes. As in the original Wedding Ring, the dimensions of the grid space could be considered not just as spatial distances, but also as social distances [6], or, in our example, a combination of both. The model uses a grid space 72 squares long on each edge, with an initial population of 800 agents, which allowed for a sufficient population density to observe interesting population dynamics.

In our model—hereafter dubbed the Wedding Doughnut, given the new spatial arrangements—several core components of the original model were altered. The Wedding Ring was built on the assumption that each agent had only one spatial coordinate to record, so in the Doughnut we altered the methods used to calculate spatial separation, and substantially altered other parameters in order to allow the agents to properly search this space.

We also allowed the agents to move on the grid. When an agent forms a partnership, they move to a new location, the distance to which is inversely proportional to the size of the network of their relevant others. Any future offspring are placed at this new household. For simplicity, however, we follow the original model's lead and assume that partnerships are permanent, and that agents cannot form partnerships until the age of 16. Future extensions of this model might allow for more detail, such as same-sex partnerships and the possibility of partnership dissolution.

The other details of the model have not changed in this implementation; we use an identical function to the Wedding Ring for age influence (a piecewise linear function which varies with age) and for social pressure (a sigmoid function). For these we used identical parameter values to those in Billari et al. [6] in their base scenario.

### 12.2.3 Extending the Model: Demographic Elements

The original Wedding Ring made some significant simplifying assumptions in order to make the model run smoothly. Agents died only when reaching age 100, and birth rates were adjusted regularly in order to keep the population constant [6]. These restrictions were removed in the current Doughnut implementation, and ageing, mortality, and fertility were implemented using elements drawn from statistical demography.

We wished to include in this extension a serious consideration of the underlying demographic processes that influence partnership formation. Modern societies are ageing, and older agents have smaller networks of relevant others. Therefore, we added a realistic model of mortality, as otherwise the model risks failing to capture the complexities underlying these trends. Similarly, we added a realistic model of fertility to capture the current shift towards later childbearing and lower birth rates.

The initial population in the model is generated at random, but the distributions of agents by age, sex, and marital status correspond to the observed data from England and Wales in the 1951 Census [21]. As the simulation progresses, fertility and mortality rates are based on empirical data and projections for the UK population. The first 60 years of the simulation use age-specific mortality rates drawn from the Human Mortality Database for 1951–2009 [17].

These rates were then projected forward using the popular method for forecasting mortality developed by Lee and Carter [19]. This method uses the leading vectors of a singular value decomposition of the matrix of centred mortality rates to construct a model for mortality with only one time-varying element. This allows easy forecasting using standard times series methods; more details about procedure and estimation are available in [19]. Projections to 2250 using this method show a continual but slowing increase in life expectancy over the period.

Fertility rates for the simulation were obtained in a similar way. Age-specific fertility rates from 1973 to 2009 for UK women of childbearing age were obtained from the Eurostat database [13], while earlier data for the period 1950–1972 were taken from the Office of National Statistics data for England and Wales [21].

A Lee-Carter model was again fitted to the data to obtain future rates, but, in contrast to the mortality projections, two components of the singular value decomposition of the matrix of fertility rates were needed, as two time indices better captured the trends in fertility. The resultant projections to 2250 see the total fertility rate increase initially before converging at a value just above replacement fertility, and also display a continuation in the empirical trend towards later childbearing in the UK.

### *12.2.4 Extending the Model: Health Status*

In order to make the model more relevant to real-world policy concerns related to the ageing UK population, particularly problems in social care provision, we also added a simplistic model of health status to the Wedding Doughnut. Agents have a probability of transitioning into a state of ill health—here defined as a state of illness or disability requiring significant care—which increases with age. Once agents transition into this state, they remain ill until death. We do not model the impact of illness on mortality, given that an appropriate representation of this would require further analysis on empirical data to determine the effect of unmet care need coupled with a more sophisticated model of illness. As in the real world, males have a slightly higher probability of entering this state than females; parameter values were not based on empirical data, due to the difficulty of obtaining and analysing data on these types of illnesses.

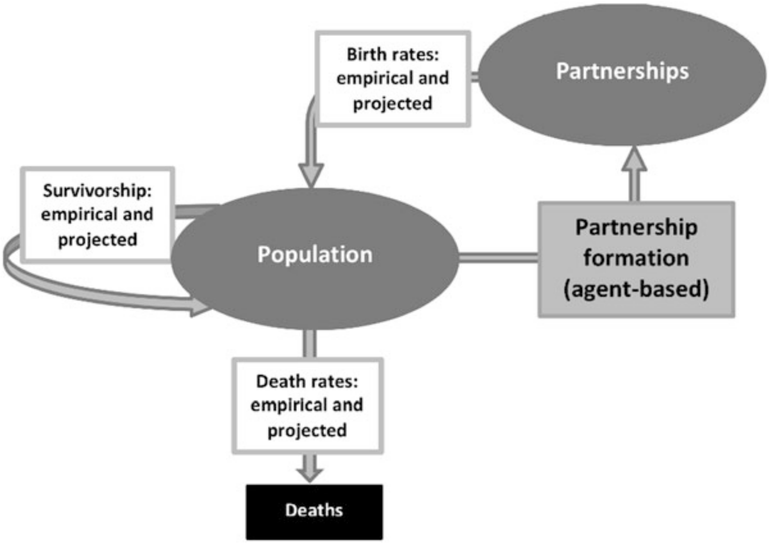


**Fig. 12.1** A representation of the flow of the Wedding Doughnut model. Agent-based methods are used to produce a model of partnership formation, which is linked to the other empirical, demographic methods shown here to produce the complete model

While this model of health status is extremely simplistic, we intended this addition to serve as a proof of concept that a simulation built on this semi-artificial framework could produce results which, due to their relationship to empirical data and projections, could bear upon issues relevant to policy-makers. As the results will show, running various scenarios even in this basic model produced interesting results, and future iterations of the model will incorporate a more robust model of health status which would allow for significantly more detail.

### *12.2.5 The Wedding Doughnut: Flow of the Simulation*

The Wedding Doughnut was written in Repast Simphony 2.0, which is a Java-based software package for agent-based modelling. Figure 12.1 illustrates the general flow and structure of the model. The simulation runs for 300 time steps, each time step being 1 year—in contrast to the Wedding Ring, which only ran for 150 years. The first time step corresponds to the calendar year 1951, and hence the simulation extends to 2250.

Each time step proceeds as follows:

1. All agents age 1 year
2. For agents without partners:
    a. For each agent, we find that agent's relevant others
    b. Social pressure is calculated
    c. Potential partners are found
    d. Partnerships form where there is mutual need/pressure
    e. New partners move to a new location
3. For agents with partners:
    a. Check fertility status
    b. Some agents will give birth according to relevant fertility rates
4. For every agent:
    a. Check health status: Some agents will become ill according to relevant rates
    b. Check mortality: Some agents will die according to relevant mortality rates
5. Remove dead agents from the simulation
6. Place newborn agents into the simulation

## 12.3 Results

Initial runs of the model were designed as a pure replication of the original Wedding Ring: agents were placed on a 1D ring, and none of our modifications were incorporated. Results were consistent with the original paper, which indicated that we could progress to developing our modifications.

Once our modifications based on empirical demographic projections were included, our initial set of 1,800 runs indicated qualitative similarity to the patterns of marriage observed in modern Britain. As shown in Fig. 12.2, the simulation produced populations with proportions of individuals who married at some point during their life course, as we see during 2010–2011 in the UK (the last year for which data is available). The results show greater stochasticity, which is likely due to our small initial population, small simulated world, and the short running time of the simulation by the time it reaches calendar year 2011. The current implementation has the advantage of short running times, and thus allows for a more in-depth analysis, which carries significant benefits when testing a new modelling approach.

Using our initial parameter settings, we were able to broadly replicate the pattern of marriage that we see in empirical data. Sensitivity analysis further showed that significantly altering the basis of the simulation by reducing social pressure or age influence parameters to constants produced marriage hazard rates inconsistent with reality (as shown in Fig. 12.3). The base scenario, in which age influence varies according to the age of the agents and social pressure is calculated using a sigmoid function, more closely resembles hazard rates of marriage that we see in modern European states.

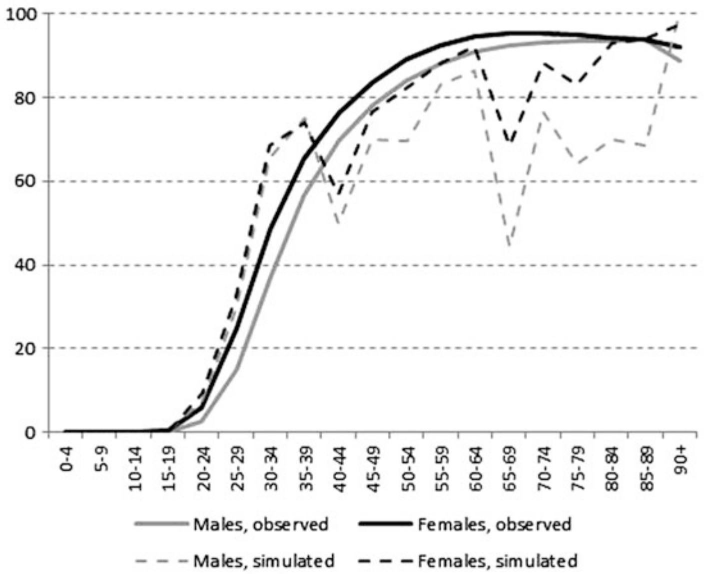


**Fig. 12.2** Example of a comparison between observed and simulated populations showing the percentage of the population which has ever married by 2010–2011

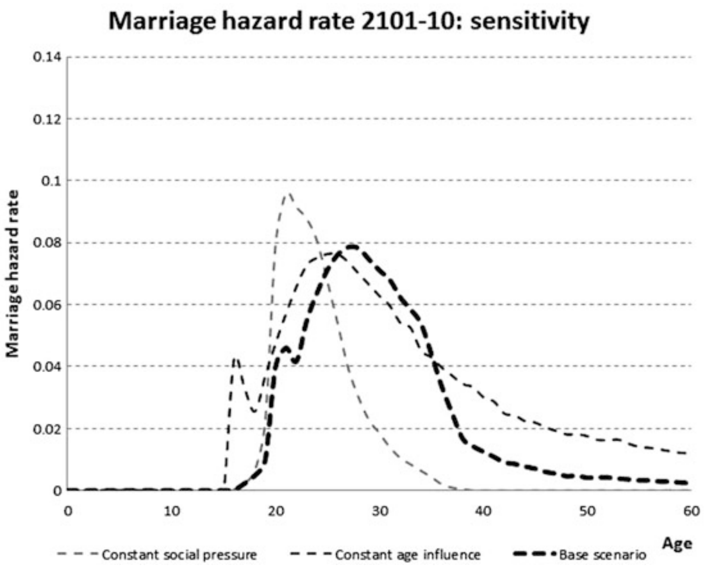


**Fig. 12.3** Comparison of marriage hazard rate results in three scenarios: the base scenario, constant social pressure, and constant age influence

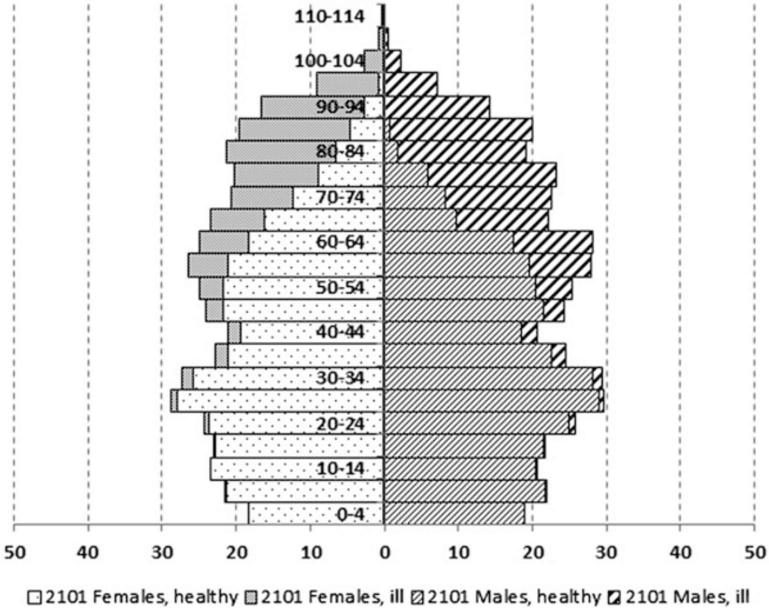


**Fig. 12.4** Population pyramid for the year 2101 in our simulated population. Note the increasing incidence of long-term limiting illness as age increases

Figures 12.4 and 12.5 provide a breakdown of a simulated population in the year 2101. While these results obviously cannot be compared with empirical data, we do see a pattern here that intuitively fits our expectations for future population dynamics. As expected in any long-term demographic projection, results at the end of the simulation in year 2250 tend to be more variable, so we chose 2101 for our analysis, as it is more illustrative. In Fig. 12.4, we see that the population becomes increasingly dominated by the older age brackets of society, and further, many of those individuals have become ill and will require care (according to our simplistic model of health status in which only long-term limiting illness is represented, as noted in Sect. 12.2.4). Figure 12.5 shows that as our simulated individuals age, many of those who are ill have not had the opportunity to marry, meaning that they will not have spouses or children available to care for them.

Thus, results show an encouraging parity with empirical data in the early stages of the simulation (which are the only stages for which we can make this comparison). Hazard rates of marriage reflect what we expect in current society, and overall marriage rates, while displaying more stochasticity, are broadly at a level consistent with reality. As the simulation progresses, we see population change that mirrors the expectations of demographers with regard to the dynamics of an ageing population. Agent populations become increasingly dominated by the old and infirm, marriage/fertility rates slowly decline, and as a consequence we see ever-increasing numbers of agents in ill health but who have no family to provide care.

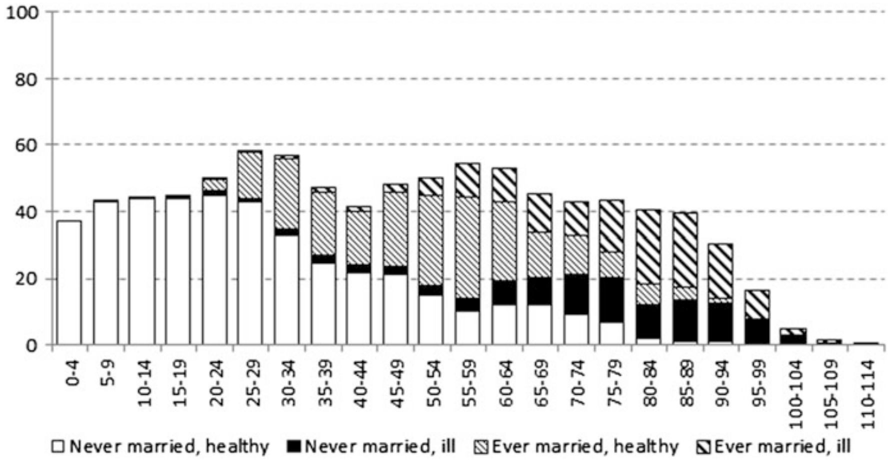


**Fig. 12.5** Breakdown of simulated population in the year 2101 by both marriage and health status

## 12.4 Discussion

The results above demonstrate our original thesis: ABMs of demographic processes, augmented with empirical data on fertility and mortality, can produce results that match our expectations of the demographics of modern European states. Despite the lack of data fully informing our model of health status, we see plausible distributions of healthy and unhealthy agents that illustrate the consequences of Europe's ageing population. This leads us to conclude that the mechanisms used here to drive basic demographic processes have captured the essential elements needed to produce a useful starting point for semi-artificial population models for the UK.

While this is a promising beginning, a number of further extensions are planned. First, our model of health status, while illustrative, is quite simplistic and does not necessarily reflect the complexity of relationships between health and ageing in the modern UK society. As such, this part of the model can be extended by incorporating empirical data on limiting long-term illness in the UK. Further, future expansions of this model will capture the effect of unmet care need on mortality, which is not modelled in the current implementation.

Second, our model of partnership seems to capture the appropriate dynamics, but it does not incorporate the possibility of partnership dissolution, or of same-sex partnerships. Currently, partnerships are defined solely as 'relationships leading to reproduction', but in the UK quite a few children are born in non-cohabiting relationships (10%) or by lone parents (6%) [22]. Future work will capture these subtleties by allowing for greater variety in childbearing partnerships.

Finally, agents on our Wedding Doughnut do not shift position in that space unless they have formed a new partnership. Natural extensions in that respect would require incorporating more sophisticated agent behaviours, particularly in allowing for agent mobility, enabling us to represent the possible causes and effects of within-country migration.

Nevertheless, in its current form the Wedding Doughnut provides an illustrative example of the power of the combined ABM-demography approach.[1] We propose that combining ABMs and statistical demography can help both disciplines in combination to improve their explanatory relevance, deepen our understanding of demographic processes, and increase our appreciation of the links between macro-level effects and micro-level behaviour. This may move us closer to the ideal expressed by the British demographer John Hajnal, who aspired to the construction of models which "involve [. . .] more cognition than has generally been applied" [15, p. 321].

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[1] See [27] for a further explication of this approach, and [28] for an additional example using a different modelling platform.

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# Chapter 13
# An Agent-Based Approach for Patient Satisfaction and Collateral Health Effects

**Masatoshi Murakami and Noriyuki Tanida**

**Abstract** The purpose of this study is to clarify the collateral health effects of health care, especially the relationship between patients and their families, using agent-based simulation. To this end we describe the general appearance of our simulation model and the simulation settings. The results of six model scenarios, each involving differing combinations of patient agents, patient's family agents, doctor agents, a government agent, and nonprofit organization (NPO) agents, are then explained and discussed. We conclude with a summary that touches on the tasks that lie ahead, including an appropriate subset of health care policies that involve the participation of NPO agents.

**Keywords** Agent based simulation • Patient satisfaction • Social cost

## 13.1 Introduction

According to the World Health Organization (WHO) and the Organization for Economic Cooperation and Development (OECD), Japan enjoys the highest medical level, as measured by life expectancy at birth, probability of dying under age 5, probability of dying between ages 15 and 60, and a low health expenditure as

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a share of gross domestic product (GDP).[1] However, according to the Cabinet Office of the Government of Japan, as well as other sources, patient satisfaction in Japan is low compared with that in other countries.[2] What is more, Japan is now facing various social problems related to health insurance, pensions, and taxation because the population is rapidly aging at an unprecedented pace. To curb the huge and rapidly expanding costs of medical treatment and to increase patient satisfaction, an increase in financial support to patients' families is needed, since family support inevitably entails substantial financial and mental burdens.

In the United States patient-centered and family-centered care has been promoted since the middle of the twentieth century. The Institute for Patient- and Family-Centered Care "serves as an information resource center for patient and family leaders, clinicians, administrators, educators, researchers, and facility designers who are interested in advancing the practice of patient- and family-centered care."[3] In Japan we have, for example, the Patient/Family Support Center at Asahikawa Red Cross Hospital.[4] Thus, in the field of health care service and medical care, it is increasingly important to provide care services not only to patients but also to their family members.

The purpose of this study is to clarify the collateral health effects of health care by means of an agent-based simulation. To this end we describe our simulation model in Sect. 13.2 and the simulation settings in Sect. 13.3. The results of the simulation are discussed in Sect. 13.4, and in Sect. 13.5 we summarize our research results and note the tasks that remain.

## 13.2 General Form of Our Simulation Model

### *13.2.1 Basic Characteristics of the Model*

There are many studies that deal with patient satisfaction, but very few focus on the relationships between patient satisfaction and the financial and mental burdens of their families. One of the few that does is [6]; it points out the importance of studying collateral health effects, in contrast with conventional views on medical care.

As shown in Fig. 13.1, on the basis of Christakis's research, our simulation model makes use of a social network model in which patients are mutually linked with their families and doctors. We also include a government health care resource. In Japan, the cost of health insurance is approximately 10% of one's income, so in our model each agent pays 10% of their income for health insurance. The total amount of

[1] For example, see [1] and [2].

[2] See Ref. [3].

[3] Quoted from Ref. [4].

[4] See Ref. [5].

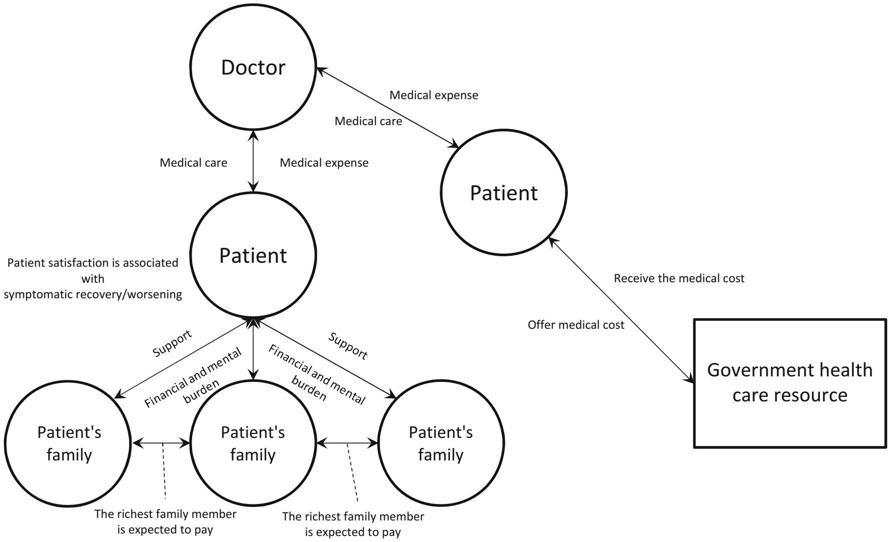


**Fig. 13.1** Simulation model

health insurance paid by each agent goes into a government fund that constitutes the health care resource. In our model patients interact with doctors through medical treatments. At such times patients make use of the government health care resource only if they do not have family support. Patients also interact with members of their family through their support and the financial and mental burdens of the family. In this instance, the family's financial and mental burdens equal the social cost[5] that is derived from patient care. If a patient cannot pay medical expenses, his family covers it. In addition, symptomatic worsening of patients affects the satisfaction of patients and their families, while symptomatic recovery and/or increased patient satisfaction will ease the mental burden of the family. Thus, the symptomatic recovery or worsening of a patient is associated with patient satisfaction. We include these mechanisms in our simulation model.

## *13.2.2 Patient Satisfaction Scale*

Based on the agent-based simulation model described above, we need to evaluate patient satisfaction using some kind of "patient satisfaction scale." There is considerable research on the enhancement of patient satisfaction in the field of medical care.

[5]Social cost is generally defined in economics as "the cost to society as a whole from an event." Here we narrowly define social cost as the financial and mental cost incurred by a patient's family in supporting that patient.

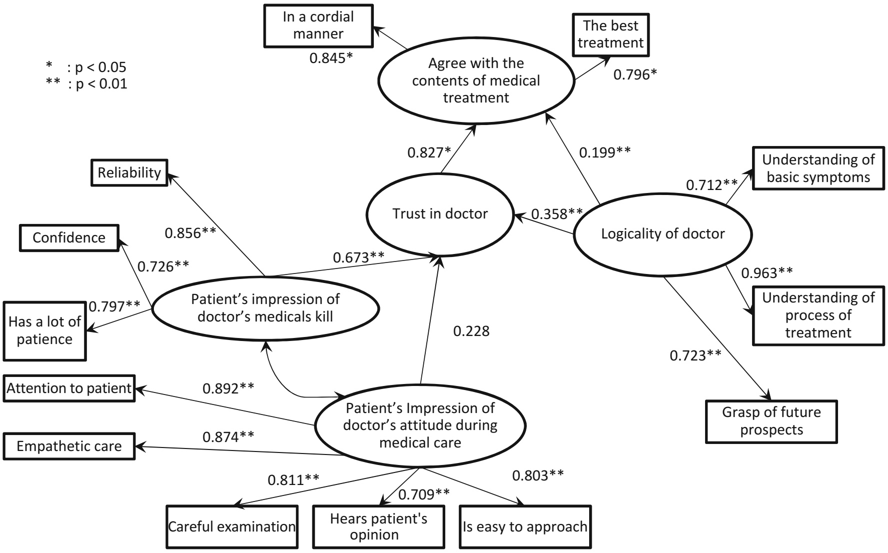


**Fig. 13.2** Path diagram for measuring patient satisfaction (*Source*: [10, p. 202])

Nevertheless, more research is needed in regard to a patient satisfaction scale. A scale based on SERVQUAL (see [7]), which is a kind of customer satisfaction measurement, has been developed and used in several studies.[6] In recent years, in order to develop a more useful patient satisfaction scale, some studies have used a structural equation model, but there is no unified methodology for constructing a patient satisfaction scale, and each study uses a different data-gathering process to construct its patient satisfaction scale (for example, see [10–13]). Given this situation, we focus on an idea from study [10] and make use of its basic structure in our simulation model.[7] We have adopted this particular study because it probes into the psychological makeup of patients using a structural equation model. In addition, the clinical department in which the 145 patients in this study were seen is not restricted.

As shown in Fig. 13.2, [10] points out that four potential factors have both a direct and an indirect influence on the patient's assent and satisfaction: the patient's impression of the doctor's medical skill, the patient's impression of the doctor's attitude during medical care, the logicality of the doctor, and the patient's trust in the doctor. These four potential factors affect eleven observed variables: "reliability", "confidence", "has a lot of experience", "attention to patient", "empathetic care",

[6] In the field of medical care, early studies that deal with patient satisfaction are [8] and [9].

[7] Other studies that deal with Japanese patient satisfaction using a structural equation model are [14] and [15]. An example of a study that deals with patient satisfaction in another country is [16].

"careful examination", "hears patient's opinion", "is easy to approach", "grasp of future prospects", "understanding of process of treatment" and "understanding of basic symptoms".[8]

From Fig. 13.2 we see, for example, that if the patient's impression of the doctor's medical skill improves, this directly leads to enhancement of trust in the doctor (0.673). At the same time it indirectly leads to improving the patient's agreement with the contents of the medical treatment (0.673×0.827). In addition, increasing patient satisfaction leads to reducing the mental burden of the patient's family. And finally, the patient's satisfaction is associated with more rapid recovery, so increasing patient satisfaction will also lead to reducing the financial burden of the patient's family. In other words, increasing patient satisfaction leads to reducing the social cost.

Each patient agent has the 11 observed variables as "expectation variables," and these variables are related with each other. Each doctor agent has "ability variables," which are at the same time "perception variables" for the patient agent. If the doctor's professional ability exceed a patient agent's expectation, patient satisfaction is improved. Furthermore, the change of a variable results in alteration of the other variables.

The financial and mental burdens of a patient's family (the social cost) are calculated as follows. If a patient cannot pay her medical fees, the patient's family must pay all of, or shortfalls in, those medical expenses. The mental burden of the patient's family is associated with the patient's satisfaction. The cost is defined as the reciprocal of total patient satisfaction.

According to [10], total patient satisfaction is calculated as follows. Technique, attitude, and logic are three potential factors (out of the four).

```
Function satisfy (technique as double, attitude as
double, logic as double) as double
{
    Dim z as double
    Dim b as double
    Dim a as double

    //The Effect for Satisfaction
    a = technique * 0.673 + attitude * 0.228
    + logic *  0.358
    b = logic * 0.199
    z = a * 0.827 + b
    Return (z)
}
```

[8]According to [10], the goodness-of-fit index (GFI) is 0.861 and the adjusted goodness-of-fit index (AGFI) is 0.781.

Each doctor agent and patient agent has the 11 observed variables described earlier. These variables randomly vary across the simulation steps. Their average is 0 and their standard deviation is 1. For example, if a patient agent's expectation variable "reliability" is lower than that of the doctor's, the function "satisfy" is expressed as satisfy (0.856, 0, 0). The other three potential factors and the 11 observed variables are similarly combined and added up. Because the resultant value is computed by multiplying decimal numbers, it is magnified one hundred times.

## 13.3 Simulation Settings

In our simulation model the number of patient agents is 1,000. The number of patient family agents is apportioned to each patient agent according to the average number of people per family (average = 2.62, standard deviation = 2) in Japan.[9] If the number of the patient family agent is below one, the patient agent is a home-aloner agent. The number of doctor agents is set at 12 as a trial.

We carried out the above simulation for three models, conducting one-hundred-times simulations. In each model the number of simulation steps was 600. As shown in Table 13.1, in Model 1 there is neither family support nor government health care resources to distribute to patients.[10] In Model 2 there is only family support. In Model 3 there are both government health care resources and family support.

We were able to ascertain the differences in patient satisfaction, in the burdens of family members, and in the amount of government health care resources in each model.[11]

**Table 13.1** Summary of each model

| | Family support | Health care resources |
|---|---|---|
| Model 1 | | |
| Model 2 | √ | |
| Model 3 | √ | √ |

[9]The average number of people per family is based on [17, p. 3].

[10]In order to analyze the rate of decrease in health care resources in our other models, we implement the mechanism of a government health care system in Models 1 and 2, although in these models no government health care resources are distributed to patients.

[11]In our simulation model we use artisoc 3.0, which is produced by Kozo Keikaku Engineering, Inc.

## 13.4 Simulation Results

### *13.4.1 Basic Simulation*

The simulation results are shown in Table 13.2 and the increase-decrease rate of each scale is shown in Table 13.3. As these tables show, with the introduction of family support the average patient satisfaction (through all steps) is increased by 71.4% compared with that of Model 1. At the same time, it drives up the social cost (comparing Model 2 with Model 1). When government health care resources are introduced, average patient satisfaction (through all steps) is increased by 16.7%. On the other hand, we see that the social cost in Model 3 is slightly lower than in Model 2 (by −1.1%), and that government health care resources in Model 3 are nearly 40% lower than those given in Model 2.

Note that, in a Model 1 scenario, patients unable to pay out-of-pocket medical costs cannot be under the care of a doctor, because of the absence of both family support and government health care resources. In a Model 2 scenario, some patients, especially live-alone agents, cannot be treated until full recovery, because they cannot get support from their family. In a Model 3 scenario, patients who cannot receive adequate treatment in Models 1 and 2 are given adequate treatment. The social cost is offset by government health care resources to some extent, but the degree of reduced health care resources is exceptionally high.

From Table 13.2 it would seem that there is little difference between the average patient satisfaction (through all steps) in Model 2 and that in Model 3. However, as shown in Fig. 13.3, the difference between the maximum value of the step-by-step average patient satisfaction in Models 2 and 3 is very high.

**Table 13.2** Simulation results

| | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| Average patient satisfaction (through all steps) | 0.70 | 1.20 | 1.40 |
| Social cost (unit: 10,000 yen) | 0.000 | 1,142.469 | 1,130.465 |
| Health care resources (unit: 10,000 yen) | 48,440.567 | 48,376.330 | 29,238.571 |

**Table 13.3** Increase-decrease rate of each scale

| | Model 1 to Model 2 | Model 2 to Model 3 |
|---|---|---|
| Average patient satisfaction (through all STEPS) | 71.4% | 16.7% |
| Social cost (unit: 10,000 yen) | – | −1.1% |
| Health care resources (unit: 10,000 yen) | −0.1% | −39.6% |

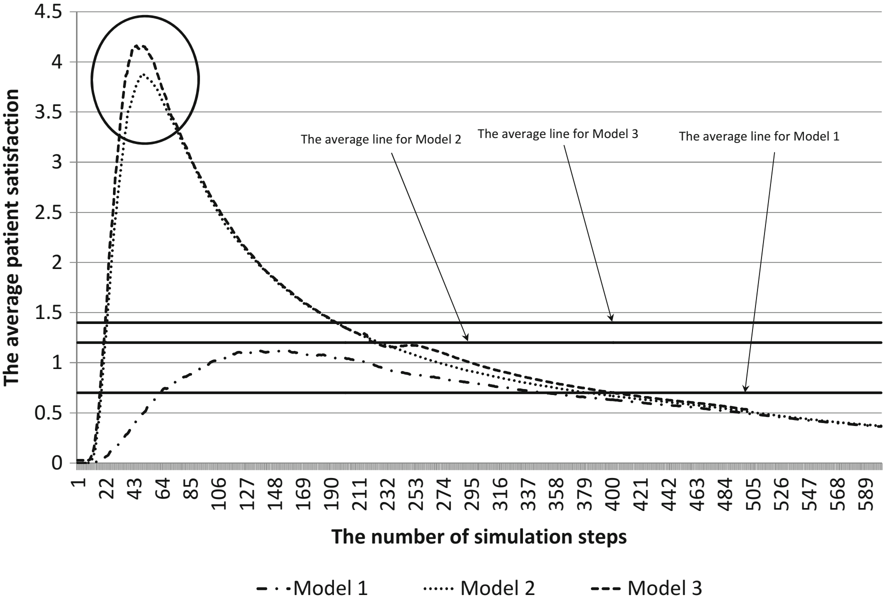


**Fig. 13.3** The time series variation of average patient satisfaction and its average line through all steps

## *13.4.2 Additional Simulation*

### 13.4.2.1 The Effect of Including NPO Agents

From the results of our simulation we conclude that a part of health care resources for treatment of a patient should be distributed to the patient's family to keep down the social cost. From Tables 13.2 and 13.3 we see that the difference between Model 2 and Model 3 in our simulation results is that social cost is offset by government health care resources to a small extent and that the degree of reduced health care resources is exceptionally high in Model 3. Given such findings, it is imperative to look for some kind of equilibrium point for cost-effective medical care that is based on an agent-based simulation model. A further direction of our study would be to build mechanisms (such as smoothing community relations) and to include other types of agents, such as nonprofit organizations (NPOs), into our simulation model, to serve as a basis for simulating the effect of interventions that minimize social cost.

We have thus decided to implement a simulation model (Model 4) with NPO agents that will help a patient's family. Eventually they minimize the social cost for the patient's family. When the patient's family agent has a link with an NPO agent, the family's mental burden is reduced. The government agent will release the resources needed for NPO agents' activities, and NPO agents will use money earmarked for their activities. The amount will be a percentage of the health care resources paid to patients in Model 3.

In addition, the intensity of an NPO agent's activity will change in proportion to the amount of funding received. We look at percentages of health care funding ranging between 10 and 40%.

The number of NPO agents is fixed at 50.[12] The budget allotment to an NPO agent is approximately 190 million yen, which is calculated from the average health care funding shown in Model 2 minus that in Model 3 (see Table 13.2). This is then multiplied by the percentage of health care funding mentioned above.

In addition to Model 4, we implement Model 5, which differs from Model 4 only in that the NPO agents take action voluntarily and do not receive government health care funding.

From the simulation results for these models shown in Table 13.4, we see that there is little difference between the average patient satisfaction in Model 3 and that in Model 4. When the percentage of health care funding distribution to NPO agents is 40%, a drastic change occurs: the social cost decreases dramatically. However, although a certain amount of health care funds is redistributed to NPO agents, the funding average is slightly reduced in Model 4. The reason for this is that patients receiving medical assistance have their benefits reduced at a constant rate; since they receive medical assistance more frequently in Model 4, their health care funding is reduced.

Compared with the health care funding in Model 3, that in Model 5 remains virtually unchanged. A percentage of health care funds allocated to an NPO agent in Model 4 can be compensated for by the organizational maturity of the NPO agent in Model 5. The declining rates of social cost seen in Model 5 depend on the intensity of an NPO agent's activity; a high level of organizational maturity drastically reduces social cost and results in a more cost-effective approach than that of Model 4. It can be said that creating conditions in which NPO agents can improve their performance and develop greater autonomy is desirable.

#### 13.4.2.2 Our Simulation's Correspondence with Reality

Now let us look at how our simulation model corresponds with the real world in Japan.

Since 1961 there has been a universal health insurance system in Japan, according to which, when people become sick, they usually go to a hospital and pay 30% of hospital expenses, with the rest being covered by "Health Insurance." So, in a simulation model adapted to suit what happens in Japan, patient agents first expect to receive health care from the government. Next, patient agents and

[12] In 2009 the average number of hospitals per a population of 100,000 was 6.9; on the other hand, the average number of NPOs per a population of 100,000 was 31.3. These numbers are published by each of the administrative districts of Japan. See, for example, the websites of [18] and [19].

**Table 13.4** The effect of including NPO agents

| | Model 3 | Model 4 | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | The percentage of funding distribution to each NPO | | | | | | |
| | | 10% | 15% | 20% | 25% | 30% | 35% | 40% |
| Average patient satisfaction (through all steps) | 1.40 | 1.39 | 1.40 | 1.39 | 1.42 | 1.40 | 1.40 | 1.40 |
| Social cost (unit: 10,000 yen) | 1,130.465 | 1,146.8433 | 1,130.6830 | 1,072.2897 | 1,025.2556 | 921.9023 | 841.1741 | 496.0975 |
| Health care funding (unit: 10,000 yen) | 29,238.571 | 28,407.973 | 27,308.359 | 26,428.145 | 25,771.625 | 21,199.159 | 22,550.839 | 23,035.060 |
| | | Model 5 | | | | | | |
| | | 1.40 | 1.37 | 1.40 | 1.38 | 1.40 | 1.41 | 1.42 |
| | | 1,150.780 | 1,138.0328 | 1,095.5390 | 1,072.8579 | 923.6590 | 836.3567 | 467.5582 |
| | | 28,467.097 | 31,030.115 | 29,118.527 | 32,185.348 | 29,415.603 | 29,213.902 | 29,861.349 |

**Table 13.5** Comparison of the results of Model 2 and Model 6

| | Model 2 | Model 6 |
|---|---|---|
| Average patient satisfaction (through all steps) | 1.20 | 1.39 |
| Social cost (unit: 10,000 yen) | 1,142.469 | 475.651 |
| Health care funding (unit: 10,000 yen) | 48,376.330 | 27,956.393 |

their family agents seek help from NPO agents. Last of all, patient agents ask their families for assistance. The results of this simulation model, Model 6, are shown in Table 13.5, where they are compared with the results from Model 2.[13]

From Table 13.5, and comparing it with Table 13.4, we see that in Model 6 average patient satisfaction is slightly lower than in Models 4 and 5. Looking at social cost in Model 6, we see that it is at a level seen in Models 4 and 5. Health care funding, however, is slightly lower in Model 6 than it is in the other two models.

Health care funding is slightly lower because all patient agents, even low-income ones, can first receive health care from the government. However, though almost all patients receive medical services, this fact does not necessarily raise patient agents' satisfaction; the degree of patient satisfaction is not connected with the order in which patients receive health care services. This may explain why average patient satisfaction is at the same level as in Models 4 and 5. After the initial visit to a hospital, before a heavy burden is imposed on patient family agents, patients and their family members may seek help from NPO agents. Note, too, that social cost is at a level close to those shown in Models 4 and 5. Hence, on the basis of our simulation results, it can be said that conditions conducive to improving NPO agents' performance and helping them develop autonomy are desirable in the context of prevailing health care. It is important that an appropriate subset of health care policies be implemented.

## 13.5 Conclusion and Future Work

From the preceding discussion we can conclude that family support, which entails a high social cost, strongly raises patient satisfaction. However, even if government health care resources are introduced, social cost does not necessarily decrease by much. The results derived from our simulation suggest a need for interventions that minimize the social costs for patients' families. There are many different methods to minimize social cost for a patient's family; for example, smoothing community relations or building a system in which local citizens and NPOs participate willingly.

In addition, we presented a simulation model that takes into account the preferences or choices of an individual patient and/or the patient's family in real life. That is, individual patients first seek to receive health care from the government.

[13]Model 6 is based on Model 4. The number of simulation times is 10.

Then they and their family agents seek some help from NPO agents. Last of all, the patient agents seek assistance from their families. Our simulation results suggest that, in the context of health care as it exists in Japan, conditions need to be created that will improve NPO performance and develop NPO autonomy. For this to happen, an appropriate subset of health care policies must be implemented.

The simulation model used in our study is a very simple agent-to-agent network model. It would be better if we could indicate in our model actual relations among patients, patient families, and doctors; for example, many patients might actually be isolated from any relatives. Also, in our study no statistical test is performed. Our simulation model is still an experimental model, and the amount of data obtained from the simulation is small. Therefore, we hope to develop our model further and obtain enough data so that we can apply statistical methods to test the differences in each model. In addition, a continuous examination and refinement of the patient satisfaction scale would strengthen the proposition set forth in this chapter.

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# Chapter 14
# Complex Evolutionary Pathways in Interacting Linguistic Communities

**Ioannis Vagias and Elpida Tzafestas**

**Abstract** We experiment with a linguistic change mechanism in a community of interacting agents and show the various phenomena that may emerge under different social constraints. We assume phonological and lexical learning and a semantic reference to external objects in the environment. Distinct groups of agents with initially different languages converge to a common language, with the relevant frequency of inter-agent interactions controlling which language dominates. Moreover, an initially monolingual community diverges due to social factors creating agent grouping, where agents interact more frequently with members of the same group. Additional cognitive features, like innovation and attention, lead to increased linguistic divergence between groups and word bistability. Finally, cultural learning leads to continuous linguistic change and occasional coexistence of multiple words, as well as revival of rare words. Overall, it appears that the initial community may evolve in arbitrary directions, and languages may dynamically form, split, mutate, and oscillate.

**Keywords** Language evolution • Multi-agent simulation

## 14.1 Introduction

The simulated evolution of language is concerned with understanding, among other things, the factors and the evolutionary forces that are responsible for the appearance of human language as well as for the dynamics of language change at the macro or population level [20]. Studies in the simulated evolution of language borrow the methodological concepts and tools that have been developed for the study of

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biological evolution[11, 18]. Thus the simulated evolution of language concerns issues such as the direction of language change, the sources of linguistic variation, the environmental pressure that biases and directs certain developments, and the evolution of linguistic complexity [4, 14].

The issue of linguistic complexity is not consensual by far. First of all, there exist many definitions of linguistic complexity and many debates over the role of typological comparison and criteria of judgement [13]. Linguistic complexity invariance has long been an axiomatic assumption in linguistics, but is now an object of serious doubt and refutation [7, 22]. Furthermore, unlike the biological domain, there is not a common linguistic ancestor or a proto-language that all or most linguists agree on [8]. One of the principal forces driving complexity change and linguistic evolution is proposed to be population and language contact [10, 12]. A study of language change dynamics and linguistic complexity could shed more light on issues such as linguistic speciation and the role of emergence of syntax or grammar. A number of theoretical proposals have appeared that discuss and relate language evolution, language change, and interaction or contact [6, 17, 21]. Phenomena of language change via population contact have also been studied with agent-based simulation. For example, Satterfield [23] has tested the hypothesis of incomplete second language learning in a creole environment, Beltran et al. [2] have studied language shift from a subordinate to a dominant language, and Castelló et al. [5] study bilingualism and linguistic competition in a social network.

Another domain in the simulated evolution of language is inspired by Wittgenstein's view that language is inseparable from its usage [3, 29]. Based on Wittgenstein's notion of language games, Parisi [19] describes several multi-agent simulations that demonstrate how linguistic forms are used by a population of individuals. A variety of models also exist in the literature, each one implementing a different computational technique that achieves success in language games or other basic cognitive games (for example, discrimination games). Steels views language as a complex adaptive system [26] and builds a model that implements a positive feedback loop between language use and success in use, leading to self-organized lexicons that are coherent among a population of agents [24, 25]. Other studies are concerned with the transmission of language between and/or within generations of speakers [1, 15].

We construct a model of language change that, first, combines both a lexical level (as in [2, 5]) and a phonological level (as in [16]) so as to have a more realistic two-factor device than the simple monofactor lexical one, and, second, is implemented in a general interaction context where many social configurations are available. Table 14.1 compares the features of the proposed model with some models found in the literature.

We perform experiments with a population of agents of a single or two distinct initial linguistic origins to capture different dynamics of interaction. One of our medium-term goals is to examine whether linguistic complexity may move in any direction from a certain starting point and under which circumstances. In what follows, we examine a few simple population scenarios that show linguistic convergence as well as differentiation, linguistic dominance as well as linguistic

**Table 14.1** Comparative presentation of various models

| Models | Lexicon | Grammar | Phonology | Scope |
|---|---|---|---|---|
| Beltran et al. [2] | N | N | N | Language shift in bilingual communities |
| Satterfield [23] | Y | Y | N | Pidgin genesis in multilingual communities |
| Oudeyer [16] | N | N | Y | Phonetic self-organization |
| Our model | Y | N | Y | Linguistic convergence, differentiation and innovation |

mix, linguistic innovation, and continuous linguistic learning through cultural learning. All of these phenomena constitute landmark demonstrations of a bottom-up evolutionary process applied to the non-biological domain of language. All are also, by definition, complex phenomena, since their appearance cannot be predicted on the basis of the initial conditions of the population, but rather they constitute the contingent outcome of continuous social interaction. This way, the presented mechanism of linguistic change may serve as the basis of more situated work in historical linguistics and sociolinguistics and of more theoretical work in linguistic change and speciation. Although the language model is fairly primitive and lacks grammar, it succeeds in reproducing the phenomena of linguistic convergence, dominance, pluralism, etc.

In Sect. 14.2, we present the linguistic model and explain its function. In Sect. 14.3, we describe the simulation, and in Sect. 14.4 we present the experiments and discuss the results. In Sect. 14.5 we conclude the chapter and give some directions of future research.

## 14.2 Expanded and Revised Model of Language Change

In our previous work we have experimented with a fundamental model of linguistic change at a double level, phonological and lexical, and we have identified the cognitive and social parameters responsible for linguistic convergence in various environments [28]. In that model, the linguistic interactions were devoid of any external reference or other meaning, so as to isolate the effects of the various parameters studied. We expand this model of language change with the introduction of semantics to allow direct connection of uttered words to stable external references so as to be able to derive more meaningful conclusions. We also apply some changes to the core of the model, in order to make it clearer and more stable. In our language change expanded model a population of agents of N types (typically two: type0, and type1), participates in M types of social activities (typically three: activity0, activity1, activity2) and uses K types of objects (typically three: object0, object1, object2). All agents are equipped with a language device composed of a phonological and a lexical module as in the original model.

### 14.2.1 The Artificial Language

The basic phonological unit of the language is the syllable, which is composed of two phonemes. The former distinction between vowels and consonants has been considered to be of no real use to the model, so it was removed. Each syllable has an id and a weight (a real number from 0 to 1, which is called *PhonoStrength*) which represents the probability that the specific phoneme combination exists in the language. We introduce the concept of a neighborhood of syllables via a neighborhood factor: a value which describes how close a syllable is to another syllable, and is defined as

$$nf = 1 - d/D \tag{14.1}$$

where d is the distance of the ids of the two syllables and D is the maximum distance between the ids. So, two syllables are neighbors if their neighborhood factor exceeds a predefined threshold (*NThresh*). A word is composed of one or more syllables, and is associated with each object through a weight called *ObjStrength*, which is a real number from 0 to 1. Every agent comes with a predefined size lexicon (*LexiconSize*), which may grow and shrink during interaction.

### 14.2.2 Social Activities and Agent Interaction

In the experiments reported later, the social activities are defined as: type0-only, type1-mandatory, and type1-free, where the participation of type1 agents is forbidden, mandatory, and voluntary, respectively.

When an agent is selected as speaker, first an object is selected at random and then a word from the agent's lexicon is selected, also at random. If the selected word's *ObjStrength* for the selected object is greater than a predefined threshold (*LThresh*) and its *PhonoStrength* is greater than a predefined threshold (*PThresh*), then it is fed as input to all the other agents who participate in the activity (listeners), and lexical learning takes place (see below). If not, another word is selected at random and is checked as above. If no word can be found that fulfills the above criteria, a new round takes place where the agent decreases in turn the thresholds *PThresh* and *LThresh* and starts over.

A listener executes in two steps: First, for each syllable of the input it checks if the *PhonoStrength* of the syllable exceeds *PThresh*. If it does, the syllable is selected; otherwise, a search for the fittest neighbor (the closest neighbor whose *PhonoStrength* is greater than the threshold) is performed. Phonological learning (see below) takes place only if such a search is performed. Secondly, a search for the processed phonological input (perceivedWord) is performed in the lexicon, and if it is not found, it is added (with *ObjStrength* $= 0$ for all objects). Lexical learning is performed to learn the word that was either found or just added.

**Table 14.2** Algorithm for the simulation cycle

```
random selection of activity
random selection of participants, based on activity rules
random selection of speakers from the participants
for the number of speech acts do
    word = speakers[i].speak(object)
    for the number of participants do
        if (j ≠ 1) then
            for Intensity do
                participant[j].listen(word,object)
            end for
        end if
    end for
end for
```

**Table 14.3** Algorithm for the speaker

```
procedure speak(object)
word=selectWord(LThresh, PThresh, object, "LThresh")
//
function selectWord(LThresh, PThresh, object, lastDecreased)
for 1000 times do
    if (ObjStrength[randomWord, object] > LThresh AND randomWord.
    PhonoStrength > PThresh) then
        selectedWord=randomWord
    end if
end for
if (selectedWord = null) then
    recursionsCount++
    if (lastDecreased = "LThresh") then
        selectedWord(LThresh, PThresh-0.1, object, "PThresh")
    else
        selectedWord(LThresh-0.1, PThresh, object, "LThresh")
    end if
end if
if (recursionsCount > 1) then
    executePLearning(selectedWord)
end if
```

An additional parameter called *Intensity* of interaction [9] controls the number of interactions between speaker and listener at each encounter and may vary for speakers of different type or even for different individuals. The *Intensity* of interaction may be thought of as the amount of attention an agent gives the speaker during interaction and corresponds to perceptual-processing speed of the linguistic imitation device. A more attentive agent is thus an agent that practically learns faster. Tables 14.2, 14.3 and 14.4 give the pseudocode of the algorithm for a simulation cycle.

**Table 14.4** Algorithm for the listener

```
procedure listen(phonoInput, object)
// step1 : phonological processing
for each syllable in phonoInput do
    if (syllable.PhonoStrength > PThresh) then
        perceivedWord.Syllables.Add(syllable)
    else
        newSyllable =getFitterNeighbour(syllable)
    end if
    //phonological learning
    if (newSyllable ≠ syllable) then
        executePLearning(newsyllable)
    end if
    perceivedWord.Syllables.Add(newsyllable)
end for
// step2 : lexical processing
executeLLearning(perceivedWord, object)
//
function getFitterNeighbour(syllable)
maxstrength=-1
for each syl in SyllablesList do
    if (syl.PhonoStrength > PThresh AND syl.PhonoStrength > maxStrength)
    then
        if (NeighbourMatrix[syllable, syl] > NThresh) then
            maxStrength=syl.PhonoStrength
            returnSyllable=syl
        end if
    end if
end for
return returnSyllable
```

### *14.2.3 Learning Mechanisms*

Lexical learning is accomplished by increasing *ObjStrength* of the target word for the specific object by a predefined value (*LRate*) and by decreasing the *ObjStrength* of the other words for the same object, and of the other objects for the specific word by another predefined value (*LInRate*).

Phonological learning is accomplished by increasing the *PhonoStrength* of all syllables of the phonological input by a predefined value (*PRate*), and by decreasing its neighbors' *PhonoStrength* by a predefined value (*PInRate*). Table 14.5 summarizes the model parameters.

## 14.3 Simulation Setup

In the experiments that follow, we use languages that are either created at random, or loaded from a previously saved simulation. There is a standard phonetic syllable alphabet, which is used as the base for all the languages created and tested.

**Table 14.5** Model parameters

| Parameter name | Explanation | Value |
|---|---|---|
| PopulationSize | Total number of agents | Default = 20 |
| Perc0 | Percentage of type0 agents | Variable |
| TotalSteps | Total number of simulation cycles = duration of the simulation run | Variable |
| LRate | Amount to add to the contextStrength of word to be learned (dominant) | Default = 0.02 |
| LInRate | Amount to subtract from contextStrength of competitive words (subordinate) | Default = 0.01 |
| PRate | Amount to add to the phonologicalStrenth of the phonetic combination to be learned | Default = 0.02 |
| PInRate | Amount to subtract from the phonologicalStrength of the competitive phonetic combinations | Default = 0.01 |
| PThresh | Phonological threshold | Default = 0.6 |
| LThresh | Lexical threshold | Default = 0.6 |
| NThresh | Neighbor threshold | Default = 0.6 |
| Intensity | Number of interactions between speaker and listener at each encounter | Variable |
| MaximumAgents | The maximum number of participants in an activity | Variable |

First, each syllable is randomly assigned a *PhonoStrength* (value from 0 to 1). Next, words with syllables whose *PhonoStrength* exceeds the *PThresh* are randomly created. Finally, for each word and each object, a relation is created (*ObjStrength*) whose value is randomly initialized between 0 and 1. Each word also has a *PhonoStrength*, which is the average *PhonoStrength* of its syllables.

Activities are either created at random, or loaded from a previously saved simulation. An activity is characterized by its type and by the maximum number of participants (MaximumAgents). The actual number of participants can be lower, but is not allowed to be less than 2.

A simulation uses a newly created or loaded world (languages, activities, and agents) and executes for *TotalSteps* times. At each cycle an activity is selected at random, and is randomly assigned a number of agents (up to *MaximumAgents* for the selected activity) according to the activity's rules. Then, the number of speakers is randomly initialized with a value between 1 and the actual activity's number of agents. Next, for as many times as the number of speakers, an agent is selected at random to be the speaker and the rest of the agents act as listeners. Each listener executes n listening cycles, where n is the *Intensity* value the listener has for the speaker type.

## 14.4 Experiments

A typical experiment consists of several simulations using the same languages and variations of the model parameters. However, some parameters remained fixed across the experiments. Those were the parameters that guided the lexical and phonological learning process (by default $LRate = 0.02$, $LInRate = 0.01$, $PRate = 0.02$, $PInRate = 0.01$), the thresholds (by default $LThresh = 0.6$, $PThresh = 0.6$, $NThresh = 0.6$), and the $PopulationSize$ (= 20).

The initial languages used in the experiments reported below are given in Tables 14.6 and 14.7.

### *14.4.1 Linguistic Convergence and Dominance*

In accordance with the findings in our previous work [28], the outcome of the competition among the words of the different types of agents is determined by the relative frequency of the interactions between the corresponding agents. The dominant language is the one that is spoken more frequently. For runs long enough, all simulations converge to a stable state, where all the agents share a common vocabulary. Because the system incorporates some random elements (for example, the selection of the reference object for each speaker), the stable state is not always the same. So for the same languages, depending on the random object selection, different words may end up meaning the same objects in different simulations. But the dominant language (the one appearing as the ancestor of the final language or the one that is represented better than others in the final language) is always the same and does not depend on the random initial conditions, but as already stated, only on the relative frequency of interactions between the agents of different types.

**Table 14.6** Original lexicon for language0

| Word | Object | PhonoStrength | ObjStrength |
|---|---|---|---|
| gmtm | 0 | 0.727 | 0.319 |
| ziau | 0 | 0.721 | 0.607 |
| kmno | 0 | 0.860 | 0.131 |
| fpup | 0 | 0.821 | 0.973 |
| rsup | 0 | 0.765 | 0.901 |
| gmtm | 1 | 0.727 | 0.528 |
| ziau | 1 | 0.721 | 0.970 |
| kmno | 1 | 0.860 | 0.888 |
| fpup | 1 | 0.821 | 0.554 |
| rsup | 1 | 0.765 | 0.670 |
| gmtm | 2 | 0.727 | 0.251 |
| ziau | 2 | 0.721 | 0.438 |
| kmno | 2 | 0.860 | 0.514 |
| fpup | 2 | 0.821 | 0.538 |
| rsup | 2 | 0.765 | 0.803 |

**Table 14.7** Original lexicon for language1

| Word | Object | PhonoStrength | ObjStrength |
|---|---|---|---|
| rpsn | 0 | 0.777 | 0.172 |
| embk | 0 | 0.805 | 0.381 |
| upob | 0 | 0.808 | 0.901 |
| kenu | 0 | 0.708 | 0.984 |
| iuig | 0 | 0.935 | 0.013 |
| rpsn | 1 | 0.777 | 0.193 |
| embk | 1 | 0.805 | 0.051 |
| upob | 1 | 0.808 | 0.465 |
| kenu | 1 | 0.708 | 0.839 |
| iuig | 1 | 0.935 | 0.695 |
| rpsn | 2 | 0.777 | 0.080 |
| embk | 2 | 0.805 | 0.356 |
| upob | 2 | 0.808 | 0.424 |
| kenu | 2 | 0.708 | 0.355 |
| iuig | 2 | 0.935 | 0.863 |

When agents are randomly assigned in each activity and *Intensity* of interaction is 1 for both types, the frequency of interactions is defined solely by the population composition. In a population with Perc0 $= 0.2$, all agents will interact approximately four times more with type1 agents than with type0 agents. As a consequence, the words of the resulting language will be closer, and in some cases directly copied, from the initial type1 language. Figure 14.1 shows the first 5,000 cycles of the simulation run (each chart shows the evolution in time (simulation cycles) of the *ObjStrength* of the words that were active (*ObjStrength* $>$ *LThresh*) for some time during the simulation. Each word has a suffix which represents its origin (for example, 0 for language0)). Many words are simultaneously present in the lexicon of both type0 and type1 agents, but some of them die out because of competition, and after about 1,500 cycles the agents become monolingual, that is, all type0 and type1 agents converge to the same words, occasionally slightly mutated.[1] (All the following results are indicative, taken from a single simulation, and should be interpreted conceptually. In all cases tested the simulations stabilize at some time.[2])

With an *Intensity* value relatively high for speakers of type0, and low for speakers of type1, the dominant language is type0, the one more frequently used. Figure 14.2 shows the results for *Intensity* $= 10$ for type0 speakers for all listeners and *Intensity* $= 1$ for type1 speakers for all listeners, in a population of *Perc0* $= 0.2$ (four times as many type1 agents), *TotalSteps* $= 2{,}000$.

[1]Mutations are introduced when the *PhonoStrength* of the perceived word is lower than *PThresh*, see Table 14.3.

[2]The actual time (number of steps) it takes for a simulation to stabilize depends on the initial languages and the interaction frequency.

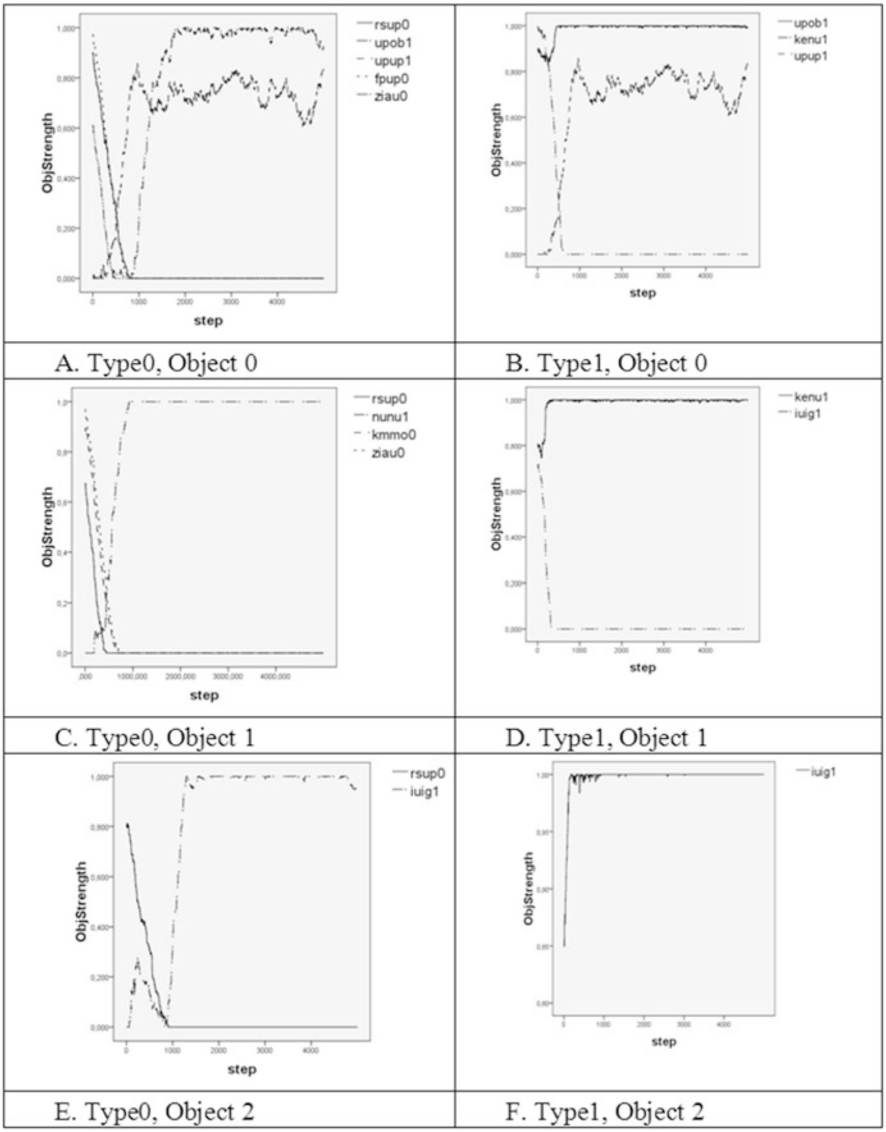



**Fig. 14.1** Average *ObjStrength* for words used by agents type0 (charts **A**, **C**, **E**) and type1 (charts **B**, **D**, **F**), for objects0 (charts **A**, **B**), 1 (charts **C**, **D**), and 2 (charts **E**, **F**), by number of cycles, for *TotalSteps* = 5,000, *Perc0* = 0.2, *Intensity* = 1 for all speakers. In all cases the winning word comes from type1 language, the language of the initial majority. Interestingly, for object0, agents' lexicon (chart **A**, **B**) contains two words: the type1 "upob", and its mutation "upup". For object1 the winner word is kenu for type1 agents and its mutation nunu for type0 agents. For object2 the winner word is iuig for agents of both types

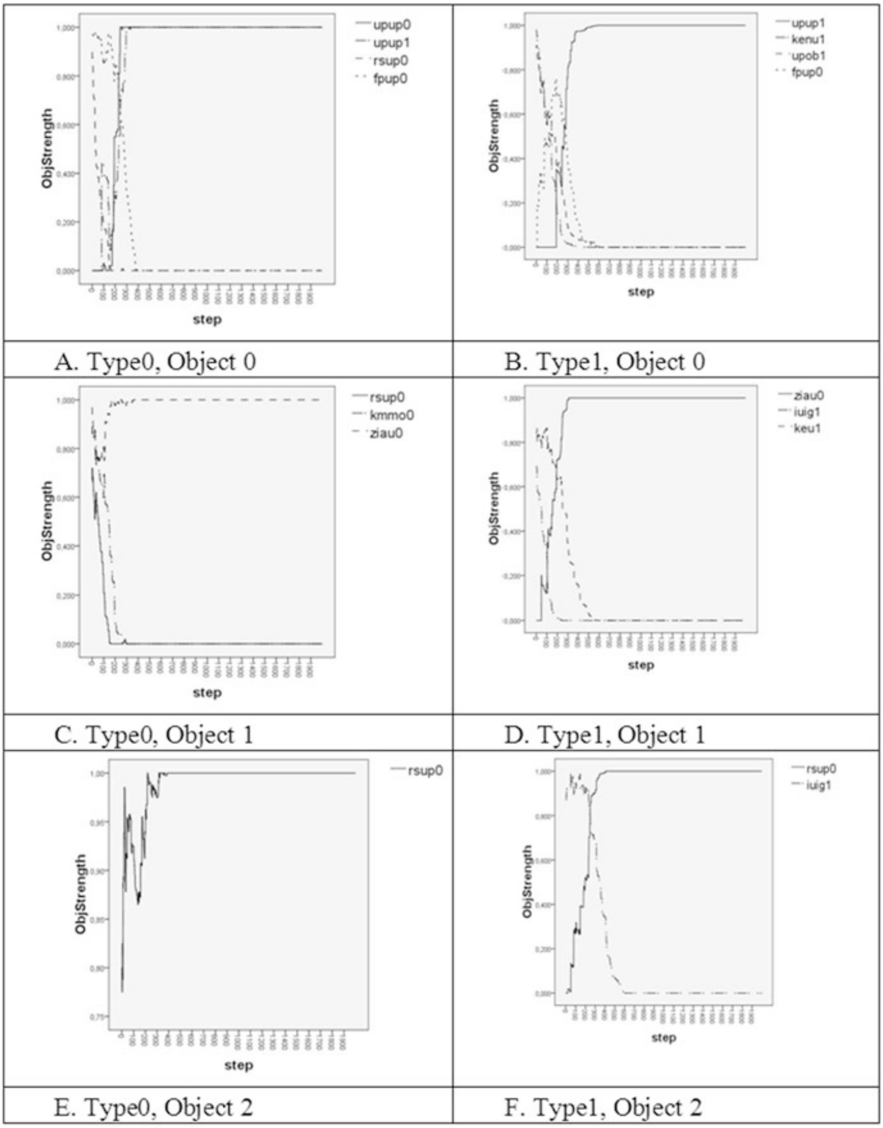



**Fig. 14.2** Average *ObjStrength* for words used by agents type0 (charts **A**, **C**, **E**) and type1 (charts **B**, **D**, **F**), for objects0 (charts **A**, **B**), 1 (charts **C**, **D**), and 2 (charts **E**, **F**), by number of cycles, for *TotalSteps* = 2,000, *Perc0* = 0.2, *Intensity* = 10 for type0 speakers and 1 for type1 speakers. In all cases the winning word comes from type0 language. Note that for object0 (charts **A**, **B**), the winner "upup" is a mutation that came up in both languages independently (type0 : "fpup" → "upup", type1: "upob" → "upup"). For object1 the winner word is "ziau" for agents of both types, and for object2 the winner is "rsup" also for both agent types

**Table 14.8** Final words for all objects for all social groups, *Intensity* = 10 for speakers of the same group and 1 for speakers of other groups and *TotalSteps* = 2,000

| Social group | Object0 | Object1 | Object2 |
|---|---|---|---|
| 0 | fpup | kmno | rsup |
| 1 | fpup | ziau | rsup |
| 2 | fpup | ziau | rsup |

Due to the formation of closed groups, the agents that belong to social group0 use the word "kmno" for object1, which is different from the word used by agents of social groups 0 and 2 (word "ziau")

In all the experiments so far, a community of linguistically interacting agents converges to the use of a specific lexicon, generally consisting of a single word per object. The final words thus obtained are derived directly or indirectly from the language that dominates in number of interactions per agent, either because of the population composition or because of increased levels of attention to and interaction with some speakers. However, the exact final set cannot be predicted from the outset, and the linguistic evolution may follow many different pathways that share only a high resemblance to the original theoretically dominant language.

## 14.4.2 Linguistic Split and Stabilization

In the next experiment we modified the model to reproduce a different scenario: that of a linguistic community whose members, due to different social influences, diverge and end up using different words for the same object. We thus introduce the concept of a social group within a linguistic community. In the following simulations there are three different social groups with each agent allowed to be a member of only one of them. We changed the three types of social activities accordingly to accommodate the social group concept. In the following simulations, there are three types of social activities: social group 0-only, social group 0-excluded, and all groups allowed. Furthermore, each agent has *Intensity* 10 for members of the same group, and 1 for members of other groups. The initial language is type0 from the preceding experiment (Sect. 14.4.1). Table 14.8 displays the final words that each group uses for each object at the end of a simulation with *TotalSteps* = 2,000 and group sizes = 7, 7, 6 for the three groups respectively. This experiment demonstrates that a linguistic community may not only converge to a common language, but may also sometimes differentiate in cases of constrained contact rates. This observation leads to two immediate conclusions: first, that variations and dialects of a language, thus linguistic subspecies, may emerge in specific microenvironments, and, second, that the mechanism allowing linguistic differentiation is the same used for linguistic convergence and general language learning. Therefore, linguistic speciation does not seem to need any special apparatus, other than the regular device used for language learning.

**Table 14.9** Algorithm for the speaker with the mutation function added

```
procedure speak(object)
word=selectWord(LThresh, PThresh, object, NThresh)
if (Innovation > IThresh) then
   mutate(word)
end if
executeLLearning(word, object)
//
procedure mutate(word)
if (RandomDouble > 0.5) then
   word.RandomSyllable=getFitterNeighbour(word.RandomSyllable)
end if
```

**Table 14.10** Final words for all objects for all social groups. *Intensity* = 10 for speakers of the same group and 1 for speakers of other groups, *IThresh* = 0.4, *Innovation* (random) pseudonormal with mean 0.5 and *TotalSteps* = 2,000

| Social group | Object0 | Object1 | Object2 |
|---|---|---|---|
| 0 | fpup | ziau | rsup |
| 1 | fpup | kmno | zdup |
| 2 | zdor | rsrs | rsor |

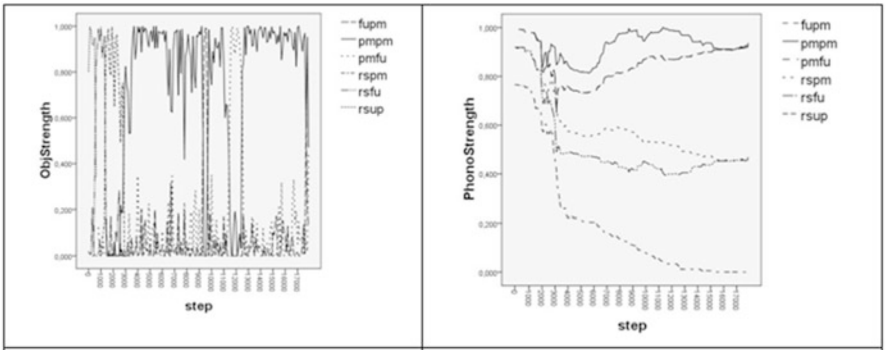
The groups diverge further, each one adopting its own mutated words for the majority of the cases

## *14.4.3 Linguistic Innovation*

In the next experiment, we introduce a new feature in the speaker's cognitive mechanism called word mutation, which can slightly change the spoken word. This feature is controlled by a new parameter called Innovation, and there is also a new threshold (*IThresh*), so that when Innovation is greater than *IThresh* the spoken word mutates with a probability of 0.5. The mutation is not random, but is guided by the same algorithm the listener uses to parse phonologically weak syllables (see Table 14.4). Table 14.9 displays the modified algorithm for the speaker.

With *IThresh* = 0.4 (default) and *Innovation* taking value from a pseudonormal distribution with mean = 0.5, each group adopts its own mutations, as is clear from Table 14.10, which displays the results of a simulation with the same configuration as in Sect. 14.4.2.

Figure 14.3 shows the evolution in time (computational cycles) of the lexicon in social group2, for object2 for *TotalSteps* = 18,000. It is immediately noticeable that there is continuous evolution, where the appearance of new winner words doesn't seem to stop. Furthermore, the results show that the divergence between the groups increases, as each group produces its own mutations, which spread among its members faster than among members of different groups. In large time-scale




| A. Social Group 2, Object 0, ObjStrength | B. Social Group 2, Object 0, PhonoStrength |
|---|---|

**Fig. 14.3** Average *ObjStrength* (chart **A**) and *PhonoStrength* (chart **B**) for words used by social group2 for object0, by number of cycles, for *TotalSteps* = 18,000, *Intensity* = 10 for speakers of the same group and 1 for speakers of other groups, and *Innovation* is (random) pseudonormal with mean 0.5 and *IThresh* = 0.4. At some point on, the system seems to switch between two words (and their mutations): "pmpm" and "fupm" (mutation "pmfu")

simulations, there seems to be a never-ending evolution where words continuously appear and disappear.

### 14.4.4 Linguistic Split and Convergence Controlled by Socio-Cognitive Factors

In the next experiment, we set up the simulation so that agents go through an attention shift at some point during the simulation. Thus, for *TotalSteps* = 10,000, *Intensity* takes the value 10 for speakers of the same social group, and 1 for speakers of a different social group for the first 5,000 cycles and the value 10 for speakers of social group0 and 1 for the other groups for the remaining cycles 5,000–10,000. Figure 14.4 shows the evolution in time of *ObjStrength* for object1 (for objects 0 and 2 there was early convergence in a common word for all groups).

The combined conclusions of possible linguistic convergence, differentiation, and mutation with one single mechanism may allow larger scale studies to be conducted, for example, to challenge some substrate approaches, because no substrate seems necessary to initially invent and later reinforce and share different linguistic subsets.

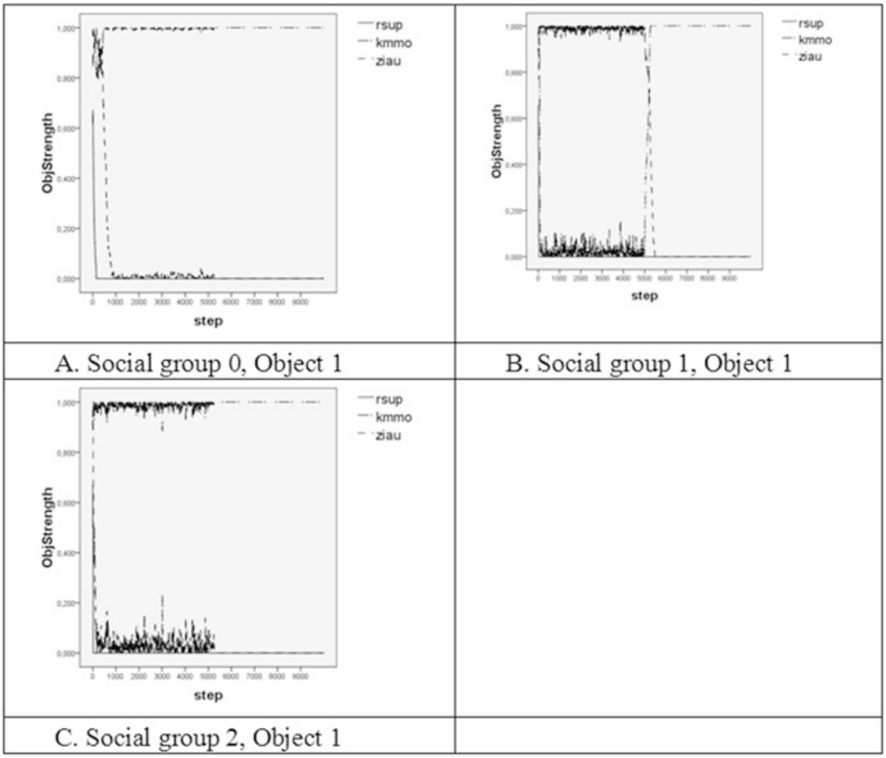



**Fig. 14.4** Average *ObjStrength* for words used by social groups0 (chart **A**), 1 (chart **B**), and 2 (chart **C**), for object1 by number of cycles, for *TotalSteps* = 10,000. Innovation = 0 and *Intensity* = 10 for speakers of the same group and 1 for speakers of the other groups for the first 5,000 cycles and *Intensity* = 10 for speakers of social group0 and 1 for speakers of the other groups. Social group1 splits and uses "ziau" for object1 for the first 5,000 cycles (chart **B**), but converges to "kmmo" soon after the attention shift to group0 speakers. Also the fluctuations that exist for the first 5,000 cycles stop, and the model completely stabilizes

### *14.4.5 Cultural Transmission of Language Between Generations*

In the final set of experiments we create a scenario of cultural transmission of the language between generations of agents. From time to time a newborn child is introduced in the population, i.e., an agent who has to learn the language by interacting with others in a pragmatic context [27].

To implement this, first the agents have to be modified in order to exhibit the feature of dying. We give them two new properties. The first one is called *age* and represents the age of the agent in simulation cycles. The second one, *maxAge*, represents the age at which the agent will die. At the end of each simulation cycle, all agents increase their *age* one unit and the agents whose *age* equals *maxAge* die.

For the new generation to emerge gradually, there is a *birth probability* (default = 0.2) that a child will be born at the end of each cycle. The newborn child will belong to one of the three social groups with equal chance. A child is a special kind of agent whose language device is not completely configured. Specifically, the lexicon is empty (the child knows no words) and all the *PhonoStrengths* are initialized to 0.65[3] (it shows no tendency towards any specific phonological combination). Its other socio-cognitive abilities are equivalent to those of an adult.

If there are no distinct social groups, there must be a balance between the birth rate and the interaction rate for the language to be successfully transmitted culturally; otherwise, the language is lost. In the following experiment the simulation starts with a monolingual adult population with children gradually added as explained before and no social groups. *Innovation* is pseudonormal with mean 0.5 and *IThresh* = 0.4. Figure 14.5 presents the evolution in time of the phObjStrength of the various words that were used for object2, with variable *intensity* values for children or adult speakers and variable *birth probability*. It is shown that attention to adults (which is represented in the *Intensity* parameter) has to be high enough with respect to the birth rate for the parent language to be passed on to subsequent generations.

In the case where social groups exist and even in the absence of adult-specific attention, a language can also be culturally transmitted, but many other intricacies arise as well. For example, in the next experiment the simulation starts with a monolingual population and three social groups. *Intensity* takes the value 10 for speakers of the same social group, and 1 for speakers of a different social group, *Innovation* is pseudonormal with mean 0.5, *IThresh* = 0.4, and *birth probability* = 0.2. Figure 14.6 shows the evolution in time of the *Sum of speakers* (the actual number of agents that use the specific word) and of *ObjStrength* for object2 and for social group2 for *TotalSteps* = 4,000.

The language is transmitted between the generations with no discontinuities, though it does not remain unchanged. There is a continuous evolution; several words coexist for one object, with some more persistent than others (for example, the words "rfaz" and "rpaz" last longer and are more widespread than "tata" or "pmif"). Analogous transitive phenomena are expected to arise when adult-specific attention coexists with group-specific attention.

## 14.5 Conclusion and Further Work

We presented a mechanism of phonological and lexical linguistic change in a community of interacting agents and have shown the various phenomena that may emerge under different social constraints. Distinct groups of agents that speak initially different languages and participate in different social activities may

[3] Which is above pThresh = 0.6.

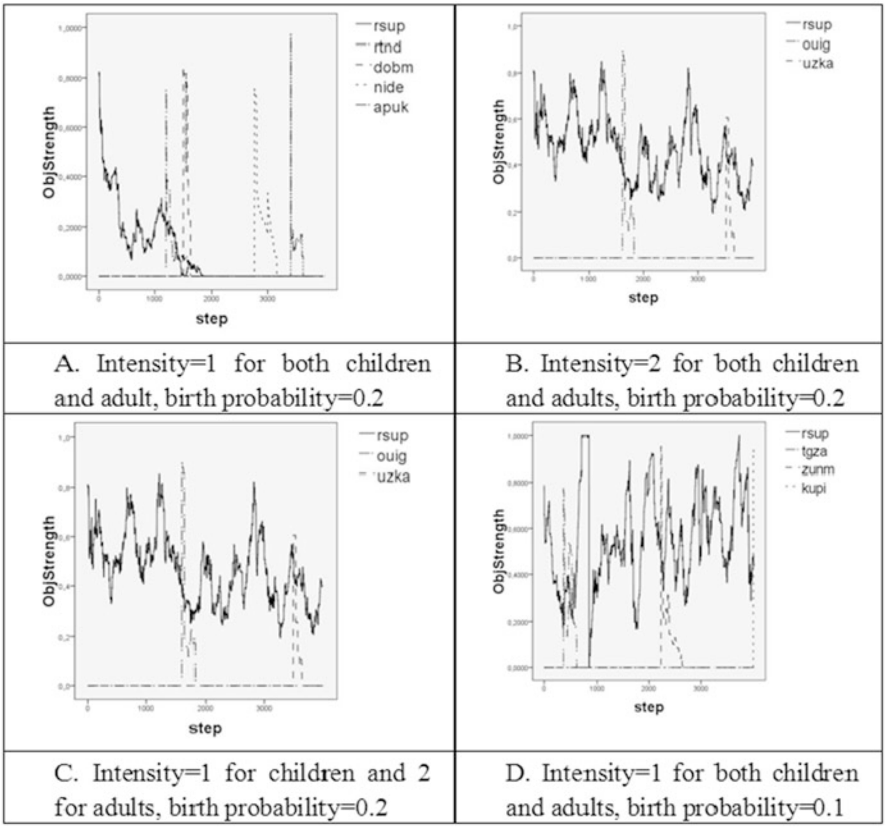



**Fig. 14.5** Average *ObjStrength* for words used for object2 by number of cycles, for *TotalSteps* = 4,000, *PopulationSize* = 20, *Intensity* = 1 for both children and adult speakers and *birth probability* = 0.2 (chart **A**), *Intensity* = 2 for both children and adult speakers and *birth probability* = 0.2 (chart **B**), *Intensity* = 1 for children and 2 for adult speakers and *birth probability* = 0.2 (chart **C**), and *Intensity* = 1 for children and 2 for adult speakers and *birth probability* = 0.1 (chart **D**). *Innovation* is (random) pseudonormal with mean 0.5 and *IThresh* = 0.4. In order for the language to be successfully transmitted between the generations (charts **B**, **C**, **D**), the *birth probability* cannot be too high in relation to the intensity, or the language is lost (chart **A**)

converge to a common language, where the relevant frequency of the interactions between agents of different types controls which parent language dominates the final population. On the other hand, an initially monolingual community splits to two or more groups in the presence of social factors that drive the agents to form closed groups, where the frequency of interaction is relatively higher between agents of the same group than between agents of different groups. Communities of agents equipped with an additional word mutation or innovation feature may exhibit increased linguistic divergence between the initial groups and bistability for dominant words. When a mechanism for cultural transmission of the language

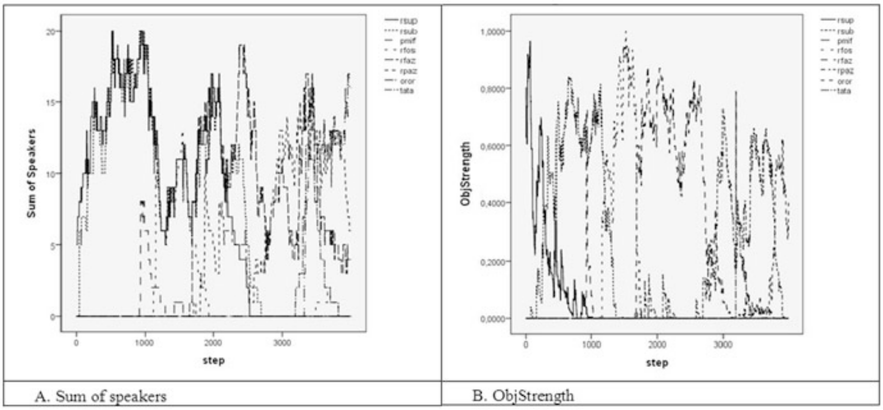



**Fig. 14.6** *Sum of speakers* (chart **A**) and *ObjStrength* (chart **B**) for words used by social group2 for object2 by number of cycles, for *TotalSteps* = 4,000, *PopulationSize* = 20, *Intensity* = 10 for speakers of the same group and 1 for speakers of other groups, *Innovation* is (random) pseudonormal with mean 0.5, *IThresh* = 0.4, and *birth probability* = 0.2. Notice that the persistent word "rpaz" exists together with the transient words "oror" and "tata"

between generations of agents is implemented, the transmission carries on without discontinuities, as long as the birth rate is balanced by the interactions rate, and there are cases where several words are used for the same object, but not all of them are equally frequent or widespread among the population.

Overall, it appears that this linguistic mechanism allows the evolution of an initial community in arbitrary directions and especially allows languages to dynamically form, split, and mutate, depending on the social constraints on interactions between agents as well as on atomic parameters, such as attention. Other intricate and dynamic external conditions or interactions with external populations may drive an initial homogeneous or heterogeneous population to form clusters, dialects, pidgin-like simpler languages, and so on. Thus, our study shows that it might suffice to attribute any linguistic feature to a specific history of past interactions rather than to a spurious and hard-to-justify construct such as a universal or a substrate. Although our study is confined to phonological and lexical change, there is no reason why the same conclusions would not hold for any other kind of change, especially grammatical change, provided that the change/learning mechanism is similar. More importantly, we have demonstrated that this wealth of complex phenomena can be obtained in the absence of complex linguistic structures, such as grammar, and in the absence of development of linguistic references to external objects or categories.

Apart from grammarization, other envisaged directions of future research that appear promising at this stage are the coupling of linguistic and exo-linguistic interactions that influence one another, such as general cultural interactions, and the introduction of personal or group factors that alter the usual language learning procedure, for example, when an individual or a population "resists" phonologically or when agents demonstrate extreme openness, and so on.

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# Chapter 15
# Socio-Cognitive Influences on Social Stratification

**Elpida Tzafestas**

**Abstract** We study a simple social competition mechanism and the effect of various cognitive variants on the emerging stratification structure. We depart from a basic mammal-inspired competition mechanism relying solely on physical strength and introduce a number of higher level cognitive parameters, especially individual imposition and submission factors that modulate the agents' decision to fight. The emerging structure is generally a society spread out in status range, without any obvious polarization. Next, the concept of a "stratification game" is introduced, where some fights are spontaneously resolved if differences between agents are mutually perceived as too large. Some game variants lead to fairly egalitarian societies, while others, based on withdrawal from fights, lead to extremely unequal societies. This property also holds in realistic competition environments involving resource sharing and task competition. Overall, our study shows how certain socio-cultural conventions may overtake cognitive factors and define the emerging social stratification outcome.

**Keywords** Cognitive adaptation • Dominance and submission • Neutrality • Perception of opponent • Sharing • Social conflict resolution • Social dependence of fight outcomes • Social stratification • Social stratification games

## 15.1 Introduction

Political theory is concerned with the power structures present in various historical periods and social environments. Every such power structure involves more or less well-defined relations between itself and the rest of the individuals, most of

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them having to do with obedience from the side of the individuals. Max Weber has theorized that no such relation may exist and be stable without a minimum of will for obedience, which may be a result of belief in the legitimacy of the power structure, of emotional factors, of attraction to a charismatic leader, and so on [1]. In the simplest of cases, such as tribal and clan power structures, it is generally accepted that leaders emerge out of competition between individuals, [2] and that this relation is put to test from time to time. In more complex societies with a multitude of occupational and other roles and more elaborate power structures, other stratification phenomena are generally observed, the two most prominent being the class hierarchy in western societies [3,4] and the caste hierarchy [5,6] in traditional Indian society. Apart from the obvious differences between them, many authors have claimed that class and caste are manifestations of a general stratification mechanism [7, 8] that tends to create hierarchies at the level of the individual, the group [9], or even within an industrial firm [10]. Stratification emerges out of some kind of competition, that may target resources, land, or symbolic power [2], and that depends on individuals' values, predispositions, and personalities [11], as well as on cultural values and processes [12]. In contrast, the egalitarian concept is sometimes deemed unnatural and hard to achieve and sustain, at least at a practical level [5] or within a free and uneven economy [9].

We adopt a holistic, systemic view of social interaction, and we explore a model of interaction that may induce stratified societies based on individuals' personalities and on the competition environment. More specifically, we want to challenge the common view that departs from a direct evolutionary hypothesis, namely that different types of stratification emerge as a result of interaction within specific competition environments. We rather believe that various stratification types may emerge as a result of particular participants' mindsets that may be cognitively defined or culturally transmitted. We therefore depart from a mammal-inspired competition model [13] and build our model by gradually integrating more advanced cognitive and cultural features that integrate both the "minimum will to obey" [1, 14] and the spontaneous urge toward neutrality, compassion, and peace [15, 16]. It is also expected that if stratification emerges within a society, it can spread and be reinforced in subsequent generations through group isolation and cultural learning [17].

A fundamental competition mechanism among mammals, but also among lower animals [13], is based on a notion of physical strength of individuals that comes into play during competition and is updated accordingly. Two agents are randomly selected from a population. The agents will interact if their strength exceeds a certain threshold and if their strength difference is not too big. Following these principles, the basic competition mechanism between two agents (agent-1 and agent-2) that interact is algorithmically implemented as follows:

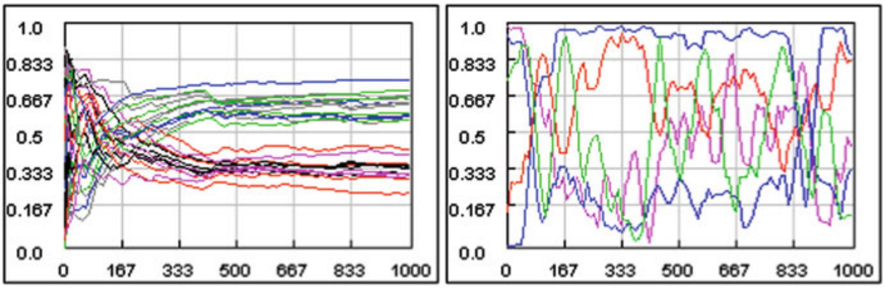


**Fig. 15.1** Experiment with 25 agents (500 interactions per cycle). (*Left*) Status graphs for all agents, where status is measured as the proportion of wins. *(Right)* Corresponding strength graphs for all agents (moving averages)

```
With a probability of interaction p = 1/((1-e^rs(1))x(1-e^rs(2))),
where rs(i) = k x strength(i) / threshold(i), (strength in [0,1])
      with k = 0.01, threshold(i) uniformly distributed in (0.05,0.3)
      (these parameters are chosen to reproduce the results of [13])
      With a probability q = strength(1) / (strength(1) + strength(2))
      Agent-1 wins, so agent-1 strength increases
            and agent-2 strength decreases
      Else agent-2 wins, so agent-1 strength decreases
            and agent-2 strength increases
```

The application of a probabilistic mode of interaction purports to capture the fact that two agents are more prone to compete and fight when their strength values are over a threshold and close to one another, whereas, for example, a very weak agent and a very strong one would be reluctant to fight, given the magnitude of difference between them. The status of an agent is defined as the proportion of wins throughout the experiment. Figure 15.1 gives the results of a system of 25 agents for 1,000 simulation cycles with 500 random pairwise interactions per cycle. The population converges quickly (after about 500 simulation cycles) to stable status values for all agents. In particular, this figure shows a permanent split of the population into two well-delimited subpopulations with comparable size, one of relatively high status and one of relatively low status. This is the less common of the two possible outcomes of such populations, the other being a final stable configuration where agents occupy a generally larger status range but without clear separation in high and low status groups. Moreover, the exact values of the final ranges are unpredictable in the beginning of the experiment; they appear to depend on the initial strength mix rather than on the exact interaction history, and they tend toward middle status. However, as Fig. 15.1 (right) shows, the strength values of agents are highly volatile, which appears in conflict with our everyday perception of social status. In reality, we would expect social conflicts to somehow depend on current social status as well. Furthermore, again from our everyday experience, we know that the personalities of any two people that interact heavily influence the outcome of the interaction. Especially in cases involving competition and/or fight, we know that self-perception and determination during interaction are important factors that count and may alter an initially expected social outcome.

The following table presents a number of parameters/processes introduced to make the model more cognitively realistic. Apart from the original brute-force model presented, these are studied in Sect. 15.2 except for the last one (SPO), which is studied in Sect. 15.3. Next, Sect. 15.4 gives the results of the application of the last model in more realistic social contexts. Section 15.5 concludes by discussing the results and providing some directions for future research.

| Type of parameter/process studied | Motivation |
|---|---|
| **Fight decision** | |
| Brute force only, original model (BF) | Physical strength or ability is the primary determinant of a fight outcome |
| Socially modulated fight (SM) | Physical strength or ability may be modulated by "cognitive" strength or fight propensity |
| Neutrality (NEU) | Individuals often opt for not fighting |
| Personalized behavioral ranges (PERS) | Upper/lower limits of strength or ability are also crucial |
| **Fight outcome** | |
| Socially dependent outcomes (SD) | Fight outcomes may be modulated by secondary features or current social status |
| **Advanced features** | |
| Perception of opponent (PO) | "Cognitive strength" of the opponent is invisible and has to be deduced |
| Cognitive adaptation (CA) | Cognitive strength is dynamic and depends on previous fight outcomes |
| Spontaneous social conflict resolution (SPO) | Fights and fight outcomes may be structured by biological evolution or by human reason |

## 15.2 Cognitive Model Dimensions

### *15.2.1 Strength-Only Versus Socially Modulated Fight*

The observation of the highly volatile strength values in the original strength-only model and the intuition of the need for the introduction of personality-level agent parameters lead us to introduce a cognitively flavored parameter, called the **imposition factor**, which stands for the **visible** strength of an agent, that is different from its actual physical strength. The imposition factor may also be thought of as corresponding to the degree of self-determination and self-confidence of agents. It is this factor that will be positively or negatively reinforced as a result of social fights, thus leaving room for individuals that have contingently risen to high status positions but may be actually weaker than others, and individuals that occupy lower status ranks despite high physical strength. We may also think of a second more elaborate model, based on both an imposition and a **submission factor**. The latter factor will be used when an agent is involved in an interaction with another agent that tries to dominate. The introduction of this factor stems from our everyday understanding of human behavior where some people may be both imposing toward lower status people and submissive toward higher status ones. We therefore modify the original model as follows:

```
On meeting agent-2, agent-1 computes the probabilities to dominate
and submit as           (impFactor in [0,1])
      p(dominate) = impFactor(1) x (1-impFactor(2)) and
      p(submit) = (1-impFactor(1)) x impFactor(2).
If p(dominate) >= p(submit), then it tries to dominate (*)
      With a probability q = strength(1) / (strength(1) + strength(2))
      Agent-1 dominates successfully, so agent-1 impFactor increases
            and agent-2 impFactor decreases
      Else agent-1 submits, so agent-1 impFactor decreases
            and agent-2 impFactor increases
Else it tries to submit (*)
      With a probability q = strength(2) / (strength(1) + strength(2))
      Agent-1 submits successfully, so agent-1 impFactor decreases
            and agent-2 impFactor increases
      Else agent-1 dominates, so agent-1 impFactor increases
            and agent-2 impFactor decreases
NOTE: For the two factor model we have   (submFactor in [0,1])
      p(dominate) = impFactor(1) x submFactor(2) and
      p(submit) = submFactor(1) x impFactor(2)
and factor change concerns only the factors used for decision:
If successful domination impFactor(1) and submFactor(2) both increase
      else impFactor(1) and submFactor(2) both decrease
If successful submission submFactor(1) and impFactor(2) both increase
      else submFactor(1) and impFactor(2) both decrease
(*)   in reality, each attempt to dominate or submit happens with
      probability p(dominate) or p(submit), respectively, otherwise
      the agent does nothing
```

Figures 15.2 and 15.3 give the results of the application of the two models in a system of 25 agents for 100 simulation cycles with 500 random pairwise interactions per cycle. Both models demonstrate a final stable social structure with homogeneous stratification spanning a large range of status values, with occasional agents having a very low or, more rarely, a very high status value. It has also been verified that high status agents are those having on average more dominations than submissions, and this corresponds to high imposition factors (coupled with low submission factors in the case of the two-factor model). The situation is the inverse in the case of low status agents. Another noteworthy result not visible in the figures is that the lower in the hierarchy an agent resides, the more fights it engages in. This is important because, if we assume that agents are engaged in social interactions, only

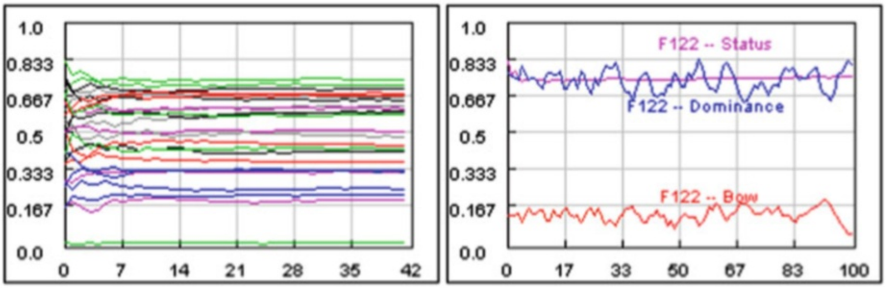


**Fig. 15.2** Experiment with 25 agents with the single-factor model (500 interactions per cycle). *(Left)* Status graphs for all agents. *(Right)* For a high status agent, the average number of domination cases is much higher than the average number of bow (submission) cases

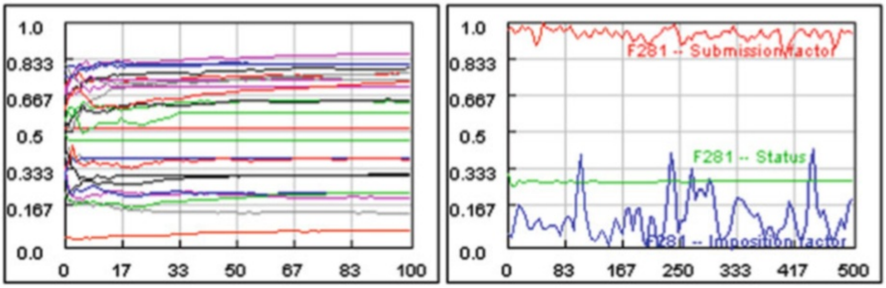


**Fig. 15.3** Experiment with 25 agents with the two-factor model (500 interactions per cycle). *(Left)* Status graphs for all agents. *(Right)* For a low status agent, the submission factor is of very high and the imposition factor of very low value. The situation is the inverse for high status agents

some of which may legally involve competition and fight, and given that agents' behavior is somehow uniform during their lifetime, then some agents may launch unnecessary fights out of inertia in other innocent social environments and thus behave aggressively or even criminally.

### *15.2.2 Neutrality*

To reduce the significant volatility of the imposition and submission factors and capture the usual intuition that people may withdraw from fights with others judged more or less equally strong, we modified the above models to include a neutrality feature, whereby if $|p(dominate) - p(submit)| < NeutralityThreshold$, the agents opt to do nothing instead of fighting. Figure 15.4 shows the results with a two-factor model and added neutrality. The status rise for some of the agents is much more impressive than in the previous models and may happen over a long time. The final status hierarchy may span an almost full range and show subranges

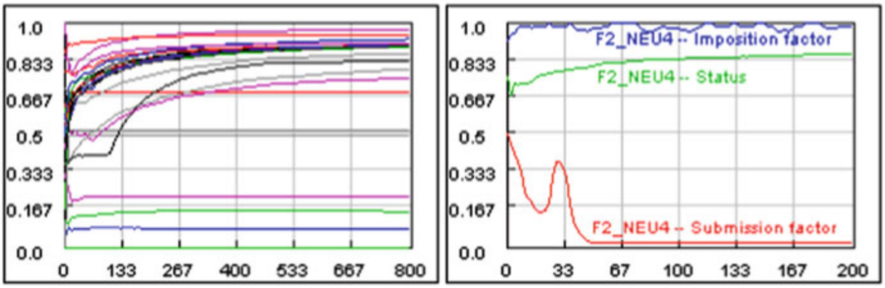


**Fig. 15.4** Experiment with 25 agents with the two-factor model and neutrality (500 interactions per cycle). *(Left)* Status graphs for all agents. *(Right)* For a typical high status agent, the submission and imposition factors have different dynamics than in the previous cases and stabilize to very low and very high values, respectively

of inhomogeneous density (like in Fig. 15.4, where a significant proportion of agents has a status over 0.66). Moreover, the exact history of interaction has a bigger influence on the final status of particular agents, so that a system rerun several times may show different final hierarchies, with the same agent occupying different final positions in each run.

### *15.2.3 Boundedness*

The preceding models suffer from unrealistic ranges for the submission and imposition factors (minimum = 0, maximum = 1). An imposition factor of 0 means that the corresponding probability will be 0 and the submission probability 1. This is unnatural and may be problematic. Moreover, the ranges are homogeneous, which is again likely unrealistic. We therefore introduce parameter boundedness in the models, where imposition and submission factors may not fall below a nonzero minimum or rise above a less-than-one maximum. We define two variants of the increase/decrease algorithms: **gradual bounding** (increase or decrease imposition factor by $Rate \times (NextImp - Imp)$, where `NextImp` is `MaxImp` or `MinImp`, respectively, and accordingly for the submission factor) and **bang-bang bounding** (increase or decrease of the imposition factor corresponds to setting it directly to `MaxImp` or `MinImp`, respectively, and accordingly for the submission factor). We have studied comparatively the regular unbounded and the two bounded models and have verified that boundedness reduces polarization in the strength-only model and status differences in the single- and two-factor models. For the rest, the stratification structure obtained remains qualitatively like the regular one, without parameter boundedness.

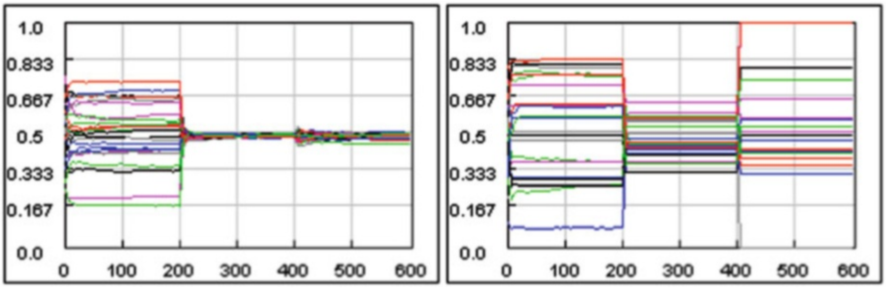


**Fig. 15.5** Comparative experiments with 25 agents with the variants of the single-factor model with neutrality (*left*, 2,000 interactions per cycle) and the two-factor model with neutrality (*right*, 3,000 interactions per cycle). Each figure shows all agents' status for three consecutive experiments of 200 cycles each with the same initial system: physical strength-dependent outcome, factor-modulated outcome, and outcome modulated by estimated status. All parameters are randomly initialized as in previous experiments

### *15.2.4 Socially Dependent Fight Outcomes*

It was already mentioned that the personalities of the two meeting partners influence the outcome of the interaction. The following experiment studies the case of fights whose outcomes are modulated by agents' imposition and/or submission factor or by their current status. In the first case, the relative strength of two agents that defines the probability of the first one being the winner, for a single-factor model, becomes

```
strength(1)*impFactor(1) /
    (strength(1)x impFactor(1) + strength(2) x (1-impFactor(2)))
```

In the second case, the relative strength is computed as

```
strength(1)*status(1) /
    (strength(1) x status(1) + strength(2) x (1-status(2)))
```

and the status of each agent is estimated by examining its last 20 interactions. Figure 15.5 gives comparative results for a single- and a two-factor model with neutrality in all three variants for the definition outcome of the interaction. Clearly, the single-factor model shows squeezing of the hierarchy toward a middle status with small deviations, whereas the two-factor model preserves the richness of the status set and may sometimes enhance status differentiation.

### *15.2.5 Perception of Opponent*

Another option comes from thinking that an agent actually does not have access to the true values of an opponent's imposition and submission factor, but rather continuously estimates them based on the interaction history. The following experiment

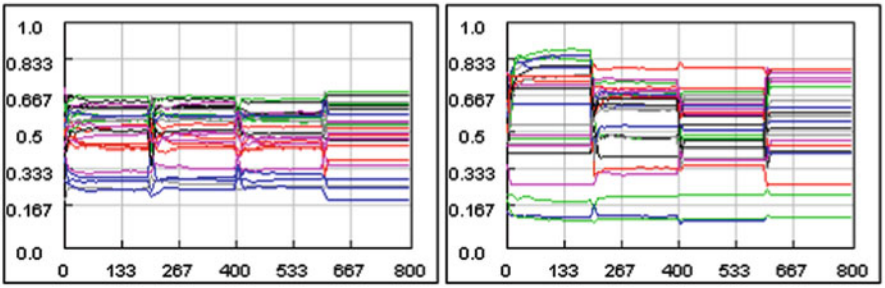


**Fig. 15.6** Comparative experiments with 25 agents with the variants of the single-factor model with neutrality (*left*, 2,000 interactions per cycle) and the two-factor model with neutrality (*right*, 3,000 interactions per cycle). Each figure shows all agents' status for four consecutive experiments of 200 cycles each with the same initial system: absolute opponent perception model, true opponent status-based model, latest opponent status-based model, and estimated opponent status-based model. All parameters are randomly initialized as in previous experiments

studies the case of fights where an agent estimates its opponent's imposition and submission factors by using the true status value, or the estimated status value as in the previous subsection, or an estimate of the status according to its own last interactions with the target agent and not according to the hardly accessible full interaction history. As Fig. 15.6 shows, all three variants give comparable results, which is a relieving observation, because it allows us to safely use the simpler absolute perception model instead of any of the more realistic models for perception of the opponent.

From the experiments so far, we should retain that ***neutrality, boundedness, and socially modulated fight outcomes are candidates for a model that reproduces lifelike stratification patterns that span a large range of status values***.

## *15.2.6 Cognitive Adaptation*

A final option has to do with adaptation of the personality factors (imposition and submission factors). It is reasonable to reinforce a personality factor that induces a rise of status or that hinders its decay. Because status is a long-term measure, any calculation has to be based on a short-term measurement or a local estimate of the status. A simple such local estimate of status is used: the proportion of dominations in the last N interactions (N is usually set to 100). Adaptation of the imposition and submission factor can happen in one of two directions, either positive or negative adaptation. For the imposition factor, these are implemented as follows:

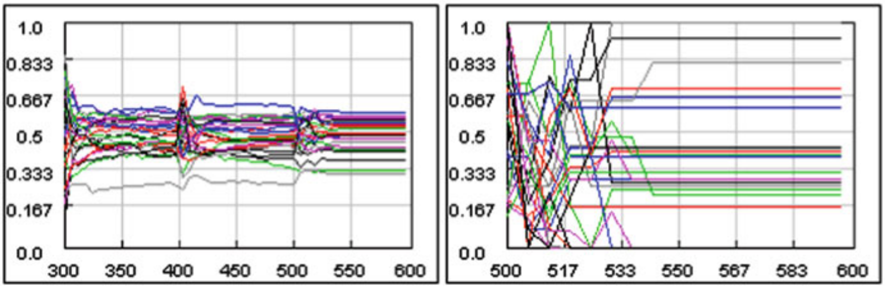


**Fig. 15.7** Comparative experiments with 25 agents for the adaptation variants of the two-factor model with neutrality: no adaptation, positive feedback, negative feedback. Adaptation affects the imposition and submission factors. Five hundred interactions per cycle. All parameters are randomly initialized as in previous experiments. *(Left)* All agents' status for the three consecutive experiments of 200 cycles each with the same initial system. *(Right)* Imposition factors for all agents in the negative adaptation case

```
On increase:
    Positive feedback
    if (local status > global status) then increase else do nothing
    Negative feedback
    if (local status < global status) then increase else do nothing
On decrease:
    Positive feedback
    if (local status < global status) then decrease else do nothing
    Negative feedback
    if (local status > global status) then decrease else do nothing
```

For the submission factor, corresponding rules are used with "<" instead of ">" and vice versa. Figure 15.7 gives the results of the application of the above cognitive regulation mechanism in the case of a two-factor model with neutrality. It is shown that the negative regulation mechanism leads the system to a stable configuration where fights become extinct and all uncertain encounters are resolved by neutrality, but the range spanned by the status values of the agents remains the same. An analogous model can be devised, where the neutrality rather than the imposition and submission factors is regulated and the latter factors remain static. The same regulation rules as above are tested for increase or decrease of the neutrality factor; the results are presented in Fig. 15.8. This time, both regulation models yield stable configurations, but the resulting societies are more unequal, and the status ranges are shifted in relation to the original case without cognitive regulation.

The results in this section have been taken with a slightly modified version of the factor models that launches action based on only self parameters and not self as well as other parameters: so `p(dominate)` is computed as `impFactor(1)` and `p(submit)` as `1-impFactor(1)` or `submFactor(1)` in the single and twin parameter models of Sect. 15.2.1, respectively. This feature is a fortunate one, because it is cognitively easier for an agent to reason on oneself only than on each encountered interaction partner, and it would be reasonable to assume that agents

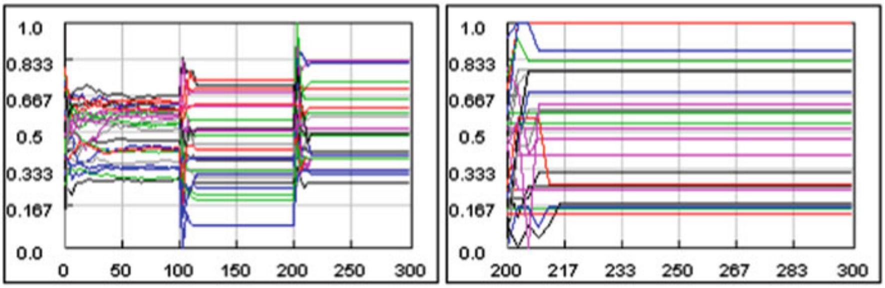


**Fig. 15.8** Comparative experiments with 25 agents for the adaptation variants of the two-factor model with neutrality: no adaptation, positive feedback, negative feedback. Adaptation affects the neutrality factor. Five hundred interactions per cycle. All parameters are randomly initialized as in previous experiments. *(Left)* All agents' status for the three consecutive experiments of 200 cycles each with the same initial system. *(Right)* Neutrality factors for all agents in the negative adaptation case

would prefer to use social conventions of any type to avoid costly reasoning as much as possible. This **self-only model** makes no difference to the results obtained in the previous sections, while the usual self-and-other model does not function well in the cognitive adaptation case because the status of agents is more unstable and its range less crisp. Overall, these experiments show that ***appropriate regulation mechanisms allowing bidirectional change in selected personality parameters may allow a system of interacting agents to self-organize so as to nullify conflicts and achieve a stable social configuration.***

## 15.3 Social Conflict Resolution

One prominent aspect of the models so far is to explicitly define and manage individualistic social perception and personal potential in the form of an imposition and eventually a submission factor. Another interesting feature is that of neutrality, which enlarges the social range.[1] However, the outcome of any pairwise interaction has been somehow fixed by design; it is computed from the standpoint of the initiating agent and is expected to incur a cost. We may now generalize the social interaction as a symbolic two-person game, where each agent will compute individually its "intention" to dominate or to bow, and the final outcome will be based on the intentions of both agents and will happen spontaneously, which corresponds to a culturally learned social contract. This stratification game may be defined as follows:

[1] A social range that spreads may not be politically correct, but it is found in many social contexts and is one of the phenomena we would like to reproduce with modeling.

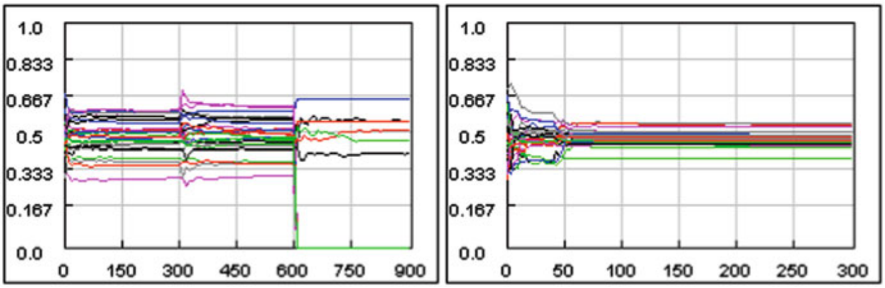


**Fig. 15.9** Stratification game experiments with 25 agents and the two-factor model (500 interactions per cycle). *(Left)* All agents' status for three consecutive experiments of 300 cycles each with the same initial system are shown: simple model, model with neutrality, model with spontaneous social conflict resolution via a stratification game with A=B=*Withdraw*, and bang-bang bounding in all cases. *(Right)* All agents' status for an unbounded simple two-factor model with spontaneous social conflict resolution via a stratification game with A=B=*Fight*. All parameters are randomly initialized as in previous experiments

| | DOMINATE | BOW | INDECISIVE |
|---|---|---|---|
| DOMINATE | Fight | Resolve | A |
| BOW | Resolve | Withdraw | A |
| INDECISIVE | A | A | B |

Each agent displays its intention which takes the value *Dominate*, *Bow*, or *Indecisive* (the latter shows neutrality or indifference). The outcome may be *Fight*, *Resolve* (when one agent prefers to dominate and the other to bow), *Withdraw* (when both agents decline to fight), and *Hesitate* (a special form of indifference whose outcome may be decided by the initiating agent). The obvious choice for moves A and B is to *Withdraw*, but other options are available.

Figure 15.9 shows the drastic effect of the stratification game in the final social structure obtained. In the case of a game with A=B=*Withdraw*, the society stabilizes extremely quickly to a configuration where very few agents have high status and all the others have very low and even 0 status. In contrast, in the case of a game with A=B=*Fight* the society stabilizes to a configuration that shows a squeezed status hierarchy that resembles an egalitarian, middle-class society. Figure 15.10 studies a stratification game with A=*Hesitate*, B=*Withdraw*. The hesitation behavior has been implemented as fight with the usual probability *p(dominate)*. Such a population stabilizes very quickly to a configuration where again very few agents have high status and all the others have very low or 0 status.

As is obvious from the above experiments, the astounding result of very unequal stratification must be due to the high percentage of withdraw moves in the interaction history after an initial short period where a few fights take place. From then on, most or all of the agents either withdraw from a fight or resolve the conflict spontaneously. Interestingly, a 0-status agent does not spontaneously bow all the time but may very well spontaneously dominate other agents with lower

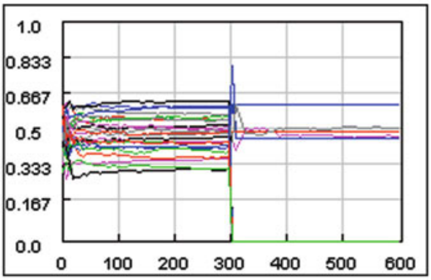


**Fig. 15.10** Stratification game experiments with 25 agents, the two-factor model, bang-bang bounding, and A=Hesitate, B=Withdraw (500 interactions per cycle). All agents' status for two consecutive experiments of 300 cycles each with the same initial system: model with neutrality and model with spontaneous social conflict resolution. All parameters are randomly initialized as in previous experiments

**Table 15.1** Six stratification game experimental setups and corresponding emergent results at the society level

| | Dom vs. Dom | Dom vs. Bow | Both indecisive | Other | Emergent society |
|---|---|---|---|---|---|
| Experiment 1 | Fight | Resolve | Fight | Fight | Egalitarian |
| Experiment 2 | Fight | Resolve | Withdraw | Withdraw | Unequal |
| Experiment 3 | Fight | Resolve | Withdraw | Fight | Egalitarian |
| Experiment 4 | Fight | Resolve | Fight | Withdraw | Unequal |
| Experiment 5 | Fight | Fight | Fight | Fight | Egalitarian |
| Experiment 6 | Fight | Fight | Withdraw | Fight | Egalitarian |

imposition factor and/or higher submission factor. To investigate the exact effect of the withdrawal option, we perform a comparative experiment with the same initial society in six different stratification game setups (see Table 15.1).

Figure 15.11 gives the results of the comparative experiment. Cases 1, 3, 5, and 6 lead to egalitarian societies, whereas cases 2 and 4 lead to markedly unequal societies. In experiment 2, only a small fraction of the agents is high ranking (4 out of 25 agents), whereas in experiment 4 the emergent society is practically split into two groups, one high ranking (15 agents that span a middle status range) and one with 0 status (10 agents). The figure shows once again that the social outcome for any particular agent depends on the exact interaction history and is therefore contingent and independent of its own personality. Overall, these results show that ***societies with increased fight rates have greater tendency to become egalitarian, while societies with increased withdrawal rates have greater tendency to become stratified.***

A couple of other things must be mentioned. The results in this section have been taken with the **self-only model** (see previous section), while the usual self-and-other model cannot function with any of the stratification game matrices because most and sometimes all of the agents consistently withdraw, no fights at all take place,

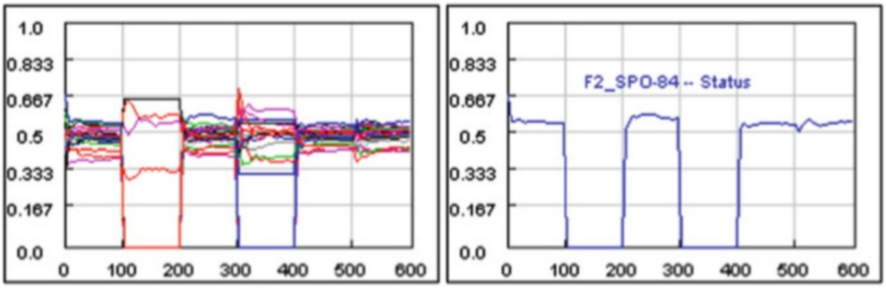


**Fig. 15.11** Comparative stratification game experiments with 25 agents, the two-factor model, bang-bang bounding, and 500 interactions per cycle for *six different stratification game matrices* and 100 cycles per game (see Table 15.1). All parameters are randomly initialized as in previous experiments. Experiments with game matrices 1, 3, 5, and 6 lead to egalitarian societies, while those with game matrices 2 and 4 lead to unequal societies. Note also that one particular agent (agent 84) may be top ranking in some contexts and bottom ranking in others

and all agents have 0 status. The other observation is that while the stratification game as modeled above is natural and reasonable and leads to results that are like some real social phenomena, it is still fixed by design for all agents and represents a rigid social contract or social convention. However, we know from experience that social interaction may sometimes truly be defined by the participants and real "negotiation" may take place, so that the social contract may be considered as flexibly applied in various cases due to the personalities and histories of the participants. One future direction of this research is therefore to model **gestalt stratification games**, where the actual outcome of any pairwise interaction will be further elaborated and resolved by the participants, the extreme version of this being the always-fight case as in the previous sections without neutrality. Our findings show that ***we may attribute some of the stratification structures of real human societies to the kind of stratification game played among the agents, which is rich and dynamic in character and may not be (actually is not!) mutually and socially agreed upon.***

## 15.4 Conflictual Contexts

Having set the scene with the meticulous study of the previous model variants and the introduction of the various cognitive factors, we proceed to experiment in more realistic social contexts that are known to produce and induce stratification. One is a resource sharing context where a number of resources is present in various quantities and some are more preferable than others (for example, some kinds of food, or some immaterial resources such as professions or titles), so that agents will have to compete on the most preferable ones. The other is a task partitioning context where a number of tasks must be fulfilled and where some of the tasks are attractive and

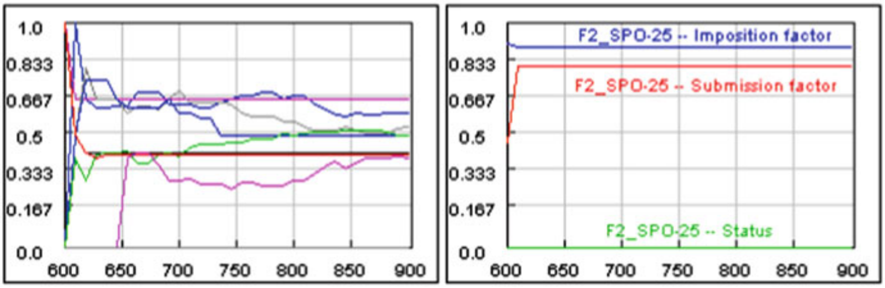


**Fig. 15.12** Stratification game experiment in a resource sharing context with 25 agents and the two-factor model with spontaneous conflict resolution and bang-bang bounding, A=B=*Withdraw*, and 15 interactions per cycle. *(Left)* Status for all agents. *(Right)* The imposition and submission factor for a 0-status agent. It has lost a few fights in the beginning and from then on it either spontaneously resolves conflicts or withdraws, despite high imposition factor. All parameters are randomly initialized as in previous experiments

others repulsive (for example, teaching is generally an attractive task and cleaning a repulsive one). We have performed experiments to try to understand the degree of influence of realistic competition contexts to the emerging stratification structures.

### *15.4.1 Resource Sharing Contexts*

In this experiment we model a society whose agents are presented with resources of varying preference for them. This is modeled as follows: the usual simulation cycle consists of a number of random pairwise interactions where two agents and one or two resources of the same type are selected, depending on availability. If there are two pieces of the resource, then the agents may consume them one each without any conflict. If only one piece is available, then there is some conflict over which of the two agents will consume the resource. The conflict is solved with the aid of a stratification game as in the previous section. The simulation cycle is initialized with a number of resources and runs until their exhaustion. When the resources start to become scarce, conflicts will arise.

Figure 15.12 shows the results of a typical resource sharing context where the resource vector is initialized as [1–5] with the first resource being the most preferable and the fifth the least preferable. As is obvious from the results, the final stratification structure is again a very unequal distribution where few agents retain a fairly high status and the majority has 0 status. Moreover, agents may have high actual imposition and submission factors and still be of 0 status, because of frequent withdrawals, as Fig. 15.12 (right) shows. Typically, a higher status agent consumes significantly more resources than a low status one, and the difference is more pronounced for higher preference resources. Occasionally, a higher status agent may emerge with a consumption profile that resembles that of a lower status

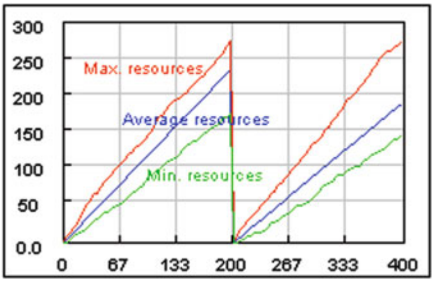


**Fig. 15.13** Comparative resource consumption results (maximum, average, and minimum agent consumption) for the first two experimental setups of Table 15.1. Average consumption is lower in the second (unequal) case, despite maximum consumption by highest ranking agents being similar to that of the equal case

agent; this happens when high status goes hand in hand with both high imposition and high submission factors and reminds us of the behavior of upper level officers in a bureaucratic society. Average withdrawal from fight is usually around 60 %.

Figure 15.13 shows comparative consumption results for the first two experimental setups of Table 15.1. Average consumption is lower in the case of the unequal society, despite the fact that the highest ranking agents consume markedly more than the 0-status agents and about as much as the highest ranking agents in the egalitarian case (where differences between agents are small). This observation could provide a clue as to why unequal societies could be better adapted to an environment with scarce or slowly regenerating resources.

### *15.4.2 Attractive and Not-So-Attractive Tasks*

In this experiment we model a society whose agents are presented with tasks of varying degrees of attractiveness. This is modeled as follows: the usual simulation cycle consists of a number of random pairwise interactions where two agents and two random tasks are selected. If the tasks are of the same type, then the agents will undertake them one each without any conflict or complaint. If they are not, then there is some conflict over which of the two agents will undertake the most attractive task and which the other one. The conflict is solved with the aid of a stratification game as before. Unlike the resource sharing context, there is no such thing as exhaustion of tasks, but all tasks may be presented to the agents with certain probabilities. Figure 15.14 shows the results with a task interaction context where the task probability vector is initialized as [0.35, 0.25, 0.2, 0.15, 0.1] with the first task being the most repulsive and the fifth the most attractive. As is obvious from the results, the final stratification structure is a very unequal distribution where few agents retain a fairly high status and the majority has 0 status. Other results do

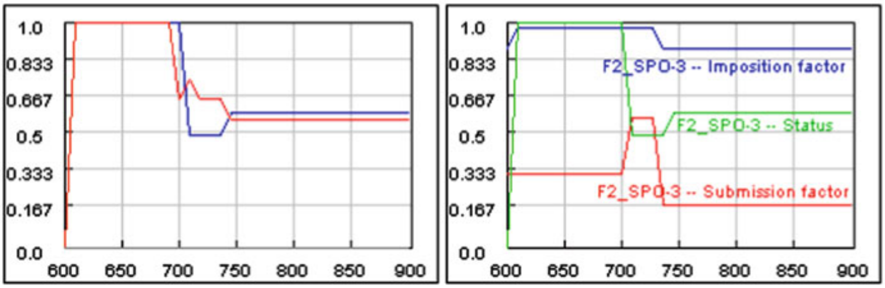


**Fig. 15.14** Stratification game experiment in a task interaction context with 25 agents and the two-factor model with spontaneous conflict resolution and bang-bang bounding, A=B=*Withdraw*, and 15 interactions per cycle. *(left)* Status for all agents. *(right)* The two factors for one of the two emerging nonzero-status agents. It is shown that loss of a couple of fights around cycle 700 dramatically reduces the agent's status and a few unexpected wins shortly after (which affect its submission factor which drops abruptly, but not its imposition factor which remains intact) restore a slightly higher status value. All parameters are randomly initialized as in previous experiments

not differ from the resource sharing context case. Typically, a higher status agent executes significantly more attractive tasks than a low status one, with average withdrawal again around 60 %.

As the experiments with both contexts show, the type and constraints of the interaction context play no role at all in the finally obtained stratification structure. It seems that the only parameter that defines this particular structure of a highly unequal society is the type of stratification game played, which involves a significant withdraw component. Therefore, it appears that ***the resulting stratification structure is not due to environmental factors and pressure, such as resource scarcity or task demands, as usual evolutionary thinking would propose, but owes its emergence to the particular social convention used*** (the stratification game), which is a cultural product of many generations and may at first appear arbitrary.

## 15.5 Discussion

In this chapter we have studied the emergence of social stratification in communities with mechanisms of competition and dominance between interacting agents. We have departed from a basic mammal-inspired mechanism of competition that relies solely on physical strength and have progressively introduced a number of higher level cognitive parameters: individual imposition and submission factors that modulate the agents' decision to fight, the option of neutrality, and bounding of parameters within individual ranges. In all cases, from initially random communities there emerges a society spread out in status range, without polarization as is often obtained in the strength-only case. The influence of more parameters was studied: the dependence of the fight outcomes on the cognitive parameters or the actual status of the agents (where the two-factor model shows amplified stratification results), perception of the opponent status (without effect on the stratification structure), and cognitive adaptation (with minor effect). Next, a more elaborate scenario of a stratification game was introduced, where some fights are spontaneously resolved if differences between agents are mutually perceived as too large. Several variants of the game matrix have been indicatively studied. Those inducing high numbers of fights have been found to lead to fairly egalitarian societies whose agents all have a medium status, whereas those based on fight repulsion and high probability of withdrawal from fights lead to extremely unequal societies with only a few agents having high status and the majority having a very low or 0 status. This property has been found to hold also in realistic, rather than "free," competition environments involving resource sharing or task competition. In sum, our study shows the influence of cognitive parameters and social conventions on the emerging social stratification structure and how some social conventions of cultural and historical origin may overtake the cognitive profiles present and define the emerging social stratification outcome. The above conclusions are summarized in the following table, which parallels the one in the introduction.

| Type of parameter/process studied | Resulting social status structure |
|---|---|
| **Fight decision** | |
| Brute force only (BF) | Spread-out range of social status or (more rarely) split to two status groups |
| Socially modulated fight, with submission and/or imposition factors (SM) | Smooth and fairly homogeneous status range |
| Neutrality (NEU) | Broader status range than SM |
| Personalized behavioral ranges (PERS) | Broader status range than SM |
| **Fight outcome** | |
| Socially dependent outcomes (SD) | Middle-class society (Imposition-only based SM) or broad status range (Imposition and submission based SM) |
| **Advanced features** | |
| Perception of opponent (PO) | Preservation of status range (thus irrelevant for the study of stratification ) |
| Cognitive adaptation (CA) | Tighter (broader) and more stable status range for factor (neutrality) adaptation |
| Spontaneous social conflict resolution (SPO) | Social contracts with more spontaneous encounter outcomes and more withdrawals lead to more unequal societies. |

Our approach is situated one level below the more complex approach taken by several social science researchers [18–20]. First of all, these researchers are interested in status characteristics emergence, creation, and diffusion, where particular characteristics, such as math ability, acquire status significance. In contrast, we have focused on a simple, animal-inspired abstract notion of status as proportion of past wins in generally unconnotated pairwise encounters, without any reference to external objects. Moreover, although it is undeniable that exceptional abilities exist and can function socially, we are interested rather in lower level fights through which abstract status may be acquired and we consider ultimate status objects as arbitrary, contingent, and largely culturally specific. In our basic competition context, actual "strength" of individuals, physical and cognitive, is expected to be dynamic and/or adaptive through behavioral interchange, whereas interaction is not necessarily zero-sum (strong ones may become stronger, but weak ones may not become weaker or not to the same degree, and many combinations are imaginable). Despite these differences, which make our approach a methodological tool for the above social science program rather than an alternative to it, we retain the same fundamental mechanisms of status salience, status cues [21] and personality indicators [22] (models SM and SD), relation of cues to performance expectation (models SD and PO), and translation of expectation to behavior (all decision models and models SD and SPO).

The wealth of phenomena produced with the studied competition models invites us to reflect on what might emerge in communities that are diverse in agents' behavior, i.e., that include agents reasoning about themselves and the society in different ways, some very simple, others more intricate. Diversity may be further assumed in the type of exchange or stratification game that may differ for different pairs of agents, thus opening ample room for the development of gestalt stratification games that are actively constructed by participants during interaction. Systematic or contingent emergence of status objects in various social interaction contexts is also worth investigating. All of these issues will be the object of future research on social stratification. Other parameters are finally envisaged for further study, mainly the memory constraints in relation to the perception and construction of the history of agents and the effect of age that allows for both memory diversity (younger agents will have direct access to shorter term history) and cultural learning and transmission.

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# Part V
# Participatory Modeling

# Chapter 16
# A Computational Study of Rule Learning in "Do-It-Yourself Lottery" with Aggregate Information

**Takashi Yamada and Takao Terano**

**Abstract** This chapter computationally studies Barrow's "do-it-yourself lottery" where players choose a positive integer that is expected to be the smallest one that is not chosen by anyone else. Here, we employ and modify the rule learning framework by Stahl (Games Econ Behav 32:105–138, 2000) based on the experimental findings by Östling et al. (Am Econ J Microecon 3:1–33, 2011), and incorporate them into our simulation model to see individual and collective behavior by changing the numbers of players and the upper limit. Our main conclusion is threefold: First, the game dynamics depends on both the number of players and the upper limit. Second, a lottery with a large sensitivity parameter divides the players into winner(s) and losers. Third, finding the "stick" rule immediately makes a player a winner and imitating behavior is not observed in four-player games.

**Keywords** Agent-based computational economics • Learning • Multi-player and multi-strategy game

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## 16.1 Introduction

The definition of Barrow's "do-it-yourself lottery (DIY-L)" is that $N$ players submit one of the positive integers up to $M$ and the one choosing the smallest number that is not chosen by anyone else is the winner [2, p. 79].[1] Suppose there is a DIY-L with three players, A, B, and C, with the upper limit being 3. If the submission set is $(A, B, C) = (1, 2, 3)$, then player A wins the game. If the submission set is $(A, B, C) = (1, 1, 2)$, then player C wins. But if the submission set is $(A, B, C) = (1, 1, 1)$, then there is no winner.

DIY-L is a multi-player and multi-strategy game in which players need to "imagine what others will choose" [2, p. 80]. In this sense, DIY-L is similar to the minority game (MG) [4, 8, 9] and the $p$-beauty contest game ($p$-BCG) [12, 21, 27, 28]. But, although players commonly do not know what their opponents play for their decision making, the main difference is that DIY-L has a unique skew-symmetric mixed strategy equilibrium which depends on both the number of players and their strategies (for more details, see the next section). In other words, DIY-L is not dominance solvable (vs. $p$-BCG) and the strategies wherein are not symmetric (vs. MG).

DIY-L is also a special case of the Swedish Lottery (SL), the lowest unique bid auction (LUBA) [13,15,22,30,32], and the highest unique bid auction (HUBA) [33]. These games have been investigated theoretically, empirically, and experimentally. In particular, one can regard DIY-L or related games as repeated games, and learning in a game theoretic situation is one of the main topics in the behavioral economics literature. Indeed, Östling et al. implemented a laboratory experiment on SL to compare the empirical and the experimental data [29]. Their findings show that the players are heterogeneous [20] and that some of them switch their behavioral rules from time to time. According to Crawford et al. [10], conventional strategic thinking models such as the level-$k$ reasoning model and the cognitive hierarchy model do not successfully explain the individual behavior in SL. But there was only one experimental setup and the number of runs was not so large enough to see long-run individual and collective behavior in [29]. Also, it seems that individual behavior and learning in multi-player and multi-strategy games with unique symmetric mixed strategy equilibria have not been intensively studied (cf. [25]).

The agent-based computational economics approach is one promising way to examine long-run behavior and learning of individuals and the transient collective dynamics [1,16,19,23,24]. The learning in each computational model usually makes use of current and past contributions from the psychological and experimental economics literature [5, 11]. As in other related fields, learning in the socio-economic

[1] The "do-it-yourself lottery" is also called the "Swedish lottery" [29, 42]. Indeed, Winkler's book was published earlier than Barrow's. However, since the corresponding author (Yamada) first came to know this game from Barrow's book, we will continue to use "do-it-yourself lottery" in the rest of this chapter.

systems with more than two agents has not been well established. For instance, Shoham et al. have criticized that most of the studies about learning focus only on games with two players (p. 373) and put a heavy weight on convergence to equilibrium [35, p. 373]. On the other hand, Erev and Roth have argued that a simple descriptive model can reproduce multi-agent learning even if the number of agents becomes larger [14, p. 424]. After all, although multi-player game is more usual than two-player one in socio-economic systems, many aspects may have not been clarified [6, 26, 31, 39]. Likewise, DIY-L may be suitable for testing whether micro- and macro-level dynamics really depend on the game setup, the numbers of players, and the strategies.

The aim of this study is to analyze how players behave and learn in DIY-L and consequently study the entire game behavior by using the agent-based computational economics approach. Here we consider a game with only three or four players and three or four strategies based on the experimental findings by Östling et al. [29] and the framework of Stahl's *rule learning* model [36, 37], and we then perform computational experiments to see individual and collective behavior. To this end, we will see, based on the fact that people in empirical and experimental SL are boundedly rational and heterogeneous, whether an agent may perform well or badly when others do not behave rationally [34] and whether the aggregate dynamics is dependent on the numbers of players and strategies. To quote Barrow:

> It would also be interesting to see how players changed their strategy if they played the game over and over again. (p. 80) [2]

The rest of this chapter is organized as follows. The next section explains the basic framework of DIY-L. Section 16.3 presents the experimental setup and computational results. Finally, Sect. 16.4 gives the concluding remarks.

## 16.2 Do-It-Yourself Lottery

### *16.2.1 Game Design*

There are $N$ players, each of who chooses one positive integer from 1 to $M$ $(> 1)$. All of them know this setup. The player who submits the smallest integer that is not chosen by anyone else is the winner. The winner receives a positive payoff, usually normalized by 1, and the losers do zero. If there is no uniquely chosen integer, all players become losers.

Here we consider DIY-L with $N \geq 3$ and $M \geq 3$. In the case of a bimatrix game, there are three equilibria: (1) both players choose 1 and (2) one player chooses 1 and the other does 2. But, since one never makes one's opponent a winner so long as he

**Table 16.1** Mixed strategy equilibria in simplified DIY-L

| $N$ | $M$ | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 3 | 3 | 0.464102 | 0.267949 | 0.267949 | |
| 3 | 4 | 0.457784 | 0.251643 | 0.145286 | 0.145286 |
| 4 | 3 | 0.448523 | 0.426330 | 0.125147 | |
| 4 | 4 | 0.447737 | 0.424873 | 0.125655 | 0.00173500 |

keeps on choosing 1 [29], this kind of game is not worth investigating. Then, each game form has a unique mixed strategy equilibrium as in Table 16.1 in cases of $(N, M) = (3, 3),\ (3, 4),\ (4, 3),$ and $(4, 4)$.[2,3]

## 16.2.2 Related Games

On the one hand, the main differences between DIY-L and other related games, e.g., SL, LUBA, and HUBA, could be summarized as follows. First, DIY-L is not an auction, meaning that there is not a good or a participation fee. Likewise, every player must submit only one positive integer at every turn, i.e., she is not allowed not to participate or to bid two or more integers. Second, the number of players is always fixed to $N$ and every player knows the upper limit $M$. Third, this is a strategic form game. Hence, no player knows whether his submitted integer is unique (cf. [15]). Fourth, there is no tie-breaking rule. Finally, this is a repetitive game.

On the other hand, the possible differences between DIY-L and several multi-player games are the following. The players in the minority game (MG) are three or more odd numbers and they choose one of the two symmetric strategies to be on the minority side (see, e.g., [4, 8, 9]). As a result, the game has $\binom{N}{(N-1)/2}$ asymmetric Nash equilibria in pure strategies, a unique mixed strategy equilibrium, and infinite asymmetric mixed strategy equilibria. In DIY-L, unlike MG, even numbers of players are allowed, and the number of strategies is two or more. Besides, the mixed strategy equilibrium is unique but skew-asymmetric because there is only one winner if it exists and there are ranks in positive integers. The $p$-beauty contest game ($p$-BCG) is another similar game to DIY-L in the sense that there are at least three players guessing which integers other players will choose and that there is usually only one winner (see, e.g., [12, 21, 27, 28]). While $p$-BCG is a dominance solvable game, level-$k$ reasoning in DIY-L does not lead to such a state because level-$k$ thinkers always choose one of the two integers, 1 ($k$: odd) or 2 ($k$: even) [29].[4]

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[2]The mixed strategy equilibrium in DIY-L with $N \geq 3$ and $M = 2$, namely the binary choice game, is independent of the number of players; the mixed strategy equilibrium is 0.5 for each integer. Hence, we have omitted this kind of game setup.

[3]Östling et al. have a succinct algorithm to calculate the mixed strategy equilibrium in this setup [29].

[4]We thank the anonymous referee for pointing this out.

As in MG, the equilibrium in $p$-BCG is independent of the number of players. Or, in the well-known multi-player versions of the prisoner’s dilemma game (PD) and the battle of the sexes game (BOS), the payoff matrices usually depend on how many players will choose a strategy (cooperate or defeat in PD or ballet or boxing in BOS) (see, e.g., [38, 43]).

## 16.3 Computational Experiments

In this section, we present the results of computational experiments using a modified rule learning model by changing a learning parameter. The objectives of this section are mainly to investigate (1) the distributions of submitted and winning integers in each game form, and (2) the behaviors of players, especially the differences between the winning agent and other players.

### *16.3.1 Setup*

A behavioral rule in rule learning theory is officially “a mapping from information to the set of probability measures on the actions” [37, p. 110]. Here, a rule $\rho$ ($\in R$ where $R$ is a family of behavioral rules) will be given a probability when a piece of information, namely a game result, is revealed.

Let $p(\rho, t)$ be a probability measure over the rules which gives a probability for rule $\rho$ at turn $t$. Following the framework of Stahl, it is determined by the following logit function:

$$p(\rho, t) := \frac{\exp(w(\rho, t))}{\int \exp(w(x, t))dx} \tag{16.1}$$

where $w(\rho, t)$ is a logit propensity for rule $\rho$ at turn $t$.

The logit propensity is updated as follows:

$$w(\rho, t+1) = \phi \cdot w(\rho, t) + \psi \cdot g(\rho, \Omega^{t+1}) \tag{16.2}$$

where $\phi$ and $\psi$ are positive constants ($\phi > \psi$) and $g()$ is the “reinforcement function for rule $\rho$ conditional on information $\Omega^{t+1}$” [37, p. 110]. For simplicity, we rewrite this equation as

$$w(\rho, t+1) = \phi \cdot w(\rho, t) + \psi \cdot f(a_1, \cdots, a_N) \tag{16.3}$$

where $f(a_1, \cdots, a_N)$ is a digital payoff function *s.t.* a winner receives 1 point and the losers do nothing with $a_i$ being player $i$’s strategy.

The last element in rule learning is a rule set. Stahl considers four kinds of rules: level-1 reasoning, level-2 reasoning, Nash equilibrium, and first random and then "follows the herd" afterward [37]. However, it is not appropriate to follow this setup here because, as mentioned, it is almost impossible to play a mixed strategy equilibrium. Instead, Östling et al. have implemented a laboratory experiment under the SL condition and have shown that the behavioral rules are classified into four categories: "random", "stick", "lucky", and "strategic" [29, p. 28].

1. Random
   Since we do not see the probabilities with which subjects using this rule choose a positive integer, we defined this rule by saying that they submit a positive integer with probability $1/M$.
2. Stick
   The subjects in this category submitted "fewer distinct numbers" or only one number [29, p. 28]. Here the "stick" agents always choose the smallest integer, 1.
3. Lucky
   The "lucky" subjects tended to choose an integer "with a higher mean and higher variables" [29, p. 28]. Since the number of strategies, $M$, is quite small here, the agents in this category submit one integer except 1 with equal probability, $1/(M-1)$.
4. Strategic
   "Strategic" means that some subjects followed the previous winning integers. The statistical analysis by Östling et al. shows that the winning integers for the last three turns may affect the behavior of subjects but that this effect diminishes later [29]. In this sense, we can see this rule as imitation, although players cannot browse the behavior of others [7, 17, 41] (cf. [40]).

   Based on mild evidence, we determined this rule in two ways: Before choosing an integer, the agent using this rule collects the winning integers except zero (no winner) for the last three turns. Then she selects (a) one integer with probability

$$\frac{v_k(t)}{\sum_{k'=1}^{M} v_{k'}(t)}$$

   where $v_k(t)$ is the number of wins for integer $k$ for the last three *nonzero* turns or (b) that most observed, namely

$$\arg\max \frac{v_k(t)}{\sum_{k'=1}^{M} v_{k'}(t)}$$

   (if there are plural candidates, then she chooses one of them with equal probability).

Now that there is a total of four rules considered, Eq. (16.1) is rewritten as

$$p(\rho, t) := \frac{\exp(\lambda \cdot w(\rho, t))}{\sum_{j=1}^{4} \exp(\lambda \cdot w(\rho_j, t))} \tag{16.4}$$

where $\lambda$ is a sensitivity parameter.

With this learning procedure, we run the computational experiments under the following conditions:

- The number of players $N$ and the upper limit $M$ are both 3 and 4. Hence, $(N, M) = (3, 3)$, $(3, 4)$, $(4, 3)$ and $(4, 4)$ (see Table 16.1).[5]
- Each player uses the rule learning with the same initial and parameter values.
- Each game has 10,000 turns, iterated 100 times.
- Each player knows the current turn, her previous submission, and the previous winning integer (if there is no winner, then this input is zero) for her decision making, which means that she does not know the previous submission of others.
- The parameters are as follows:

  $\phi$ 0.90,
  $\psi$ 0.10, and
  $\lambda$ 0.1, 1.0, 10.0 and 100.0.[6]

- The initial value for each propensity $w(\rho, 1)$ is set to $1/J$ where $J = 4$ (the number of rules).

  The initial input, the winning integer at turn 0, is set to zero.

### 16.3.2 Results

The results are from the data for all 10,000 turns in each simulation run. This allows us to see how the rule learning model affects the behavior and learning of the players.

Figures 16.1 and 16.2 illustrate the boxplots of the submitted (left panel) and winning (right panel) integers for strategic rules (a) and (b), respectively. Each panel includes the quartile for all four $\lambda$'s. Since there seems to be little difference between the two tables, several common characteristics can be easily observed. In the three-player games (panels a and b), the submitted and winning ratios for integer 1 become larger as $\lambda$ increases. The winning ratios sharply increased for $\lambda = 10.0$

[5] The computational setup is not the same as those explained in Östling et al. [29]. In this sense, the comment by one of the anonymous referees is right.

[6] As one of the anonymous referees pointed out, we need to consider more which value is the most appropriate. Since there is no related experimental study in this game setup, we intend to see the relations between the value of this parameter and the game dynamics rather than to find a value that better explains, for instance, the experimental results of Östling et al. [29].

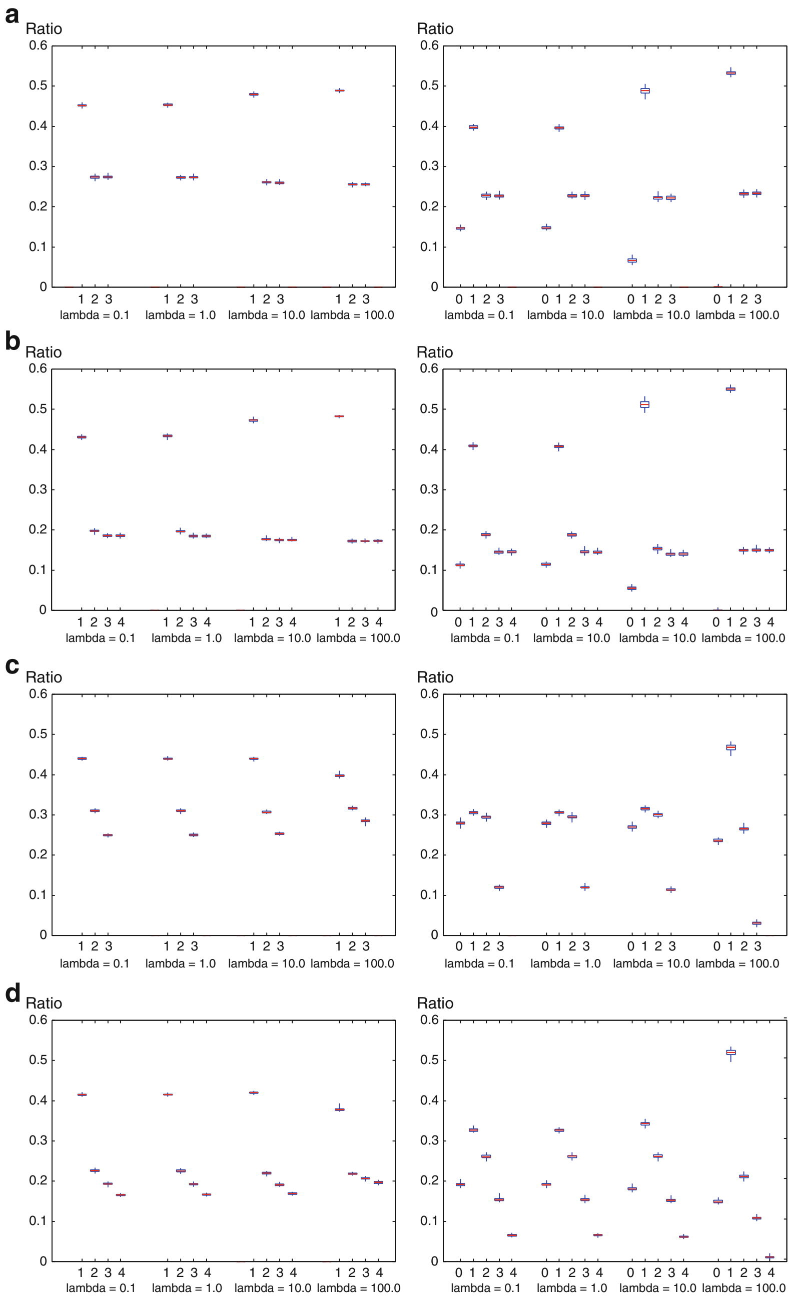


**Fig. 16.1** Distributions of submitted (*left panel*) and winning (*right panel*) integers for "strategic rule (a)". (**a**) $(N, M) = (3, 3)$, (**b**) $(N, M) = (3, 4)$, (**c**) $(N, M) = (4, 3)$, (**d**) $(N, M) = (4, 4)$

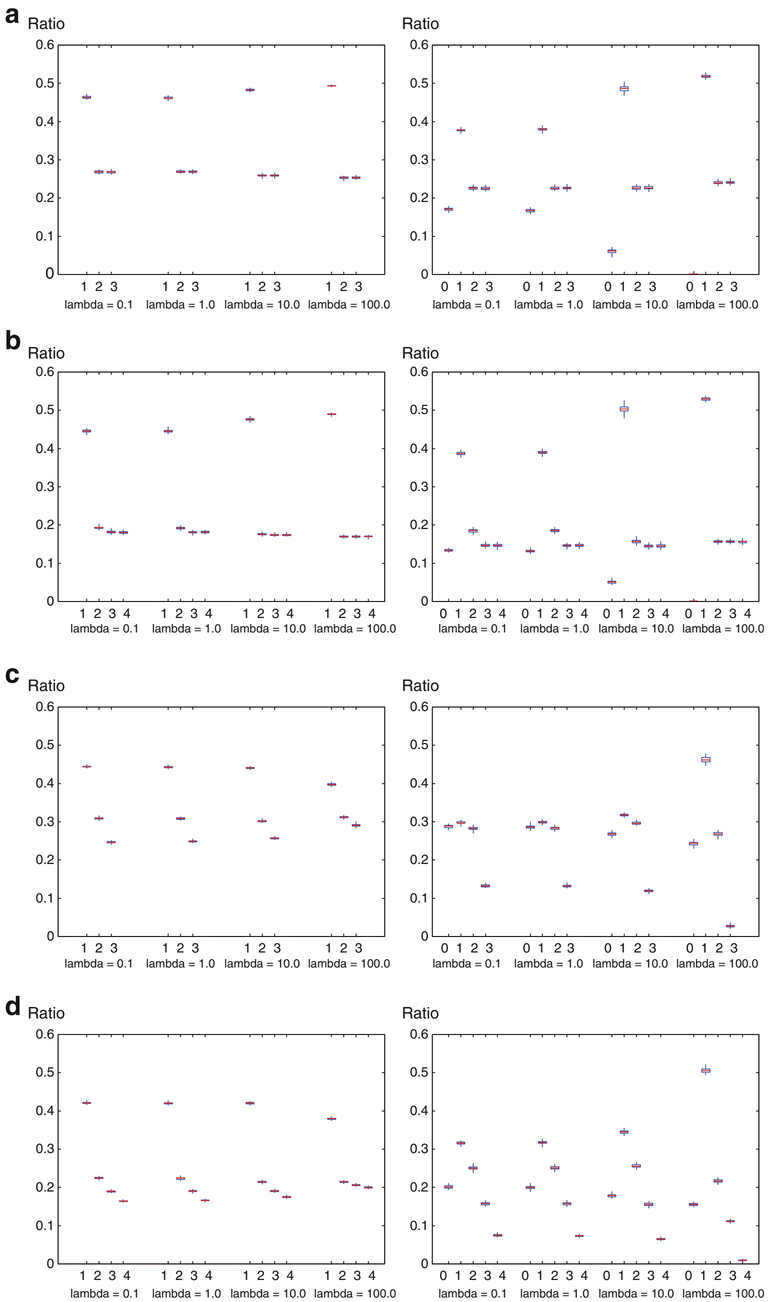


**Fig. 16.2** Distributions of submitted (*left panel*) and winning (*right panel*) integers for "strategic rule (b)". (**a**) $(N, M) = (3, 3)$, (**b**) $(N, M) = (3, 4)$, (**c**) $(N, M) = (4, 3)$, (**d**) $(N, M) = (4, 4)$

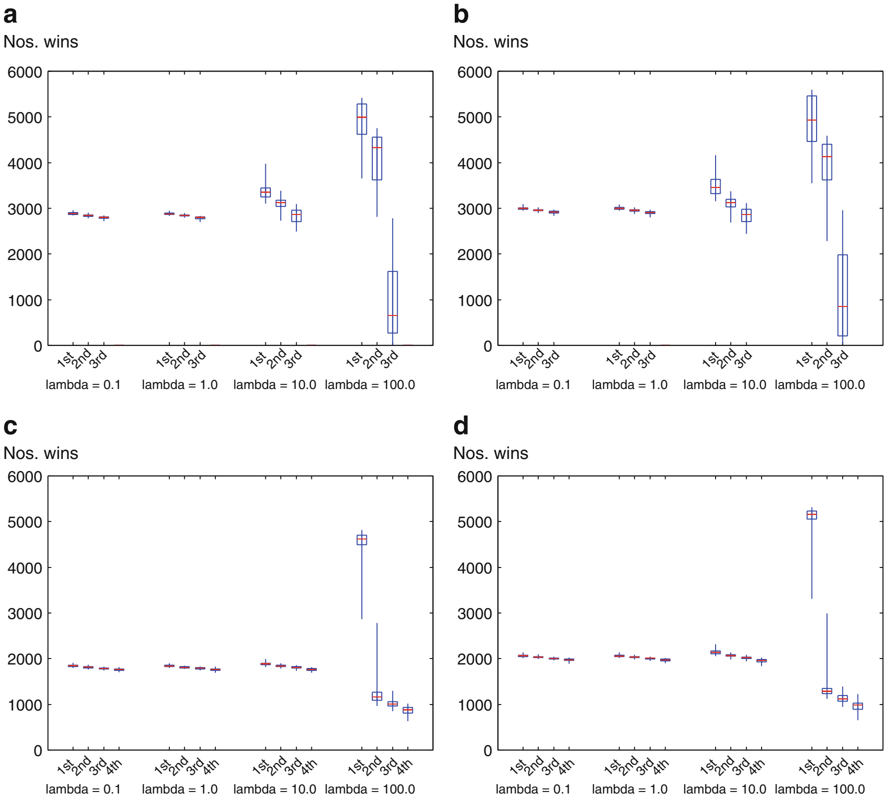


**Fig. 16.3** Distributions of the numbers of wins for "strategic rule (a)". (**a**) $(N, M) = (3, 3)$, (**b**) $(N, M) = (3, 4)$, (**c**) $(N, M) = (4, 3)$, (**d**) $(N, M) = (4, 4)$

and 100.0, whereas the no-winner situations eventually disappeared. With respect to other integers, the ratios are not different from each other or dependent on the sensitivity parameter. However, in the four-player games, the submission ratio for integer 1 is decreasing as a function of $\lambda$ and the same is true for integer 2 on the whole. Instead, the larger integers, 3 and 4, seem to be submitted more often. But, the outcomes of the game are a bit different because the winning ratio for integer 1 becomes larger and the no-winner situations are about 10–20 %. Although we cannot make a comparison between these results and some benchmark such as mixed strategy equilibrium or completely irrational behavior, what the two figures indicate is that some players were shrewd enough to find a good behavioral rule to win the game as the sensitivity parameter becomes larger. We will check this next.

Figures 16.3 and 16.4 present the distributions of how many turns the ranked agents win in a simulation run. As in the preceding two figures, the quantile is given. Although we cannot see any significant differences between the two strategic rules, similar characteristics are also displayed in terms of the number of players.

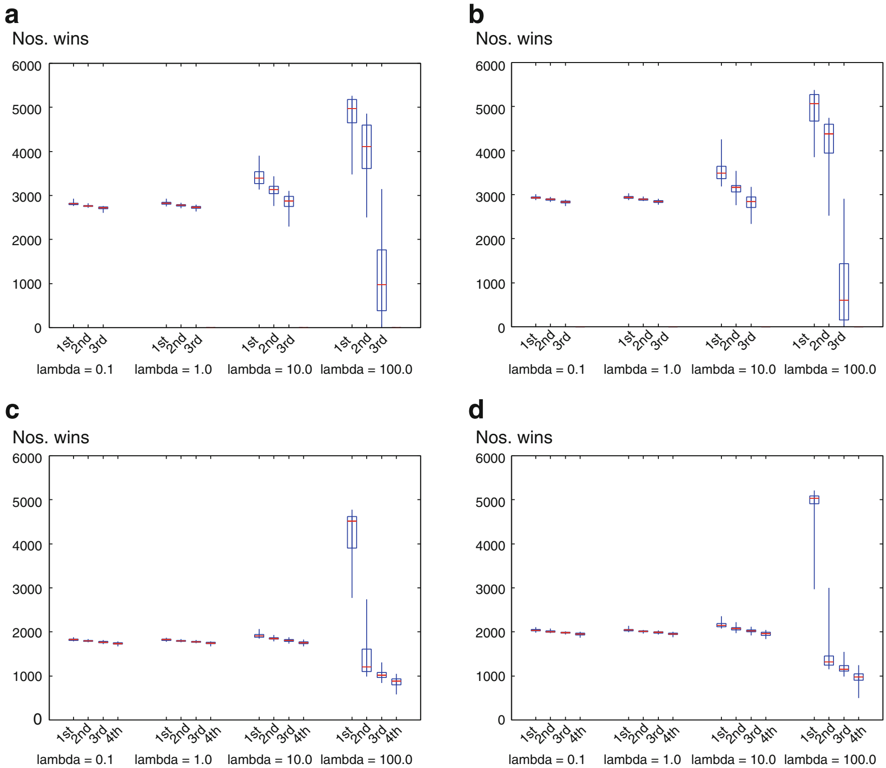


**Fig. 16.4** Distributions of the numbers of wins for "strategic rule (b)". (**a**) $(N, M) = (3, 3)$, (**b**) $(N, M) = (3, 4)$, (**c**) $(N, M) = (4, 3)$, (**d**) $(N, M) = (4, 4)$

In the three-player game with a small sensitivity parameter, $\lambda = 0.1$ or 1.0, all the players almost equally win 3,000 turns or less on average (panels a and b in Figs. 16.3 and 16.4). But, as $\lambda$ becomes larger, the 1st and the 2nd prize players tend to win more while the 3rd prize player tends to have less chance of winning. In the four-player games, on the other hand, it is difficult to differentiate between top dogs and underdogs when $\lambda$ is 10.0 or smaller (panels c and d in Figs. 16.3 and 16.4). It was not until $\lambda = 100.0$ that a clear difference appeared. But, unlike the cases of the three-player games, only one player won more. To capture what leads to such a specific result, we need to know in more detail how the agents played in each setup.

Thus, Figs. 16.5, 16.6, 16.7 and 16.8 exhibit time series plots of selection probabilities for each rule and ranked agent. The whole game outcome is classified into mainly three groups in accordance with the sensitivity parameter and the game setup:

1. The games with a smaller $\lambda$ show a somewhat randomized behavior.
   This distinction is typically observed in the games with $\lambda = 0.1$ and 1.0. In addition, the initial condition for the propensity $w(\rho, 1)$ is $1.0/J$. As a result,

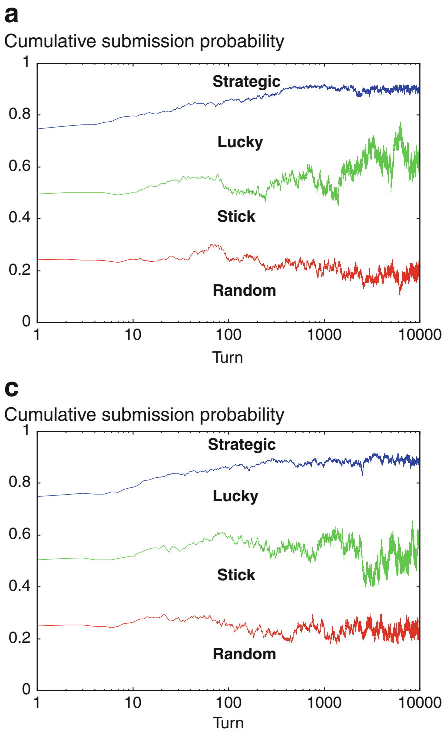


**Fig. 16.5** Time series plots of cumulative submission probability for each rule in $(N, M) = (3, 3)$ with $\lambda = 10.0$ ("strategic rule (b)"). (**a**) 1st Prize, (**b**) 2nd prize, (**c**) 3rd prize

each logit function $\exp(\lambda \cdot w(\rho, t))$ takes a value close to unity. That in turn makes it difficult for each player to learn from the past, which then prevents anyone from dominating the game. To this end, the individual behavior has still been unsophisticated. This process holds for the games with $\lambda = 1.0$. Therefore, a smaller sensitive parameter often misleads players into behaving almost completely irrationally (we have omitted the related figures).

2. The game results for $\lambda = 10.0$ may depend on the number of players (see Figs. 16.5 and 16.6).
   A possible reason why the winner agent could not dominate the four-player games is the number of her opponents. Figure 16.6 explains this. The 1st prize agent tends to "stick" to one integer, 1, but the propensity of other players for the rule is not small enough to give up. Accordingly, at least one player also sticks or happens to submit 1 using another rule. On the other hand, in the three-player game (Fig. 16.5), since there are only two opponents, there are more chances to win the game so long as she persistently employs "stick".
3. A larger sensitivity parameter, $\lambda = 100.0$, easily splits the players into top dog(s) and underdogs (see Figs. 16.7 and 16.8).

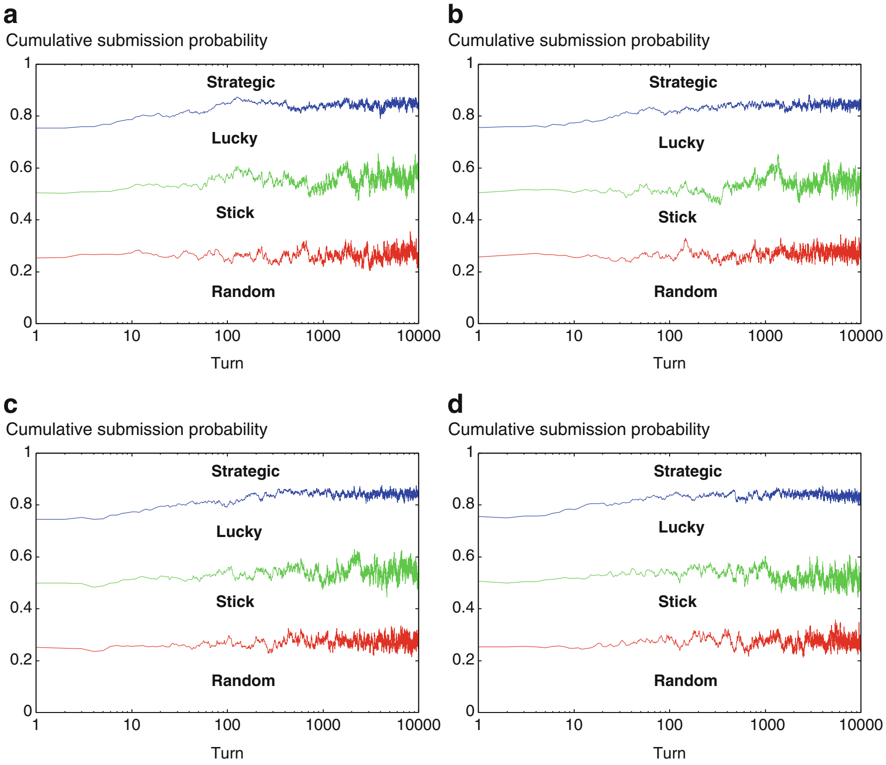


**Fig. 16.6** Time series plots of cumulative submission probability for each rule in $(N, M) = (4, 3)$ with $\lambda = 10.0$ ("strategic rule (b)"). (**a**) 1st prize, (**b**) 2nd prize, (**c**) 3rd prize, (**d**) 4th prize

The microscopic behavior in this pattern is dependent on the number of players. In three-player games, the 1st prize agent immediately adopts the "stick" rule and keeps using it (Fig. 16.7a). The 2nd prize agent then puts more weight on the rule "lucky" so that she will be a silver medalist (Fig. 16.7b). The 3rd prize agent uses the "stick" rule at first, but in no time gives up and seeks a better way to win the game. At around 1,000 turns or later, she tries "random," "lucky", or "strategic", but at this stage one player occupies the smallest integer and another one gives up beating the "stick" player, so that the 3rd prize agent has no chance to win (Fig. 16.7c). This switching also helps the 2nd prize agent win more. However, in four-player games, while the behavior of the 1st prize agent is not different from the one in the three-player game, those of the other players are similar to each other; namely, they eventually give up selecting the "stick" rule and then use the "lucky" rule. But, since no other players select "random" or "strategic", they cannot win the game as often compared to the cases of three-player games (panels b, c, and d in Fig. 16.8). The reason why the underdogs did not employ "random" or "strategic" often is that, compared to the "lucky" rule, these rules have smaller

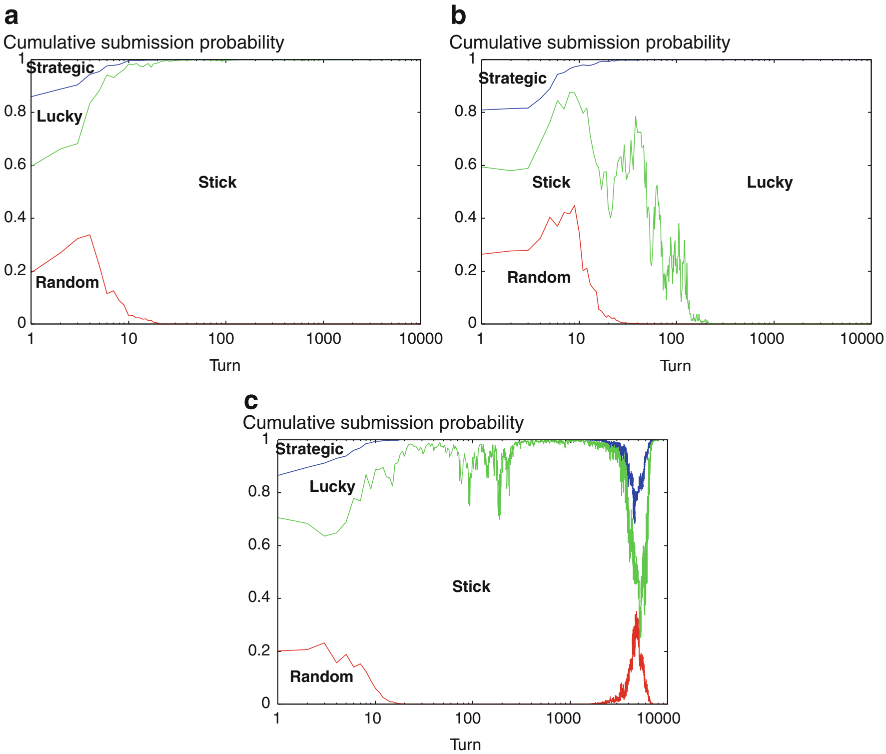


**Fig. 16.7** Time series plots of cumulative submission probability for each rule in $(N, M) = (3, 4)$ with $\lambda = 100.0$ ("strategic rule (a)"). (**a**) 1st Prize, (**b**) 2nd prize, (**c**) 3rd prize

probabilities to submit the second smallest integer (1/4 for "random", 1/3 for "lucky", and almost zero for "strategic" because the winning integer is often 1).

## 16.4 Concluding Remarks

This chapter uses an agent-based approach to study how players using the rule learning developed by Stahl [36, 37] behave and learn in a multi-player game with a (skew-symmetric) mixed strategy equilibrium. For this purpose, we have employed and simplified the original rule learning model and implemented computational experiments using a "do-it-yourself lottery" based on the experimental findings of Östling et al. [29]. We have considered small numbers of players and strategies and performed computer simulations. Our computational results show that a proper setup leads to dynamics where we can differentiate between winner(s) and losers.

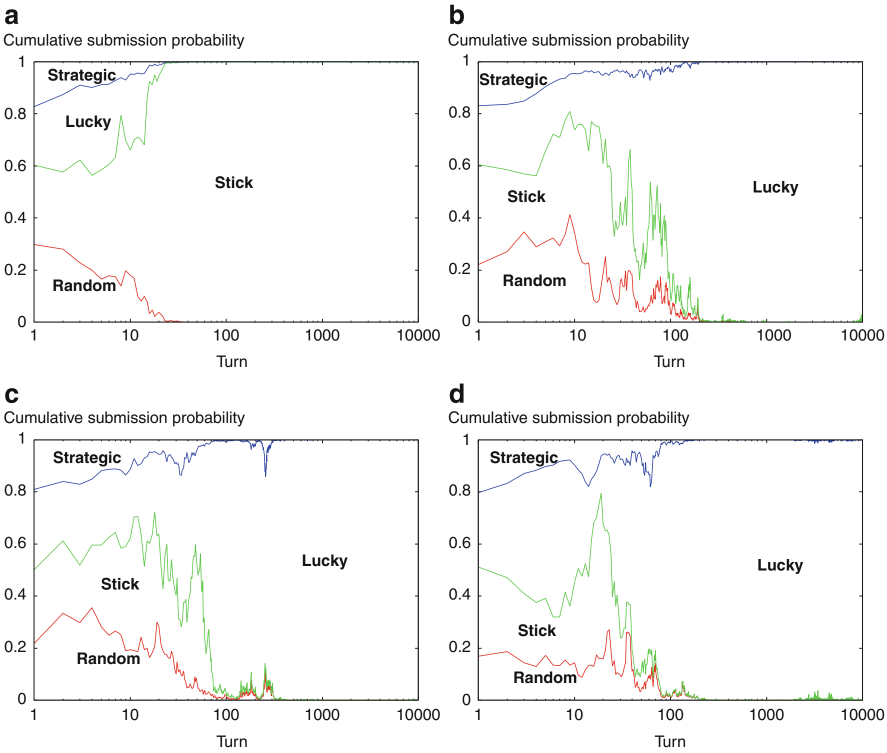


**Fig. 16.8** Time series plots of cumulative submission probability for each rule in $(N, M) = (4, 4)$ with $\lambda = 100.0$ (“strategic rule (a)”). (**a**) 1st prize, (**b**) 2nd prize, (**c**) 3rd prize, (**d**) 4th prize

Since the agent-based computational approach is a promising and powerful tool to analyze long-run behavior at the micro- and macro-levels with lower costs, it may be much more meaningful when one has experimental and empirical findings in a socio-economic study [11]. But, since we have just conducted computer simulations, as Duffy has also pointed out, we need to implement follow-up experiments. In this sense, what Binmore addresses on computer simulations is correct [3], but we also strongly believe that the agent-based approach would help progress economic studies [16, 18].

**Acknowledgements** This work has been revised and extended from the earlier version presented in WCSS 2012. The questions and comments are all incorporated into this study. Financial support from the Japan Society for the Promotion of Science (JSPS) Grant-in-Aid for Young Scientists (B) (24710163), from the Canon Foundation in Europe under a 2013 Research Fellowship Program (Yamada), and from JSPS and ANR under the Joint Research Project, Japan—France CHORUS Program, “Behavioral and cognitive foundations for agent-based models (BECOA)” (Terano) is gratefully acknowledged. We thank the two anonymous referees for their helpful comments and suggestions. All remaining errors are our own.

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# Chapter 17
# Agent-Based Social Simulation as an Aid to Communication Between Stakeholders

**Kotaro Ohori, Shohei Yamane, Noriyuki Kobayashi, Akihiko Obata, and Shingo Takahashi**

**Abstract** Various methods provided in conventional agent-based social simulation (ABSS) research are useful for modelers and analysts in evaluating its effectiveness. We know very little about how ABSS contributes to the decision-making process for practical business problems when used by managers and employees who are not familiar with it. In this research we talked to stakeholders in two complex and uncertain business situations about using the simulation results with our models. We found that ABSS helped to promote communication between stakeholders.

**Keywords** Agent-based social simulation • Communication • Systems approach

## 17.1 Introduction

Agent-based models are classified into abstract models, middle range models, and facsimile models [6]. Abstract models, e.g., the segregation model [17] and Sugarscape model [4], assist in understanding basic social dynamics generated from important factors in social systems. Facsimile models, e.g., a theme park model [13] and an infection model for bird flu [14], help in assessing the effects of concrete policies in specific problem situations by reproducing factors in their target system quantitatively. The middle range models can generate certain social behaviors qualitatively and can be applied to the explanation of a number of social systems,

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but not of one specific system. The models partly contribute to support decision makers who want to understand the effectiveness of specific policy alternatives by concentrating on a focal point.

Recent research using facsimile and middle range models has tried to support decision makers who want to evaluate certain policy alternatives. Several researchers have created useful methods to build valid models and provide helpful information for decision makers. These methods have included modeling and simulation methods, e.g., role playing [2, 3], participatory simulation [8, 10] and an effective analysis method known as scenario analysis [7, 11]. Various calibration and validation methods have also been used [1,5,15]. All of these methods help modelers and analysts to evaluate the effectiveness of agent-based models and simulations. We know very little about how agent-based social simulation (ABSS) actually contributes to the decision-making processes used by managers and employees who are not familiar with it. Our research, by identifying the main contributing factors in practical business situations, provides modelers and analysts with a new guideline for evaluating their models and simulation results.

We talked with managers and employees about using ABSS for their decision-making processes. We engaged with stakeholders who wanted to decide on an accurate policy or strategy for achieving their purposes in two kinds of business problems by using ABSS with the two types of models that were built into our previous research. The business problems were: (1) a knowledge management problem in a service-oriented organization and (2) a layout design problem in a supermarket. Based on the experimental results, we aim to clarify how ABSS aids communication between stakeholders in a series of decision-making processes.

## 17.2 Two Business Problems

This section explains the problem situations and policy alternatives in our two target case business problems: a knowledge management problem in a service-oriented organization and a layout design problem in a supermarket. The problem situations and policies are derived from our field research, such as interviews with stakeholders and the observation of human behavior in the two cases. Both include complex interactions among various elements and the uncertain environmental factors that strongly affect them. ABSS can provide a way to analyze the complex behavior of agents affected by essentially uncertain factors in complex systems, so it is helpful in adequately representing the problem situations.

### *17.2.1 Service-Oriented Organization*

First we targeted an organization that mainly provides a contract renewal service. This company provides computer maintenance, a service business in Japan. In the organization there are many service profiles to define contracted services, including customized service requests. This compels workers to resolve the problem of handling different customer demands. The knowledge required in a service-oriented organization is accumulated in each worker through interactions with different customers. Each operation in the organization is therefore dependent on an individual worker's tacit knowledge. If this worker leaves the organization suddenly, its performance may be significantly reduced. To prevent productivity decline, managers therefore want to manage the various types of knowledge successfully.

*Problem Situations*

Through our fieldwork in the organization we were able to identify problem situations as follows: (1) the number of tasks varied at different periods; (2) an existing work manual was not helpful in resolving most tasks because new customized services were often generated by interactions between workers and customers; (3) although one of the managers wanted to update the existing work manual, he postponed it because it took too much time; (4) there were different skill levels among workers, so entry-level workers often had to ask other workers or a supervisor (SV) to resolve some tasks; (5) highly skilled workers had to spend time teaching entry-level workers how to resolve tasks.

*Policy Alternatives*

Next, we extracted four types of policy alternatives that the managers wanted to carry out in the organization: (1) job rotation, (2) improved knowledge base (KB), (3) assignment of service agents to teams, and (4) use of spare time. One of the managers strongly believed that they should conduct job rotation, so that workers would become multi-skilled. The reason was that an increase in multi-skilled workers would prevent production decline if a worker with important tacit knowledge left the organization suddenly. Managers were concerned, however, that job rotation might have a negative impact on productivity, if it did not work as a policy.

### *17.2.2 Supermarket Checkout Area*

Second we focused on management problems in retail stores, such as supermarkets and drugstores. Some studies have analyzed sales promotion and category management strategies by using agent-based models [16, 18], and store management is one of the typical problems in ABSS. In this study, we targeted a layout design problem, which is a different store management issue from that examined in other studies.

Many supermarkets or drugstores have recently introduced a self-checkout system to stop customer congestion, but this requires fewer workers. However, stakeholders are concerned about whether the system really reduces the number of people standing in checkout lines. Store managers therefore need accurate information to verify the effectiveness of a new checkout system before introducing it.

We contacted stakeholders who wanted to design their checkout area more effectively. We first interviewed them about their concerns and then observed customer behavior in the checkout area.

*Problem Situations*

The checkout system separates the scanning and self-payment stations. Each checker is assigned to a scanning station only; the customers pay their money themselves at a self-payment station. Stakeholders expect that the number of people queuing for scanning goods would be reduced compared with that in a conventional checkout system that has cash registers with both functions of scanning and payment.

Before this research started, the stakeholder faced an unexpected situation soon after the introduction of the new system into a supermarket. Long queues of customers formed in front of scanning stations, while there were only short queues in front of payment stations. It was not possible for them to evaluate the situation easily because of uncertain factors, such as the number of customers, the amount of goods in the shopping carts, and the scanning speed of the checkers.

*Policy Alternatives*

Stakeholders were mainly concerned about the number of scanning and payment stations they should introduce to the supermarket. Station layout issues arose, such as the distance between two scanning stations and that between scanning and payment stations. Their policy alternatives were very simple compared with the organizational problem already described.

## 17.3 Models and Simulations for the Two Business Problems

We have built two types of agent-based models for representing the business problems explained in the previous section. We developed various scenarios relevant to the problem situations and policy alternatives and then conducted simulations based on the scenario settings. We only give a summary of the models and simulations because the purpose of this paper is to show how the communication between stakeholders with the simulations was conducted. For detailed model structures see our previous studies [12, 20].

### *17.3.1 Service-Oriented Organization*

*Model Summary*

The service-oriented organization model consists of two departments, workers (called service agents in the model) and the SV, with various types of tasks. In the organization each task is generated and then assigned to a service agent. An agent

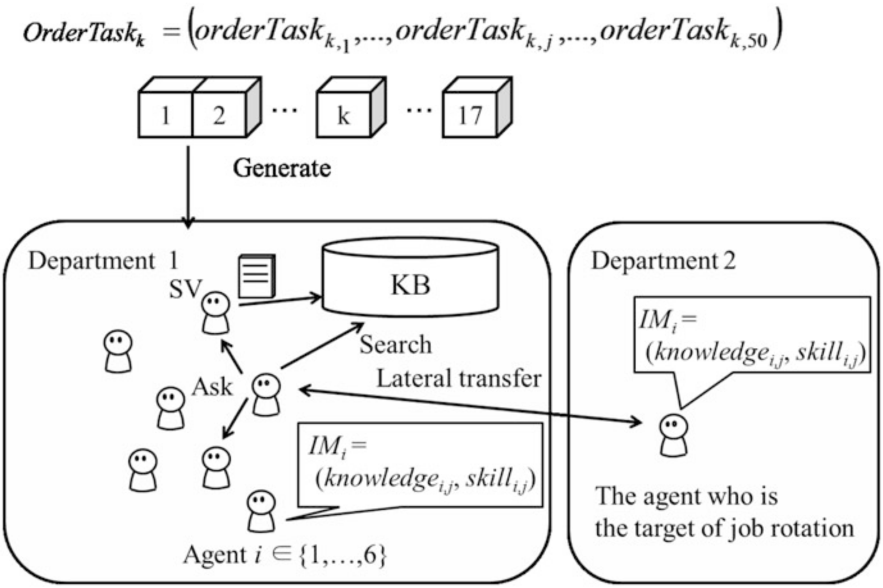


**Fig. 17.1** Summary of service-oriented organization model

resolves the task by using its knowledge. The resolution time is calculated based on a combination of the agent's skill and the difficulty of the task. The value of a skill increases according to how long it takes to resolve the task. When an agent does not resolve a task for a certain period of time, it forgets the knowledge and skill that is required to do so. If the agent does not have this knowledge, it asks an SV or another agent how to do it so that it can acquire the knowledge.

Depending on the scenarios used in our simulation, we also built additional model components such as KB and another department that contains the agent who has to do the job rotation (see Fig. 17.1).

*Simulation Experiments Example*

We conducted many kinds of simulation experiments with our model by using various scenarios. Here we show one of these experiments that analyzed job rotation policies for creating multi-skilled agents. This chapter only looks at the rotation intervals as policy scenarios used in the simulation experiment. The policy scenarios (job rotation interval) are: Scenario (1) 1 month; Scenario (2) 2 months; Scenario (3) 3 months; and Scenario (4) 4 months. In the scenario analysis, for comparison we also add a Scenario (5), in which the managers do not rotate agents in the organization. We simulated 100 trials for each scenario, and then calculated a sum of the skill values of all agents. As a result we describe a landscape of the sum of skill values by plotting the results of all 100 trials in each scenario. A dotted line connects the average rates of the 100 trials in each scenario (see Fig. 17.2). We also use individual behaviors (such as the transition of agents' knowledge and skills

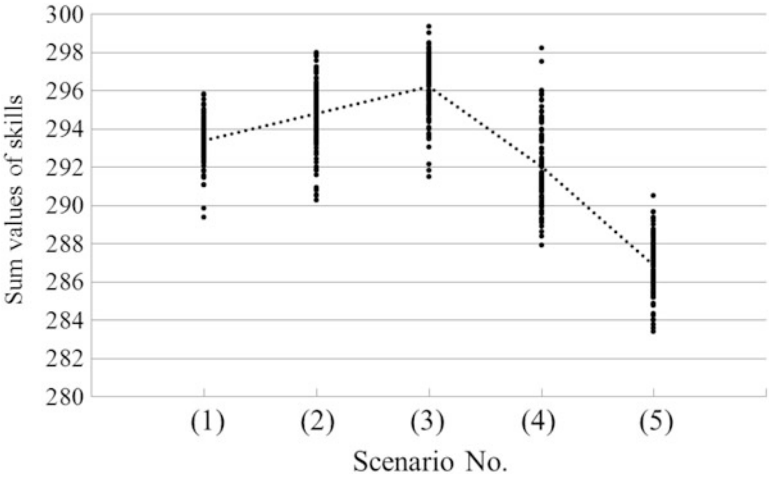


**Fig. 17.2** Sum values of all agents' skills

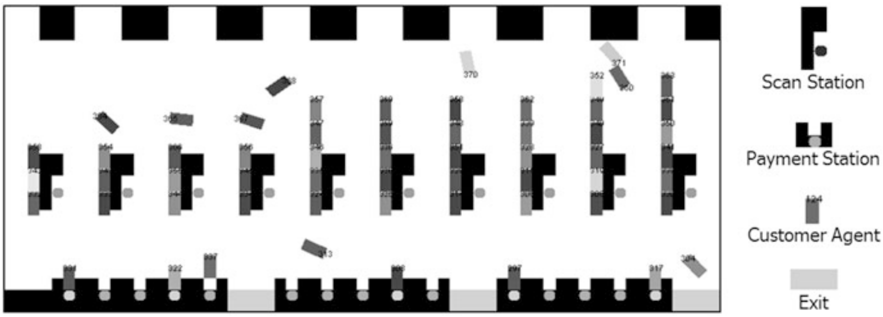


**Fig. 17.3** GUI of our simulator

to others) to explain to stakeholders why differences in organizational behavior are generated in various scenarios. This analysis of individual behaviors is called micro-dynamics analysis [11].

### 17.3.2 Supermarket Checkout Area

*Model Summary*

The checkout area model consists of customer agents, checker agents, scanning stations, payment stations, item shelves, and exits. Figure 17.3 shows the graphical user interface (GUI) of our simulator.

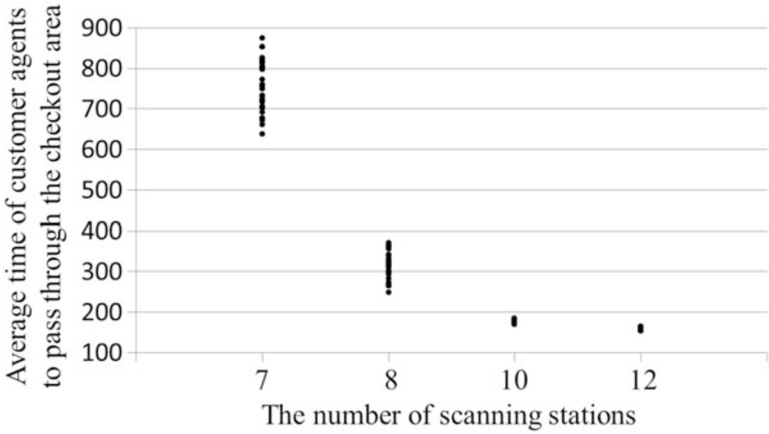


**Fig. 17.4** The average time to pass through the checkout area

Each customer agent appears from between two item shelves. They each have an internal model including several information factors such as the congestion situation around the scan and payment stations and the decision rule of selecting the stations. First they select a scanning station based on their internal model, and then they go to the station. After the scanning process, they choose a payment station based on their internal model and then they go to the station.

Each checker, who has scan speed set as its parameter, is assigned to a scanning station and scans the items of the customer agent who comes to it.

*Simulation Experiments Example*

In our simulation experiments, we set various scenarios by changing some parameters, such as the number of scanning and payment stations, the amount of customer items, and the scanning speeds of scan agents. Then we calculated the number of queues of the scanning and payment stations and the time required for customer agents to pass through the checkout area.

We only show the average time for customer agents to pass through the checkout area by changing the number of scanning stations as an example of the simulation results. We performed 30 simulation trials for each setting and described the landscape by plotting the average values (see Fig. 17.4). We also described the transition of a number of people standing in line at each station and showed the micro-individual behavior of customer agents. This was done to explain to stakeholders the differences in congestion situations between scenarios using different checkout area designs.

## 17.4 Discussion with Stakeholders to Support Decision Making

To show how ABSS aids communication between stakeholders, we discussed with them the right and wrong of policy alternatives based on the various changes of system behavior gained in our simulation results in the two business problems.

### *17.4.1 Discussion with Managers and Workers in the Service-Oriented Organization*

We held a meeting for improving the organizational performance with two managers and three workers in department 1 as shown in Fig. 17.1. We first presented the simulation results based on the landscape and micro-dynamics analysis.

They immediately expressed surprise at the results of these simulations. For example, one manager recognized that organizational performance is profoundly affected by not only learning knowledge but also forgetting knowledge.

After developing new perspectives from the simulation results, the stakeholders gave feedback that they had not provided in our fieldwork. For example, one of the workers presented her viewpoint about a heavy workload on a particular worker. This opinion helped managers to understand an organizational problem that they did not notice in their daily work. Then a worker delivered another opinion about the necessity of job rotation on the basis of tasks and workload in other departments. This suggests that we have to include other workers as new stakeholders in the next meeting and revise model components by adding new elements for evaluating some job rotation policies.

Finally, the managers said that they had to consider new policies relevant to the "evaluation of individual performance" and "method of task assigned for increasing performance." We were able to get more of their opinions, and they were classified into the three categories of "developing new perspectives," "sharing potential problem concerns," and "creating new policy ideas." Table 17.1 shows the opinions aired in the meeting.

### *17.4.2 Discussion with Designers About Supermarket Checkout Area*

We presented our simulation results to designers who wanted to provide a new layout design in the supermarket. Based on the results, they provided various opinions.

**Table 17.1** Opinions shared in the meeting for improving organizational performance

| Categories | Opinions |
|---|---|
| Developing new perspectives | • I had always thought that it is most important to allow workers to learn various types of knowledge, but I now recognize that the accumulation of forgetting the knowledge gained in their past experiences strongly affects organizational performance.<br>• I found out that we have to create an accurate job rotation policy by considering the skills of target workers and the time period. |
| Sharing potential problem concerns | • Although managers have focused only on organizational productivity, I would like them to focus on individual productivity. The reason is that very few workers have a heavy workload, so organizational productivity depends on only some workers.<br>• I think that an entry-level worker cannot resolve some irregular tasks even if they intensively work for about 3 months.<br>• There is a particular department whose tasks are very hard.<br>• I believe that managers should evaluate organizational performance based on not only the productivity, but also the rate of errors.<br>• I want to be assured that job rotations will not be determined by only some members in our department. The characteristics of tasks vary greatly depending on departments. We think that the managers should consider the integrated effects on some departments of job rotation. |
| Creating new policy ideas | • I would like to consider the method of tasks assigned.<br>• I might have to introduce a new method of individual performance evaluation based not only on the number of task resolutions, but also the contribution of knowledge sharing. |

First, they were surprised at the results because some of them showed unexpected store congestion situations. For example, one designer found out that they misestimate the number of payment stations.

The designers then began to share their experience about the store layout design and the assignment of checkers with each other. Examples of shared opinions were meaningful knowledge, especially about the distance between scanning stations and the assignment of a few checkers to a service counter. Typical shared opinions were "I heard from a manager in another supermarket that the length between scanning stations strongly affects the congestion situation in a checkout area" and "We might have to consider the assignment of a few checkers to a service counter when we decide on the shift times of checkers."

They also told us about further concerns to consider when designing a new checkout area layout. For example, one of them said "I remember the heavy congestion generated in between a bagging area and an exit in a supermarket" and "I think that the assignment of checkers to scan stations should be considered depending on the ability and tiredness of checkers." The opinions suggest that we might need to add the bagging area as a new element of the model and that we should include the checkers as stakeholders in the decision-making process.

Finally the designers created some new policies, such as "distance between some objects such as scanning and payment stations" and "design shifts depending on

**Table 17.2** Opinions shared in the meeting for the checkout area design

| Categories | Opinions |
|---|---|
| Developing new perspectives | • I had thought that at least ten payment stations were needed, but I now find that eight payment stations are enough to stop congestion.<br>• If a checker temporarily leaves their assigned scan station when the peak crowding at scan stations starts, the number of people queuing to scan stations continues to rise. |
| Sharing potential problem concerns | • I heard from the manager in another supermarket that the length between scanning stations strongly affects the congestion situation in a checkout area.<br>• Based on my experience, I think that having only a scan station failure causes a great deal of confusion in a checkout area.<br>• I think that the assignment of checkers to scan stations should be considered depending on the ability and tiredness of checkers.<br>• I recall that heavy congestion is generated between the bagging area and the exit in a supermarket.<br>• We might have to consider the assignment of a few checkers to a service counter when we decide on the shift times of checkers.<br>• We might need to consider how to combat shoplifting based on various payment station layouts. |
| Creating new policy ideas | • We should consider not only the number of stations, but also the distance between some objects such as store shelves, scan stations, and payment stations.<br>• We should design shifts depending on the checkers' ability and the expected number of customers. |

the checkers' ability and the expected number of customers." As with the opinions shared in the meeting for improving organizational performance, the designers' opinions are classified into three categories (see Table 17.2).

## 17.5 Contribution of ABSS

The opinions shared in the two meetings showed three types of contributions of ABSS to the communication between stakeholders for determining an appropriate policy. The first contribution is to give new perspectives to stakeholders. This is the essential role of ABSS, which can help stakeholders understand the behavior of complex systems.

Second, they can share their potential problem concerns with other stakeholders by using ABSS as a common language for communication between them. This contribution is similar to the role of a soft systems approach, which can deal with plural situations so stakeholders who share the same values and beliefs can handle the disagreements and conflicts that occur among themselves [9]. ABSS also undertakes a role which is similar to emancipatory systems thinking and that aims to ensure the proper participation of all stakeholders in decision making [9]. Some opinions suggest that we should incorporate other stakeholders into the decision-making process and revise our model by adding new elements. We discussed policy alternatives based on limited and particular presuppositions in the meetings. As Ulrich pointed out, systems designers should judge the boundary that represents what is relevant to a design task [19]. In this respect, ABSS shows us an opportunity to reconsider the boundary by revealing what is of concern inside the system and what belongs to its environment. In practical situations ABSS can also be a new systems methodology to promote communication between stakeholders who have different values and concerns and support them in their boundary judgments.

ABSS also helps stakeholders create new policy ideas. The creation is not directly generated by simulation results, but is a natural offshoot of a series of opinions on new perspectives and potential problem situations. The new policy ideas therefore support modelers and analysts in developing new scenario settings.

## 17.6 Conclusion and Discussion

Most ABSS research states that the simulation results contribute to support decision making in a target system by helping one understand a system's behavior generated by various scenarios. However, there are no studies that show how the decision supports are conducted in practical situations, so in this study we talked with stakeholders about two business cases. We clarified that ABSS can help in developing new perspectives, creating new policy ideas, and sharing potential problem situations. The latter is the most important contribution shown in this study. As with the role of the conventional system approaches, such as soft systems approaches and emancipatory systems thinking, ABSS also helps promote communication between stakeholders who have various concerns and values. There are distinctly different contributions given by the conventional simulation results compared with mathematical models that aim to predict how the system changes in the future or to optimize system conditions by focusing on only a few elements.

However, in this research we only engaged with stakeholders about two cases. This work might therefore provide limited perspectives about the contributions of ABSS. In future work, we need to gain further insights into this area by applying it to various business cases. We would then like to develop a methodology using ABSS to help promote communication between stakeholders that will support their decision making. System practitioners and designers could then effectively develop a new system by combining systems approaches and ABSS.

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# Chapter 18
# Hybrid Approach of Agent-Based and Gaming Simulations for Stakeholder Accreditation

**Yusuke Goto, Yosuke Takizawa, and Shingo Takahashi**

**Abstract** We propose a hybrid approach of agent-based and gaming simulations for stakeholder accreditation. This approach assumes greater uncertainties about an agent's decision-making and learning processes, severe time constraints on stakeholder participation in the modeling and simulation process, and limited understanding of an agent-based modeling language by stakeholders. The approach transforms an agent-based model into a game with adequate similarities between them, and it allows stakeholders to understand an agent-based model by playing the game. We developed a transformation-modeling protocol to convert an agent-based model into a valid and playable card game, and we introduce an example in which an agent-based model is transformed to assist the design of a performance measurement system in a sales organization. We report preliminary results for our approach.

**Keywords** Accreditation • Agent-based modeling and simulation • Gaming simulation • Hybrid approach • Validation

## 18.1 Introduction

In recent years, various agent-based modeling and simulation (ABMS) methods have been used to analyze several management systems in an organization [7, 10]. These methods assume more complex interactions among agents and higher

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uncertainties within and outside organizations when compared with other methods [9]. Thus, agent-based models (ABMs) have become more complex and of larger scale, and they introduce many assumptions about uncertain modules according to the current understanding of the target organization. We often recognize uncertainties in an agent's decision-making and learning models, and these uncertainties make it difficult to evaluate a model's validity.

With these approaches, ABMS experts conduct field studies and build an ABM. After performing an agent-based simulation (ABS), they prepare a presentation of the result of the ABS to their stakeholders, who include decision makers of the ABMS project. The decision makers often contribute to only a small part of the entire ABMS process because of their time constraints, and most of them are unfamiliar with the field because they are removed from it. Moreover, they are unfamiliar with the language of ABMs because they are not ABMS experts. Therefore, it takes time for stakeholders to understand a large-scale complex ABM, and they cannot evaluate the validity of an ABM that includes inherent uncertainties. As a result, they do not accredit the ABM and ABS results presented. To achieve stakeholders' accreditation [11] of the ABS result, methodological support plays a significant role in advancing ABMS practices regarding the analysis of organizational management systems.

There are two related approaches in the area of stakeholders' accreditation: (1) the simulated tabletop exercise [5] and (2) the companion modeling (ComMod) approach [6]. Both approaches introduce stakeholder participation in an ABMS process. The simulated tabletop exercise is a type of gaming simulation (GS) [8] in which participants act as decision makers, and it consists of three steps: briefing, simulation and analysis, and debriefing. Through these three steps, the exercise is designed to facilitate participant accreditation. This approach implicitly assumes that the participants have already evaluated the validity of an ABM, because it ignores the stakeholders' participation in the modeling process.

The ComMod approach allows stakeholders to participate in the modeling process. In this process, stakeholders and ABMS experts co-construct an ABM to effectively include local knowledge. To externalize stakeholders' implicit knowledge and behavior, they play a role-playing game (RPG) based on a conceptual model of a target problem situation. This process leads the stakeholders to elaborate on the ABM and accredit it. In addition, the ComMod approach incorporates stakeholders in the simulation and analysis. This participatory analysis approach is more likely to lead to stakeholders accrediting the ABS result. The ComMod approach has worked well for various natural-resource management problems in which stakeholder involvement is essential for effective decision making [6]. However, most of the ComMod practices require several years for completion because the ComMod approach is premised on a comprehensive participation in the entire ABMS process [1].

We recognize the weakness of these approaches from the viewpoint of achieving stakeholders' accreditation of an ABS that analyzes management systems in an organization. In practice, an ABM inherently includes uncertainties, and decision makers are unfamiliar with its language. Therefore, we recognize that a simulated tabletop exercise cannot evaluate the actual validity of an ABM for stakeholders' accreditation. Meanwhile, most of the decision makers in an organization face severe time constraints. To develop an RPG in the ComMod approach, we require a relatively clear description of a decision-making model, a learning model, and interactions among players, while we often recognize their uncertainties. Therefore, the ComMod approach is inappropriate for such a problem scenario, and we need another participatory approach that can achieve stakeholders' accreditation of the ABS result when the stakeholders analyze an organization's management systems.

The primary objective of this study is to propose a novel participatory approach for achieving stakeholder accreditation of the ABS result when the stakeholders analyze an organization's management system. This chapter is organized as follows. Section 18.2 proposes a hybrid approach of ABS and GS for stakeholders' accreditation. We introduce the basic ideas and an outline of the approach. Section 18.3 introduces the core process of the approach regarding the method used to transform an ABM into a game. We use a transformation-modeling protocol to validly and smoothly convert an ABM into a game, and introduce an example of the transformation. In Sect. 18.4, we report a preliminary test of our approach. We use the ABM which was transformed in Sect. 18.3 in conducting a workshop to facilitate stakeholders' accreditation. Section 18.5 summarizes the study and describes our future initiatives.

## 18.2 Hybrid Approach of ABS and GS for Stakeholder Accreditation

### *18.2.1 Core Concept*

We use GS in a form different from its conventional use to address the accreditation problem. The GS process assumes a complex problem situation in which we cannot easily understand the whole system through a model document, and the original intention is for players to understand the whole system through their gaming experience. Thus, with a conventional approach, we develop a game that incorporates actual problem situations in an organization.

In our approach, we develop a game that is similar to an ABM. This game functions as a pilot study illustrating the effect of a considered scenario if game players are actual stakeholders of the problem. After comparing the results of ABS and GS, the stakeholders can evaluate whether the ABM accurately represents an actual problem situation, because they would have experienced a game that is similar to the ABM of the actual problem situation. The stakeholders would then accredit the ABS result if they recognize adequate similarities, or if they can suitably revise the ABM.

We adopt a hybrid approach using two types of simulation, ABS and GS, to achieve the stakeholders' accreditation of the ABS result. We recognize the

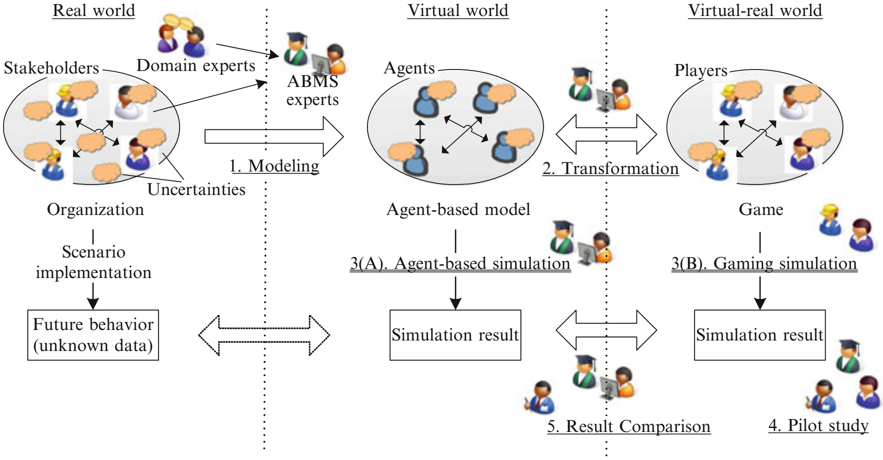


**Fig. 18.1** Hybrid approach of ABS and GS for stakeholders' accreditation

uncertainties regarding human behaviors and introduce uncertain assumptions into the agent's behavioral model in the ABM. These assumptions may become hurdles preventing stakeholders' accreditation, even if ABMS experts have already validated them by alternative methods.

In the GS process, a game is played with stakeholders who behave as if they were in an actual target problem situation. GS is *virtual* because it is a simulation that exists in a virtually constructed world, but in GS, we can observe real human behaviors that should be captured in an ABM. We expect GS to play a supportive role for ABS in achieving stakeholders' validation of the ABM and accreditation of the ABS result.

## *18.2.2 Outline of Our Approach*

Figure 18.1 shows the entire process of our approach. We assume that ABMS experts have recognized the uncertainties of various factors in a target organization system. Stakeholders are concerned about the effect on organizational behavior and performance after a specific management system is introduced into the organization. ABMS experts developed an ABM that was based on information from stakeholders and domain experts. These experts introduce various uncertain assumptions that reflect their current understanding of a target organization system, because they must tentatively specify an operational ABM to perform ABS. After developing an ABM, ABMS experts transform the ABM into a game that has adequate similarities to the ABM.

ABMS experts conduct a workshop to facilitate stakeholders' accreditation for the ABS result after the model transformation. In this workshop, ABMS experts perform two types of simulation and analysis: ABS and GS. The experts perform ABS to analyze the effect of management-system scenarios. The experts invite stakeholders into a GS session, and the stakeholders play games that implement the same scenarios.

The stakeholders experience surroundings similar to that of the ABM by playing a corresponding game. The GS result is derived from actual members of the target organization who act as agents in the ABM. Therefore, we regard the GS result as a pilot study of the effect of the considered management-system scenarios in the target organization.

Stakeholders compare the results of ABS and GS, and evaluate whether uncertain factors in the ABM are accurately modeled. Through this process, our approach facilitates stakeholders' accreditation for the ABS result. We describe our approach in terms of (1) the stakeholders' experience of GS, (2) a pilot study with GS, and (3) an analysis of hybrid simulations.

#### 18.2.2.1 Stakeholders' Experience of GS

GS can assist players in understanding the whole system of the complex problem situation. In GS, stakeholders, who function as players of the game, can virtually experience a mock situation, which is consistent with an ABM if the transformed game has adequate similarities. Therefore, the stakeholders who are not ABMS experts can understand the complex ABM by playing the game.

In our approach, a game is derived from an ABM (a model of a real-world problem situation), whereas most games are directly constructed from real-world problem situations in the traditional GS approach. This difference is due to the differing purposes of traditional GS and our GS. Our goal is for players to understand an ABM representing a real-world problem situation, whereas the traditional GS approach intends that players understand a real-world problem situation in itself.

The ComMod approach, which uses an RPG, is similar to our approach, in that both approaches use GS to involve stakeholders in the ABMS process. However, there is a difference: an RPG in the ComMod approach aims at obtaining local information and knowledge that is hidden from ABMS experts. In our approach, GS aims to deepen stakeholders' understanding of an ABM without the stakeholders having to read a model document or attend a presentation, which are often time-consuming activities. An RPG generally depicts stakeholders and elements in the real-world problem situation, and the players in the RPG directly correspond to the actual stakeholders in the real organization. The games transformed by our approach can depict a virtual world that is different from the real-world problem situation, but, at the same time, our approach can maintain adequate similarities between the game and the ABM. We can find a potential benefit in that it helps a context-free discussion of the model structure without any stakes and biases in the real situation. This would serve to facilitate an accreditation process.

#### 18.2.2.2 Pilot Study with GS

The ABS result is only a logical consequence of the developed ABM. Thus, we cannot expect that the effect of the concerned scenario in ABS will be exactly reproducible in a real-world problem situation, unless we implement the actual management system. Our approach organizes a small group of stakeholders who are actual members of the organization and regards this group as a miniature version of the organization. A game that is similar to the ABM is played in this miniature version, and we indirectly simulate the effect of a concerned scenario with this miniature version. We believe that this GS may serve as a pilot study before an actual implementation of the scenario.

Our approach considers that stakeholders examine the effect of a scenario in an actual organization using GS as a pilot study, whereas GSs have traditionally had an educational purpose, in which game players obtain specific knowledge or insight through the GS process.

#### 18.2.2.3 Analysis of Hybrid Simulations

In terms of the validation of an ABM with the ABS result, we note that traditional ABMS practices have examined whether the ABS results are consistent with real data of the past or data that are not used in the modeling process. Unfortunately, however, unless we implement the actual system, we cannot obtain real data for ABM validation when analyzing the effect of a management system in a specific organization. Thus, we cannot examine these data-fitting processes with the ABS result.

We believe that this problem can be resolved using virtual data generated from quasi-situations of a target organization. We can examine the validity of an ABM from the correspondence between the results of ABS and GS if we assume that there are adequate similarities between the ABM and the game. The GS result is regarded as virtual data that are generated from actual members' behaviors in a miniature version of the target organization.

In contrast to traditional ABMS approaches, our approach does not use real data to validate an ABM, but instead uses virtual data generated in a quasi-constructed miniature organization. We believe that this approach can also resolve the problem of the model grounding to a specific organization.

#### 18.2.2.4 Need for Transformation-Modeling Protocol

In our approach, for the effective validation of an ABM, it is critical to ensure the successful transformation from the ABM into a game. Games have been developed in an artisanal way [2, 8] because we can choose various archetypes of the game and do not have a modeling language. Thus, it is often difficult to develop a game that satisfies a given purpose in an a priori manner, and we must go through a trial-and-error process. Moreover, there is no framework to ensure adequate similarities between an ABM and a developed game.

Our approach will address this problem as discussed below. We develop a transformation-modeling protocol to ensure adequate similarities in the transformation process from an ABM into a game, and use it to develop games. This protocol is based on the object-oriented approach, which is common to ABMs and games.

## 18.3 Transformation-Modeling Protocol and Its Application

We propose a transformation-modeling protocol that enables users to transform ABMs into card games, because card games can adequately represent multi-agent interactions. Agents perform their assigned tasks with their skills and resources. They take part in various activities and interact with each other [4]. Agents' activities in an ABM correspond to players' card-actions in a card game, and agents' skills and resources correspond to cards.

This protocol bridges the representations of ABMs and card games, and it achieves consistency with them via an object-oriented notation. We introduce three types of diagrams based on the Unified Modeling Language (UML)—class diagrams, state-machine diagrams, and sequence diagrams—because they can capture essential aspects of ABMs [3] and card games. In this protocol, these diagrams are partly modified from the original UML specifications. We transform an ABM into a card game in three steps: (1) an abstraction step from the ABM, (2) an intermediate step, and (3) an abstraction step into GS.

### *18.3.1 ABM to be Transformed*

This section introduces the transformation-modeling protocol and presents a case study involving the transformation of the ABM to analyze a performance measurement system (PMS) in a sales organization. We use the model presented in [7], which describes salesperson's behaviors under the PMS (Fig. 18.2). We consider a sales organization that has salespeople. The salespeople are engaged in selling goods. Salespeople take part in four activities: (1) sales, (2) market cultivation, (3) education of teammates, and (4) training. Sales refers to the process of selling goods to a customer. The probability of sales success is equivalent to a salesperson's capability. Market cultivation refers to the process of seeking new customers for a good. The education of teammates increases the capability of all teammates. Training increases the salesperson's capability. Salespeople have individual attitudes toward sales activities, and their actions are based on these attitudes.

A sales manager evaluates salespeople using a PMS in a sales organization. Salespeople learn their attitude and change their actions to improve their evaluation

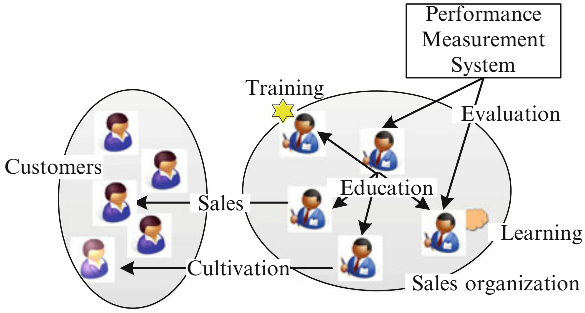


**Fig. 18.2** ABM of sales organization under PMS

under the PMS. We consider four PMSs as scenarios: (1) an individual-sales-based evaluation system, (2) a group-sales-based evaluation system, (3) a behavioral-evidence-based evaluation system, and (4) a behavioral-evidence-based evaluation system that is not announced officially. We therefore transform four ABMs that have different scenarios into four card games that have different rules.

### *18.3.2 Abstraction Step from the ABM*

In the first step, we reformulate an ABM because it is not always represented in an object-oriented notation. First, we should exclude peripheral variables from the ABM and choose core variables that are to be subsequently represented in the game because most ABMs are too large-scale and complex to be directly transformed into a playable game. We should include the variables that are relevant to the uncertainties to be examined. We then classify the involved variables into two categories: the agent's internal variables and variables of the agent's environment. The former corresponds to the agent's attributes (e.g., ability, skills, and evaluation), whereas the latter corresponds to information recognized by the agent (e.g., tasks, market, and other agents).

We then make three types of diagrams. A class diagram highlights what are represented as objects in the game, and the agent's internal variables and behaviors need to be included in the diagram. In addition, variables of the agent's environment are involved in the diagram, whereas variables that are relevant to the uncertainties to be examined are involved in the diagram but are shaded for clarity, and we abstract them in the subsequent steps. We allow users to describe super classes or interfaces in the diagram if they deepen the user's understanding of the ABM. In the diagram, relationships among objects should be specified. Figure 18.3 is an example of a class diagram in this step.

We prepare a state-machine diagram for every variable represented in the class diagram, except for the shaded variables. For every selected variable, we identify

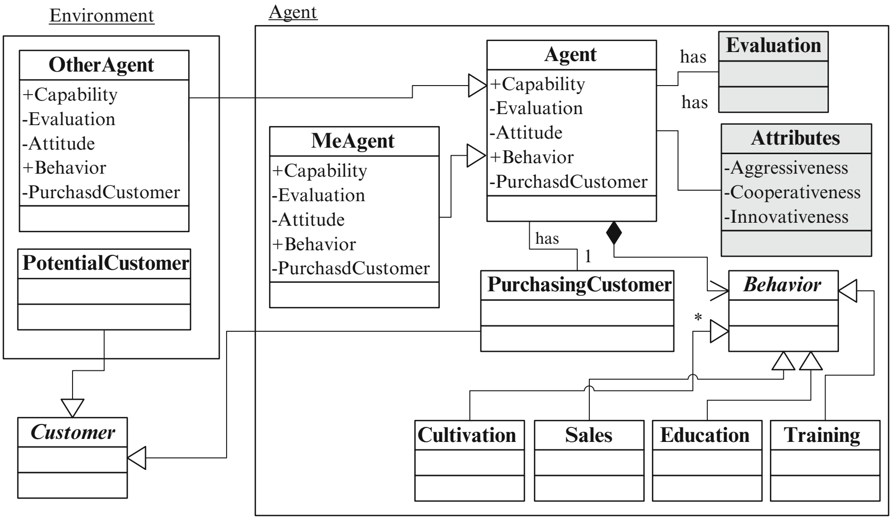


**Fig. 18.3** Example of a class diagram in the abstraction step from the ABM

states, triggers of transitions to a next state, and outcomes with the transitions. We recommend specific states of a variable as a minimum value, a maximum value, and intermediate values other than the two states. If the transitions include a probabilistic process, or if the values of the variables are continuous, we describe them as is without any abstraction in this step. Moreover, we prepare a sequence diagram for each behavior of the agents. A sequence diagram summarizes the effect of the behavior on other objects in the class diagram.

### *18.3.3 Intermediate Step*

In the intermediate step, we carry out a minor abstraction and adjustment process to develop a playable card game. The time required to play a card game should be short. We need to define the number of players and the playing time for a game, and reexamine assumptions made in the ABM for playing a card game.

Most of the state-machine diagrams are abstracted in this step. The rules of a card game must be simple to understand. The card game cannot handle continual variables, and a good card game allows players to have behavioral options and to behave according to their wishes subject to following the rules. Therefore, we abstract peripheral, probabilistic processes, and reformulate them as deterministic processes. We redefine the continual variables as discrete ones, and specify the smallest unit of their change. Figure 18.4 shows an example of an abstracted state-machine diagram in this step.

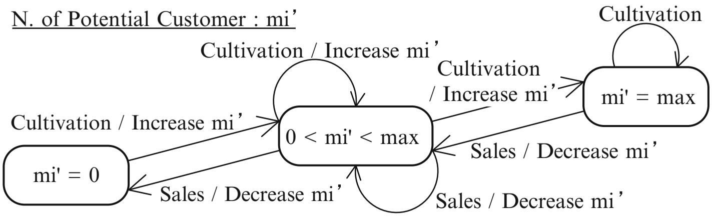


**Fig. 18.4** Example of a state-machine diagram in the intermediate step

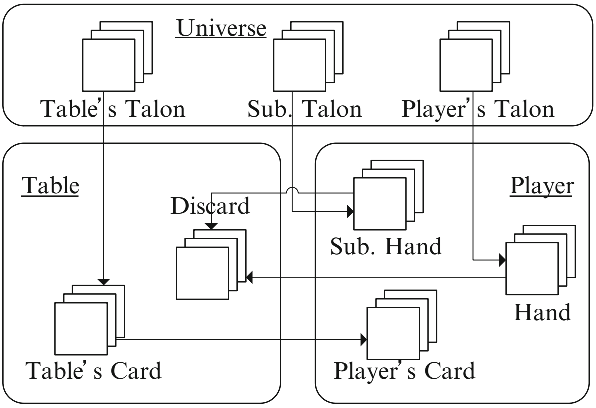


**Fig. 18.5** Card-game archetype

## *18.3.4 Abstraction Step into GS*

In the final step, we abstract the model represented by the three types of diagrams in the previous step and represent the class diagram shown in Fig. 18.3 with a card-game archetype. Figure 18.5 shows a card-game archetype that defines players, tables, cards, and flow of cards. We associate objects in Fig. 18.3 with cards in Fig. 18.5 and associate behavioral classes in Fig. 18.3 with flow of cards in Fig. 18.5.

We revise the sequence diagrams on the basis of a revised class diagram. We replace objects with cards, and describe each behavior's outcome in the diagram. Figure 18.6 shows an example of a sequence diagram in this step. In this case, a player decides which card to discard from his/her hand, and places a sales card on the table. He/she takes the customer's cards from the table, and stocks them as his/her cards.

## *18.3.5 Generation of the Game*

We develop game rules from three kinds of diagrams. An abstracted class diagram defines a static structure of players, tables, and cards in the card game.

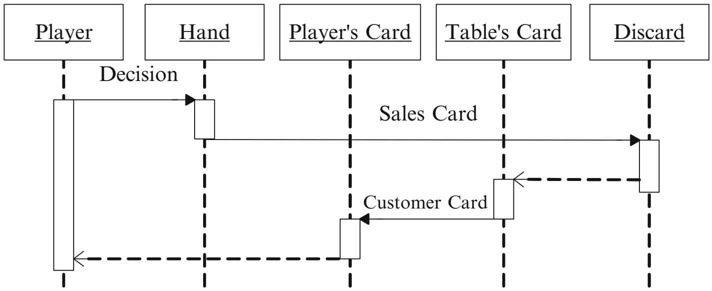


**Fig. 18.6** Example of a sequence diagram in the abstraction step into GS

State-machine diagrams define rules and constraints associated with each card. Sequence diagrams define each behavior and its outcome. We refer to these diagrams and specify a set of game rules that satisfies these definitions. Note that we can specify various sets of game rules that satisfy the definitions, but all display homomorphism because they are from the same model and maintain the same system structure. We should consider our card resource while developing the rules. We show an example of a developed card game in the following subsections.

#### 18.3.5.1 Outline

This card game requires four players at a table and two or more tables. Each table has a deck of UNO cards and four decks of poker cards. The dealer deals 12 poker cards to each player, face down, beginning with the player on his/her left. The player tells the dealer the composition of his/her cards privately. This composition defines how many cards of respective suits are dealt by the dealer. Each player attempts to stock numbered UNO cards. At the end of the game, the player with the maximum score wins.

#### 18.3.5.2 Game Rules

Each player discards a card from his/her hand, and then he/she receives a result specified by its suit and number. If the player discards a card of diamonds, he/she can stock numbered UNO cards on the table up to the number of the discarded card. For example, if the player discards a nine of diamonds and there are four UNO cards numbered 5, 4, 3, and 1 on the table, he/she can stock a set of UNO cards: (5, 4) or (5, 3, 1). If the player discards a card of hearts, four new UNO cards appear on the table, regardless of the number of the discarded card. If the player discards a card of spades, he/she gets two draw-two UNO-cards as special cards. The number of a diamond card increases by two per special card. Therefore, when the player discards a nine of diamonds and two special cards, it is the equivalent of discarding a thirteen of diamonds. If the player discards a card of clubs, then the other three players receive a special card.

**Table 18.1** Correspondence between the agent-based model and the card game

| Agent-based model | Card game |
|---|---|
| Performance measurement system | Score calculation formula |
| Attitude | Composition of cards |
| Capability | Diamond cards and special cards |
| Learning of attitude | Changes in the composition of cards |
| Sales | Discarding a diamond card |
| Market cultivation | Discarding a heart card |
| Education of teammates | Discarding a club card |
| Training | Discarding a spade card |

After all four players discard all 12 cards from their hand, the round ends and the dealer calculates players' scores. The formula used to calculate a score corresponds to a PMS in an ABM. For example, each player's score is the summation of the face values of his/her cards of diamonds when we transform a scenario of the individual-sales-based evaluation system. Table 18.1 shows the correspondence between the ABM and the card game.

## 18.4 Preliminary Test of Our Approach

### *18.4.1 Experimental Design*

In November 2011, we conducted a 3-day workshop as a preliminary test of our approach. In this workshop, we prepared four games that have been converted with the transformation-modeling protocol. These games require four players per table. A total of 32 undergraduate/graduate students as participants were divided into eight tables, and two dealers occasionally helped the players to progress smoothly. Some of the students are majoring in ABMS study. Note that the participants in this experiment are not actual stakeholders, because we first try to confirm whether the transformed games are playable. We provided financial incentives coupled with their game performance to ensure that the participants played the games seriously. We believe that this incentive system would have no harmful effect on the player's behavior because it is consistent with the target situation on which the game is based.

This workshop consisted of the following parts: briefing (30 min), GS (520 min), and debriefing (150 min). During debriefing, participants reviewed the ABS and GS results and their experiences gained by playing the games. In addition, they completed a questionnaire focusing on their accreditation of the ABS results. The photographs in Fig. 18.7 were taken during the workshop.

**Fig. 18.7** Workshop photographs: game playing (*left*, *center*) and debriefing (*right*)

**Table 18.2** Summary of the questionnaire result

| | Strongly agree | Agree | Neither agree nor disagree | Disagree | Strongly disagree |
|---|---|---|---|---|---|
| 1: You enjoyed this GS. | 21 (70.0 %) | 8 (26.7 %) | 0 (0.0 %) | 1 (3.3 %) | 0 (0.0 %) |
| 2: You really feel the effect of PMSs via this GS. | 17 (56.7 %) | 12 (40.0 %) | 1 (3.3 %) | 0 (0.0 %) | 0 (0.0 %) |
| 3: The learning model is specified adequately. | 4 (13.3 %) | 16 (53.3 %) | 9 (30.0 %) | 1 (3.3 %) | 0 (0.0 %) |
| 4: You feel the similarities between the ABM and the game. | 5 (16.7 %) | 21 (70.0 %) | 4 (13.3 %) | 0 (0.0 %) | 0 (0.0 %) |
| 5: You accredit the ABS result. | 2 (6.7 %) | 24 (80.0 %) | 4 (13.3 %) | 0 (0.0 %) | 0 (0.0 %) |

### *18.4.2 Experimental Results*

Table 18.2 summarizes the questionnaire results that were obtained during debriefing. We received 30 valid responses from 32 participants. All of the participants completed tutorials in the briefing section, and played the games smoothly with an instruction sheet, and all four games were completed on time. The results show that more than 90 % of the participants enjoyed the GS. We therefore conclude that, in this case, our approach can produce playable games.

During the briefing session, we instructed the participants only about the game rules. Thus, at the beginning of the first game, they were not aware that the games are based on an ABM for the design of a PMS in an organization. However, during the debriefing, more than 90 % of the participants actually felt the effect of the PMSs via GS. More than 90 % of the participants believed that the learning model of the ABM was adequately specified. Around 85 % of the participants recognized the similarities between an ABM and the game. Finally, approximately 85 % of the participants accredited the ABS result.

While debriefing, we noted participants' comments regarding their understanding of typical situations occurring in organizations in which PMS is introduced, their opinions about the differences between an ABM and the game, and suggestions for improving the game. In addition to quantitative results obtained from the questionnaire, verbal responses indicated that the workshop contributed to their accreditation of the ABS result, their awareness of the need to revise an ABM, and their awareness of the need to elaborate a game.

## 18.5 Summary and Future Studies

In this work, we proposed a hybrid approach of ABS and GS to realize stakeholders' accreditation. Our approach compares the results of ABS and GS that are similar to an ABM. When there are higher uncertainties about an agent's decision-making and learning models, the approach facilitates the stakeholders' accreditation of the ABS result and improves the awareness of requirements to revise an ABM. We developed a transformation-modeling protocol to convert an ABM into a game with adequate similarities, and introduced an example of the transformation. We conducted a preliminary test of our approach. In this test, we used games that were transformed from the ABMs and confirmed that our approach facilitates the participant accreditation of the ABS result.

We have at least four challenges ahead. First, we must improve the representation in the transformation-modeling protocol. We need a more rigorous definition of the representation of the intermediate language between ABMs and card games. Second, we should extend the card-game archetype because it does not help to smoothly generate detailed game rules, especially about the role of a dealer. We must reconsider the intermediate language to introduce the concept of playing card games. Third, we should clarify what is realizable by playing card games. The card game generated by our transformation process does not need to depict the world in the ABM exactly as it is. The game can depict another virtual world. This would help realize a less-context discussion. Fourth, we should attempt to transform various ABMs into card games and clarify the scope of the applicable ABMs.

The approach needs to be applied to real stakeholders, since the present study only involved a preliminary test undertaken by undergraduate/graduate students who are not actual stakeholders of the ABM. We note potential problems generated by applying the hybrid approach to actual stakeholders. First, we expect that the actual stakeholders who are concerned about their problem situation would more fully realize the effect of PMSs via GS than non-stakeholders. However, the actual stakeholders would more strictly evaluate the correspondence between ABMs and transformed games because they can imagine specific scenes in the real-world problem situation.

Second, if the world view of transformed games is quite similar to that of the ABM, the actual stakeholders as game players may behave in a way that is highly affected by a real power structure and human relationships in addition to the game rules. In our approach, while the users guarantee that the transformed games and ABMs display homomorphism, the users can define an independent world view of the game removed from that of the ABM. A tentative solution to observe less-context behavior in such a situation is to define an independent world view of the game removed from that of the ABM.

Another potential problem relates to the selection of game players from actual stakeholders. We have no firm conviction that the actual stakeholders should play in the same position as in the real world. We can recognize the positive effect of understanding the ABM (or the real-world problem situation) from different positions. We perhaps need to develop an effective debriefing process that achieves a synthesized and shared understanding of the whole ABM from stakeholders' understandings derived from each different position.

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# Part VI
# Methodology

# Chapter 19
# When Does Simulated Data Match Real Data?

## Comparing Model Calibration Functions Using Genetic Algorithms

**Forrest Stonedahl and William Rand**

**Abstract** Agent-based models can be calibrated to replicate real-world data sets, but choosing the best set of parameters to achieve this result can be difficult. To validate a model, the real-world data set is often divided into a training and a test set. The training set is used to calibrate the parameters, and the test set is used to determine if the calibrated model represents the real-world data. The difference between the real-world data and the simulated data is determined using an error measure. When using evolutionary computation to choose the parameters, this error measure becomes the fitness function, and choosing the appropriate measure becomes even more crucial for a successful calibration process. We survey the effect of five different error measures in the context of a toy problem and a real-world problem (simulating online news consumption). We use each error measure in turn to calibrate on the training data set, and then examine the results of all five error measures on both the training and test data sets. For the toy problem, one measure was the Pareto-dominant choice for calibration, but no error measure dominated all the others for the real-world problem. Additionally, we observe the counterintuitive result that calibrating using one measure may sometimes lead to better performance on a second measure than could be achieved by calibrating using that second measure directly.

**Keywords** Agent-based modeling • Calibration • Genetic algorithms • News consumption • Web traffic

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## 19.1 Motivation

Agent-based models (ABMs) and other computational simulations tend to produce a large quantity of data, which is often longitudinal in nature. Moreover, in order to properly analyze these models, since they are stochastic, it is often necessary to carry out several runs of the same parameter settings to create multiple data sets so that the statistical variance present in the stochastic model can be observed [18]. The goal of many ABMs is to show that they can simulate real-world behavior, a process known as *validation* [4, 20]. However, in order to match a model data set, $M$, against a real-world data set, $R$, there is often a large space of parameters, $P$, that must be calibrated so that the simulated data best matches the real data, but choosing the set of parameters that will maximize this match can be difficult. On the one hand, if the calibrated model does not match the data very well, then the model may not be useful. On the other hand, if the calibrated model matches the data too well, then the model may not be generalizable outside the data on which it was trained.

In order to ameliorate this problem and help choose the best set of parameters, the real-world data set may be divided into two subsets: (1) the training set $R_{train}$, and (2) the test set $R_{test}$. Ideally, $R_{train}$ and $R_{test}$ will both be equally representative of the phenomena being modeled and collected under similar real-world conditions. However, these two data sets may vary in a number of ways, such as the size of the data set, the environment in which they were collected, etc. Thus, modelers must consider an additional set of environmental variables, $E$, for each scenario: $E_{train}$ and $E_{test}$. The problem of calibration can now be posed as a straightforward search problem: Identify the set of parameters $P^*$ such that some error measure $\epsilon(R_{train}, M(P^*, E_{train}))$ is minimized. Once the model has been calibrated using $P^*$, the results can be validated by comparing the model data to the test set using, $\epsilon(R_{test}, M(P^*, E_{test}))$. If this result is less than some threshold, $T$, then the model is said to be validated.

Many techniques can be used to search for the parameter set, $P^*$, but if the problem contains many interdependent variables, then an evolutionary computation approach has been shown to be suitable [7, 11].[1] In order to conduct this search, a population of potential parameter sets is generated and the fitness of each individual, $P_i$, is measured using the error measure, $\epsilon(R_{train}, M(P_i, E_{train}))$. In the context of an evolutionary algorithm, the error measure, $\epsilon$, becomes the fitness function, and so choosing the appropriate error measure is critical not only to choosing a good set of parameters, but also to the evolutionary process. As is the case for many evolutionary computation problems, the question then becomes which fitness functions to choose [7, 14]. To investigate this question we examine a toy and a real-world problem, and analyze how different fitness functions affect calibration and validation.

[1] Our goal here is not to argue for the superiority of genetic algorithms for model calibration, but to examine the use of different error measures as fitness functions. We expect our findings to generalize to other metaheuristic search algorithms, but this should be confirmed in future work.

## 19.2 Related Work

Agent-based modeling is an increasingly popular form of computer simulation, wherein a set of behavioral rules are specified at the individual level, the execution of which results in trends emerging at the system/aggregate level [2, 6, 18]. Along with other simulation techniques, it often requires the specification of a large number of parameters that affect both individual behavior and environmental factors in the simulation, and machine learning approaches, such as genetic algorithms (GAs) are often brought to bear in these circumstances. While GAs [7, 11] have long been used to explore computer simulation parameters (see, e.g., [29]), there is an increasing quantity of research using GAs in conjunction with ABMs. For example, Midgley et al. [15] used a GA to explore an ABM of a consumer retail environment, and Stonedahl et al. [24] demonstrated the use of GAs for searching for ABM parameters in the context of discovering good viral marketing strategies. Miller's [16] seminal work on "active nonlinear testing" (ANT) proposed the use of nonlinear optimization techniques (including GAs) for a number of important model analysis tasks, including calibration. In contrast to Miller's work, which examined a system dynamics model, we are attempting to calibrate a stochastic agent-based model that we have developed, and more importantly, are investigating the use of a variety of calibration measures and their impact on the GA's performance. Calvez and Hutzler used a GA for an artificially constructed calibration task in an ant colony foraging ABM [3]. In recent years there has been a general trend toward the further integration of data into both the design and analysis practices of agent-based modeling [9, 10]. For example, Wahle and Schreckenberg incorporate real-world road traffic data in the creation of an ABM that simulates urban traffic patterns [28], which is similar in spirit (if not in details) to the Web traffic model we present in Sect. 19.3.2. More generally, our work aims to contribute to this data-driven modeling trend by providing additional insight into the interplay between calibration error measures and search algorithms to perform automated calibration using those measures. Recently, Stonedahl and Wilensky [23] demonstrated the effectiveness of GAs for calibrating the parameters of an agent-based archeology model. In this paper, we show that choice of error measure can make a difference in both the parameter settings ($P^*$) that result, as well as the GA's performance.

The model we are calibrating is in the application area of online news consumption. There have been several surveys of how people consume news [1, 5] such as the Pew Internet & American Life Project's recent report [19], but these surveys describe *stated preferences* and not *revealed preferences*. Tewksbury [25, 26] examined both survey and URL data, but was primarily focused on what topics people choose to read about and not how they consume news. Our work fills this gap by empirically examining not just what consumers read, but how consumers browse, and the connection between browsing behavior and the underlying hyperlink network.

## 19.3 News Consumption

A brief description of the purpose of the model will help motivate its use as an example. Before the growth of the Internet, newspapers essentially had a geographic monopoly on the area that they served. However, with the development of the Web and hyperlinked structures of content, every newspaper had to compete with every other newspaper in existence. As a result, they had to develop new revenue models, such as paywalls, public-sponsored journalism, or consortiums of independent journalists, in order to deliver the same level of quality they were able to deliver in the past. Unfortunately, these new models are not based on rigorous models of consumer behavior. Before a newspaper can understand the implications of these new revenue models, it is first necessary to understand how users consume news online so that projections can be made as to the effect of different revenue models.

Besides being a highly topical and relevant research area, this domain also has benefits for investigating the effect of calibration measures, because there is a large quantity of real-world data, it is embedded in a distributed network, and the question revolves around finding the parameters of an individual-level model that will produce emergent-level outputs that resemble the real-world patterns. Additionally, the large amount of temporal data available allows us to calibrate the model in one time period and then test the results on a separate data set.

### *19.3.1 The Data*

The data used for this analysis was clickstream data from comScore. This data set contains approximately two (2) million domain views per month, from a random sample of roughly 90,000 Internet users during the year 2007. We divided this data into two smaller data sets: one containing only January browsing (for training) and one containing only December browsing (for testing). Among other information, these data sets contain the referral domain and the destination domain for every link clicked by each of the tracked users. For each of the two data sets, we created a weighted directed graph where each node (vertex) represents a Web domain (e.g., nytimes.com), and a directed edge was placed between any node A and node B if there were any hyperlinks clicked to travel from domain A to domain B. Each edge was also assigned a weight, based on the amount of traffic (number of hyperlinks clicked) from one site to another.

Because our focus is on online news consumption and because modeling the whole Web is infeasible, our selected unit of analysis is a news-serving domain (like AOL.com or CNN.com). Thus, we filtered the large network data set to a sub-network containing 455 domains identified as top news websites. Specifically, we included any site that was in the top 100 news category from Alexa traffic rankings, combined with a list created by Hasan et al. [8] of the top news websites and blogs from the time period. We kept only those edges for which the source and destination nodes were both in the list of news sites. This reduced the size of the networks from over 80,000 website nodes to 422 news website nodes and 3,113 edges (for January) and 417 news website nodes and 3,086 edges (for December). Since we were primarily concerned with cross-site browsing (e.g., when a user browsing CNN.com follows a link to browse Digg.com) and due to data limitations (our data set contained only domain-level information), we did not include intra-site links in our analysis (i.e., since we only use links between domains and not within domains, our network is a *simple graph*, excluding self-loops). We also recorded the total amount of incoming traffic for each node that arrived either directly (e.g., via bookmark, clicked link from email, etc.), or via some website not in our list of news sites.

In order to examine this data, we constructed a simulation that models the traffic across the network. The training data ($R_{train}$) that we will be trying to match with our ABM (described in Sect. 19.3.2) consists of the quantity of traffic on each of the edges during January, with the environment ($E_{train}$) consisting of the unweighted version of the graph (which is a proxy for the hyperlink structure) and the probabilities of entering the graph (from the outside world) at each node. Similarly, $R_{test}$ and $E_{test}$ are composed of the equivalent data for the month of December. Things move quickly in Internet time: the December network and traffic is substantially different from in January, with only around 60 % of traffic volume remaining on the same links. A visualization of the January graph is shown in Fig. 19.1, illustrating a dense cluster of sites in the center, with many peripheral (mostly low-traffic) sites surrounding it.

### *19.3.2 Model Implementation*

Using the NetLogo [30] multi-agent modeling language, we developed a simple agent-based model of consumer browsing behavior, premised on the idea that a consumer's decision of which link to click on may be approximated as a function of the structure of the observable inter-site hyperlink network. That is, given an *unweighted* directed network, which merely shows the possible links to other news websites, an agent may choose among the link options based on network-theoretic properties of the candidate destination nodes.

Of course, it is ludicrous to imagine that consumers actually compute network measures for each candidate website, when they are considering whether to follow a link to site A or site B. Rather, these measures should be taken to characterize (or be correlated with) unobserved properties of the site. For example, a site with a high betweenness centrality is one that serves a connecting role in the news website world, whereas one with a high number of out-links to other sites is likely to be more of a news aggregator, and one with a high in-degree or PageRank might be interpreted as being a producer. We also acknowledge that this model ignores one of the most obvious factors that people (consciously) use when consuming Web-based news stories—namely, the title and/or content of the news article the link is pointing

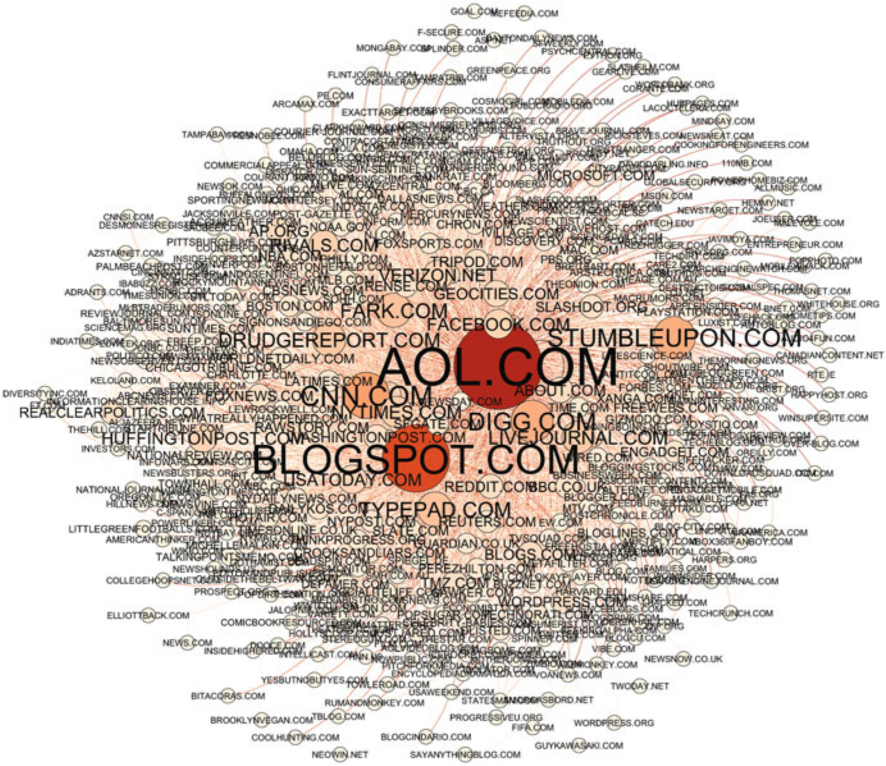


**Fig. 19.1** Visualization of the link network for the January comScore data set

to, i.e., the implied quality of the content. However, a key purpose of building this model was to discover how much leverage we can get out of the network structure, in terms of predicting consumer traffic, while ignoring the content.

To explore this hypothesis, agents are given a ranking function, $f(N)$, which is parameterized by weighting coefficients corresponding to the relative importance of structural node-level network statistics. This ranking function takes a candidate node $N$ as input, and produces a real-valued score representing the appeal of moving to that node. The ranking function is a linear combination of weighting coefficients corresponding to each of the following properties: (1) randomness—random value injecting noise into the ranking, allowing agents to choose links stochastically, (2) in-degree—# of incoming links to this node, (3) out-degree—# of outgoing links from this node, (4) in-component—# of nodes that can reach this node, (5) out-component—# of nodes reachable from this node, (6) pagerank—PageRank score (with $\alpha = 0.85$) [13], (7) hits-hubs—HITS hub score for this node [13], (8) hits-authorities—HITS authority score for this node [13], (9) clustering—clustering coefficient for this node (calculated on the undirected version of the graph), (10) betweenness—betweenness centrality of the given node, (11) eigen—eigenvector centrality of the given node.

Each of these coefficients is a parameter that can vary between $-1.0$ (biased against) and 1.0 (biased for), except for the special randomness weight, which varies between 0.0 and 1.0. For example, assuming all other weights were 0, an in-degree weight of 0.8 and a clustering weight of $-0.4$ would correspond to a movement rule that prefers following links to nodes that have a large number of in-bound links and a low clustering coefficient. Since the randomness weight is 0, this movement rule would deterministically choose the same path, given the same starting point.

Besides the ranking function, we include two additional parameters to control the behavior of the agent: no-backtrack (Boolean), which prevents an agent from going back to a node it just visited, and random-restart (between 0 and 1), which controls how often the agent starts a new browsing session. Given the ranking function and these parameters, the Web surfing agent's behavior is as follows.

1. The agent starts at a random node, chosen with a probability proportional to the empirically observed likelihood of someone arriving at that node (either from a non-news website, or a bookmark, etc.).
2. The agent forms a set of candidates from all nodes that are reachable by outgoing links from its current location. If no-backtrack is TRUE, then the node from which the agent just traveled is excluded from the set.
3. If the candidate set is empty, or with probability equal to random-restart, the agent will restart at a new location, i.e., go to step 1.
4. Otherwise, the agent computes the appeal of following each link by computing the ranking function across the candidate nodes. To guarantee that the network characteristics are each being given equal weight, the node-level characteristics of each of the candidate nodes are normalized by dividing by the sum of that characteristic across all candidate nodes.
5. The agent then chooses the candidate with the highest ranking function score. The agent follows the link to that node, and we record a "click" on the link.
6. Until some specified number of clicks has occurred, go to step 2 and repeat.

The output of the model ($M$) is the simulated traffic distribution (how many times each link was followed). When the model is run on an empirical network, this output can then be compared with real-world traffic data, and we can attempt to calibrate the 13 model parameters to improve the match (as described in Sect. 19.4).

Since the real-world network is complex and since we do not actually know the underlying rules that consumers use when moving between nodes in a network, we created a "toy" network and data set so that we could explore the effect of calibration measures in a scenario with a known ground truth. We generated a random graph of 10 nodes and 23 links (see Fig. 19.2). We then initiated the model using a set of parameters that were similar to parameters discovered in the real-world data set based on early runs of the GA: random-restart $= 0.15$, randomness $= 0.40$, out-degree $= -0.1$, in-component $= 0.2$, out-component $= 0.2$, eigen $= 0.1$, no-trackback $= false$, and all other parameters set to 0.0. We also assumed that the likelihood of starting at each of the nodes was equal. We then ran this model once to generate a ground truth data set similar to the real world news consumption data set.

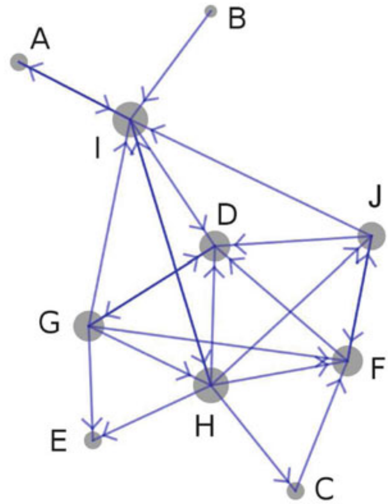


**Fig. 19.2** The directed network for the *toy problem*. Each node represents a website domain, and each link represents one or more hyperlinks which a user clicked to move from one site to another site

## 19.4 Calibration

Regardless of whether we are examining the toy problem or the real-world problem, in order to match the model data, $M$, against real-world data, $R$, we must first divide $R$ into $R_{train}$ and $R_{test}$, with corresponding environmental variables $E_{train}$ and $E_{test}$. Calibration is then accomplished by identifying the set of parameters $P^*$ such that an error measure $\epsilon(R_{train}, M(P^*, E_{train}))$ is minimized, and the model's validation can be examined using $\epsilon(R_{test}, M(P^*, E_{test}))$. In our case we use a GA with the error function, $\epsilon$, as the fitness function, and each individual being a parameter set, $P$.

### *19.4.1 Calibration Measures*

For this work, we assume that the real-world data $R$ and the model's output $M$ can both be represented using fixed-length vectors of numeric values ($V_R$ and $V_M$, respectively). Since it is impossible to make a comprehensive list and test all possible error measures, we chose to investigate a set of five specific error measures for model calibration: correlation, and four different measures of the $L^p$ norms.

1. *corr*—Pearson's product-moment correlation coefficient is computed by:

$$corr = \frac{\sum_{i=0}^{n-1}(V_M(i) - \bar{V_M})(V_R(i) - \bar{V_R})}{(n-1)\sigma_{V_M}\sigma_{V_R}} \tag{19.1}$$

where $\sigma_{V_M}\sigma_{V_R}$ are the standard deviations of $V_M$ and $V_R$ respectively.

2. $L^0$—This is an extension of the $L^p$ norms to the case where $p = 0$. $L^0(V_M, V_R) =$ (the number of positions where the two vectors differ). Note that the magnitude by which they differ does not matter.
3. $L^1$—The $L^1$ norm, a.k.a. the Manhattan distance, is computed by:

$$L^1 = \sum_{i=0}^{n-1} |V_M(i) - V_R(i)| \tag{19.2}$$

4. $L^2$—The $L^2$ norm, a.k.a. the Euclidean distance, is computed by:

$$L^2 = \sqrt{\sum_{i=0}^{n-1} |V_M(i) - V_R(i)|^2} \tag{19.3}$$

5. $L^\infty$—The $L^\infty$ norm, a.k.a. the Chebyshev distance, is computed by:

$$L^\infty = \max_i |V_M(i) - V_R(i)| \tag{19.4}$$

The *corr* function has several potentially desirable properties, including the fact that it is invariant to both location and scale. The four $L^p$ norms comprise a spectrum of calibration choices: $L^0$ ignores magnitude and cares only about the quantity of errors, while $L^\infty$ ignores quantity and cares only about the magnitude of the largest error. The $L^1$ and $L^2$ measures fall in between these extremes. Also, note that minimizing the $L^1$ norm is the same as minimizing the mean absolute error, and MINIMIZING the $L^2$ norm is equivalent to minimizing either mean square error (MSE) or root mean square error (RMSE).

Thus, this family of error measures covers many of the functions commonly used for the purpose of comparing simulated and observed data, and it provides some diversity in the emphases of the different measures. However, this list of error measures is not intended to be comprehensive, and many other measures may be useful for calibration depending on the type of data you are working with and your modeling/analysis goals. For instance, the earth mover's distance [21] might be applied when the order of data within the vectors is meaningful (not applicable for our news-browsing model), and KL-divergence [12] might be used when the analysis takes an information-theoretic focus. Recently, Thorngate and Edmonds have advocated for using *ordinal pattern analysis* [27] as an alternative to minimizing squared error (in some cases). If applicable to the context of the model, any of these (or many other) alternative measures could be used for quantifying error, and thus serve as fitness functions to guide a genetic algorithm in the calibration search process. The subset of five error measures chosen above is sufficient to demonstrate how different error measures affect model calibration, but further investigation is warranted to explore the effect of other potential error measures.

### 19.4.2 Calibration Method

To perform the calibration, we used a tool called BehaviorSearch [22], which provides facilities for exploring the parameter space of agent-based simulations using GAs. Specifically, within BehaviorSearch we used a steady-state GA with population 50, tournament selection (tournament size 3), and replacement strategy of replacing a random individual in the population. We used one-point crossover with a 70 % crossover rate, and a mutation chance of 5 % per locus.

We ran 30 repeated searches using the GA for each calibration function and for each data set (the toy problem and the real-world problem). We ran each search for 200,000 fitness evaluations (model simulations) for the toy scenario, and 100,000 fitness evaluations for the comScore January data set (the much larger data set and longer simulation run-time necessitated running shorter searches). After the evolution finished, we chose the best search result from each of the 30. This gave us five parameter sets, $P$, for each problem; one for each error measure.

## 19.5 Results and Discussion

### 19.5.1 Toy Problem

The results for the toy problem are given in Table 19.1.

**Finding 1:** We were surprised to discover that the GA was able to find parameter settings that matched the target data *better* than the original settings that were used to generate the target traffic data. For instance, the average correlation measure from 30 runs with the best settings found in the GA-*corr* searches was slightly better than the

**Table 19.1** Calibration measure cross-comparison for the toy problem

| Settings | *corr* | $L^0$ | $L^1$ | $L^2$ | $L^\infty$ |
|---|---|---|---|---|---|
| *original* | 0.993 (0.0012) | 22.8 (0.4) | 1,392.2 (123.8) | 527.5 (47.6) | 345.1 (35.0) |
| GA-*corr* | **0.999** (0.0002) | 22.5 (0.6) | **409.4** (74.8) | **113.8** (24.7) | **61.9** (18.4) |
| GA-$L^0$ | 0.619 (0.0021) | 23.0 (0.0) | 7,370.9 (56.9) | 3,074.5 (13.7) | 2,579.5 (15.4) |
| GA-$L^1$ | 0.996 (0.0011) | 22.9 (0.3) | 991.7 (158.0) | 282.9 (37.7) | 180.8 (19.2) |
| GA-$L^2$ | 0.995 (0.0007) | 22.6 (0.5) | 1,150.5 (87.8) | 323.6 (21.9) | 156.8 (13.0) |
| GA-$L^\infty$ | 0.991 (0.0010) | 23.0 (0.0) | 1,694.7 (89.8) | 436.9 (22.4) | 172.2 (12.5) |

Each cell gives the mean (and standard deviation) from 30 replicate simulations.

The best GA-found parameter settings when optimizing using each calibration measure were evaluated against the target data using all five calibration measures. GA solutions were also compared to the *original* settings that generated the target data. The best value for each column (when significant) is shown in boldface (correlation is maximized, $L^p$ measures are minimized) correlation when the model was run 30 times with the $original$ settings. Similarly, better $L^1$, $L^2$, and $L^\infty$ error measures were achievable with the GA's settings than with the $original$ settings. How is this even possible? The finding relies on the fact that the model is stochastic; different random choices by the surfer agent result in some variation in traffic distributions among the links. If the surfer agent was allowed to run for an infinite number of steps, the traffic distribution would converge to a steady state. However, after 10,000 link-follows, results can still vary, meaning that when running the model with the original settings, and trying to match the data generated from one specific run, you do not automatically get a perfect match. Moreover, it is possible that other parameter settings can more consistently generate patterns of traffic data that are closer to the target data, as the GA demonstrated.

**Finding 2:** The $L^0$ error measure performed poorly (mean $L^0$ error of 23). In fact, $L^0$ error measurements are out of a maximum of 23, which corresponds to failing to perfectly match the traffic of any of the 23 links in the graph, and regardless of the error measure this value was always near 23. Even when the GA was searching for the best $L^0$ error value, the parameter settings it found failed to match the data on any link on any of the 30 runs. On the other hand, some of the best calibrated parameters using other methods (e.g., GA-*corr*) managed to match exact traffic values occasionally. The poor performance on the GA-$L^0$ search can be attributed to its providing an insufficient search gradient, as well as the objective being very hard to achieve (as evidenced by the generally poor $L^0$ values obtained by all searches).

**Finding 3:** In this experiment, the GA-*corr* search proved to be the clear winner. Quite surprisingly, searching for good correlation yielded parameter settings that also provided lower $L^1$, $L^2$, and $L^\infty$ error measures than the parameters discovered when attempting to optimize for those quantities directly. In other words, the *correlation* calibration measure served as the most effective fitness function for this problem, regardless of which calibration measure you were most interested in. This suggests that the correlation fitness function somehow smooths out the fitness landscape and more directly leads the population towards a fruitful area of the search space than the $L^p$-based error measures do. Perhaps the $L^p$-based searches are more likely to get trapped in local optima, or it is even possible that these functions are deceptive. In any case, this result was surprising to us, since we expected that GA searches for a specific calibration measure (with the exception of the $L^0$ measure, which we anticipated might fail) would excel in optimizing its own value (though possibly at the expense of other calibration measures). This would be an important and useful discovery if the superiority of correlation-based calibration were generally true; unfortunately, this is not the case (as will be demonstrated in the following section).

**Table 19.2** The best GA-found settings when optimizing using each calibration measure on the January training data were evaluated against the comScore January training data (top) and the comScore December testing data (bottom) using all five calibration measures

| Settings | *corr* | $L^0$ | $L^1$ | $L^2$ | $L^\infty$ |
|---|---|---|---|---|---|
| GA-*corr* | **0.72** (0.0002) | 2,912 (15) | 44,364 (73) | 7,246 (49) | 6,190 (45) |
| GA-$L^0$ | 0.33 (0.0068) | **2,811** (17) | 42,364 (135) | 4,198 (40) | 2,906 (49) |
| GA-$L^1$ | 0.30 (0.0048) | 2,836 (13) | 42,744 (67) | 5,977 (39) | 3,406 (51) |
| GA-$L^2$ | 0.02 (0.0039) | 2,883 (12) | **40,499** (104) | **3,197** (4) | 2,211 (2) |
| GA-$L^\infty$ | 0.20 (0.0056) | 2,959 (10) | 47,293 (84) | 3,527 (17) | **1,743** (23) |

Calibration measure comparison using the comScore January training data set

| Settings | *corr* | $L^0$ | $L^1$ | $L^2$ | $L^\infty$ |
|---|---|---|---|---|---|
| GA-*corr* | **0.41** (0.0014) | 2,843 (14) | 48,843 (64) | 9,515 (46) | 5,260 (48) |
| GA-$L^0$ | 0.37 (0.0024) | 2,799 (15) | 45,482 (114) | 6,792 (48) | 4,584 (67) |
| GA-$L^1$ | 0.24 (0.0031) | 2,806 (13) | 46,145 (93) | 7,513 (40) | 3,915 (52) |
| GA-$L^2$ | 0.03 (0.0058) | 2,860 (14) | **44,480** (109) | **4,774** (5) | **3,324** (5) |
| GA-$L^\infty$ | 0.08 (0.0029) | 2,923 (12) | 50,911 (75) | 5,238 (17) | 3,343 (0) |

Calibration measure comparison using the comScore December testing data

Each cell gives the mean (and standard deviation) from 30 replicate simulations. The best value for each column is in boldface (correlation is maximized, $L^p$ measures are minimized). (For December, there was no clear best $L^0$ measure)

## *19.5.2 Real-World Problem*

### 19.5.2.1 Training Set

Next we examine the problem of matching empirical Web traffic on the larger real-world data set, where it is unknown how good a calibration we can expect. The results from both the training and test set error measure comparisons are presented in Table 19.2, and the best parameter values found in each search are given in Fig. 19.3.

**Finding 1:** Unlike in the toy problem, the *GA* is able to make some progress optimizing the $L^0$ calibration measure, as evidenced by it finding parameters yielding lower mean $L^0$ than the searches optimizing correlation or the other $L^p$ norms. This makes some sense, because whereas the toy problem only had 23 links that could either match or not match, the comScore January network had 3,113 links, which means that the $L^0$-based fitness function can discover some gradient to the search space. However, an $L^0$ measure of 2,811 means that the simulated traffic did not match exactly on 2,811 links, out of the 3,113 links in the network. Thus, even in the best case, the GA was only able to find settings that could match about 10 % of the network's links on average, while leaving 90 % mismatched. This underscores the fact that requiring perfect matching of historical data is a harsh criterion for calibration. In some cases, perfect matching of real-world data may be feasible, but even in such cases, we predict that calibrating using either correlation or an $L^p$ norm where $p > 0$ will provide more information to the GA and permit more efficient search.

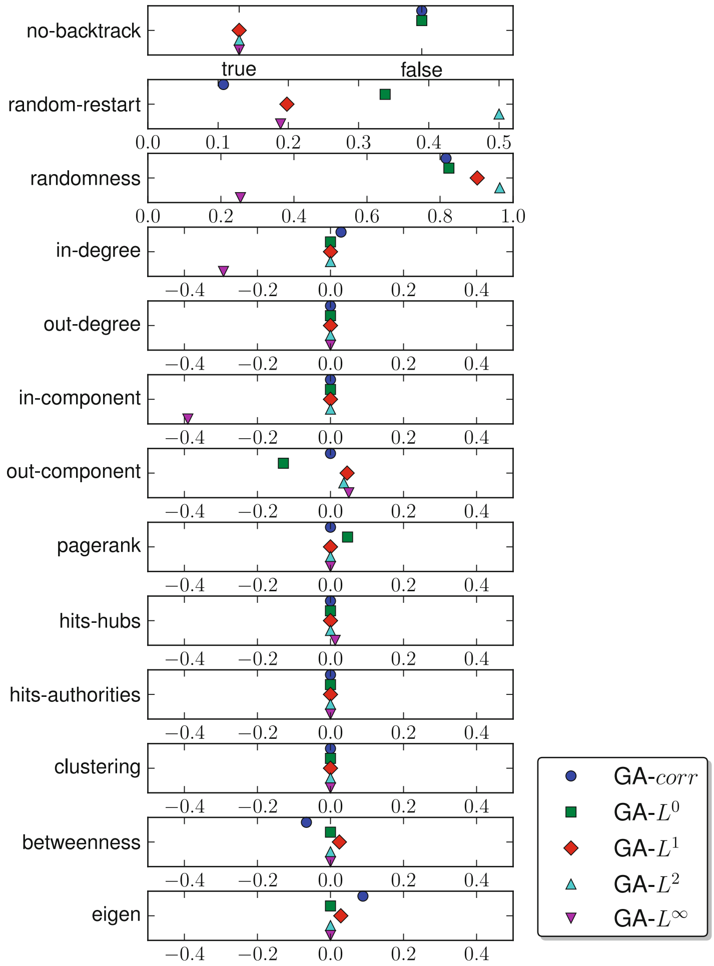


**Fig. 19.3** Calibrated parameter settings from the best GA searches for each error measure

**Finding 2:** Unlike the toy problem where all the model results, regardless of the error measure, match well with the data using the correlation measure, in the real-world data set those parameter settings which were specified using one of the other error measures do not generate model results which match well using the correlation measure. In fact, there are statistically significant different results on all of the measures, but nowhere is this difference more striking than in the correlation measure. The model data generated using the correlation error measure settings correlated twice as well with the data as any other model data set that was generated. In the case of $L^2$, in particular, the data was almost uncorrelated with the real-world data, indicating that a random result would have done almost as well as the results generated by the GA search using the $L^2$ measure. This indicates that correlation is capturing a different element of the matching problem than any of the other measures.

**Finding 3:** Unlike the toy problem where correlation Pareto-dominates (it is as good as or better than) all the other error measures, in this real-world problem no error measure dominates all other error measures (though $L^2$ does dominate $L^1$). Given that there is no pure dominant measure, researchers must be careful about which measure to choose when calibrating their models. This is especially true given that Fig. 19.3 shows that the actual parameter settings discovered by the various measures were not too different, and yet those different settings had a large impact on the error measure scores. As we discussed in Sect. 19.4, these different measures all take into account different choices; researchers should use $L^0$ if they are interested in the quantity of errors, and $L^\infty$ if they are interested in the magnitude of the largest error, but there is no measure that subsumes all the others.

This finding dashes any hope of finding "one error measure to rule them all."[2] Instead, it suggests that multi-objective optimization could be an appropriate method to apply here. Multi-objective optimization would allow researchers to search for parameter settings that simultaneously yield low error values on a collection of error measures, while also keeping track of the best settings to achieve minimal error for each error measure. This would be particularly valuable when the appropriate choice of error measure is uncertain, or when researchers wish to minimize several error measures that may conflict with one another. Multi-objective evolutionary algorithms have previously been used successfully for optimization of multi-agent based models (see, e.g., [17]), and so this approach offers a natural avenue for future research in calibration methodology, similar to the exploration in this paper.

#### 19.5.2.2 Testing Set

Finally, we take the parameter settings, $P^*$, calibrated on the January data $R_{train}$ and examine the same five error measures on the December data set $R_{test}$, which was collected 11 months later.

**Finding 1:** As before, the $L^0$ measures are generally poor, indicating an inability to calibrate well with the data using the criterion that the simulated traffic value must match the empirical value exactly. This again begs the question of whether this measure is too difficult for complex problems. In fact, there may by necessity be a trade-off where any model that is able to fit this measure well, will also not be very generalizable. The best model for this measure may very well be a model which does nothing but specify the exact values of all of the links, which is a model that could not be applied to any other network or data set.

**Finding 2:** The $L^p$ results are not substantially worse on the December data than they are on the January data. For instance, for the $L^1$ measure the error only goes

[2] Our apologies to J.R.R. Tolkien.

up by 10 %, though the increase in error appears to go up as you move toward $L^\infty$, which indicates that the model is matching the same quantity of data points, but the magnitude of the worst difference is growing. Given that the model was trained on an entirely different data set (some empirical results indicate that these two data sets have very different traffic patterns), this indicates that the parameter settings that the GA discovered using the various error measures on the January data set are somewhat generalizable.

**Finding 3:** The relationship between the results within the correlation measure has changed. Though $L^1$, $L^2$, and $L^\infty$ all do worse with regards to the correlation measure than they do on the January data set, $L^0$ does better in terms of matching correlation values than it does on the January data set and approaches the correlation value achieved when the fitness function is the correlation measure. This suggests that although the $L^0$ measure is a difficult error measure to use as calibration, the parameter settings that it finds may be useful with respect to other error measures.

## 19.6 Conclusion

We have formalized the notion of calibration and validation of an agent-based model using five different error measures in the context of both a toy problem and a difficult real-world problem. We have shown that there is not an easily defensible Pareto optimal error measure among the ones that we investigated that works in all cases, and we have illustrated some of the benefits and drawbacks these measures can have for model calibration using an evolutionary algorithm. To continue this comparative research on error measures, one could use multi-objective optimization with multiple calibration measures to discover a Pareto front that characterizes trade-offs between these measures. Although this study only examined a single application area (simulation of Web traffic for news consumption), it emphasizes the more general point that the choice of an error measure for calibration must not be taken lightly. Some of the results (such as which calibration measures fared better than others) are potentially problem- or at least scale-specific, as evidenced by the difference between the synthetic toy data set and the real-world data set. Given that calibration of models in different application domains will likely show similar variation, we caution against reading too much into the specific performance values or relationships between error measures. Rather, this work underscores that it is imperative that modelers realize how error measures affect the model calibration process, and as a result, alter the eventual parameter values determined to be "optimal."

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# Chapter 20
# Towards Validating a Model of Households and Societies in East Africa

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**Abstract** One of the major challenges of social simulations is the validation of the models. When modeling societies, where experimentation is not practical or ethical, validation of models is inherently difficult. However, one of the significant strengths of the agent-based modeling (ABM) approach is that it begins with the implementation of a theory of behavior for relatively low-level agents and then produces high-level behaviors emerging from the low-level theory's implementation. Our ABM model of societies is based on modeling the decision making of rural households in a 1,600 km (1,000 mile) square around Lake Victoria in East Africa. We report on the first validation of our model of households making their living on a daily basis by comparing resulting activities against societal data collected by anthropologists.

**Keywords** Agent-based modeling • East Africa • Household decision making

## 20.1 Introduction

One of the major challenges of agent-based modeling (ABM) is the validation of a model. When modeling societies where experimentation is not practical or ethical, validation of models is inherently difficult. However, one of the significant strengths of the ABM approach is the faithful implementation of a theory of behavior for relatively low-level agents and their associated environmental dynamics and then the observation of high-level behaviors emerging from the low-level theory's implementation. That is the approach we have taken toward validating our model.

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A team of scientists at George Mason University and at Human Relations Area Files (HRAF) at Yale University has been working for a few years on an agent-based model of a large area of East Africa, including validation-related fieldwork in 2010. The purpose of this project is to answer research questions on social dynamics, such as internal conflict and responses to natural disasters and humanitarian relief. This follows earlier validation efforts in the same project on other components [1–4].

The work reported here is the progress of our efforts to validate our model of household subsistence decision making. We will discuss our validation efforts organized by the layers of our model up to the model of household decision making. Later papers will describe further work with this model and address the reaction of people suffering from disasters that affect their subsistence activities, such as a prolonged drought.

Our model includes detailed representations of the environment, specifically land types, water supplies, and weather. From these we have modeled vegetation growth for grazing of domestic herds and farming activities. We have modeled the people in the region at the household level; households manage herds, farming, and labor activities. These subsistence activities are modeled down to actions taken on a daily basis, such as deciding when to plant, when to harvest, and where to move the herd each day.

It is relatively easy to compare modeled vegetation to actual data on vegetation. To test the macro-level performance of our model of household behavior, we use anthropological data from local ethnographies, such as primary sources from HRAF and secondary sources from the extant literature (e.g., [5–7]). Anthropologists have catalogued approximately 135 different ethnic groups in the modeled area, including data on how the people of each culture make their living. Therefore, by implementing theoretical decisions at the household level driven by the environmental conditions, we can see if the simulated results match the anthropological data. We report on the validation of our household model against the anthropological data for the region, which will provide insights into model validation for models of societies.

## 20.2 RiftLand Model Overview

Our model of the Rift Valley of East Africa surrounds Lake Victoria. Our model, called "RiftLand," was developed using the Multi-Agent Simulator Of Neighborhoods (MASON) system [8, 9] and represents the area and the modeled actors at a scale appropriate for our research questions. The subject area is shown in Fig. 20.1. As an agent-based model, we attempt to model the environment and agents at a relatively low level and allow their interactions to produce macro-level results. The environment is represented at the 1 $km^2$ level throughout the 1,600 by 1,600 km area. The time scale has one step of the model representing 1 day. People are modeled at the household level, keeping track of the number of individuals in each household. Our model runs are typically performed over several years of simulated time,

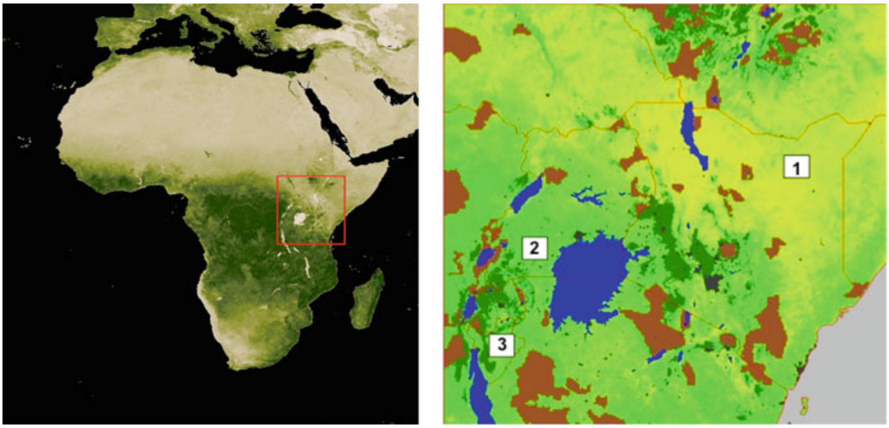


**Fig. 20.1** The RiftLand model area and three test regions identified. *Sources*: NASA (*left*) and RiftLand model output with different land/water types (*right*)

or thousands of days. Major model components and behaviors are detailed below to a level necessary to discuss our validation efforts. A more detailed description of the model to support replication of our work will be published later [10].

### 20.2.1 Reference Data for Validation

Many anthropologists have lived among and studied the people of the Rift Valley, and their observations have been collected into an atlas of the people of this region and how they make their living. The atlas was published by G.P. Murdock as a series of journal articles [11, 12] in the journal *Ethnology* in the late 1960s. This information has been updated by HRAF. The 135 HRAF-coded ethnographic cultures of the Rift Valley region are shown in Fig. 20.2.

### 20.2.2 Modeling the Environment

The subject area includes several biomes, cultures, and polities. We represented the 1,600 by 1,600 km area as data representing each 1 km$^2$ parcel of land or water. This level of resolution supports reasonably accurate representation of the landscape, political borders, and locations of the people. We, of course, did not model every rock and blade of grass, but did model major factors, actors, and interactions affecting the macro-level behavior of interest. We represent differences in land use by different types of parcels. Parcels can be all water, either saltwater (in the Indian Ocean) or freshwater (1 km$^2$ parcels of Lake Victoria, other named lakes, and some

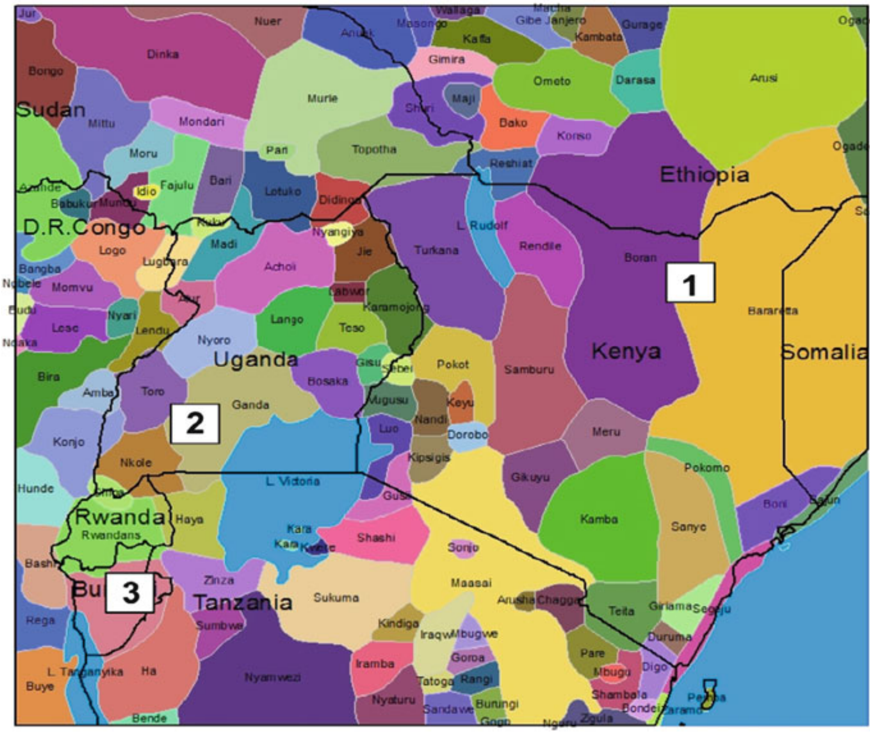


**Fig. 20.2** Cultural map of Rift Valley region, based on HRAF-coded ethnographic cultures. *Source*: HRAF

major rivers). On land, we differentiate urban areas, forests, parks, and open parcels available for grazing or farming. The major difference is the impact on vegetation and people.

Given the importance of water in this region of the world, we carefully modeled water sources in the area. The easy part is placing water sources along large rivers and around freshwater lakes. Using the elevation information for the region, we also placed water sources in the lowest areas to represent seasonal water sources and man-made watering holes. Using available data on the number of water sources in some areas, we are able to appropriately populate a given region with water sources.

### 20.2.3 Modeling Vegetation Growth

Vegetation growth is very important to local populations through its impact on both agricultural and pastoral activities. We modeled vegetation based on three factors: local rainfall, land fertility, and remotely sensed data on the resulting vegetation over time. Using rainfall data collected frequently over large parts of this area, we developed approximately 50 weather cells covering approximately 30 $km^2$ regions. For each region and covered parcels, we generate a rainfall amount each day, which is used to determine the vegetation produced on each parcel.

The amount of vegetation produced on a parcel is computed using a logistic equation with rainfall as input. We use the Normalized Difference Vegetation Index (NDVI) [13], which provides daily vegetation data based on remote sensing, to validate results. We then determine appropriate land fertility values for each parcel as the residue of a linear regression model of rainfall and NDVI data, based on the NDVI as reference vegetation, our vegetation growth model, and rainfall data. These factors together allow the simulation to grow vegetation based on the land's fertility and rainfall for both agriculture and pastoral modeling purposes.

### *20.2.4 Modeling Herds*

Domesticated animals are modeled as generic tropical livestock units (TLUs), which represents 1.0 head of cattle, 0.7 camel, 11 sheep, 10 goats, and other numbers of other animals [6]. Using this abstract unit, we did not need to differentiate the types of animals in a herd. As a herd of TLUs, we modeled the herd's need for water and vegetation. These physiological parameters allowed us to model the daily intake needs, current levels, and general health of the herd. We also assumed a birth rate and death rate when these physiological needs were not met, resulting in each herd being modeled as a number of TLUs with daily needs and health status as a function of water and vegetation.

## 20.3 Household Modeling

The model keeps track of the number of people engaged in different daily subsistence activities, although people are modeled as households who make decisions. The primary activities of households are farming and herding. Family members are also modeled as engaged in wage labor, bringing cash to their household. Household activities are semi-independent subsistence activities. Ideally, each would be self-sufficient, but the model recognizes the activities as part of one household and, if necessary, the people of one activity can live on the resources of another. After describing the activities that household members could engage in, we describe how they decide on these activities.

### *20.3.1 Farming Activity*

Only the key parts of farming were modeled. These included planting a specified amount of land and harvesting its crop. Part of the household's population was assigned to farming. This was envisioned to include small children and to occur on the household's farm, one of the parcels suitable for grazing or farming. Those engaged in herding, which could be a relatively independent activity, were expected to be at the household's farm to provide labor from 2 weeks before planting until after harvest.

Farming involves deciding when to plant, how much land to plant, and how long the growing season will be. Vegetation growth was then modeled daily over a growing season of approximately 90 days. Planting (i.e., starting from zero vegetation), occurs on a specific day and, after the adjustable growing season, the crop is harvested. We included a farming productivity factor that increases the yield on tended farmland over what would grow wild. However, we did not specify the crop type. Vegetation was modeled as producing a yield in units of kilograms of dry matter, for which we had production and consumption data.

The history of rainfall on the farm indicated the best month to plant. Based on the region's weather pattern, there could be one or two best times to plant and the farm was modeled to have one or two growing seasons. A week before the scheduled harvest, the farmer makes an assessment of the crop's potential yield. The farm's next growing season is then extended or shortened based on a comparison of the potential harvest a week before the actual harvest.

At harvest, the crop's yield is added to the farm's grain store. The farm's store is the source of daily food for farmers and other household members, if needed. After harvest, those assigned to the herding activity take their TLUs and go to open land to graze the herd until next season.

### *20.3.2 Herding Activity*

Herding is concerned with where to move a herd each day. To make that decision, we have employed a "fast and frugal" decision tree that prioritizes concerns for a need to change watering holes, avoid conflict, and move a herd to graze or to water it. The decision-making process was described previously [3].

Herders make their daily living directly from animals. A set number of TLUs is necessary to support a herding household. If the number of TLUs in the herd decreases below the number necessary to support the herding household, then its subsistence depends on whether the herd is in the field or at the household's farm. If at the farm, the unsupported herders can subsist from farm store or cash reserves. If in the field, we presume that they can find a living from other sources. If the herded TLUs increase beyond what the herding household can manage and the herd has returned to the farm, the animals are sold to increase the household's cash assets.

With the general practice of sending teenage boys with the herd when there is a household base on a farm, the people engaged in herding do not reproduce. However, if the household does not have a farm and the household is therefore moving with the herd, normal reproductive activity takes place.

### 20.3.3 Labor Activity

All households in the RiftLand area need cash for some obligations, such as paying taxes and paying for schooling. We address this need by including labor activities when households involve more than ten members. Household members involved in labor activity generate cash for the household and are presumed to not need to subsist through other household activities. However, human resources in labor can be reassigned to support farming or herding activities, if needed. Also, if herding or farming activities are not self-sufficient, the unsupportable individuals will be transferred to labor activities. However, if the fraction of the household involved in labor becomes too great, those persons become internally displaced persons (IDPs) and are no longer part of the household.

### 20.3.4 Displaced Persons

Displacement is generated as an emergent phenomenon in the model, and displaced persons are part of the model's rural household decision making. The intent, in a later version of the model, is that displaced people move to urban centers for subsistence and, if their numbers exceed the capacity of the local urban center, they will move to larger urban centers, possibly also moving across national borders and officially becoming refugees.

### 20.3.5 Household Decision Making

Each household makes decisions concerning human resources to apply to its subsistence activities. If all goes well, a household will have an operating farm, a herd, and enough members to have some members engaged in labor. On a daily basis when the herd is at the farm, all activities share the resources necessary to meet daily food needs, and excesses become accumulated wealth. If an activity does not do well enough to feed its assigned people for some period of time, some of the people are reassigned to another activity, as shown in Fig. 20.3. The reason for all reassignments is based on the success of the activity in providing food for the household; changes in effectiveness of the activity result in transfers of household human resources among activities. The lines indicating reassignment from the farming and herding activities to labor are different because the transfer to labor only occurs if the other major activity cannot feed its assigned people. Farming activities are evaluated at each planting and harvest, while herding activities are evaluated every 4 months.

If farming or herding activities fail completely, the household will try the failed activity again after some time by re-employing laborers. If the primary activities of

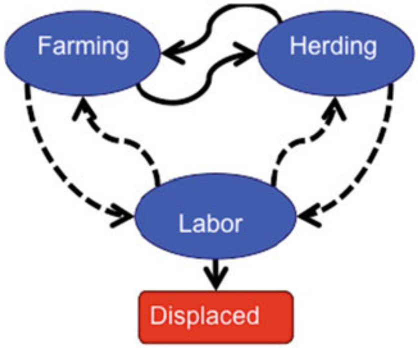


**Fig. 20.3** Re-assignments of household human resources among activities

farming and herding fail and too many people are simply laborers, the household becomes displaced. On the positive side, successful farming or herding will result in starting a new household with approximately half the original household's assets. Successful households divide their resources, creating a new farm and herd as appropriate and, if large enough, some labor. Our 1 $km^2$ parcels can support several co-located farms and herds. However, each parcel has a maximum carrying capacity.

## 20.4 Modeling Household Behavior: Preliminary Results

The RiftLand model has been run under a variety of conditions to demonstrate how households make a living throughout the region. The expectation is that environmental factors will cause different subsistence strategies in different regions. We have focused on three different regions to validate our model of household decision making in the RiftLand area, since overall variability is exponentially (not just linearly) proportional to the number of individually validated regions: one valid region is good, two are better, three are far better. The three regions studied are shown in Fig. 20.1 as white squares. In each of the three study areas, our simulations involved placing 1,000 households in the region and simulating their behavior over 3,650 days (i.e., 10 years). Households are initialized with a number of persons divided nearly evenly between farming and herding activities. If the household has more than ten persons, then approximately 10 % are initialized as being engaged in labor to generate cash for paying taxes, educational, or other needs. Households start with both farming and herding, approximately balanced, and subsequently adjust human resources applied to each activity based on their success in feeding the household. The model actively manages the number of people involved in those two activities, and only if there are more than ten people in the household are any assigned to labor. The labor activity is mostly used as a placeholder for herders or farmers that cannot be fed by their activity. Preliminary results are presented in the next three subsections.

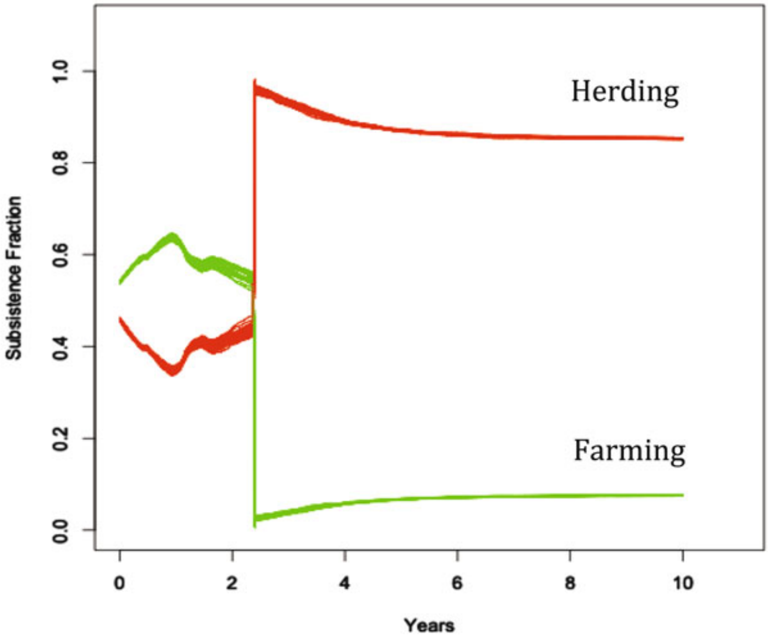


**Fig. 20.4** Results of household decision making in region south of Mandera

### *20.4.1 Survival in Semi-Arid Regions of Northeast Kenya (Region 1)*

The first area tested is in the relatively dry northeast region of the modeled area. We focused on an area 150 km by 150 km in northeast Kenya indicated as a white square numbered 1 in Fig. 20.1 (right). This area, near the Bokhol Plain (500–1,000 m elevation) in Wajir District is close to the Mandera region studied in previous work [3, 4]. The area lacks major population centers (the closest is Wajir, population ca.30,000, 100 km away), water supplies, forests, and parklands. This is an arid, open area with a low population density (less than 10 inhabitants/km$^2$) inhabited primarily by Somali people. Figure 20.4 is a plot of the simulation's results. This plot presents the mix of subsistence activities as the average of 1,000 households and shows those results for 30 runs.

Figure 20.4 shows average results of 1,000 households deciding how to make a living over 10 years. The dramatic change after 2 years is the result of many household agents deciding to give up their farming because it is not effective in feeding the household members. The evaluations occur at harvest times and they are relatively in sync early in the simulation, and so many make the switch at the same time. After more time, household reassignments are more diverse due to local differences in the weather and land fertility such that reassignments at harvest are

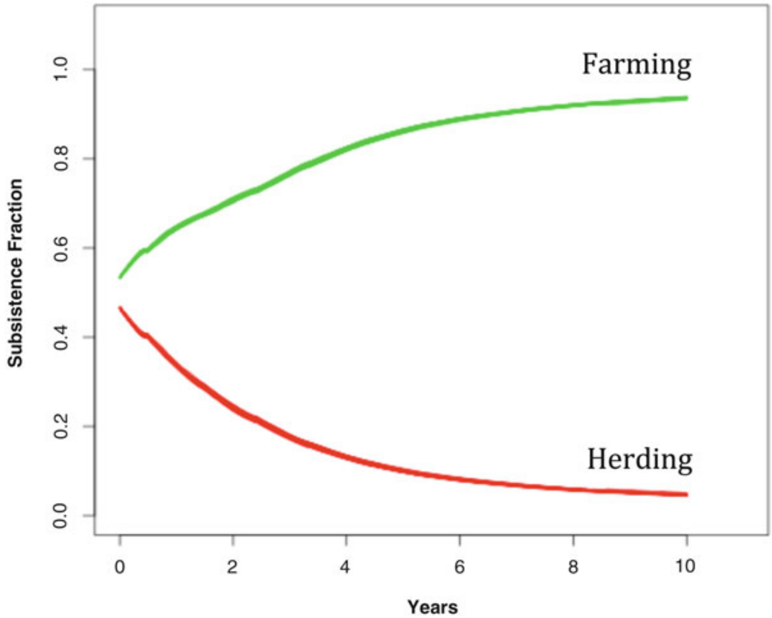


**Fig. 20.5** Results of household decision making in a southwest (Ganda) region of Uganda

no longer visible for the whole society. After the initial nearly synchronized major change and several more years, the agents in this region settle on about a 90/10 preference for herding over farming, in small households with very little labor activity.

The reference anthropological data for this region is contained in the *Ethnographic Atlas* [11, 12] as updated by HRAF. With the modern-day updates, the people of this region, the Bararetta [5], are described as "PA," meaning they are both pastoralists (herders) and agriculturalists (farmers), generally consistent with our simulation results.

### *20.4.2 Survival in a Relatively Wet Area, Southwest Uganda (Region 2)*

The second area tested is in the relatively wet region west of Lake Victoria. We focused on an area 100 km by 100 km in southwestern Uganda as indicated in Fig. 20.1 (right). The area size was selected to be primarily rural and to avoid major population centers, forests, and parklands. This region consists of open areas, available for farming and grazing family herds, with a relatively high population density (100–300 inhabitants/km$^2$). Figure 20.5 is a plot of the simulation's resulting population in this region for 30 runs.

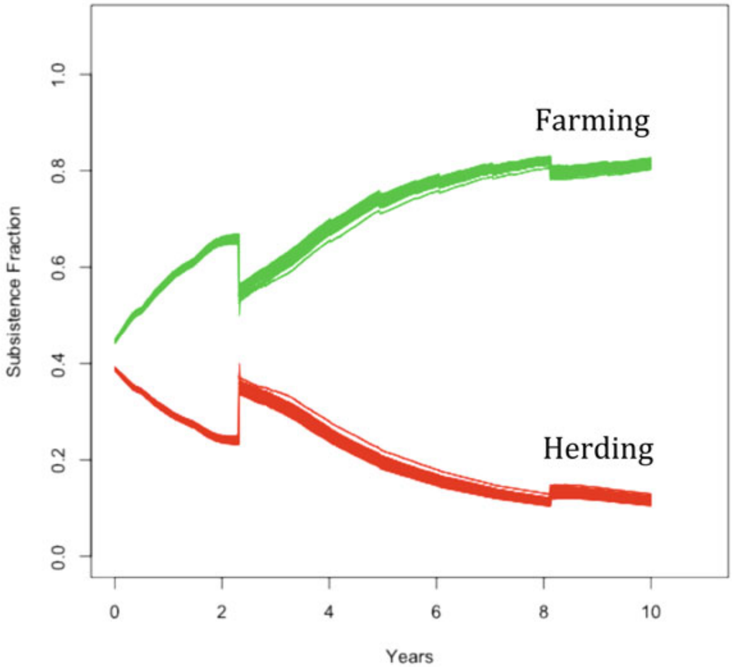


**Fig. 20.6** Results of household decision making in central Burundi

The simulation results show that the households settle on their mix of subsistence activities much more gradually than in the previously discussed region. During each of the first several years' harvests, there were large shifts in activities before a few years of consistent trends settled on approximately a 90/5/5 % division between farming, herding, and labor.

Murdock's 1967 atlas reported that the Nyoro people [14] in this region are coded as "Ap," primarily agriculturalists with some pastoralist activity, specifically in the band of 56–65 % subsisting on agriculture and 16–25 % subsisting on animal husbandry. In our model, our agents are more heavily focused on agriculture.

### *20.4.3 Survival in Burundi (Region 3)*

The third area tested was less arid (500–1,000 mm annual precipitation), in Burundi, southwest of Lake Victoria. We again focused on an area 100 km by 100 km to be primarily rural and to avoid major population centers, forests, and parklands. This region of our model consists of some open areas available for farming and grazing family herds. Figure 20.6 is a plot of the simulation's resulting survival strategies in this region for 30 runs.

In this region, we see different behavior. Unlike the first region where most households gave up farming after 2 years, here many do, but not as many as in the first region. There is another shift, but much less dramatic after year eight. These shifts are likely caused by poor rainfall, leading to farming being less productive for a short period of time but better than herding over the long term. There is also an interaction between the amount of land involved in farming, making herding less viable in this region. However, overall farming was very good and produced households large enough to support more labor activities than the other regions. The resulting distribution was approximately 80/10/10 for farming, herding, and labor. The anthropological data for the Rundi people of this region are coded as "Ap", but with the largest subsistence fraction being in the band of 46–55 % in agriculture and the second largest fraction being 26–35 % in pastoral/herding.

## 20.5 Progress in RiftLand Model Validation

Our approach to validating this agent-based model is to start with micro-level models from which emerge societal-level behaviors that match available empirical (in this case ethnographic) data. Our models of subsistence activities employed in East Africa are based on available data, weather, TLUs, vegetation, and other socio-natural features. Household agents adjust their assignment of human resources based on the performance of their subsistence activities. Based on these inputs and modeling dynamics, the aggregation of household decisions results in distributions of farming, herding, and labor activities available for comparison with anthropological data. The available anthropological data coded subsistence activities in five categories, and we are attempting to have our model match the top two activities (farming and herding). So far, our model has matched the primary subsistence activity in each region—either as farming or herding—but it does not yet match the approximate percentages reported for the three regions. However, data in the atlas are recorded assessments of one or more anthropologists based on local observations at some time in history. Some of these observations are more than 100 years old. As such, these assessments can vary from current, "on-the-ground" truth by quite a bit. For our purposes, the comparison of model results to anthropological data is primarily of ordinal value, not interval or ratio value.

## 20.6 Conclusion and Future Work

We modeled the weather, parcel type, vegetation, and household subsistence activities in a 1,000 by 1,000 mile area around Lake Victoria in East Africa at the 1 $km^2$, 1 day, and household level. Results from the MASON RiftLand agent-based model match the types of primary and secondary subsistence activities, farming and herding, as reported in the anthropological data for the three tested regions.

However, we do not yet match the exact percentages of those activities. We are also continuing our modeling efforts, improving the modeling of the weather, vegetation, and watering holes behavior as well as redesigning the farming, herding, and household decision making to support full-scale runs of the model in reasonable times and have achieved a nearly 1,000 times improvement. As a result of our continuing to improve our modeling, we will need to revalidate our model. This initial "modal" or "ordinal" validation in behavioral patterns is a necessary step in the direction of more extensive validation to be accomplished via additional tests based on more stringent interval and ratio standards.

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# Chapter 21
# Social Simulation Comparison in Arbitrary Problem Domains: First Steps Towards a More Principled Approach

**Stuart Rossiter, Jason Noble, and Keith R.W. Bell**

**Abstract** We outline a simulation development process, backed by a software framework, which focuses on developing and using a *partial* conceptual model as a 'lens' to compare and possibly re-implement existing models in a chosen problem domain (as well as to design new models). To make this feasible for existing models of arbitrary structure and background social theory, we construct our (partial) conceptual model in a way that acknowledges that it is a base representation which any individual model will typically add detail to, *and* abstract away from, in various ways which we argue can be formalised. A given model's design is fitted to the conceptual model to capture how its structural architecture (and selected aspects of the system's state and driving processes) map to the conceptual model. This fit can be used to produce incomplete skeleton code which can then be extended to produce a simulation. Along the way, we use robust decision-making to provide a useful frame and discuss how our approach differs from others. This is inevitably a preliminary approach to a broad and difficult problem, which we explore in the conclusions.

**Keywords** LTPA • Model comparison • Model-driven design • Modelling process • M2M analysis • Robust decision-making • Software framework

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## 21.1 Motivation

Model comparison is a key process needed to help mature social simulation as a discipline, and encompasses related interests in model reuse, alignment and replication [1, 2, 6, 17]. It is also highly relevant for the use of social simulations in long-term policy analysis (LTPA). The robust decision-making approach [9, 10] has focused on interactive scenario exploration, as part of a process whereby policy options can be developed which are *robust* to as wide a range of plausible scenarios as possible.[1] The scenarios are produced by a **scenario generator**, which could be a single model (varied parametrically to produce scenarios) or some ensemble of models.[2] The inherent deep uncertainty in social systems means that attempting to assign 'likelihoods' to each scenario is inappropriate, and thus the generator aims only for plausibility and variety of scenarios. (The devil is, of course, in the details of how one assesses plausibility, and when a policy is 'robust enough'.)

In our view, the scenario generator should really be some ensemble of models that represents *theoretical plurality*, not just parametric variation of a single model or family of related models. This is vitally important because, even if we ignore (or refute) the deep uncertainty of social systems, the reality is that there is a lack of consensus on valid theory, and the predictive accuracy of social simulation is extremely limited, particularly across longer timeframes. (Moss [13] takes a strong stance on this.) Thus, although time and funding often preclude it, a scientifically honest approach would include simulations covering a wide range of theoretical alternatives. In concrete terms, this means that *variation in model structure is at least as important as the variation of parameters (and the related focus on the accuracy of any empirical data used)*. Robust decision-making has focused much more on the scenario exploration tools and process than on how to construct a good scenario generator. An extended example for sustainable development [10] uses a single system dynamics (SD) model. Bankes [3] used an ensemble of models, but using bootstrap resampling of training data to create a family of neural net models (i.e., although the differing neural nets created different model 'structures', there is still a single overarching theoretical backdrop).

One of the reasons why we are interested in this robust-decision-making frame is that it also represents a reasonable analogue for the field of social simulation in general. For a given problem domain, models in the literature that investigate it can be identified (assuming we can decide what is 'close enough' to the chosen domain to count). This set of models effectively acts as a scenario generator, producing a variety of possible future scenarios. Our aim as scientists is ideally to be able to compare all these models, and advance our understanding of the domain by adding, extending and combining their theoretical elements (as well as validating

[1] The authors also term it computer-assisted reasoning (CAR), but we feel this is too general a term to be useful, and prefer 'robust decision-making'.

[2] Boundaries between *a model* and *models* can begin to blur where, for example, a model has parameters which act as switches to turn on and off different structural alternatives (e.g., alternative decision-making algorithms).

and replicating their results).[3] However, this is made very difficult by aspects such as disciplinary (or paradigm-specific) silos, a multiplicity of implementation languages and frameworks, lack of access to model code, overly brief documentation in papers and, perhaps above all, radically differing theoretical or conceptual frameworks. (Different modelling paradigms tend to exist because of differences in overarching conceptual tenets, though these historical differences may be weakening as hybrid modelling becomes more common.) In contrast, this is *unlike* robust-decision-making, in that the exact 'levers' (interventions) to be investigated, and the measures by which the outcomes are judged, may differ considerably amongst different pieces of research; robust-decision-making sets these up as part of the process, and the scenario generator has to conform to them.[4]

Therefore, in general, it is important to be able to compare a plurality of models for the same problem domain. However, this plurality makes model comparison more difficult: we really need ways to compare alternative model designs via some common 'lens', even when they appear to radically differ structurally. Ideally, this comparative process would also extend into the realm of model implementation, where it also facilitates code reuse.

### *21.1.1 Existing Approaches*

Conceptual frameworks exist for specific problem domains which aid model assessment, understanding and comparison; e.g., Chappin and Dijkemma's for energy transitions [4], AMES for particular forms of electricity markets [19] and MR POTATOHEAD for land use models [14]. All of these provide some support for translating this conceptual model into software: what software engineering terms **model-driven design** [7, Sect. 4]. However, all these examples are tied to an agent-based paradigm, and focus more on a *minimal* representation level. This does not meet our intuitive idea of a lens as some potentially incomplete base representation *which does not constrain how a model might be mapped to it*. That is, we would expect individual models to both add detail to, *and* abstract away from, this base representation in arbitrary ways. This is a key principle we attempt to include (inevitably in a limited fashion), and we term it **representational flexibility**.

We can also regard modelling paradigms and their software frameworks similarly (as conceptual frameworks supporting model-driven design), but where the conceptual framework is a generalised one for any system. We would like some process which does not restrict the modelling paradigms of the models compared.

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[3] Indeed, the ultimate aim of this understanding is often to inform policy, and thus there is the same idea of designing policy robust to a range of theories.

[4] They use the XLRM analysis framework. The 'relationships' (R) comprise the model, which takes into account externalities (X) and the policy levers (L) in place to produce outcomes, where we are interested in particular measures (M) of scenario desirability.

Finally, there has been some research on protocols that try to standardise how models are described [15, 16], which should definitely aid in model comparison. However, much of this is tied to modelling paradigms and focuses on cross-cutting aspects of models (such as the treatment of time or the representation of space) rather than how the theory-driven structure relates to the real-world system. It is also, by its nature, a textual process unrelated to model construction.

## 21.2 High-Level Approach

The overall proposed process is shown in Fig. 21.1, which we attempt to explain in what follows.

In simulation terms, the envisaged common lens can be regarded as a *partial* conceptual model of a system, where the system's scope is determined by the problem domain: "The art of model building is knowing what to cut out, and the purpose of the model acts as the logical knife. [...] Always model a problem. Never model a system" [18, Sect. 3.5.1].[5] Unlike other model-driven approaches, it is *not* a complete model design: it focuses only on those aspects which can realistically be generalised, limiting itself to the structural 'architecture' of the system, and selected aspects of system state and driving processes. The structural architecture defines behavioural classifications, but no further behavioural details (which will necessarily differ in ways which we cannot capture in a prescribed way). Our process defines ways to build this conceptual model and fit existing models to it, incorporating the required representational flexibility.

Setting its partial nature aside, this conceptual model is almost exactly what is termed a **domain model** in software engineering [7], and we use this term henceforth (with the 'partial' implicit). Evans' book [7] does a good job of characterising the benefits that it can bring (such as a 'ubiquitous language' for shared discussion).

### *21.2.1 Domain Model Structure*

Intuitively, these generalisable details will often be structures that are imposed by legal, technical, political or social constraints that we do not envisage changing over simulation timescales (roughly 'medium-term': very few, if any, social simulation

[5] Theory also drives system scope to some degree, and we explain why this is less problematic than it might seem later.

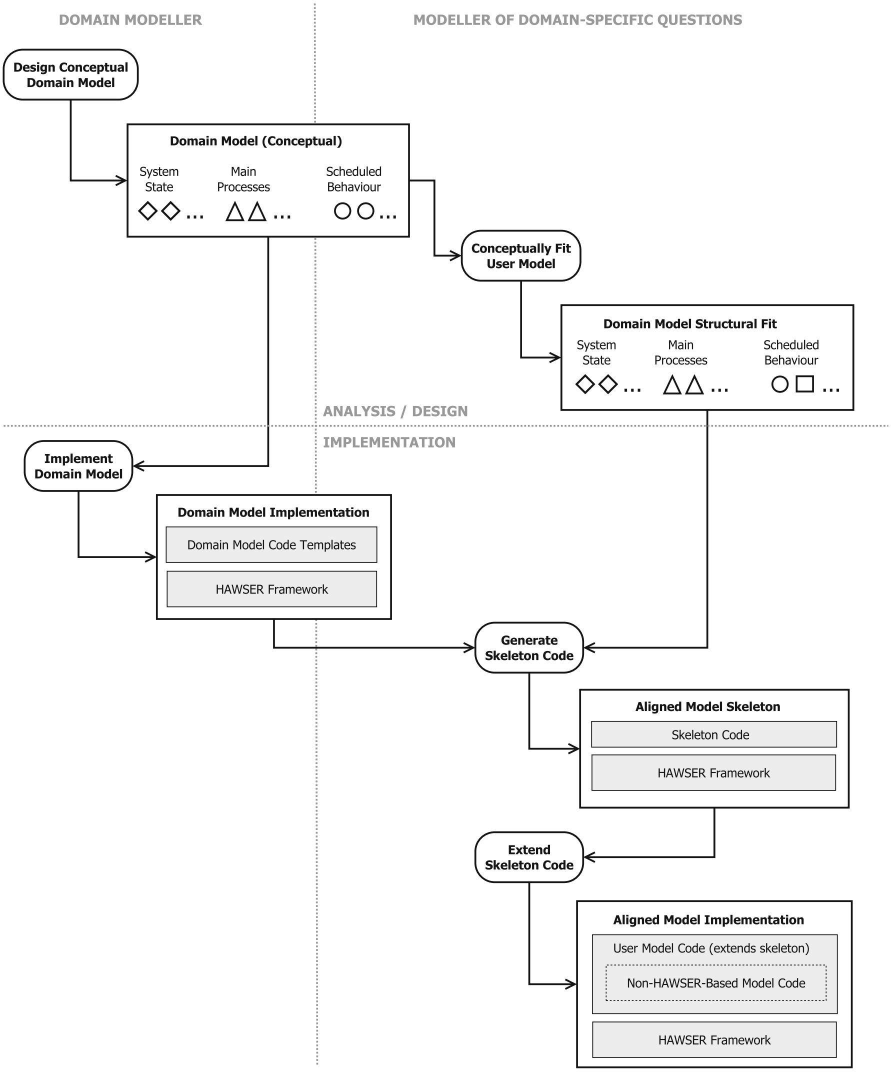


**Fig. 21.1** A summary of the overall proposed modelling process, as a UML activity diagram with partitioning for different roles (*vertical*) and stages (*horizontal*) in the process. *Shaded boxes* represent code. The *diamond*, *triangle* and *circle* represent instances of each of the main types of domain model element. The *square* in the Domain Model Structural Fit box (parameter) highlights how the behavioural fit can result in new entities, as well as existing entities

researchers would think it appropriate to go beyond this).[6] Such features are also ones which *presuppose as little social theory as possible*, which is what we should expect since social theory is the main mechanism by which models differ (and thus is not generalisable).[7] They are aspects that concretely exist 'out there' and would be included in an expert participant's account when no conceptually constraining elicitation method (such as systems thinking's causal loop diagrams [18, Sect. 5]) was used. This lends itself to an **object-oriented representation**, with object classes corresponding to real-world entities, and is similar to a systems-theoretic design [22, Sect. 1.1.1]. We supplement this with **workflows** [21] to model system processes.

In practice, the approach will work best for problem domains where there are enough of these constraints for the conceptual model to be 'meaty' enough to be useful. Two good examples are (a) electricity markets, where the physics of electricity flow and the difficulty of storing it mean that electricity markets and infrastructure *have* to work in a certain way (at least unless radical disruptive technologies emerge); (b) healthcare, where the biological constraints of disease pathologies and available treatments are allied to structures of health systems that tend to define generalised care pathways. We use the example of electricity markets in what follows.

The entities whose behaviour drives the system are termed **behavioural entities**. In the real world, this behaviour is often governed by **processes**, some of which can also be generalised in the same way as the entities. For example, because electricity cannot easily be stored, it has to be generated in real time as it is consumed (and this demand can only be approximated beforehand). Thus, *all* electricity markets have 'balancing markets' where generators make bids and offers to increase or decrease generation as required in real time. Equally, constructing a new power plant requires planning permission, consent from the transmission network operator and local work to physically connect it to the grid.

In addition, there is often specific information in the real world that is consulted by many actors to guide decision-making. This typically relates to the shared environment in which the participants are operating. In our electricity markets example, one obvious candidate is information on the topology of the electricity transmission network and what is attached to it, since that governs who can use and supply electricity, and thus the strategic options for buyers and sellers in the market. If we abstract away the *access* to this information (and aspects such as unreliable transmission of it), we can view this as **core system state** shared as information.

These distinctions (behavioural entity, process and core system state) are also made with one eye on model implementation. They correspond to aspects we

[6] That is, there will not be any changes over the course of the simulation which are fundamental and disruptive enough to change these 'structural goalposts'. This assumption is implicitly embedded in *all* simulation models, unless they are explicitly trying to model such change. (Even then, they can only cover a set of possibilities which the modeller can conceive of.)

[7] See Sect. 21.4 for some discussion on the use of the word 'theory'.

typically see in an object-oriented simulation: a set of object classes, some form of schedule to centrally drive object behaviour, and objects encapsulating system state which are often visualised and/or have statistics derived from them. We typically derive our measures of scenario favourability from the latter.

### *21.2.2 Analysing Models Using the Domain Model*

The domain model can then be used either to design new models or, more commonly, to analyse and compare existing models. As a general scientific principle, all models should be able to explain how their theory relates to a more atheoretical understanding of the real-world system. (Indeed, many computational sociologists reject orthodox economics precisely because they feel it fails on this count [12].) Thus, they should be able to explain themselves in terms of the domain model, and the process of doing so is a valuable scientific exercise as well as being extremely useful for model comparison. We refer to this step as **structural domain model fitting** (of the individual model in question).

This does *not* mean some kind of 1–1 mapping, or that the model must only extend the basic building blocks of the domain model: it means that the model's design can be derived from the domain model via a series of extensions *and abstractions*, which could be more or less 'radical' depending on the model. (The domain model is a partial, 'atheoretical' view of the domain, not some normative design for any model of it.)

Both domain models and the fitting process have a particular form and set of design heuristics which makes this possible in a relatively formal way. Because we are trying to model entities and some of the processes which drive their interactions, we are necessarily building up a *causal-mechanism view* of the system. Thus, we should expect that models which abstract away the causal mechanism (e.g., statistical regression models) or abstract away the entity-instance aspect of reality (e.g., system dynamics) will necessarily require a more 'involved' fit: such models have to work harder to explain themselves in real-world terms. Since a regression model has the core relationship between its independent and dependent variables as an 'unknowable' statistically fitted set of associations, the process will make that clear whilst mapping the variables to existing or new parts of the system that they relate to (see Sect. 21.3.3.1).

This is also why our technically incorrect assumption that only the problem domain defines the system's scope is acceptable. Although theory also drives system scope to some degree (as well as driving the *representation* of that system), representational flexibility means we are not excluding anything outside our domain model and thus theory-driven differences in scope will come out in the fitting process.

### *21.2.3 Model Implementations*

Model implementations are based on a shared implementation of the domain model. The domain model fit provides ways to formally specify the main structural extensions and abstractions, which can then be used to produce *skeleton model code* from the domain model code; i.e., a partial implementation for the model which is then fleshed out by the modeller with code for the detailed behaviour of entities within the structure.

For existing models, one can either *re*-implement them in this mapped-to-the-domain-model way or extend this skeleton code to act as a 'wrapper' for the existing model (i.e., code which controls the execution of the existing model, and manipulates its inputs and outputs so as to conform to the domain model fit).[8]

Primarily due to space limitations, we focus on analysis and design in the remainder of this chapter, making some passing comments on implementation aspects. (Section 21.4 gives a summary of what we have actually realised to date.)

### *21.2.4 Possible Usage Modes for the Process*

There are different ways in which the process could be used, some of which represent grander visions than others. At the simpler scale, a domain model could be constructed just to guide the design and development process for a single model (or a closely related set of models). It may prove valuable later, unexpectedly or not, in trying to compare this model with others, or in developing new models for the same domain.

In a more comparative mode, a domain model could be produced to help understand and compare a set of existing models. If done convincingly, this could influence subsequent research, with those in agreement ensuring that their model designs can be mapped to it.

Finally, in a policy mode, a domain model could be defined by, or with, policy-makers. It would be used to state the 'lens' that is expected, so that 'real-world' concepts and data definitions understood by the stakeholders would be used. This would then allow competing models (say from different groups of academics), which could be compared at this shared level.

[8]In software design pattern terminology, this wrapper code acts as a gateway [8, p. 466].

## 21.3 Details via an Abstracted Example

Figures 21.2 and 21.3 provide representational summaries of the 'whole picture' for a hypothetical domain model (Fig. 21.2) and a particular model implementation which is being fitted to it (Fig. 21.3). We explain this detail in stages below, but space restrictions require us to omit many subtleties.

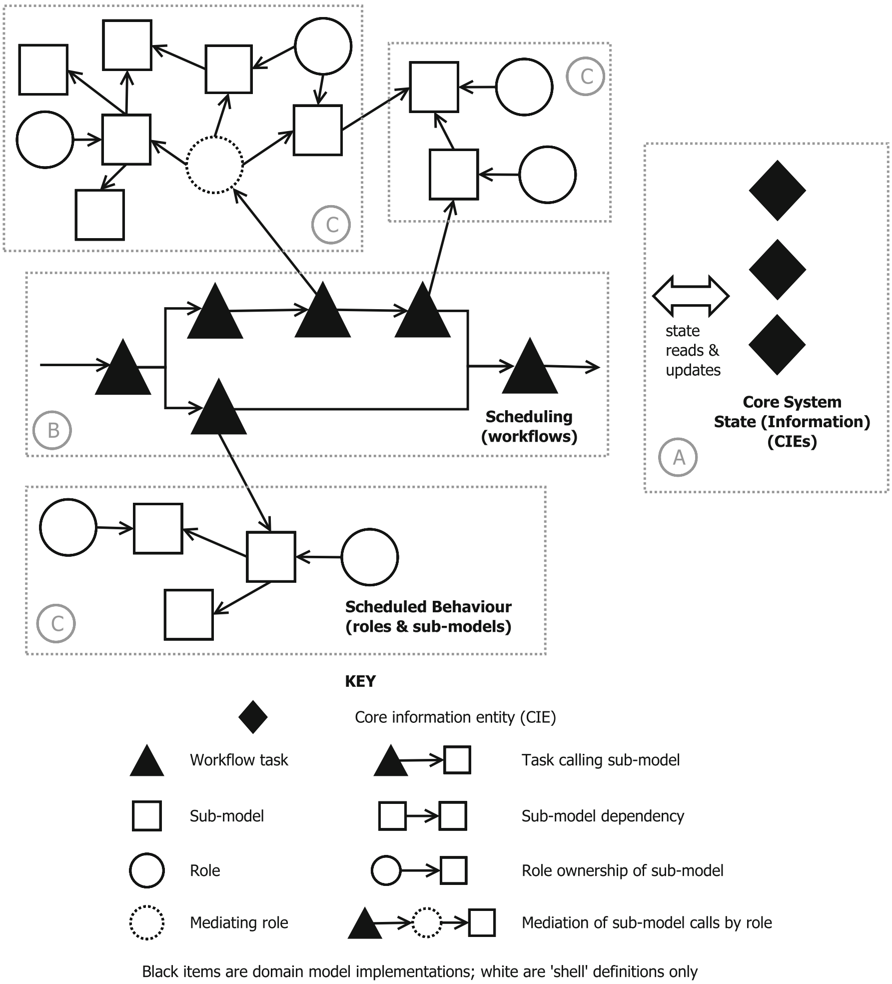


**Fig. 21.2** An example representational domain model, showing the conceptual elements of the process. The terminology and lettered areas are explained in the main text. To avoid clutter, some of the workflow tasks are not 'expanded out'

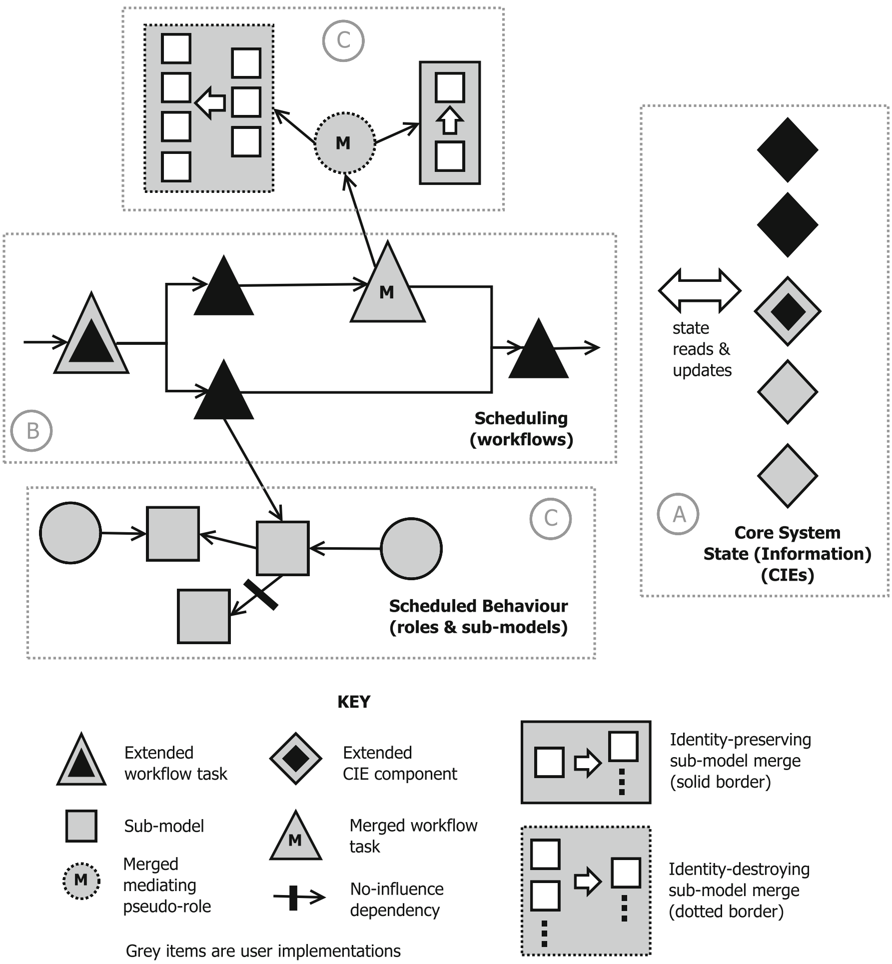


**Fig. 21.3** An example representational model implementation, showing how one possible existing model might be fitted to the domain model of Fig. 21.2. The terminology and lettered areas are explained in the main text. The key extends that of Fig. 21.2

## *21.3.1 Core System State*

The domain model provides a set of **core information entities (CIEs)**, which capture state that conceptually acts as information many actors would tend to want to consult for decision-making if it was available. (Models may or may not model the accessibility of information that exists in reality.) This state is supported by metadata and visualisations that reflect the statistics and trends which are of interest (both to system actors and to the researcher running the simulation).

If we consider the example of electrical power generation system topology discussed earlier, there are obvious useful visualisations of the network and metadata such as the total theoretical supply and demand capacities. Representational flexibility is supported in various ways: representing the system as a network of zones allows differing levels of abstraction (including a single zone where network structure is not required); configuration options allow certain levels of detail (e.g., voltage levels) to be omitted; and flexible technology definitions for power plants allow models to define their own technology classification, whilst still getting the benefits of shared visualisations and metadata.

In the domain model implementation, CIEs are a set of runnable-as-is objects. A user model implementation will configure these as required, and may extend them (perhaps with extra objects). Areas labelled A in Figs. 21.2 and 21.3 show this schematically.

### *21.3.2 System Processes (Scheduling)*

Generalisable processes in the real-world system are represented as **workflows**, which allows the conceptual design and implementation to be closely related: workflows can be designed conceptually in the same tool used to implement them, in our case the Yet Another Workflow Language (YAWL) [20] platform. Workflows provide a rich set of scheduling patterns and, crucially, can conceptually represent the parallelism that almost always exists in the real-world system.

Representational flexibility is achieved by allowing user models to **merge** workflow tasks, extend existing ones, and control the ordering of task execution (thus specifying how conceptual parallelism translates into sequential computation); there are also various related design heuristics. User models thus specify a set of workflows derived from the domain model ones; see the areas labelled B in Figs. 21.2 and 21.3. Since merging tasks may mean that there is now no well-defined sub-model to call, special mediating roles (similar to those in Sect. 21.3.3) may be required.

At the implementation level, the Hybrid Agent-Workflow Simulation Engine for Research (HAWSER) framework provides the bridge from these to behavioural entities, with the latter using the MASON [11] agent-based framework. This separation of concerns (behaviour and its orchestration) is a core software engineering concept [5], promoting reuse and layered design.

### *21.3.3 Scheduled Behaviour*

We classify the behaviour into a set of well-defined **sub-models**, with sets of **sub-model dependencies** which define the main interactions and informational dependencies that occur in the real-world system.[9] The detail *within* these sub-models is unspecified. There are general restrictions on what sub-models can represent, which help avoid some particular conceptual difficulties; this just means that such things are part of the 'full' detail outside the scope and/or resolution of the domain model. (We do not discuss this further here.)

As is generally required in causal-mechanism-based models, we define a conceptual boundary between internal and external sub-models (see, e.g., Sterman [18, Sect. 3]), though this can be 'overridden' during the fitting process. Internal models are generally more fine-grained, and are expected to provide most of the modelled interaction.[10] They are related to **roles**, which are taken up by individuals or well-defined groups of such (e.g., firms). As in the real world, implementing entities can take on multiple roles (and this provides some modelling flexibility). External sub-models have no associated roles. They may be relatable to groups of individuals (e.g., an industry sector) or environmental processes (e.g., weather).

The domain model fit will result in an adjusted set of sub-models and dependencies. Models may break down 'external' sub-models into much more detail, and these may interact extensively with 'internal' ones; thus, which behaviour is endogenous and which exogenous is still up to the model. More importantly, the fit may include new sub-models which are **merges** of others, and behaviour originally in one domain sub-model may be split amongst new ones.

Workflow tasks normally call behavioural sub-models directly. However, there are occasions when the temporal flow of actions is, by its nature, unspecifiable as a meaningful generalisation. For example, consider modelling the trading of electricity in some time period. In the real world, buyers and sellers interact via various market mechanisms, depending on the country (e.g., centralised spot/pool markets, government tenders or decentralised bilateral contracts). We can generically model the roles and behaviours involved, but not the 'control logic' of what would drive what in a computational model. Thus, we support artificial **mediating roles**, which workflow tasks can call in such circumstances. It is then this role's responsibility to orchestrate the actions of a defined set of sub-models.[11]

Figures 21.2 and 21.3 show these ideas schematically (the areas labelled C). The top-left C area in Fig. 21.2 shows a mediating role.

[9] The dependencies specify only what interactions of information and possible action occur (i.e., that a dependency exists), not when and how these occur (i.e., not how the dependency should play out in implementation terms). Dependencies also have types, but we do not discuss that here.

[10] This does not necessarily mean that they are the main *drivers* of system-level patterns: that is a question of sensitivity analysis.

[11] This idea has analogues with concepts in theory, such as Adam Smith's 'invisible hand'.

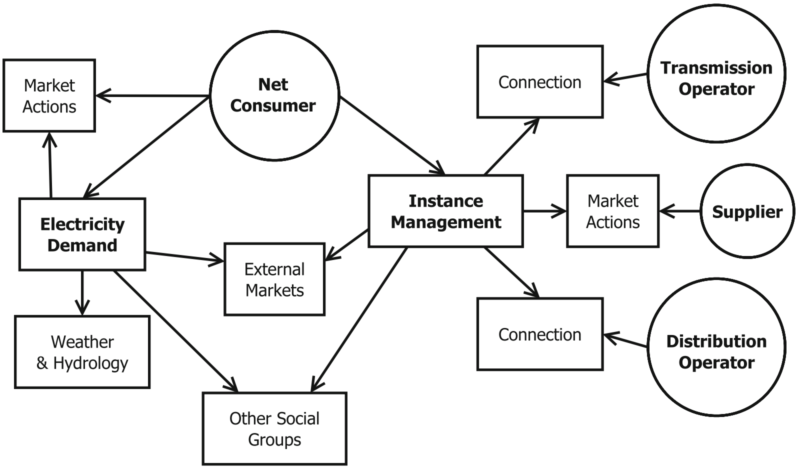


**Fig. 21.4** Sub-model dependencies and role relationships for two sub-models of the Net Consumer role (called as part of a workflow task representing the real-time operation of the power system). The *symbols* used are as in Fig. 21.2. Sub-models without owning roles are external ones. Only direct dependencies are shown

#### 21.3.3.1 A More Concrete Example

Figure 21.4 shows an example of some explicitly named sub-models, roles and dependencies. The Net Consumer role represents net consumers of electricity.[12] Their main behaviour is to produce demand for electricity (Electricity Demand sub-model), but this is also a role where the set of instances of the role typically changes as consumers enter or leave the system; the Instance Management sub-model is a convention to represent this.[13]

In this case, Instance Management includes things such as changes in numbers of households (hence demographic factors and the dependency on social groups) and industrial consumers (hence the dependencies on supplier price schemes, connection criteria by operators and non-electricity markets).

Figure 21.5 provides an illustrative example of a fit to the domain model concepts in Fig. 21.4. Let us assume the existing model has a component calculating total electricity demand for each new time step, where this is: the previous value, plus a term representing relative gas prices, plus some fitted constant; all multiplied by a value representing the number of consumers via some population projection data.

[12]They may have small amounts of generation, such as a household with photovoltaic panels, but they are a consumer on balance.

[13]This convention is appropriate here because the process governing changes in consumer instances is largely independent from that governing electricity demand per consumer. If it were not, there is an alternative convention.

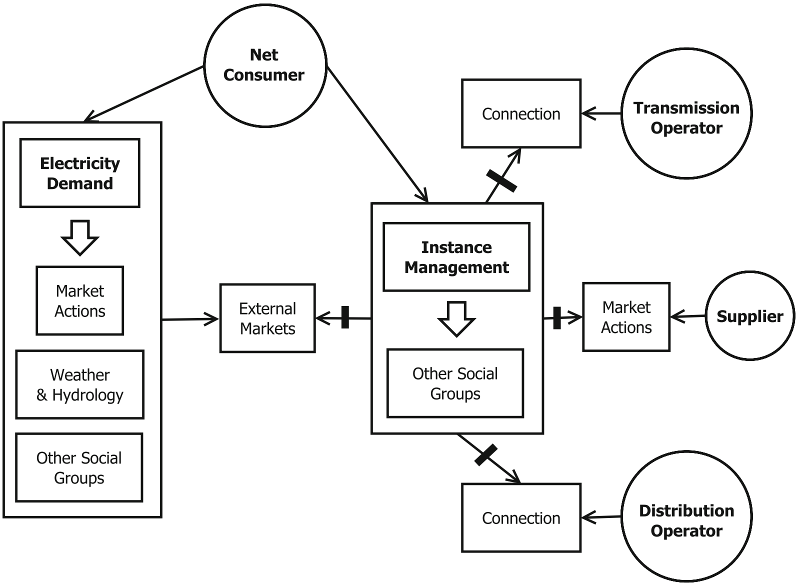


**Fig. 21.5** The fit of (a component of) an example model to the Net Consumer sub-models shown in Fig. 21.4. The *symbols* used are as in Fig. 21.3

Firstly, we can still consider this as explicitly modelling a Net Consumer role, but with only a single instance (for the whole system). Secondly, the structure of the demand function cleanly separates out into a term for electricity demand (Electricity Demand sub-model) and a multiplier for the number of consumers (Instance Management sub-model). The latter uses only population projection figures, which thus relate only to household changes and do not separate out household level decisions from the social groups to which those households belong. Therefore, we can take the model as making an assumption of **no-influence** (a 'null assumption') for the industrial-user-related dependencies, and we have to merge Instance Management with Other Social Groups.

In terms of the Electricity Demand sub-model, the relative gas price term relates to the External Markets dependency (the gas market). This models the fuel price drivers of shifts from electricity to gas (or vice versa) in terms of both domestic and industrial users. The remainder (fitted constant) is not separable into any other sub-models, being a black-box numeric fit. This therefore merges 'unknowable' assumptions from all other dependencies, but the Electricity Demand sub-model still remains a well-defined thing in itself.[14]

[14]There is always some subjectivity in this fitting process. We assume here, for example, that there are no other external-market-related factors which could be folded into this fitted constant.

Note how Other Social Groups is split; i.e., different aspects of behaviour relating to it are included in separate merged sub-models.

The modelling process more formally defines the different types of fit which are possible. As a very brief further example, imagine if this demand function was just a linear function over time (with the angle and intercept fitted to historical data). A single role instance still exists, but the actions of consumers are not separable from the external changes which affect them, nor from changes in the set of consumers. Thus, there is a single new 'artificial' sub-model which merges both Net Consumer sub-models and all their dependencies.

## 21.4 Conclusions

We have outlined the rationale for the approach and the main design principles (via some examples). Outside of this work, we have currently (a) defined the process, and the required implementation features, in detail; (b) tested it in conceptual fits to several published models; and (c) developed partial implementations of the software framework and some domain-model-conformant models. This has currently focused on the electricity markets domain, but we are working on applying it to a health and social care domain.

### *Future Work*

There are still some features to build into the implementation, which we hope to release as open source. Given the approach's inherent abstraction and generality, there is also a clear need for future work to publish detailed, practical examples which give demonstrable benefits in various areas: conceptual comparison, especially when transdisciplinary; model reuse and alignment; and engagement with policy-makers. Regarding the latter, our ultimate aim is to help move towards model-centric, comparative debate (*à la* Lempert et al. [10]), using scenario generators encapsulating theoretical plurality. The fine-level detail of the process is also difficult to capture in a single paper, so we intend to release a 'user-guide-style' technical report which provides a definitive working reference.

Our object-oriented domain model design does not seem particularly commensurate with paradigms such as system dynamics, but we currently believe that it is usable. At the conceptual level, this boils down to translating the abstract system-level attributes (stocks) into the entities that they relate to, with their flows relating to workflows. This will typically involve many merges, which just reflects the general abstraction of system dynamics from individual real-world entities. The implementation level is trickier, since the model is a set of continuous coupled differential equations (albeit resolved numerically with an implicit dependency graph), but we have some ideas on things we can do here which we hope to try out soon.

### *Difficulties with the 'Atheoretical' Design Criteria*

There are potential communication difficulties due to the slippery meaning of 'social theory'. Our restrictions on what can go into a domain model (and how models are mapped to it) obviously constitute a theoretical framework in one sense, and the things in a *particular* domain model constitute some view on the (partial) structure of a real-world system which one could label a social theory (despite our informally defined intention to include 'as little social theory as possible').

The bottom line is that the domain model tries to include elements that it would be hard to argue as not existing and generalisable in the real world, whether one wishes to label this as a theory or not. Attempting to fit existing models will show how much their conception differs from this partial base one. If *all* models fitted end up with very large numbers of merges and new entities, this *might* suggest that our domain model is lacking in some regard. Or it might suggest that existing models are all based on very abstract theory as regards the system's structure (which may or may not be a bad thing). The process at least forces us to make these judgements and compare with some more 'common sense' view, which is a valuable scientific endeavour in itself (and promulgates things such as shared vocabularies in the process).

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