Simulation in Computational Finance and Economics:
Tools and Emerging Applications

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Preface

MOTIVATION

Simulation techniques are useful, versatile, and powerful tools, which have been applied to study and analyze different types of complex problems in many areas, such as medicine, telecommunications, games, transport, manufacturing, etc.; finance and economics are not the exception. In finance, the application of simulation has been extensively used to study many problems, such as market risk, portfolio optimization, and credit risk, among many others. In the field of economics, the application of simulation models has permeated slowly due to the preference of well-established methods over simulation, although these methods have failed to predict the recent financial crisis. The strong (sometimes simplistic) assumption to allow mathematical tractability of economic problems is one of the most criticized aspects in the economic analytical models. This limitation has opened the opportunity for new trends, in which different ideas and approaches are being explored to study some problems in the area. Moreover, policymakers and financial authorities have shown unprecedented interest in exploring new techniques to study and understand the complex reality of the global financial world. In this respect, computational simulation in economics and finance has been one of the disciplines that have gained a considerable number of researchers and financial authorities. Probably, the most prominent example of simulation in economics is Agent-Based Computational Economics (ACE), a paradigm which proposes the use of computational (bounded rational) agents instead of the perfect rational representative agent. ACE has a well-established community, which has applied such paradigm in very different areas like financial markets, game theory, power markets, payment systems and methods, etc. To that end, the application of these novel modeling techniques to study different aspects of economic phenomena requires that researchers have deep understanding of the problem as well as the capability of putting in place complex computational simulation programs. Certainly, this is not a trivial task given that the success of the simulation depends critically on the computational skills of the researchers. Furthermore, this approach has to gain more recognition in the economic sciences community as some of its members are skeptical about its usefulness is this important field.

Despite all this, the literature about computational simulation for economic problems has been growing in the last few decades; in the coming years, it is expected that the number of studies applying these techniques will be growing even faster worldwide. This creates the urgent necessity to present a current view of some of the relevant works developed in the field, in order to give useful insights of how different simulation tools are applied to tackle complex phenomena in economics and finance. The main objective of this book is to promote the computational simulation techniques as fundamental tools to model financial and economic problems. In order to achieve our objective the first intention is to mo-
tivate young and well-established researchers to develop their own simulation-based methods to study different problems in economics and finance. To that end, the readers are provided with useful insights of the way different problems are tackled, and some of the chapters present detailed information of the critical issues to be faced during the different stages of project development. Furthermore, we would like to give practitioners in this area a comprehensive account of the current advances of computational simulation in economics and finance.

The remaining part of this introduction is organized as follows: first, the concept of simulation is introduced and some selected references are given; afterwards, the description of the book structure is presented; and finally, a brief introductory section for each of the three parts of the book is included.

Simulation: Simulation has been a powerful tool, which allows researchers to explore different scenarios of complex problems in order to scrutinize and analyze some relevant characteristics of the simulation model. According to Sokolowski and Banks (Credit Suisse, 1997) modeling and simulation is a discipline that consists of developing a simplified representation of the problem in order to address a predefined set of goals. After that, several runs of the experiment are executed in order to represent multiple scenarios that will be used to observe and study the phenomena; the analysis of such executions will be used to create predictions of the system behavior under unseen circumstances (Tayfurd & Benjamin, 2007). Two of the most relevant simulation techniques are Monte Carlo and Scenario simulation. Scenario simulation was proposed by Farshid and Yu for quantitative risk analysis. The reader interested to acquire basic knowledge about modeling and simulation is referred to Principles of Modeling and Simulation: A Multidisciplinary Approach (Sokolowski & Banks, 2009), which provides an excellent starting point to understand how simulation modeling works. Furthermore, to learn about the mathematical framework behind financial simulation the book Simulation Techniques in Financial Risk Management (Wong, 2006) is recommended. In the same vein, the book Monte Carlo Methods in Financial Engineering (Glasserman, 2004) provides a collection of chapters related to the foundations of the Monte Carlo method, together with the explanation of how to apply the generation of random numbers and discretization methods, as well as a useful selection of applications on risk management. Finally, the book Modeling Risk (Glasserman & Li, 2005) provides information about simulation in the specific topic of credit risk.

Book structure: The book is composed by eighteen chapters, which are organized around three sections: 1) payment systems and methods, 2) risk management, and 3) agent-based and other simulation approaches. The classification was conceived only for organization purposes, but some works could fit in more than one of the previously described sections. For example, some chapters, which study payment systems or methods, are agent-based simulations. Additionally, some works belonging to the first section of the book consider important risk implications from the payment systems perspective. Finally, agent-based simulations can be found in the three different sections, which constitute this book, causing the artificial separation to become blurred.

SECTION ONE: PAYMENT SYSTEMS AND METHODS

The economic dynamics observed in the payment and settlement systems falls in the set of complex social phenomena, difficult to tackle. Globally, in the last decade, the role of payment systems has rapidly changed together with the adoption of the technological innovation (Bech & Hobijn, 2007). In developed countries, it has been a long tradition to model different aspects of payment systems and
due to the complexity of the economics of payments, studying it through simulation models has been a sensitive choice (Leinonen, 2005). Furthermore, the last crisis underlined the consequences of the interconnectedness among countries all over the world and stressed one more time the relevance of the smooth functioning of payment systems in a global scale. Thus, in order to go further in our understanding, authorities in charge of the payment systems oversight, in particular in the emerging economies, are facing the challenge of modeling payment systems through simulation.

This task requires researchers on the one side to have knowledge about liquidity management, settlement algorithms, and stress testing analysis, and on the other side, to be familiar with the setting up of computer simulations. In this context, with the intention to close the gap between experts in the field of payment system models and newcomers, we have included in the present volume a rich collection of chapters aimed to illustrate how simulation is applied to study the economics of payments.

In order to provide wide options to the reader, the chapters presented in this book have different degrees of complexity. We start the section dedicated to Payment Systems and Methods, focusing on the retail side of the payment industry. In the first chapter, we present an agent-based model, which realistically represents some of the characteristic features of the payment card, namely the interactions at the point of sale among consumers and merchants and the network externalities among them. Further, the rest of the chapters presented in this section are dedicated to simulation methods applied to study Large Value Payment and Settlement Systems. More specifically, we present four introductory chapters in this group, together with three excellent examples of how computational simulation has been applied in formal studies. In particular, chapters 2, 3, and 4 are aimed to introduce the reader with a thorough perspective of how the complex economics of payments could be studied using the computational simulation as an analytical tool. Following, chapter 5 presents a discussion of why agent-based modeling is a prominent simulation technique to understand payment systems participants’ behavior, whilst chapter 6, 7, and 8 give specific real life research applications.

Let us briefly describe individually each of the eight chapters that compose the first part of the book. Chapter 1, “The Adoption Process of the Payment Cards: An Agent-Based Approach,” studies the adoption process of the payment cards with the aim of analyzing the payment adoption rate under consumers’ and merchants’ awareness of network externalities. Two levels of Interchange Fees in a multi-agent card market were given and the effects are analyzed over the complete process of adoption. Chapter 2, “The Use of Simulations as an Analytical Tool for Payment Systems,” is especially recommended for researchers and students who want to initiate in simulation techniques, since this chapter provides an inside view into the use of simulations as an analysis tool for payment systems as well as settlement systems. Additionally, an epistemological assessment of simulations versus other analytical tools is shown and the range and limits of simulation are highlighted. Chapter 3, “Preparing Simulations in Large Value Payment Systems using Historical Data,” presents a simulation in large value payment systems. In this context, the authors identify the important elements that must be prepared for the simulation. This chapter is also a good example for beginning practitioners who aim to create their own simulation models. Chapter 4, “Simulation Approaches to Risk, Efficiency, and Liquidity Usage in Payment Systems,” presents an agent-based model to understand the payment system mechanisms; the objective of this work is to find optimal balances of risk, efficiency, and liquidity. Chapter 5, “Liquidity Management in the Large Value Payment Systems: Need for an Agent-Based Model’s Complex Approach,” reviews the current state of computer simulation of payment systems, including some of the operational aspects of simulations with payment system data, and offers some considerations on simulation design. The authors present an overview of the three categories of applications: liquidity analysis, identification and
quantification of risk, and evaluating the impacts of rule changes or system setup. Chapter 6, “Liquidity Saving Mechanisms and Bank Behavior,” studies the effect of Liquidity Saving Mechanisms (LSM) in interbank payment systems; the simulation applies an innovative technique that combines agent-based modeling and game theory. A stylized two-stream payment system is modeled, where banks choose 1) how much liquidity to post and 2) which payments to route into the each of two “streams”: a Real Time Gross Settlement (RTGS) stream and a LSM stream. Chapter 7, “Liquidity Saving in CHAPS: A Simulation Study,” proposes to use a simulation methodology and real payment data to quantify the liquidity efficiency that could be obtained in CHAPS, the UK’s large-value payment system, by the implementation of a liquidity saving mechanism. Finally, Chapter 8, “Managing Intraday Liquidity: The Mexican Experience,” presents a study that calculates the liquidity usage of the Mexican Real Time Settlement Payment System, SPEI, during a one-month period. The main interest is to get insights of how payment systems’ participants manage the settlement in real time of low and large value payment transactions. An artificial environment, which reproduces the operational conditions of SPEI, was created to measure the liquidity usage in different settings of settlement speed requirements.

Finally, we can say that simulation is a versatile technique, which is capable of modeling complex aspects of payment systems. This allows central banks to monitor potential risks that could affect the financial stability.

SECTION TWO: RISK MANAGEMENT

Risk analysis is an important subject of study since this involves the identification of uncertainties and risks that institutions, organizations, and persons have to face (Byrd & Cothern, 2005). The objective of recognizing potential risks is to understand and estimate the impact of those hazards with the aim of planning actions that would help to mitigate the consequences. Since organizations are daily confronted with diverse risks, the development of techniques to estimate those risks has become an important issue. Financial institutions have to identify and quantify their risks in order to guarantee that they have sufficient capital to maintain solvency even if the worst possible scenario occurs. According to the Basel Committee on Banking Supervision (1999), the main source of severe banking problems is concerned about with the lax credit standards for borrowers and counterparties, deficient portfolio risk management, or the inadvertence of environmental changes that may induce that bank’s counterparties suffer deterioration in their credit positions. According to van Greuning and Brajovic (2009), banks are exposed to many kinds of risks that are classified in three types: financial, operational, and environmental risks. Those risks are categorized in Table 1.

As it can be observed from Table 1 that financial institutions have to face many types of risks. In this book, chapters 9, 10, 11, and 12 are focused on analyzing systemic risk, interconnectedness, and contagion. Chapter 13 analyzes market risk, while Chapter 4, which is not included in this part of the book, is an approach, which studies risk from the payment systems perspective. Let us briefly describe the chapters presented in this part of the book. Chapter 9, “Measuring and Charging for Banks’ Systemic Interconnectedness,” presents two methodologies for computing surcharges based on the institution’s contribution to systemic risk. The chapter also illustrates ways to lessen their procyclicality. The authors discuss practical cross-border, data, and communication issues for an effective implementation of sys-
temic capital surcharges. Chapter 10, “Systemic Risk, Stress Testing, and Financial Contagion: Their Interaction and Measurement,” presents a model whose aim is to measure the systemic risk by obtaining a distribution of losses for the banking system as a whole. The model considers many aspects, such as an initial macroeconomic shock, which weakens some institutions, a contagion process, and the resultant losses for the banking system. The authors argue that by using their framework it is also possible to perform stress testing in a coherent way, including second round effects like contagion through the interbank market as well as to follow the evolution of certain risk measures, like the CVaR. Chapter 11, “What Matters in Determining Capital Surcharge for Systemically Important Financial Institutions?” studies the systemic importance of individual banks by measuring not just the size but other factors such as interconnectedness. This work considers different network structures of the banking system that are characterized by two different centrality measures. The authors found that the systemic importance must be supplemented with detailed information on interbank exposures. Chapter 12, “Multi-Agent Financial Network (MAFN) Model of US Collateralized Debt Obligations (CDO): Regulatory Capital Arbitrage, Negative CDS Carry Trade, and Systemic Risk Analysis,” investigates how a CDS negative carry trade combined with incentives provided by Basel II and its precursor in the US, the Joint Agencies Rule 66 Federal Regulation No. 56914 on synthetic securitization and Credit Risk Transfer (CRT), led to the unsustainable trends and systemic risk. The resultant market structure, with heavy concentration in CDS activity involving 5 US banks, can be shown to present too interconnected to fail systemic risk outcomes. The simulation package can generate the financial network of obligations of the US banks in the CDS market. The objective is to show how such a Multi-Agent Financial Network (MAFN) model is well suited to monitor bank activity and to stress test policy for perverse incentives on an ongoing basis. Chapter 13, “Risk Assessment Using High-Frequency Data and Scaling Laws,” uses high frequency data to estimate scaling law models and then apply appropriately scaled measures to provide long-term market risk forecasts. The aim is to analyze extreme price movements from tick-by-tick real-time data to trace back the footprints of traders that eventually form the overall movement of market prices and potential bubbles. The framework is applied to empirical limit order book data from the London Stock Exchange.

Table 1. Banking risk spectrum (see Greuning and Brajovic, 2009)

<table>
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<tr>
<th>Financial Risks</th>
<th>Operational Risks</th>
<th>Environmental Risks</th>
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<tbody>
<tr>
<td>Balance sheet structure</td>
<td>Internal fraud</td>
<td>Country and political risks</td>
</tr>
<tr>
<td>Earnings and income statement structure</td>
<td>External fraud</td>
<td>Macroeconomic policy</td>
</tr>
<tr>
<td>Capital adequacy</td>
<td>Employment practices and workplace safety</td>
<td>Financial infrastructure</td>
</tr>
<tr>
<td>Credit</td>
<td>Clients, products, and business services</td>
<td>Legal infrastructure</td>
</tr>
<tr>
<td>Liquidity</td>
<td>Damage to physical assets</td>
<td>Banking crisis and contagion</td>
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<tr>
<td>Market</td>
<td>Business disruption and system failures (technology risks)</td>
<td></td>
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<tr>
<td>Interest rate</td>
<td>Execution, delivery, and process management</td>
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<tr>
<td>Currency</td>
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SECTION THREE: AGENT-BASED AND OTHER SIMULATION APPROACHES

Agent-based simulation in economics and finance is a relatively new approach, which has been gaining prominence recently. However, agent-based simulations are not exclusive in economics and finance; there is a well-established area of research on agent-based modeling (Wooldridge, 2002) with applications in engineering, computer science, and social sciences, in general. Agent-based models are also known as multi-agent systems, and in economics and finance there is even another associated term: Agent-Based Computational Economics (ACE). Most of the related literature has been reviewed in the past (Chen, 2007; Tesfatsion, 2006), and it is not our intention to provide an exhaustive literature review here.

The surge of agent-based models and simulations in economics and finance is intended to overcome some of the limitations of theoretical models and to relax some of the strong assumptions in standard economic and financial theory. For example, many of the analytical results in economics are made under the assumptions of fully rational representative agents. Under this new approach, one can depart from homogeneous, fully rational agents to heterogeneous, bounded rational (Simon, 1957) agents. Some important characteristics of these models are: first, they consist of many interacting agents; second, such agents are independent, autonomous, and heterogeneous; third, agents adapt and learn in the changing environment; and finally, the agents’ micro behavior and interaction results in complex emerging collective phenomena, which is observed and analyzed by the researcher. This approach is also known as a bottom-up modeling in contrast to top-down conceived models.

In the context of this book, applications of agent-based modeling range from the study of optimal patent design, systemic risk analysis, foreign exchange markets, retail markets, and self-coordination problems, to payment systems and methods. This wide variety of applications make this and other related sections of the book very useful for researchers who are interested in starting agent-based research in economics and finance. Furthermore, some of the chapters from this section are complex agent-based simulations that can shed some light on problems, which are difficult to handle with other approaches. Finally, from the wide range of works presented in this and other sections, the reader can appreciate a variety of design issues present in agent-based models including agents’ learning and interactions, decisions that are of key importance in any agent-based model. This section of the book provides the reader the opportunity to consider the wide variety of applications of modeling and simulation that can be developed. Chapter 14, “Optimal Patent Design: An Agent-Based Modeling Approach,” presents an agent-based model to analyze the relationship between patent policy and the rate of societal technical advance. The authors conclude that simulation results raise questions about the real utility of patent policy in promoting technological advance and suggest that other policy instruments are actually more important. Chapter 15, “Modeling the FX Market Traders’ Behavior: An Agent-Based Approach,” proposes an agent-based modeling approach to simulate trading behavior in Foreign Exchange markets by using high-frequency dataset of anonymous OANDA individual traders’ historical transactions on an account level spanning 2.25 years. Chapter 16, “Predicting Volatile Consumer Markets using Multi-Agent Methods: Theory and Validation,” presents a behavioral model that incorporates utility-based rational choice, which has been enriched with psychological drivers. The model is used to study a consumer goods market, which is characterized by repeat purchase incidences by households. The psychological drivers integrate purchase strategies of loyalty and change-of-pace, which affect the choice set of consumer agents in an agent-based simulation environment. Agents’ specific memories of past purchases guide these strategies, while attributing specific preferences, and prices drive the utility-based choice function. Chapter 17, “Agent-Based Modeling of the El Farol Bar Problem,” is focused on the study
of the self-coordination problem in the context of the Farol Bar Problem, which is also known as the minority game in the econophysics community. The authors developed an agent-based model to study the efficiency and equality in the Farol Bar Problem. The main question is to find out if it is possible that a decentralized society can self-coordinate a result with the highest efficiency while also maintaining the highest degree of equality. Chapter 18, “Simulation Analysis as a Way to Assess the Performance of Important Unit Root and Change in Persistence Tests,” illustrates a way to assess the performance of some of the most popular unit root and change in persistence tests by means of the simulation analysis specifically by using Monte Carlo simulations.

From these introductory paragraphs, the reader can realize the versatility and the great potential of computational simulation techniques in economic and financial problems. It is important to highlight that some of the chapters provided in this book present serious studies, which can definitely aid in important decisions based on simulation. Finally, a potential audience for this book is the financial authorities who favor the simulation-based research for policymaking and regulatory purposes.

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