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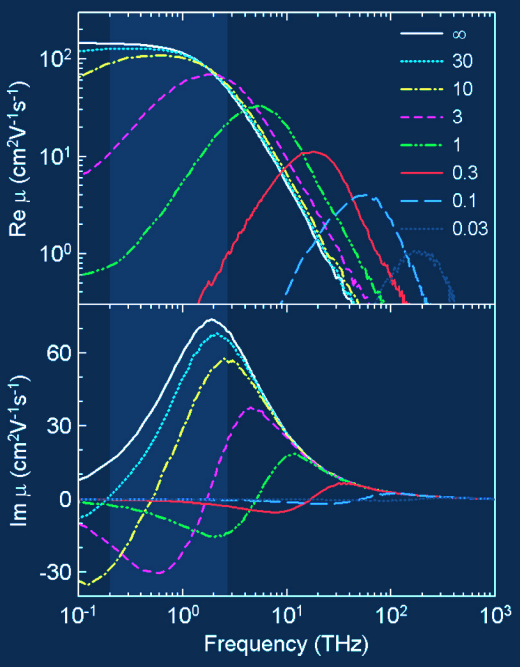
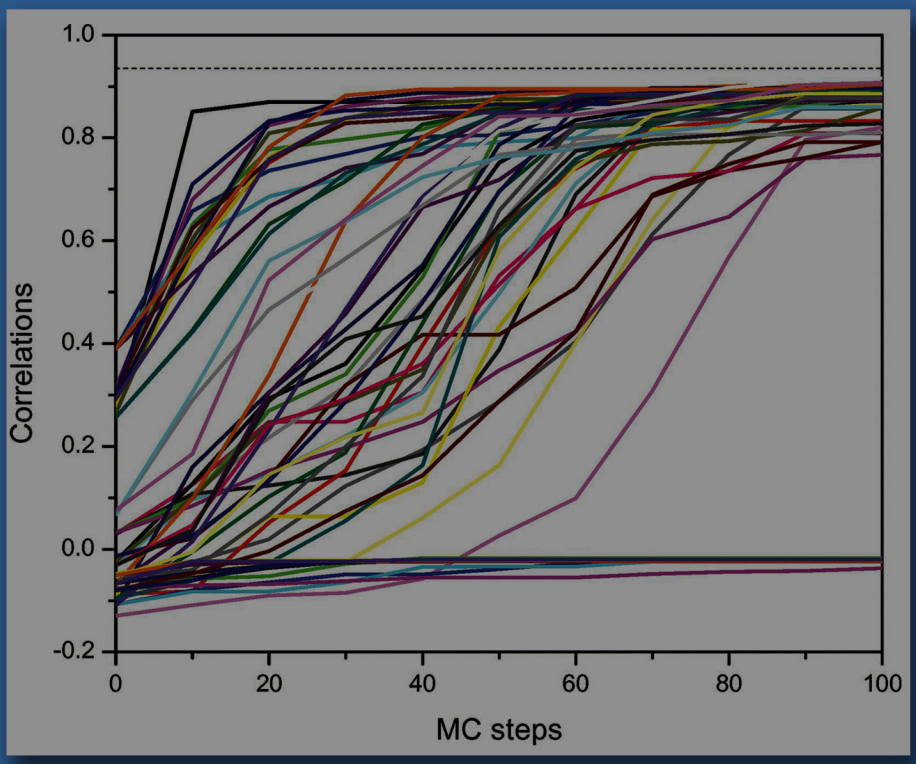
Agent-Based Computational Economics Using NetLogo





Romulus-Catalin Damaceanu

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Agent-Based Computational Economics Using NetLogo

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FOREWORD

The eBook explores the techniques, researchers can create, use and implement multi-agent computational models in Economics by using NetLogo software platform. Problems of economic science can be solved using multi-agent modelling (*MAM*). This technique uses a computer model to simulate the actions and interactions of autonomous entities in a network, for analyzing the effects on the entire economic system. *MAM* combines elements of game theory, complex systems, emergence and evolutionary programming. Monte Carlo method is used to introduce random elements. The models simulate the simultaneous operations of several agents in an attempt to recreate and predict complex economic phenomena. The process is one that starts emerging from the micro to macroeconomic level. Individual agents are presumed to act in what they perceive as their own interest such as reproduction, economic benefit, social status, provided that their awareness is limited.

NetLogo is a software platform designed by Uri Wilensky in the year 1999. NetLogo is in the process of development and modernization in the frame of Centre for Connected Learning and Computer-Based Modelling - Northwestern University, Illinois, USA. NetLogo is written in Java language and can be run on all major platforms (Windows, Mac, Linux *etc.*). In addition, individual models can be run as Java applets inside web pages. NetLogo is freeware and can be downloaded from the web address mentioned below: http://ccl.northwestern.edu/netlogo/

This eBook contains the following chapters:

(i) The first chapter is an introduction of the eBook that provides readers the essential information regarding the field of Agent-based Computational Economics;

(ii) The second chapter describes the multi agent-based computational model of an artificial economy;

(iii) The third chapter describes the implementation in NetLogo of the multi agent-based model described in the second chapter;

PREFACE

Agent-based Computational Economics applies an interdisciplinary approach that combines knowledge from Agent-based Computational Modelling and Economics with the scope to observe, analyze and discuss the evolution of an economic system composed by intelligent agents. From 1990 till now, agent-based computational modelling has gained much attention but despite this phenomenon a fundamental issue is provoked by the next key question: Can agent-based computational model represent economic reality? To answer this, we must say that any agent-based model is a model of a real economic system that takes input data and creates output data by running computer experiments.

The development of theory and applications of agent-based computational models determined in the last years has brought a real revolution regarding the modelling of complex social systems. Presently, we can say that there is a real confrontation between the adepts of equation-based modelling and of agent-based modelling. A similar "war" was encountered at the end of 19^{th} century and the beginning of 20^{th} century between classical economic school and neoclassical one that lasted till the middle of 20^{th} century with the victory of neoclassical school of Economics. Starting from 1990, Agent-based Economics started an offensive movement in order to obtain important position in the system of mainstream Economics.

The confrontation between these two modelling techniques can be won by agent-based modelling only if there lies a clear strategic plan that must be followed by the scientists that are adepts of this specific technique. In our opinion, this strategic plan must contain the following objectives:

(i) Creating a general economic theory starting from the concept of agent considered as an entity that encapsulates parameters, variables, procedures and other sub-agents;

(ii) Using this general theory, there must be created a set of agent-based models feasible for analyzing different aspects of economic reality;

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CHAPTER 1

Introduction

Abstract: In this introductory chapter, we offer our readers the essential information regarding the field of Agent-based Computational Economics. The development of theory and applications of agent-based systems determined in the last years has brought a real revolution regarding the modelling of complex systems in the field of Economics. The main construction blocks of any agent-based computational model are the following: the set of agents (A), the initializations (I) and the simulation specifications (R). In order to validate an agent-based model, we must follow the following steps: (1) The analysis of pure theories of Economics; (2) Defining the objectives of research and the precise tasks of the model; (3) Building the conceptual model; (4) Validation of conceptual model; (5) Transformation of conceptual model in a computerized model using a software platform; (6) The operational validation of computerized model; (7) The analysis of experiments results and interpretation from an economic point of view.

Keywords: Agent-based Computational Economics, equation-based modelling, agent-based modelling, theory of systems, NetLogo software platform, conceptual and operational validation of agent-based models.

Agent-based Computational Economics applies an interdisciplinary approach that combines knowledge from Agent-based Computational Modelling and Economics with the scope to observe, analyze and discuss the evolution of an economic system composed by intelligent agents. Agent-based Computational Modelling involves research in areas of science where computing plays a central and essential role, emphasizing agents seen as entities that encapsulate other agents, procedures, parameters, and variables. Agent-based Computational Modelling is a branch of Applied Computational Mathematics that is currently the field of study concerned with constructing mathematical models and numerical solution techniques by using computers in order to analyze and solve scientific, social scientific and engineering problems (Damaceanu, 2010).

On the other hand, in Economics, the purpose of simulation tools was at the beginning purely theoretical and used equation-based modelling as we can see in (Fig. **1**) where from using the combination of definitions and assumptions, the scientist builds a theory (that in most cases is an equation-based model) to be confronted with the real economic phenomena.

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CHAPTER 2

The Multi Agent-Based Computational Model of an Artificial Economy

Abstract: In this chapter, we describe the multi agent-based computational model of an artificial economy and proceed to the conceptual validation process by describing the observer *O* with its parameters, variables, procedures and sub-agents T_i and P_{xy}.

Keywords: Validation of conceptual model, parameters, variables, procedures, agents, sub-agents.

The multi agent-based computational model of an artificial economy created using NetLogo has the following characteristics:

(i) The mobile agents called turtles T_i are of two types: consumers CO_i and producers PR_i;

(ii) Consumers are in number of $m = \{1,2,3,..,100\}$ and producers are in number of $n = \{1,2,3,..,100\}$;

(iii) The immobile agents P_{xy} have a certain amount of resources $0 \leq r_{xy} \leq 10$, where x, y are integer numbers in interval [-20,20];

(iv) Consumers obtain their income by extracting resources and selling them to producers for a certain price rs_{it} that is the amount of money offered for every unit of harvested resources.

(v) Producers buy resources from consumers and process these resources to produce goods;

(vi) Consumers buy goods from producers; usually, every consumer has a need of one unit of the good produced by producers per every period if the available income permits him to buy this unit;

(vii) Every consumer uses two matching algorithms: one is used for selling resources to producers; the other is used for buying products;

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CHAPTER 3

The Implementation in NetLogo of the Multi Agent-Based Model

Abstract: The implementation of the conceptual model using NetLogo is the process of transforming the algorithms described in Chapter 2 in procedures recognized by NetLogo. Any agent-based computational model implementation must be operational validated and verified. A model is considered operational valid to the extent provides a satisfactory range of if it accuracy consistent with the intended application of the model.

Keywords: Implementation of conceptual model, evolutionary system, NetLogo software platform, observer, turtles and patches own procedures.

Agent-based modeling facilitates a more direct correspondence between the entities in the target system and the parts of the model that represent them and enhances the descriptive accuracy of the modeling process, but it can also create difficulties (Edmonds, 2001). Under these circumstances, almost every implementation of agent-based models may contain bugs defined as code that does something different in comparison with what you expected (Gilbert, 2007). As Axelrod (1997) underlines, you have to work hard to confirm that the implemented model was correctly programmed. Axtell and Epstein state that "the robustness" of macrostructures to perturbations in individual agent performances is specific to agent-based models and makes very hard to identify bugs (Axtell *et al.*, 1994).

An-agent based model implementation is the result of three different types of scientist: the thematician, the modeller and the computer scientist (Drogoul *et al.*, 2003). Thus, discovering inconsistencies in programming languages lines is in general a difficult task. Several authors have identified the concept of ontology (Christley *et al.* 2004; Pignotti *et al.*, 2005; Polhill *et al.*, 2006; Polhill 2007), defined as formal, explicit specification of a shared conceptualization (Gruber, 1993), to be particularly promising for this purpose, especially in the domain of agent-based social simulation.

The implementation of the conceptual model using NetLogo is the process of transforming the algorithms described in Chapter 2 in procedures recognized by NetLogo.

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CHAPTER 4

The Computational Experiments

Abstract: In this chapter, we perform five computer experiments that simulate the functioning of the artificial economy with different values for the three control parameters: rs={-2,-1,0,1,2}, NoProducers={1,2,3,.,100}, and NoConsumers={1,2,3,.,100}. Based on these five experiments, we measure five indexes: Herfindahl-Hirschman index, Gini index, mean value of prices for products, mean value of prices for resources, and mean value of obtained production.

Keywords: Computer experiments, Herfindahl-Hirschman index, Gini index, composite index that measure economy performance.

In the scientific context, a computational experiment or a computer experiment refers to mathematical modeling using computer simulation and typically implies two phases. The modeling phase and the experimentation phase (Sacks *et al.* 1989). In such experiment a computer model is used to make inferences about a system. The computer model takes the place of an experiment we cannot do. Under these circumstances, the phrase *in silico* experiment is used (Sieburg, 1990).

Computational experiments can be seen as a branch of applied statistics, because the user must take into account the next sources of uncertainty:

(i) First, the models may contain parameters whose values are not certain (are random);

(ii) Second, the models themselves are imperfect representations of the studied system;

(iii) Third, data collected from the system that might be used to calibrate the models are imperfectly measured.

However, most practitioners of computational experiments do not see themselves as statisticians (Santner *et al*. 2003). Experimentation to study complex systems can be conducted at different levels of accuracy or sophistication.

CHAPTER 5

Conclusions

Abstract: In this chapter, we draw the conclusions regarding the evolution of Agent-based Artificial Economy described in Chapter 2, implemented in Chapter 3 using NetLogo, and utilized them for a set of computational experiments in Chapter 4.

Keywords: Global performance of economy, computer experiments.

Global performance (competitiveness) of an economy is a comparative concept of the ability of a economy to sell and supply goods and services in a given market. Although widely used in economics and business management, the usefulness of the concept is vigorously disputed by economists. In recent years, the concept of competitiveness has emerged as a new paradigm in economic development. Competitiveness captures the awareness of both the limitations and challenges posed by global competition, at a time when effective government action is constrained by budgetary constraints and the private sector faces significant barriers to competing in domestic and international markets. The Global Competitiveness Report of the World Economic Forum defines competitiveness as "the set of institutions, policies, and factors that determine the level of productivity of a country" (Schwab, 2009). The term is also used to refer in a broader sense to the economic competitiveness of countries, regions or cities. For example, the way for the European Union to face competitiveness is to invest in education, research, innovation and technological infrastructures (Muldur, 2006; Stajano, 2009).

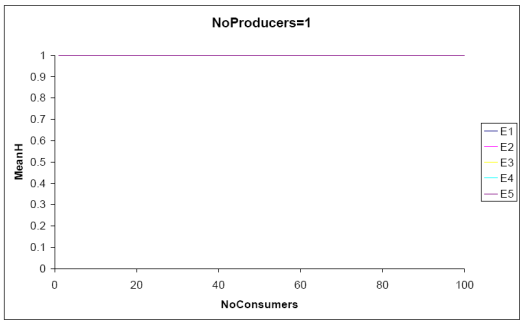
For our book, in order to study global performance (competitiveness) of an economy based on data obtained after running the five computer experiments, we computed a new composite index pe_j that measures the performance of the economy for j producers using the following formula - see (Fig. **1**):

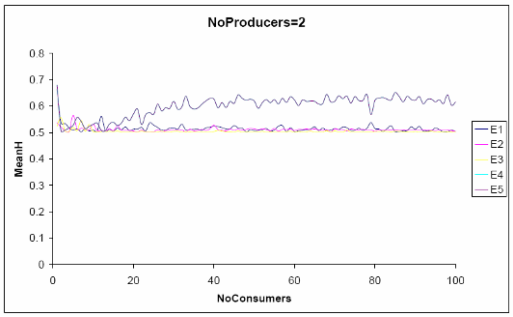
$$pe_j = (R_j(h)+R_j(g)+R_j(p)+R_j(r)+R_j(y))/5,$$

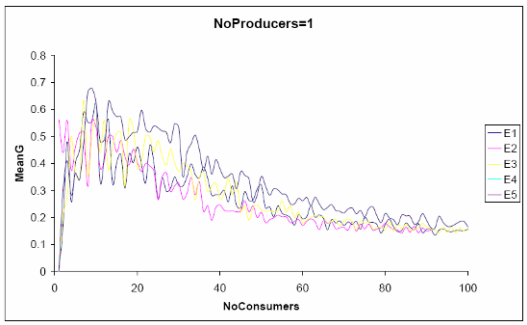
where:

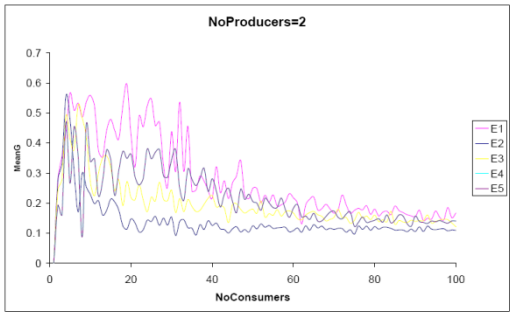
- $R_j(h) = \dfrac{h_{\max} - h_j}{h_{\max} - h_{\min}}$ is the rate obtained for Herfindahl-Hirschman index, where $h_{\max}$ and $h_{\min}$ are maximum and minimum value of h_{ij};

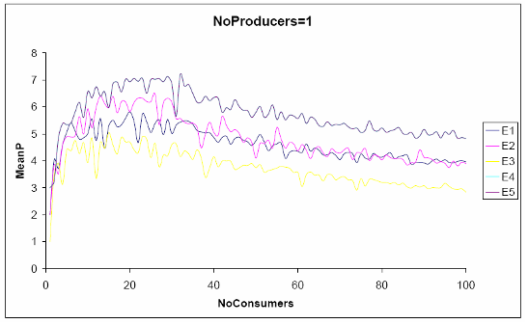
Detailed Results of Computational Experiments

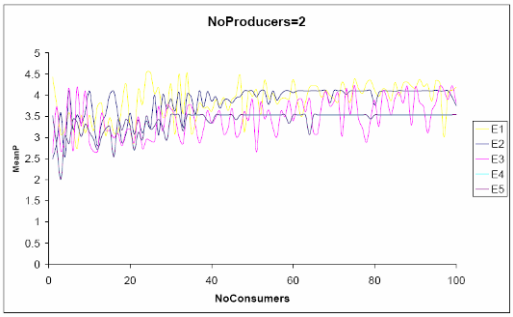


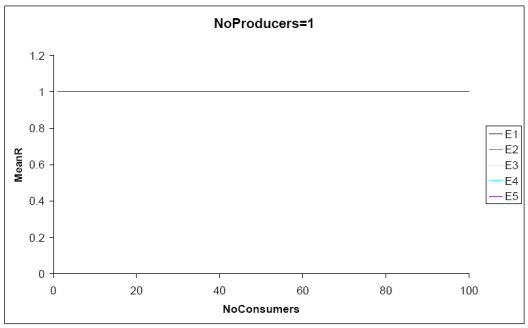


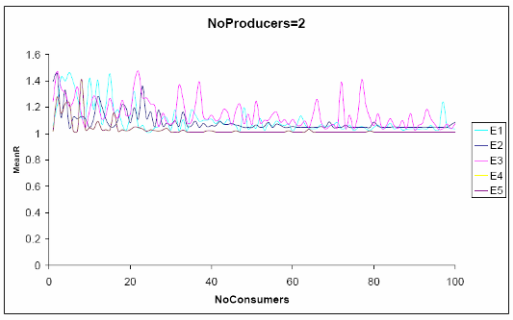












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