HETEROGENEITY, SIMPLE HEURISTICS, and THE ESCAPE FROM DEVELOPMENT TRAPS

A theoretical and computational study

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by

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Abstract

Drawing on accumulating experimental evidence that people are heterogenous and boundedly rational, we propose to explore the robustness of standard representative-agent, rational-expectations, general equilibrium models to changes in two of their key ingredients: homogeneity of agents and rational expectations. We are in particular interested in the subset of such models that has been used to model economies with complementarities and development traps. Such models typically feature multiple equilibria that are Pareto-ranked. We conjecture that heterogeneity and boundedly rational behavior of agents interact to allow economies to escape from development traps. Relatedly, we are interested in identifying the minimalist set of rules ("simple heuristics") that would allow economies an escape from development traps.

We propose to employ "agent-based" models and computational simulations to study the effects of changes in the assumptions of representativeness and rationality. Specifically, we shall employ genetic algorithms and "condition-action" classifier systems using as a benchmark a simple representative-agent, rational-expectations, general equilibrium model with two Pareto-ranked equilibria. This environment will allow us to calibrate our model in a straightforward manner.

This first, primarily theoretical and computational stage of our project is designed to build a solid foundation for a second, more policy-oriented stage. Even our first-stage results, however, will have obvious policy implications.

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Introduction

The macroeconomic literature abounds with general equilibrium (GE) models with multiple, often Pareto-ranked steady states. Typically, these models are of the representative-agent (RA), rational-expectations (RE) variety and they feature economies that get locked into Pareto-dominated steady states that are surprisingly robust against real or belief shocks. For a review of the relevant literature, see Slobodyan (2001). We note that widespread and systemic "coordination failure" has also been documented in the experimental literature on coordination games, i.e., strategic decision situations that are characterized by Pareto-ranked equilibria and the tension between payoff-dominance and risk-dominance, see Cooper (1999) and Van Huyck et al. (1995).

Drawing on rapidly accumulating evidence from experimental economics (e.g., Camerer (*forthcoming*)), we propose to explore the robustness of standard RA RE GE models to changes in two of their key ingredients: homogeneity of agents and rational expectations. Heterogeneity and bounded rationality (adaptive behavior) have been shown experimentally to be important behavioral constants (e.g., Camerer (*forthcoming* especially chapter 5); Nagel (1995), Nagel et al. (1999); Costa-Gomes, Crawford, & Broseta (*forthcoming);* Ho, Camerer, & Chong (2001)).

We shall employ "agent-based" models and computational simulations to study the effects of changes in the assumptions of representativeness and rationality. In agent-based computational economics (ACE) an economy is modeled as an evolving system consisting of autonomous agents who are endowed with some beliefs about the economy, rules for interactions with each other and the environment, and a method by which agents update their beliefs. This "ground-up" approach is well suited to accomplish our goal of studying the robustness of standard models, as each "agent" can be modeled as its own boundedly rational type. It is our conjecture that introducing more "realism" into the model will make it easier for our model economies to escape bad lock-in equilibria; the first goal of our study is to verify, or falsify, this conjecture.

ACE modeling of boundedly rational agents requires the specification of decision rules (heuristics). Such rules (and their updating mechanisms) can run the gamut from complex to simple. The experimental evidence suggests strongly that people rarely use complex rules. Typically, people employ satisficing behavior, see Simon (1957, 1982). Recent experimental and computational evidence suggests furthermore that relatively simple heuristics fare astonishingly well in a wide variety of environments (e.g., Gigerenzer, Todd & the ABC Group (1999); Todd, Gigerenzer & the ABC Research Group (2001)), rationalizing people's observed boundedly rational behavior. The second goal of our study is the analysis of a minimal set of decision rules that would allow an escape from bad lock-in equilibria.

While our primary interest is theoretical and methodological, it is motivated by issues of predation, corruption, (lack of) property rights enforcement, and their very real consequences, such as underinvestment in education and health services, underinvestment in physical and moral infra-structure, or development traps (for a review of some of the empirical evidence, see Mauro (1995, 1998); Tanzi (1998); Gupta, Davoodi & Tinogaon (2000)). Accordingly, our choice of a benchmark RA RE GE model draws on microeconomic and macroeconomic models of illegal activities. More on our choice of a benchmark below.

On the appropriateness of ACE and a review of some recent literature

Agent-based computational economics (ACE) has emerged as a viable alternative to standard RA RE GE models. Its attractiveness springs first and foremost from the fact that modeling heterogeneity and boundedly rational behavior is easier to accomplish in an ACE environment. ACE, furthermore, allows researchers to study transitional dynamics and the emergence of global behavioral patterns out of simple local interaction rules. In ACE environments, equilibrium is defined as the limit behavior of some learning process. Note that such a conceptualization provides similarly a solution to the equilibrium selection problem so pervasive in the literature on coordination failure and in the class of RA RE GE models that is our reference point. Needless to say, ACE also allows us to do comparative statics exercises. (Not to say that ACE does not have its drawbacks. We will discuss the key problem of ACE modeling, and our solution to it, presently.)

Notable early work in the ACE mode is reviewed by LeBaron (2000) in his insightful discussion of early research. Two recent special issues of *the Journal of Economic Dynamics and Control* and *Computational Economics*, both edited and introduced by Leigh Tesfasion (2001a, 2001b), document the wide range of useful applications that ACE researchers have identified since those path-breaking articles, including the study of efficiency and welfare outcomes in various markets, the evolution of social norms, and the evolution of trading networks. Recent use of genetic algorithms (GA) - an ACE technique that we intend to employ - have produced promising results. For example, Arifovic (1996) successfully employs a GA model to explain persistent fluctuations in exchange rates, an empirical fact observed in actual economies but not yet successfully modeled theoretically. Of particular relevance in the current context is Arifovic (1997), which shows learning as an equilibrium selection device in models with multiple equilibria and with empirically relevant transition dynamics between them.

Other notable work in the ACE mode is Riechmann (1999, 2001). He relates the three components (stochastic operators) of classic GA learning - namely, selection/reproduction, crossover, and mutation - to three characteristics of evolutionary models in economics: namely, in matching order, learning by imitation, communication, and experiment. In essence, Riechmann argues that genetic algorithms are nothing but evolutionary games. This conception is rather useful since a number of experimental economists have recently, with significant success, explored to what extent evolutionary game theory can be usefully employed to explain experimental results. For an early example, see Van Huyck et al. (1995); more recently see Ho, Camerer & Chong (2001), and the literature reviewed therein.

Within the ACE paradigm there are different approaches to modeling the way agents learn about their world. In computational finance, a common way is to look at the agents' action choices, which are typically expressed by a single real number such as the quantity demanded of the risky asset. The search for the optimal quantity is modeled as a genetic algorithm. A complementary approach is the use of "condition-action" classifier systems. Here every agent has a "toolbox" consisting of different forecast, and/or decision, rules which are invoked conditional on the realized state of the economy. In the simplest implementation of the method, the set of rules is fixed as are the parameters specifying the rules (e.g., minimum acceptable quality of a student in Ortmann, Slobodyan & Nordberg (2001)). The mapping from the states to rules is again subject to learning by a genetic algorithm (GA). In other words, the agents are trying to learn which decision rule is the best in any given state of the world. For exposition of the idea and its implementation in computational finance, see LeBaron et al.(1999).

The ACE approach has been criticized, in our view rightly so, for the large number of adjustable parameters. Parameter choice has to be made, for example, in the determination of the support of the error terms of the stochastic reproduction, crossover, and mutations operators, or the frequency of the crossover (for a good discussion of some of these issues see Mitchell 1996, chapter 5). Not surprisingly, computational results are often dependent on the parameter choice.

Details of the planned work

We are interested in understanding economies with complementarities. Such economies might require economic agents to coordinate on effort levels because complementarities often lead to multiple equilibria (see Cooper (1999) for a recent authoritative survey of theoretical and experimental work). Under certain conditions, these equilibria can be Pareto-ranked and the economy faces a problem of selecting the most efficient one. Alternatively, one may ask if it is possible for an economy to escape from a Pareto-inferior (sometimes called bad lock-in) equilibrium. Economies with complementarities have been extensively used in modeling development traps and in attempts to explain persistent differences in levels and growth rates of economic development among different countries (see, for example, Azariadis (1996), or Hoff (2000)). The question of equilibrium selection in such situations has important policy implications.

To anchor our study, we will take as point of departure one of the available RA RE GE models of economies with complementarities. Our current favorite is a simple but insightful model by Dabla-Norris & Freeman (1999). Following the lead of earlier authors such as Murphy, Shleifer & Vishny (1993), Tirole (1996), Andvig & Moene (1990), and Lui (1986), but endogenizing the determination of effort, Dabla-Norris &

Freeman (DNF from here on) built a RA RE GE model of the interaction between productive economic activity, expropriation, and its deterrence. Enforcement of property rights is needed to deter "predators" (corrupt bureaucrats, managers, workers, etc.) and encourage productive market activity. The degree of enforcement is chosen by optimizing agents interested in protecting the results of their productive economic activity.

One of the appealing features of this model is the existence of two distinct equilibria (and their basins of attraction), one of which is characterized by enforcement of property rights (and/or, maybe, a corresponding moral foundation of the economy as conceptualized in Smith 1759, and Binmore 1994, 1997), a low level of expropriation, and a high level of economic activity, while the other is characterized by a lack of enforcement with the obvious consequences.

Our work will proceed in three stages: During the preliminary stage we will implement a GA model that allows us to "experimentally" link the predictions of the DNF model to our parameterizations and definitions of reproduction ("imitation"), crossover ("communication"), and mutation ("experimentation"). Then we will systematically explore the sensitivity of both the good and the bad lock-in equilibrium to parameter changes in the imitation, communication, and experimentation operators. This preliminary step is an important benchmarking exercise that we undertake to address the already mentioned standard critique of GA modeling, the large number of adjustable parameters.

Specifically, we are interested in the sets of initial conditions (including the set of beliefs that the agents are allowed to hold) that define the basins of attraction of the two equilibria. How "large" is the set of initial conditions that defines the basin of attraction of the Pareto-superior equilibrium, and, therefore, how likely is convergence to it? A related issue, and <u>the first goal of our project,</u> is the study of economies that have drifted to the Pareto-inferior equilibrium (poverty trap). Will the introduction of a small number of mutants with different beliefs and/or learning rules allow the economy to escape from the poverty trap?,

As mentioned, ACE modeling of boundedly rational agents requires the specification of decision rules (heuristics). The <u>second major goal of our project</u> is therefore the analysis of a minimal set of decision rules that would allow an escape from a bad lock-in equilibrium. Specifically, we want to run a "contest" between simple heuristics rules, similar to those described in Gigerenzer, Todd & the ABC Research Group (1999), and more sophisticated predictors, probably based on statistical inference. As already mentioned in the review of recent literature, simple heuristics seem to be the rules that actual human beings are following in decision making under certain conditions, for example under time constraints. However, they are not "rational" in the sense that agents who employ them do not take into account all the available information.

In the DNF model that we are likely to use as our point of departure, predators and producers face different decisions. Producers have to decide on the division of time between production and leisure, and on amount of resources allocated to law enforcement. Producers face a two-dimensional continuum of decisions. It seems unlikely that a sensible simple heuristics is possible in this situation. Therefore, producers can have two numbers as their decision rules, share of time devoted to production and the share of output allocated to law enforcement. Predators, in contrast, have to make a simple Yes/No decision, to steal or not to steal, and have two basic groups of decision rules. The first includes a simple heuristics that says, "refrain from stealing if caught last time". Alternatively, it may include a version of "Take the Best", where every predator keeps track of several state variables, such as proportion of predators caught, its period-to-period change, level of production, etc., and records the correlation between those states and a binary variable "caught/not caught". The state variable with highest past predictive power is selected to predict the probability of being caught this period. The second group of decision rules might use a probit regression of past experience on past states to forecast the current probability of being caught. The decision rules are fixed and are not included in the GA learning. Every individual predator will learn if one conditional-forecast, say "if no significant change in the production level, steal only if not caught last time; in case of rapid changes use probit regression", is better than the other, "steal only if not caught last time" or "always use probit regression" or "never steal".

We are specifically interested in the simplest set of rules available to the agents that could induce convergence to the REE. As mentioned, ACE suffers from a large number of adjustable parameters, and the results are often dependent on the parameter choice. Finding the most parsimonious set of rules will help to create the simplest possible learning environment, which could be applied to other models with multiple equilibria, and thus allow one to disentangle the economic dynamics related to the existence of multiple equilibria from the behavior caused by the evolution of decision rules.

Fit of the Proposed Project with Competition Goals

The project proposed here deals with equilibrium selection in models with multiple steady states or equilibria, and evolution of decision rules which could be considered as social norms. Modeling persistent poverty as a Pareto-inferior equilibrium is one of the most promising research paradigms in development studies.

Understanding of social norms is important in designing policy advice on private sector development, because norms that were well suited to one state of the society might come into conflict with attempts to move it into some other state. If this is the case, it is important to know how stable such obsolete norms are, and what is the minimal external shock that can bring their downfall. Both poverty and private sector development are important research areas of the sponsor agency (World Bank/GDN).

Authors' Qualifications

Ortmann has studied simple heuristics (see his contributions to Gigerenzer, Todd, & the ABC Research Group (1999), Todd, Gigerenzer & the ABC Research Group (2001)) and the evolution of conventions and norms (e.g., Van Huyck et al. (1995) and Blume & Ortmann (2000)). Other areas of research are the internal organization of colleges and universities, their strategic interaction, and the emergence of for-profit providers in post-secondary education (for his various publications in this area see his CV). He is currently involved in a GDN project that employs genetic algorithms to study whether, and under what conditions, e-learning might successfully address the human capital mismatch problem in transition economies.

Slobodyan's Ph.D. thesis dealt with dynamic general equilibrium macro models with multiple steady states and global evolution of economies trapped in a low-growth state. In this context, he studied the possibility of escaping development traps through self-fulfilling beliefs, and attempted to establish how the magnitude of the belief shock influences the probability and expected time of escape.

Ortmann and Slobodyan are currently involved in a joint project (with a former student of Ortmann) in which they explore by way of a sophisticated genetic algorithm model the evolution of post-secondary education in the USA.

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Appendix 2: Detailed curricula vitae of principal investigators

Appendix 3: Budget proposal and time table

Preliminary Phase: ***January - May 2002***

Preliminary Step of the Detailed Plan of Work.

Modeling Phase One: ***May - August 2002***

Step One [goal One] of the Detailed Plan of Work.

Modeling Phase Two (concurrent with writing phase): ***July 2002 - December 2002***

Step Two [goal Two] of the Detailed Plan of Work.

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