ISLAMIC ECONOMICS IN A COMPLEX WORLD

Explorations in Agent-based Simulation

Sami Al-Suwailem

1429H – 2008

King Fahad National Library Cataloging-in-Publication Data

Al-Suwailem, Sami

Islamic Economics in a Complex World Explorations in Agent-based Simulation/Sami Al-Suwailem

Jeddah, 2008

151 p; 24 × 17 cm

ISBN: 978-9960-32-182-0

1- Islamic Economy	I- Title
330.121 dc	1429/4112

L.D. no. 1429/4112

ISBN: 978-9960-32-182-0

بسم الله الرحمن الرحيم

TABLE OF CONTENTS

FOREWORD

Research in Islamic Economics started more than 30 years ago. Over the years, considerable efforts have been spent to tackle the main questions faced by researchers in this area: Why and how. The first question is normative: What rationalizes Islamic principles and rules governing economic behavior? The second is positive: How the system behaves with and without these rules?

The two questions are interlinked and cannot be answered separately. To suitably describe how the economy behaves implies how it should be regulated. Hence, without a good positive theory, a normative theory cannot be reasonably justified.

This paper by Br. Sami Al-Suwailem attempts to provide a step in this direction. It suggests a certain model of economic behavior, based on which it argues that certain Islamic rules can be rationalized. On both accounts, the paper builds on existing research. In essence, the paper does not develop a new theory or methodology. It simply applies some recent developments in complexity theory and agent-based simulation to matters related to Islamic rules of financing. Yet the results appear to be promising. This might be a good area to be explored by researchers seeking to analyze and contribute to the theory of Islamic economics.

I pray that Allah (*s.w.t*) accepts this work and make it a valuable contribution to our understanding of the wisdom of Islamic economic principles.

Bashir Ali Khallat
Acting Director, IRTI

ABSTRACT

This paper introduces to researchers in Islamic economics a framework and a research tool. The framework is complexity theory, and the tool is agent-based simulation. The paper surveys this rapidly growing field, and how this alternative framework relates to the Neoclassical paradigm. The paper argues that the alternative framework and research technique might be more suitable to Islamic economics than their conventional counterparts. In addition to many examples frequently cited in the literature, the paper provides an application to Islamic economics that shows how *riba*, markup finance, and charity affect economic performance.

I

INTRODUCTION

For a long time, researchers in Islamic economics were looking for a laboratory to examine how Islamic rules impact economic performance. The lack of a suitable tool was not independent from the approach taken by Neoclassical theory to economic analysis. The Neoclassical approach by nature favored a certain set of techniques that served its purposes. The apparent incompatibility of both with many aspects of Islamic economics, therefore, is not surprising.

The recent developments in complexity theory and agent-based simulation represent an important departure from the Neoclassical framework. Although this departure is yet to be endorsed by established schools, it is essential for economists to follow these developments in their early stages to be able to evaluate them with a reasonable degree of freedom. More important, these developments appear closer to the Islamic framework of economic behavior. If this proves to be true, research in Islamic economics would greatly benefit from these developments.

The "discontent" with the Neoclassical framework is not limited to Islamic economics. Titles like *The End of Economics* (Perelman, 1996), *The Changing Face of Economics* (Colander et al., 2003), and *Debunking Economics* (Keen, 2004), reflect an increasing realization of the defects of the mainstream approach. It is hoped that a consistent framework would emerge that can successfully address these deficiencies.

The remainder of the paper is organized as follows:

Section II summarizes the basic features of the Neoclassical approach, complexity theory, and how they compare to each other.

Section III discusses characteristics of complex systems and how they can be modeled analytically. It also introduces agent-based simulation and its relevance to economic research.

Section IV applies some features of complex systems to evaluate Islamic economic principles regarding *riba*, markup financing, and charity, using agent-based simulation.

The Conclusion is given in section V.

Overview

The main drawback of the Neoclassical theory of economics is its separation of outcomes from processes. Choice sets are determined without accounting for learning and discovery, which are essential to know the choice set in the first place. Accordingly, innovations and entrepreneurship are excluded from the theory at the outset. Utility is assumed independent from how a decision is reached, thus values and ethics are assumed out of the theory. Competition is postulated without accounting for imitation and relative behavior that lead to it. The result is an inherently static and fixed world where agents are isolated calculators, rather than human beings with emotions, values, and social relations. Not surprisingly, economics became a "dismal science," since, in such a world, life becomes meaningless.

From Islamic economics point of view, economic theory cannot be separated from moral and social dimensions. Hence, Neoclassical theory was not the best starting point for researchers in this field (and many others for that matter). While there were many competing schools of economic thought, apparently few were able to provide an alternative paradigm with productive analytical tools. The parallel development of Complexity theory and agent-based simulation in the late eighties and early nineties provided a very good moment for the birth of an alternative approach. Each reinforced the other, and the field is now growing almost exponentially. It is a very good time for researchers in Islamic economics to consider a potentially fruitful theory and a very productive tool that reasonably suite their objectives.

The paper relies on Complexity theory to extend the traditional consumption function to include consumption of close neighbors, then analyze the resulting behavior using agent-based simulation. Although the extension seems limited and innocent, the results were dramatic. With the new model, different modes of financing have vastly different consequences. It became very clear from the simulation how interest-based lending causes acute instabilities and loss of wealth, in contrast to markup financing that achieved much better stability and efficiency. The value of charity and donations also became more visible, as *both* donors and receivers are better off with charity. The model can be extended in several dimensions, some of them are pointed out at the end of the paper.

Acknowledgments

When I was planning this project in early 2005, my intention was merely to survey the growing field of agent-based simulation. My colleagues at IRTI, however, insisted that there must be a "solid" application of the new tool, so that its value becomes more visible to researchers and practitioners. As I was digging to find one, I was surprised to realize that the basic structure of natural complex systems might have dramatic consequences when applied to economic behavior. While the idea of relative behavior is not new, its implications from Islamic-economics point of view, for me at least, was totally unexpected. Since it was a new domain, I had to learn a lot from many people in different areas.

In particular, I thank Robert H. Frank, Cornell University, for helpful email correspondence. Abbas Mirakhor, formerly at the International Monetary Fund, and Jacob Gyntelberg, Bank of International Settlement, carefully read the paper and provided insightful comments. I appreciate their time and effort. K. Vela

Velupillai, University of Trento, Italy, was very helpful through email corresponding, and I am especially thankful to him. I had insightful and stimulating discussions with my colleagues at IRTI: M. Umer Chapra, M. Fahim Khan, Munawar Iqbal, Habib Ahmad, Tariqullah Khan, and Salman Syed Ali. Three anonymous referees provided constructive comments. Participants of the NetLogo user group were very helpful and supportive. I am appreciative to them all. It goes without saying that none of those scholars and professionals is responsible in any manner for the claims and propositions included in this paper.

My colleagues at IDB Library provided immense help and support. I'd like to thank Dr. Tijani Ben Dhia, Mamoun Abdul Karim, Ibrahim Gharbi, and all the Library staff for their kind assistance.

I owe a great deal of debt to my family, who sacrificed this time much more than they usually do for other works. Without their warm and affectionate support, it would have been a very unpleasant journey. The only debt that exceeds theirs is the one I owe to my late mother, may Allah (*s.w.t*) bless her with His mercy. Above and over what a son gets from a caring mother, her support during the early stages of the project, when I was suffering both illness and loneliness, was immeasurable by all standards. I have no way to repay these debts except by submitting to Allah, the Merciful, to forgive and gratify my parents and my family for all what they have unconditionally granted me over the years.

Whatever achievement made in this project, it is due primarily and ultimately to the endless grace and mercy of Allah (*s.w.t*). All errors and mistakes are my sole responsibility, for which I seek His mercy and forgiveness.

II
The Neoclassical Paradigm

The Neoclassical theory of economics is an elegant logical system that represents markets and economic agents in a coherent and consistent manner. The theory, however, assumes a certain worldview not explicitly stated in conventional references.

Here we will take a quick look at the most important assumptions underlying Neoclassical theory (NT), and how they compare to those of Complexity Theory (CT). Although CT did not originate within the economics profession, we shall see that its approach to social systems contrasts sharply to that of NT, and this leads to important departures in economic analysis.

II.1 Essential Features of NT

The underlying assumption of NT is that the world, in principle, is a clockwork that has been made and completed in the past (few billion years ago), and it has been ticking since, and will continue to do so indefinitely. This is usually referred to as the Newtonian view, where all objects follow the same laws of motion (Dopfer, 2005). It is attributed to the strong historical influence of 19th century physics on economics (Mirowski, 1989; Galbraith, 1994; Smith and Foley, 2005). The world, accordingly, is basically fixed and complete. Change occurs only repetitively and mechanically. The economy thus is a gigantic machine that works mechanistically (Arthur, 1999). This view is reflected mainly in the following aspects of NT:

Choice Set

In consumer theory, the "consumption set" represents all possible combinations of commodities the consumer can conceive of (e.g. Jehle, 1991 pp. 116-117). The set is predetermined and assumed to be convex and closed. The consumer's problem then is to choose from this set the "best" bundle; i.e. the one that maximizes his utility function.

Similarly, in theory of the firm, the "production possibilities set" is the set of all possible combinations of inputs and outputs. Again, the set is assumed to be closed and convex (Jehle, 1991 p. 218; Varian, 1992 pp. 7-9), and the firm's problem is to choose from this set the production plan that maximizes its profits.

In this world, it becomes apparent that no room exists for novelty and surprise. Since all possibilities are predetermined, well defined and perfectly known, discovery and innovation are absent from the picture. Nobel laureate Kenneth Arrow (1988) observes that "Innovations, almost by definition, are one of the least analyzed parts of economics, in spite of the verifiable fact that they have contributed more to per capita economic growth than any other factor." (p. 281.) Accordingly, research and development (R&D) appears irrelevant, since all possibilities are known a priori (Luna, 2005). For the same reason, entrepreneurship appears to be absent from standard Neoclassical theory.

New York University economist William Baumol (1993) points that, for fifty years, he was particularly puzzled why formal economic theory has so little to say about entrepreneurs, where "virtually all theoretical firms are entrepreneur-less." (p. 12.) He writes (p. 13):

> Explicitly or implicitly, the firm is taken to perform a mathematical calculation which yields optimal (i.e. profit-maximizing) values for all of its decision variables ... There matters rest, forever or until exogenous forces lead to an autonomous change in the environment. Until [then], the firm is taken to replicate precisely its previous decisions, day after day, year after year.
>
> Clearly, the entrepreneur has been read out of the model. There is no room for enterprise or initiative. The management group becomes a passive calculator that reacts mechanically to changes imposed on it by fortuitous external developments over which it does not exert ... any influence. One hears of no clever ruses, ingenious schemes, valuable innovations, or any of the other stuff of which outstanding entrepreneurship is made; one does not hear of them because there is no way in which they can fit into the formal optimization model.

According to Freeman (1998), "empirical studies of innovations and their diffusion have provided mounting evidence that mainstream neoclassical theories of firm behavior, competition, international trade and consumer behavior, are seriously deficient in their assumptions and conclusions" (p. 860).

Innovation not only affects production, it also affects consumption. Innovation introduces new goods and services that were not included in the consumption set. Accordingly, arguments in the utility function increase, which may upset existing preferences (Martens, 2000 p. 7). This implies that preferences must be at least partially endogenous to account for new goods, and not exogenously fixed as NT assumes.

One can see how far the NT mechanical worldview impacts its behavioral assumptions, and how these assumptions are inconsistent with the real world.

Convexity

If we go deeper into the assumptions of NT, it is the assumption of convexity that by design excludes novelty and creativity. A set is convex if any linear (weighted average) combination of two points in the set results in a point that also belongs to the set. This is one of the most important conditions in economic analysis (Debreu, 1959 p. 23, 1991; Takayama, 1993 p. 53; Newman, 1998). It is not difficult to see that the world is not convex. While hydrogen and oxygen are both gases, water, which is a combination of the two, is liquid, not gas. Preferences are likely to be non-convex. One might be indifferent between tea and coffee, but is unlikely to enjoy a mixture of the two

(Hildenbrand and Kirman, 1988 p. 65). In other words, the world is nonlinear, so a combination of two objects does not necessarily preserve their properties.

Discoveries and breakthroughs are achieved by finding combinations that produce very different outcomes from their constituents (Hargadon, 2003). If all combinations still belong to the same set, there would be no room for creativity. Convexity therefore excludes novelty from the outset.

Convexity also excludes increasing returns to scale (Debreu, 1959, p. 41), which can produce economic effects starkly different from the world envisioned by NT, as surveyed by Heal (1998). Convexity thus becomes inconsistent with one of the most established economic facts of modern times: Specialization improves productivity and return much more than it costs. This is the fact upon which division of labor and production lines have been developed, which in turn were instrumental for the industrial advancement in the West. This fact is excluded by convexity, since an average of two extremes is assumed to be just as good, or even better under strict convexity. Specialization by definition excludes middle, half-way skills. In a convex world, therefore, specialization simply doesn't pay.

Decreasing returns exclude the possibility of positive feedback in economic processes. Economic processes are assumed to dampen out and reach equilibrium smoothly. But we know that the world is much different than that. If more consumers use mobile phones, they become more useful, which makes more consumers use them. Network structure creates self-reinforcing effects (e.g. Barabási, 2003), which are excluded by convexity (Arthur, 1988). Further, science is abundant with examples of positive feedback mechanisms (e.g. Gleick, 1987). In other words, convexity is inconsistent with both natural and social systems. According to Paul Samuelson (1947) "the fine garments [of NT] sometimes achieved fit only by chopping off some real arms and legs. The theory of cones, polyhedra, and convex sets made possible 'elementary' theorems and lemmas. But they seduced economists away from the phenomena of increasing returns to scale and nonconvex technology that lie at the heart of oligopoly problems and many real-world maximizing assignments" (p. xix; cited by Auyang, 1998 p. 140).

We shall see later how these two features, novelty and positive feedback, distinguish Complexity Theory from the Neoclassical approach.

Uncertainty

Uncertainty reveals to what extent NT can be unrealistic. Debreu (1959) points to this when addressing "questions left unanswered" in his *Theory of Value*: "One may stress here the certainty assumption made, …, according to which every producer knows his future production possibilities and every consumer knows his future consumption possibilities … This strong assumption is weakened, albeit insufficiently, in the last chapter." (p. xi.) The extension to the uncertainty case is made by listing all possible future states of the world, define commodities by their date or event, and have all properties of a certain economy readily apply (Debreu, 1959, ch. 7). Thus uncertainty is resolved simply by adding another subscript indicating the state of the world. Alternatively, the von Neumann and Morgenstern approach can be adopted, whereby future commodities are replaced by gambles or lotteries, listing each commodity with its probability. If objective probabilities are unknown, subjective ones are used instead, and the results are basically the same (Takayama, 1993, p. 258).

Again, all possible future states of the world are fixed and predetermined. Novelty and creativity are inherently absent. This clearly contradicts the history of scientific discovery that fueled the enormous growth and advancements in the West. No wonder that philosophers of science hold a different view.

Karl Popper, a prominent philosopher of science, argues that, "for strictly logical reasons, it is impossible for us to predict the future course of history." The reasoning Popper provides is that history is strongly influenced by the growth of human knowledge. But we cannot predict the future of our scientific knowledge; if we are able to do so, then that knowledge belongs to our knowledge today, not to the future. According to Popper, "no scientific predictor –whether a human scientist or a calculating machine– can possibly predict, by scientific methods, its own future results." Consequently, we cannot predict the future course of human history (Popper, 1957 pp. ix-x).

This means that the growth of human knowledge makes it impossible for us to list all possible future states of the world. Whatever states we list today will change as our knowledge grows. Superconductivity, for example, was simply inconceivable before it was discovered (Strogatz, 2003 p. 128). From our human point of view, therefore, the set of possible states cannot be fixed or predetermined.

Note that it is not that the probabilities of future states are unknown, nor that the number of possible states is very large or infinite. Rather, it is the case where the states themselves are not pre-defined in the first place where real uncertainty arises. The choice set therefore is not pre-determined, and even if it is so in the short run, it could change dramatically by our own actions or by interactions with other agents.

Self-Referential Loop

These interactions, in turn, are influenced by agents' perceptions of future possibilities, as well as their perceptions of each other's perceptions. These perceptions of perceptions of perceptions, etc., need not converge, and therefore the set of possible future states may not be predictable at all (Koppl and Rosser, 2002; Foster and Young, 2001). The economic landscape thus becomes an outcome of mutual perceptions and expectations. Trying to predict this economy implies agents predicting their own predictions, leading to a self-referential loop. It becomes a "logical indeterminacy" that represents a "logical hole in standard economic theory" (Arthur, 1999 pp. 36-37). Nobel laureate Herbert Simon (1978, p. 9) describes this problem as "the permanent and ineradicable scandal of economic theory." He also points that "the whole concept of rationality became irremediably ill-defined when the possibility of outguessing was introduced," and that a different framework and methodology must be adopted to explain behavior in these conditions (cited in Rubinstein, 1998 p. 188).

Integrability, Path Dependence, and Non-economic Factors

NT assumes agents make their choices solely based on economic factors, namely prices and income. While it is clear that choice is influenced by a myriad of other factors, social and psychological, these factors are subsumed into the market and their impact is reflected into market signals. This is "methodological individualism," also described as "independent-individual models" (Auyang, 1998 ch. 4).

With this view, economic choice is determined purely by market signals. From economic choices, preferences, under NT assumptions, can be inferred. This is the well known "integrability" condition (e.g. Varian, 1992 pp. 125-131; Silberberg, 1990 pp. 373-381); namely, demand functions can be integrated to recover the underlying preference function if standard NT requirements are satisfied (symmetry and negative semi-definiteness of the substitution matrix). Integrability implies that the process of choice, or how preferences are translated into actions, is ignored (Mirowski, 1989 p. 371). Accordingly, choice is *path-independent* – i.e. it doesn't matter how one arrives at choosing a given bundle of commodities, or what were the initial conditions or past experiences; utility or satisfaction is the same regardless. According to mathematical economist Akira Takayama (1993, pp. 632-633), path-independence follows almost trivially from the existence of the Neoclassical utility function; conversely, path-independence requires integrability, which in turn ensures the recoverability of a utility function.

This approach makes it irrelevant how one earns his income, whether by hard work or by blind luck; by honesty or by cheating. Utility is insensitive to these aspects. Values and ethics therefore have no place in NT; a result that many economists find difficult to accept (e.g. Ben-Ner and Putterman, 1998).

Further, with increasing returns and positive feedback mechanisms, past events and initial conditions may have significant impact on present decisions. The fact that "history matters" clearly indicates that many fundamental economic processes are path-dependent (David, 2005; Puffert, 2003). In addition, conditions required for integrability are poorly supported by empirical studies (e.g. Deaton and Muelbauer, 1980 ch. 3). Experimental tests (e.g. Camerer et al., 2004) consistently show that choice can be influenced by endowment, loss aversion, framing, and similar context-sensitive factors. This makes choice *reference-dependent*, which invalidates integrability conditions (Hands, 2006). Thus the "inhumane" and "immoral" perspective of NT is simply inconsistent with the reality.

Methodology

Given the fixed, predetermined, and mechanistic worldview, it is not surprising that NT adopts a deductive approach to economic analysis. Since the choice set is given, the problem is not to explore or discover new options; it is simply to choose *the* optimal option from the given set.

Axiomatic formal systems accordingly became a landmark for economic theorizing, from which characterizations of economic choices are derived and established (see e.g. Weintraub, 2002). The best way to analyze a complete world is to use a complete formal system. Worldview and methodology therefore are in perfect harmony.

Unfortunately, the axiomatic approach, as such, has its own limitations. Renowned mathematician Kurt Gödel showed, in 1931, how an axiomatic system must be either "incomplete" or "inconsistent," and cannot be both consistent and complete. He shows that, in an axiomatic system, a statement can be constructed that reads like:

"This statement cannot be proven," akin to the liar's paradox. If this statement is proven from within the system, the contradiction renders the system inconsistent. If not, it becomes true that it cannot be proven within the system, which makes the system incomplete. That is, the axiomatic system cannot contain all the truth about the system itself (Penrose, 1989; Goldstein, 2005). Furthermore, Chaitin (1998, 2002) argues that there are infinite irreducible mathematical truths that cannot be deduced from preliminary axioms.

So despite the elegance of equilibrium economic models of NT, not all economic properties of these models could be characterized deductively. Truth extends beyond the reach of axiomatic deduction, and it might go to a very far extent. This is not to say that axiomatic deduction is not useful or important; it certainly is. But to say that it is useful is one thing; and to consider it as the ideal approach for economic analysis, is totally another.

Computability

Even if axiomatic models are valid, they are not always "computable." That is, if equilibrium prices and allocations exist, that doesn't necessarily guarantee that we can systematically compute these prices and allocations. A function is computable if there exists a procedure (or an algorithm) for calculating the value of the function. An algorithmically non-computable function however can be solved by trial and error, or by induction (Markose, 2002).

Lewis (1992) proves that many key economic concepts, like Walrasian general equilibria and many aspects of game theory, are not effectively computable, i.e. there exists no algorithm for computing the solution to these problems in a finite time. Mathematical economist K. Velupillai (2000, 2008) shows that rational choice, understood as maximizing choice, is undecidable; i.e. no algorithm exists that can solve the decision problem.

Rust (1997) shows that even if we are looking for approximate, rather than exact, solutions, these problems are "computationally intractable." That is, cost of computation increases exponentially with the dimension of the problem. In general equilibrium models, dimension represents the number of goods in the economy, which can easily run in the hundreds of thousands. As the dimension increases, the number of calculations quickly grows so large that "the world's fastest supercomputers would be unable to find an approximate solution to the problem in any reasonable period of time" (p. 10). Furthermore, he argues that these limitations represent lower bounds on computing time using *any* possible algorithm, regardless of whether or not these algorithms have been discovered (see also Axtell, 2005).

Velupillai (2005*a*, 2005*b*) argues that numbers used in real life are predominantly rational numbers (integers or ratios of integers). Accordingly, economic relations are represented by "Diophantine equations": polynomials whose solutions are rational numbers. However, solutions to Diophantine equations are not guaranteed to exist (see also Prasad, 1991). Accordingly, economic agents frequently face unsolvable Diophantine decision problems. They are hence forced to limit their choices to solvable and decidable problems. This situation arises not because agents' rationality is bounded; it is the nature of the world they live in (Velupillai, 2005*a*, p. 173).

The view that the world is discrete rather than continuous is not new. It started with quantum theory and quantum mechanics, and many prominent physicists, like Albert Einstein and Roger Penrose, are pointing to the viability of this direction (cited in Velupillai, 2005*a*, pp. 191-192; see also Fredkin, 2000).

Luna (2005) argues that the production possibility set is generally not computable. That is, there is no procedure that can identify all processes belonging to the feasible production set. Further, there is no general procedure that can be applied automatically to decide wither a production process has predetermined properties, e.g. quasi-concave and increasing in inputs. Accordingly, there is no alternative for investing resources to investigate and evaluate each candidate production process. In this worldview, R&D becomes of necessity, and discovery and innovation natural consequences.

Aragones et al. (2005) examine the problem of selecting a small set of variables from a given choice set for linear regression in order to obtain a certain value of R^2. They find that this problem is computationally "hard" (called NP-complete in computer science). That is, at present, no polynomial algorithm is known to solve it. Hence, it is quite possible that one comes with a different set of variables from the same choice set with higher R^2 that others couldn't find. This result explains why people might be surprised to find a simple solution for a given problem without any new information. The complexity of the choice set, therefore, allows for surprises, discoveries, and creativity. The authors call this sort of learning "fact-free learning" to indicate new insights without new information. This essential feature is absent from a Neoclassical world, since all choice sets are defined and known a priori, as previously pointed out. In fact, in such a world, learning itself becomes a foreign concept (Rothschild, 2000; see also Dosi et al., 2005). According to Velupillai (2007), constructing learning processes in a Neoclassical world is "either provably impossible or formally intractable" (p. 486). This problem arises from separating equilibrium concepts from finding methods to solve for it (p. 470). Velupillai therefore calls for mathematical techniques that combine simultaneously the notion of equilibrium and algorithms – hence dynamics – for solving for it (p. 469).

Homogeneity and Reversibility

The purely deductive approach resulted in several important limitations of NT. By design, deduction focuses on abstractions and generalities, and ignores differences and heterogeneities. This is most clearly reflected in the classical assumptions of perfect competition: a homogenous product and an impersonal market consisting of atomic units. Further, agents are assumed to have identical information sets and identical models to interpret and use this information.

This perspective neglects individual differences and personal interactions. Not only this escapes the human aspect of economic behavior, it more importantly ignores diversity and heterogeneity of agents and products. This is remarkable since heterogeneity is what derives gains from trade, which comprises the essence of the market, as Arrow (1986, pp. 205, 206) rightly points out. Aggregate behavior cannot be considered as simply the behavior of an average or representative agent (Kirman, 1992). If the world is nonlinear, then aggregate properties of the economy are not reducible to those of its constituents.

When homogeneity is extended over time, the system becomes reversible, i.e. it can move from one state to another and back smoothly. This implies that the system is inherently in equilibrium and any deviations can be reversed. The economy therefore is stationary or ergodic, i.e. cannot persistently deviate from its true average. However, reversibility in general is inconsistent with the laws of thermodynamics, and time moves in one direction (Prigogine, 1997). Further, economic processes, like investment, are largely irreversible (Dixit and Pindyck, 1994; Georgescu-Roegen, 1971). The human history is certainly non-ergodic, as North (2005, p. 19) clearly states. In fact, the universe is essentially non-ergodic (Kauffman, 2000). Accordingly, the economy cannot be considered as an equilibrium system (Foley, 2003, ch. 1).

II.2 The Complexity Paradigm

The word "complexity" might be somehow misleading. We all know that the world is complex, in one way or another. But Complexity Theory (CT) has much to offer other than saying that the world is complex.

CT views the world more as a living organism than as a machine. (Interestingly, Newton himself didn't see the world as a clock but rather as an evolving being. Thus "Newton was not Newtonian." Prigogine, 2005, p. 63.) Since the universe is expanding (Hawking, 1996 ch. 3), it cannot be a fixed structure. The landscape is continuously developing and changing. The word "complexity" also points to a deeper view: The world is not linear as it is assumed in the traditional view. That is, the behavior of a system cannot be reduced to the behavior of its components. "The whole is greater than the sum." Thus the degree of complexity of the system is not uniform across the levels of the system. Complexity of the system at the macroscopic level is much higher than that at the microscopic level. Such systems are highly decentralized, and they form their macro-structure and behavior through large number of local interactions of agents. More on complex systems is presented in the next section.

This worldview translates into important features of the modeling approach.

Choice Set

Choice sets are not closed or fixed. They are unbounded, nonconvex, and continuously changing. Agents do not have complete knowledge of the boundaries and components of the set. The sets are too complex to be predetermined completely.

Further, the choice sets are changing and reacting to agents' past choices. Whenever an opportunity is seized, a different set of opportunities is opened up. The system is characterized by perpetual novelty (Holland, 1988). Discovery, creativity, and entrepreneurship, therefore become at the core of the system, not an alien extension struggling to find a place in the theory.

Decision Rule

In a fixed and convex world, optimization is the suitable choice rule. All one needs is to find the option that maximizes the objective function, and choose accordingly. In this regard, economic agents are undistinguished from calculating machines. According to Nobel laureate Amartya Sen (1997), "The formulation of maximizing behavior in economics paralleled the modeling in physics and related disciplines. But maximizing behavior differs from non-volitional maximization because of the fundamental relevance of the act of choice, which has to be placed in a central position in analyzing maximizing behavior." (p. 745.) Further, since optimization requires convexity (Newman, 1998), if the choice set is nonconvex, optimization cannot be performed. Besides, if an agent is able to maximize at one stage, the landscape might change whereby he might find himself at a minimum rather than a maximum.

The relevant decision rule in a nonconvex environment therefore is not maximization, but *adaptation*. Adaptation describes the *process* through which choice is made, rather than mere maximization. Because of the nature of the environment, learning, exploration and discovery become inseparable from the choice rule. Accordingly, adaptation includes the following steps:

1. Collect available information on the choice set.
2. Construct a model of the environment.
3. Find a "satisfactory" choice.
4. After choice is made, update the information, revise the model accordingly, and recalculate the choice.

The difference between maximization and adaptation is related to the difference between "substantive rationality" and "procedural rationality" (Simon, 1978, 1986). Substantive rationality relates to the result or outcome of choice, not the act or process of choice. It assumes a perfect match between the choice set and agent's perception of it. In this case rationality means simply calculating the maximizing choice. However, if this match is broken, as Simon argues, then rationality must include the process through which the agent perceives the world. In this case one cannot reach *the* maximum value; rather, the agent chooses based on "satisficing," i.e. choosing a satisfactory option, but not necessarily the maximum one. Since the choice set is complex, an agent will never be able to find the maximum; the alternative is to find a satisfactory choice. Since humans have a limited computational power (i.e. boundedly rational, using Simon's phrase), they will not be able to find optimal choices from a complex set.

Even if agents enjoy the power of super-computers, this will not be sufficient to compute optimal choices in a discrete, Diophantine economy, as Velupillai (2005*a*, p. 173) points out. If the environment is determined by mutual predictions of agents, furthermore, the self-referential problem will make the set simply undefined. Satisficing therefore becomes relevant not only because agents are less capable, but also because the choice set is not well defined in the first place.

In a complex world, agents aim at improving their performance but not necessarily achieving maximum performance in a given environment. They maintain the flexibility to operate and progress in different environments. Maximization would produce a better performance in a fixed environment, but performance becomes poor as the environment changes. This is the same problem of over-fitting leading to poor predictions. Good predictors are less fitted to a given data set (Gigerenzer et al., 1999 p. 19). Maximization excels at exploiting a given environment. Adaptation excels at balancing exploitation *and* exploration of new environments. Learning and discovery, therefore, are embedded from the beginning in the decision process.

Adaptation is more suitable when agents interact in a coherent whole system (Arthur, in Waldrop, 1992 p. 333). As agents self-organize to form the whole system, whatever decision made by one is reflected back to it through the system. Thus optimization, in the sense that each agent maximizes his payoffs against other agents, doesn't really become optimal. In reality, agents co-adapt to each other as the system evolves. Within this framework, adaptation reaches a balance between cooperation and competition. Maximization assumes agents to compete against each other. Adaptation assumes that agents have complex relationships, and it cannot be viewed only through competition. Adaptation, therefore, allows for cooperation through viewing the economy as a whole system developing and evolving into increasingly uncertain domains. In this framework, agents are better off co-adapting rather than maximizing against each other.

Methodology

Given this worldview, deduction is not the most suitable approach for analysis. In an uncertain world with perpetual novelty and creativity, *induction* becomes of great importance.

Studies in modern psychology show that humans only moderately reason using abstract deductive logic (Holland et al., 1986 ch. 9). But human mind is superb in recognizing patterns and regularities in complex environments. These patterns then are stored in memory as simplified mental models of the environment, and used to formulate simple decision rules whenever such patterns are recognized.

But since the environment is constantly changing, patterns change and new patterns are formed. Agents therefore have to update and adjust their mental models to cope with new patterns. To recognize the new pattern, several hypotheses are postulated, and feedback from the environment is used to strengthen or weaken belief in these hypotheses. Some hypotheses may be discarded and some may be replaced with new ones, as needed. Such behavior is inductive (Arthur, 1994). Lucas (1986) describes such behavior as adaptive. But Lucas argues that adaptation would lead eventually to the optimal decision arrived at by maximization, and NT therefore would study these ultimate decision rules. However, the process through which decision rules develop and evolve cannot be ignored as it determines the nature and function of such rules (Kirman, 1997). This is mostly clear in comparing traditional game theory with evolutionary game theory: The outcomes of the two are not identical, and diverge in many cases substantially (Skyrms, 1996; Young, 1998).

Note that deductive logic is used here locally, i.e. to formulate hypotheses and evaluate them based on environment feedback, as Arthur (1994) points out. But the whole process is inductive nonetheless. Note also how induction allows agents to adapt to the environment, and at the same time provides room for creativity. As patterns are formed and deformed, new hypotheses must be generated to account for the new patterns, and thus new decision rules are created. This process makes agents always open-minded to explore new patterns, and ready to act accordingly to exploit the new environment. Exploration and exploitation therefore keep agents at the edge of creativity.

Modeling Complexity

It should be pointed that the complexity approach is not against seeking simplicity in modeling and analysis. Models by design are simplifications of the world. CT however seeks simplification at the level of *processes* generating the complex phenomena, not the phenomena itself (Brock, 2000 p. 32). NT in contrast assumes the simplicity of the world, but unusually powerful abilities of decision-making. As UCLA economist Axel Leijonhufvud points out, NT assumes "incredibly smart people in unbelievingly simple situations," while in reality we find "believably simple people with incredibly complex situations" (cited in Beinhocker, 2006 p. 52). Paradoxically, while agents are assumed that powerful, they are nonetheless assumed to be powerless atoms with respect to the market. Further, if agents were equipped with computational power to process all information on all aspects of the economy, then, as Arrow (1986, p. 208) notes, "the hand running the economy is very visible indeed." To have an *invisible* hand, agents must be much more simple, yet their local interactions produce the complex and rich phenomena we observe. CT, therefore, preserves complexity at the macro-level but seeks simplicity at the micro-level, whereby NT takes the opposite position.

Origins

Intellectually, complexity has evolved from research in nonlinear dynamics, which goes far back in history of science to Newton and Poincaré (Abraham, 2002). Throughout the twentieth century, there have been several intellectual movements built upon nonlinear dynamics with an interdisciplinary approach, e.g. general systems theory, cybernetics, catastrophe theory, chaos, and synergetics (*ibid*; Rosser, 1999). They share the view that natural and social systems have common structures that defeat reductionism and show rich and unexpected behavior. The history of the holistic approach in social sciences, and in particular the concept of "emergence," goes back to the 1920s (Sawyer, 2005 ch. 2).

Institutionally, complexity has been associated in the

U.S. with the Santa Fe Institute in Santa Fe, New Mexico, established in 1984. Outside the U.S., complexity research has been associated largely with the pioneering work of Nobel laureate Ilya Prigogine in Brussels in the 1970s onwards on dissipative systems and disequilibrium dynamics (Rosser, 1999). SFI was established by the former head of research at Los Alamos National Laboratory in New Mexico (Waldrop, 1992). LANL was an active site for research in nonlinear dynamics and chaos (Gleick, 1987). This shows the evolutionary connection between chaos and complexity. Remarkably, Kenneth Arrow, while a contributing founder of the Neoclassical program, has been also a key figure in the complexity movement (Waldrop, 1992).

Chaos vs. Complexity

The two concepts, chaos and complexity, share common properties, like nonlinearity, irreducibility, and universality. Differentiating the two thus may not be very obvious, and it would be difficult therefore to draw a dividing line between them. Tentatively, however, the following differences might be highlighted (Williams, 1997 p. 234; Brock, 2000 p. 29; Sawyer, 2005 p. 15):

1. A complex system requires a large number of interacting parts in order to be described as complex. In contrast, a system can be chaotic with a single variable. A system with a large number of parts may also be chaotic, but a system with only

one variable cannot be complex.

2. Another way to say it is that a complex system is a network of some sort. This is not necessary for a chaotic system.
3. A chaotic system shows a behavior that is indistinguishable from purely random processes. In contrast, a complex system shows recognizable patterns of organization and behavior, e.g. the brain, the economy, ant colonies, etc., that clearly differs from random processes.
4. A complex system is adaptive; that is to say, it self-organizes within its changing environment. A chaotic system is not adaptive.
5. A chaotic system is ergodic (Flake, 1998 pp. 155-156). A complex system is non-ergodic (Kauffman, 2000 ch. 7; Durlauf, 2005 p. 226).
6. A complex system is capable of universal computation; a chaotic system is not (Velupillai, 2005*c*, 2007).
7. The behavior of a complex system (its basin of attraction) cannot be systematically characterized in advance, i.e. it is not computable. But the behavior of a chaotic system, in principle, is computable (e.g. Markose, 2002). For this reason simulation is important for complex systems, since it is the only way to know exactly how the system behaves.
8. A complex system is path-dependent; that is, the impact of initial conditions lasts for prolonged

> periods. A chaotic system, while sensitive to initial conditions, is driven to the same attractor set regardless. May be that's why differences between economies, which are complex systems, persist over time. But bubbles and crashes (chaos) look similar regardless of the economy they appear in.

Edge of Chaos

Another way to compare the two systems is to view complexity as a phase between stable order and unstable chaos (Waldrop, 1992; Flake, 1998; Markose, 2005). At phase transition, complex systems are capable of producing surprising patterns and behavior for extended periods of time. According to Duncan Foley (1998, 2005), a complex system lies on the boundary between stable (point and limit-cycle) and chaotic systems, so that structures in their initial conditions can evolve without being destroyed.

Kauffmann (1993, 1995) examines a network of N units, each interacts with K other units in the network. He finds that for large values of K, i.e. when each unit is connected to almost every other unit, the network becomes chaotic. For $K = 0$, the network becomes stagnant. For small values of K, however, the network becomes dynamic but stable, i.e. in the phase of order at the edge of chaos. His findings are supported by data on gene networks from various living species, showing that "life hovers at the edge of chaos."

Although the idea is appealing, it doesn't go unchallenged (see Miller and Page, 2007 pp. 129-140). But it can be viewed as an organizing principle which can be subjected to refutation by careful analysis.

The following section examines structural properties of complex systems.

III

CHARACTERIZING COMPLEX SYSTEMS

III.1 General Features

Although there are many definitions of complexity (see Rosser, 1999), two important features generally constitute a complex system:

1. Self-organization.
2. Emergence.

Self-organization

This term indicates that a system consisting of a (large) number of interacting units, could show order at the system macroscopic level, when units only locally interact and have no access to global variables or a central control. In other words, self-organization is global order arising from local interactions. It is a decentralized order.

A widely cited example is a flock of birds moving together in an ordered manner. Scientists found that such flocks do not have leaders; rather, birds are self-organized into flocks through local interactions only. More examples will be presented later.

Emergence

There are many definitions of "emergence" (see Sawyer, 2005; Lee, 2005). Here emergence implies that the system is able to perform functions or solve problems that individual parts cannot achieve separately. The brain, for example, can perform functions a collection of neurons never can.

Frequently, emergence is defined to be the case when the "whole is greater than the sum" (e.g. Holland, 1995, 1999). Although this is true for complex systems, it also applies to non-self-organizing systems. Any man-made machine performs functions that cannot be performed by the sum of its components. But the machine does not arise spontaneously. Thus emergence is more specific than mere inequality of the whole to the sum; it is the ability of the self-organized system to perform functions that independent parts can't.

The two terms, self-organization and emergence, describe structure and function, respectively, of complex systems. In many cases, however, writers may use them interchangeably.

Self-organization depends on positive feedback mechanisms, as will be discussed later. Emergence reflects the novelty the system brings into existence. These two features are excluded by construction from the Neoclassical theory, as pointed out earlier. Hence we can see the sharp contrast between the most important features of complex systems and the fundamental assumptions of NT.

III.2 Examples

Bird Flocks

We have already mentioned how birds could self-organize into flocks that move and behave as a single body, without a leader or coordinator. This phenomenon is not limited to birds, however. Fishes also self-organize into schools that maneuver gracefully, with all members moving in the same direction in parallel. Many organisms are also able to self-organize their collective motions (Camazine et al., 2001 pp. 167-171). Such arrangements have useful functions. For example, they are better able to escape predators and find food sources than individual agents. The reason is simple: As a group, they have better "vision" and sense of the surrounding area. If any member detects food or danger, the information is passed instantaneously to the group (Kennedy and Eberhart, 2001 p. xv).

The mechanism through which flocks and schools self-organize is believed to be simple. Each member follows a set of behavioral rules based on local information only. This has been shown to lead to emerging collective motion. For example, each member may adopt the following rules:

1. Move towards average position of nearest members.
2. Keep a certain distance from surrounding members.
3. Move in the direction of average heading of

surrounding members.

4. Avoid any obstacles ahead, then repeat rules 1-3.

See Camazine et al. (2001) and Reynolds (2001).

Collective motion is also observed in social behavior. It might be surprising to know that Muslim scholars, like Ibn Qutaibah (848G), have pointed that “it has been said that people are just like flocks of birds, they follow each other” ([1], 2:5). Later, Ibn Taymiah (1300G) remarks that “people are like bird flocks, naturally inclined to imitate each other” ([2], 28:150).

In economic behavior, we could explain price setting as a collective action, where each merchant takes into account average price of his neighbors, in addition to his own cost. If each merchant were doing the same, a market price would emerge without a leader or an auctioneer. As will be explained later, agent-based simulation is a natural environment for exploring such arrangements.

Fireflies

Fireflies are small flying insects that flash at night. They exist along Southeast Asian riverbanks. One noticeable feature of fireflies is their ability to gather in hundreds or thousands, and flash in unison. They flash simultaneously as if they were a single organism. This phenomenon has attracted attention of researchers almost a century ago, and was very difficult to understand until recently (Strogatz, 2003 pp. 11-14).

Scientists were able to study the mechanism through which fireflies (or some species at least) are able to coordinate their flashing without a leader or coordinator. Each firefly has a "clock" or preset cycle for its flash. However, this clock could be reset if it receives an outside signal, i.e. flash of another firefly. The signal will shift the timing of the flash such that the next flash time will be closer to the signal time. The adjustment process continues until the two eventually synchronize their flashing time (Camazine et al., 2001, pp. 153-155). As the two flies coordinate their flashing, neighbor fireflies would also synchronize, and thus the entire group (of thousands of fireflies) would flash in unison.

Through a simple mechanism, thousands of fireflies are able to self-organize their flashing in a remarkable manner. No maestro or leader is involved. Order emerges spontaneously. It is not clear though what is the function of this synchrony, although many theories were proposed (Strogatz, 2003, p. 35; Camazine et al, pp. 145-147).

Synchronization is widely observed in physical and biological systems, e.g heart beat rhythm; brain waves; laser beam molecules, among others (Strogatz, 2003; Camazine et al., 2001 pp. 161-165).

These are called "coupled oscillators." An oscillator is an entity that shows cyclical behavior. Oscillators tend to self-coordinate their cycles under certain conditions when they are adjacent or connected to each other. Coupling is widely observed in nature, as Strogatz (2003) shows.

Goodwin (1947) was probably the first to model market interactions in terms of coupled dynamical systems (Velupillai, 2005*a*, p. 174). Ruelle (1988) and Krugman (1996) argue that free trade between countries introduces coupling of their economic systems. This makes the spread of depression across countries, and thus global reaction of international economies, much stronger than measured by actual trade as a percentage of their GDPs. Size of international trade therefore is not enough to measure the interdependence of international economies.

Traffic

Whenever the highway is crowded, we think there must be an accident or something that causes the jam. But studies of traffic movement show that this need not be the case. Jams could emerge without accidents or broken bridges (Resnick, 1994).

The mechanism is simple: Each car would follow a set of rules, including driving at a given speed, accelerating if no car is ahead, and slowing down if there is any. However, cars enter the highway at different points with different speeds. Slow cars will cause subsequent cars to slow down, causing those behind them to slow down even further. This will cause jams without any accidents or road damage. That is, patterns emerge endogenously. It should be noted that speed limit laws helps reduce jams significantly (Gribbin, 2004 p. 159).

This might help explain other phenomena, particularly in economics. Cycles in output might arise from adjustment of "speed" of production of different firms vertically related. Viewing firms in supply chains as cars on a highway, it can be easily seen how cycles in inventory and production could endogenously emerge without exogenous shocks. This is related to the so-called "beer game," where fluctuations in inventory could form from one-time shift in customers orders. See Sterman (2000). Bak et al. (1993) present a related model that reflects "self-organized criticality," whereby accumulated demand results in avalanches similar to those in a sand pile with continuous sand pouring from top (Bak, 1996; Rosser, 1999).

Segregation

Nobel laureate Thomas Schelling (1978) was among the first to point to how innocent individual preferences could lead to dramatic social phenomena. Schelling examined what would happen if two different groups were mixed together (for example, blacks and whites, male and female, etc). He made a simple assumption that each group member prefers not to be a minority in his neighborhood. For example, each member prefers to have at least 30% of his neighbors from the same group. Starting from a homogenous distribution of the mixed groups, what would happen if some members randomly were removed from their locations? The percentage of same-group members would decline. If it goes below the "tolerance" threshold for a neighbor member, he or she will move to find another location with an acceptable distribution. This move will further reduce the percentage of the same-group members in the original neighborhood, causing more members to move. As the process continues, the distribution of members will become more and more concentrated, and the two groups become increasingly segregated.

Thus segregation may obtain even when individuals are quite tolerant towards the opposing group. This is a clear example of how order at the macro-level could emerge from simple, local interactions at the micro-level. The same logic might help explain a variety of socio-economic phenomena, e.g. emergence of coalitions, alliances, firms, as well as markets. Schelling (2006) notes that if some restrictions on movement are applied, usually everyone will be satisfied with less movements and more integration.

Language and Money

Natural languages evolve and organize without a central authority (Koppl, 2001 pp. 142-143; Ke, 2004). Money can arise in a similar fashion. Both are mediums of exchange, one for ideas and feelings, the other for goods and services. They are driven by network externalities favoring convergence to a common medium. The more individuals use the currency or the language, the more it becomes preferred by others. These are examples of how positive feedback and increasing returns lead to emergence (Arthur, 1990, 1996).

The Economy

An economy is one of the most complex self-organized systems. Through simple interactions of agents based on local information, an economy emerges where production and distribution takes place across the whole economy without central authority. Agents could enjoy higher welfare through the economy than they would obtain if they were scattered in isolated islands. The "invisible hand" is the name that Adam Smith gave to self-organizing process of the economy (Foley, 2003 ch. 1). Austrian economists call it "spontaneous order" (Koppl, 2000; Sugden, 1989). For a historical account, see Barry (1982).

As pointed earlier, however, self-organization does not necessarily lead to "good" outcomes. The process might lead to stability and wealth creation, or to fluctuations and cycles (e.g. Arthur et al., 1997), and thus wealth destruction. So the "invisible hand" might as well lead to undesirable sates, even though it is clear that an economy has the potential for achieving desirable ones.

The Neoclassical theory focuses mainly on emergence of "good" order, i.e. efficient resources allocation. Undesirable states would be the result of exogenous shocks or external factors, but do not emerge endogenously (as in real business cycle models, e.g. Blanchard and Fischer, 1989 ch. 7). Further, NT assumes that agents, who enjoy full information and unlimited computational power, are the driving force for achieving global order. Paradoxically, while the essence of economics is to allocate limited resources, NT assumes that agents use *unlimited* computational and informational resources.

This is not the way complex systems work, where simple, local rules would lead to global complex phenomena. We discuss next why simple rules are important, and how self-organization could achieve complex tasks that cannot be achieved otherwise.

III.3 Why Complex Systems?

Complex systems attain complexity through local interactions of underlying units. These interactions do not require global information to be available to units or agents. Further, the interactions occur through simple rules rather than complicated processes. The logic behind this structure is consistent with the underlying worldview. Since the world is assumed highly complex, and choice sets are unbounded and nonconvex, there is no reliable computational mechanism for agents to achieve desired outcomes individually. Rather, through interactions and cooperation of agents, the system as a whole can achieve desirable outcomes and solve hard computational problems much more efficiently (Markose, 2005). Economist Vilfredo Pareto argued about a century ago that only markets are able to work out the solutions for market equilibrium (cited in Velupillai, 2007 pp. 469-470).

Complex systems therefore economize on computation as well as information in order to reach the desired solution, in accordance with Simon's (1978, p. 9) approach. From this angle, complexity is more relevant to economics than Neoclassical theory.

For this reason, market mechanism (i.e. trade based on prices) has been used in computer science to design computational processes for solving complex tasks (Miller and Drexler, 1988; Huberman and Hogg, 1995). Concepts of "parallel processing" and "distributed computing" apply naturally to complex systems, including markets and economies. The same has been applied in Artificial Intelligence (Baum, 1997, 1998). Robots where successfully designed to solve complex tasks through interactions of software agents based on market mechanism and property rights. Although these agents were not "rational," the system as a whole was very successful in learning and solving complicated problems.

"Swarm Intelligence" refers to intelligence of the group of interacting agents in solving complex problems, where no single agent is able to do so alone. Ants, for example, are able to find the shortest distance to resources even though no single ant is able to solve this problem (Bonabeau et al., 1999; Bonabeau and Meyer, 2001; Kennedy and Eberhart, 2001). This is the same logic of distributed or decentralized processing. Intelligence therefore is not characteristic of agents; it is of the system (Brooks, 1991). Individual rationality is replaced with "ecological rationality" (Gigerenzer et al., 1999, and Gigerenzer, 2004; Smith, 2003).

III.4 Simple Local Rules

Since the essence of economics is to economize on resources, this requires economizing on information and computation (Smith, 2003). Thus the economic problem becomes: How to achieve desirable global outcomes using simple local rules? We don't need to assume that agents' abilities or rationality are bounded to frame the problem in this manner. To economize on resources is a goal that should be pursued, regardless of available resources. Thus, simple local rules are of value irrespective of whether agents are bounded or not.

Simplicity doesn't imply naivety or obscurity. Given that these rules lead spontaneously to complex phenomena, their simplicity is a sign of intelligence.

In addition, simple rules would be generally more stable. Velupillai (2003, Proposition 13) shows that "an event with the highest probability of occurring is also that which has the simplest description." Stability arises from the generality of the rule, and generality arises from simplicity. Obviously, stability is an advantage since it implies survival under a variety of risks and uncertainties.

Heiner (1983) argues that the more complex and uncertain the environment, the more agents tend to follow simple rules. The reason is that as the environment becomes increasingly complex, it will be increasingly difficult to adopt "optimal" behavior, i.e. specific rules for specific situations, as implementation of such behavior becomes increasingly difficult and uncertain. Higher uncertainty therefore implies more simplicity.

Finally, simple strategies might beat sophisticated ones in performance. In the tournament arranged by Axelrod (1984) for playing repeated Prisoners' Dilemma game, the winning strategy was consistently the simplest one: Tit-for-Tat. This follows from the stability feature above: More stable rules are able to perform better under different circumstances. Another area where simple rules might outperform complicated ones is fuzzy logic, which has been applied in many commercial appliances and consumer electronics successfully (Sangalli, 1998).

III.5 Structure of Complex Systems

Although no single mechanism can characterize all complex systems, a general class could be described based on the following structure.

Let x_i denotes a certain behavior or property of unit i of a system S, consisting of n units. This could be position, speed, or any other behavior by agent i. The system S is described as complex if agents or units comprising the system are able to self-organize such that the system obtains features that are not achievable at the level of agents. This could be reached when each unit or agent's behavior is determined by two types of variables: *independent variables*, and *relative variables*.

Independent variables are variables determined outside the system, i.e. they are exogenous to all units or agents. Relative variables are variables describing the behavior of other units or agents. In particular, they describe the behavior of *local* neighbors of each agent. These variables are obviously endogenous. Thus we can write:

[1] $x_{i,t} = f(\mathbf{z}_{i,t-1}, \mathbf{x}_{-i,t-1}),\ f_1 > 0,\ f_2 > 0,$

where $\mathbf{z}_i$ represents a vector of independent variables affecting agent *i*, while $\mathbf{x}_{-i}$ represents the behavior of local neighbors of agent *i*. (If $\mathbf{x}_{-i}$ includes agent's own past behavior, it combines relative behavior with habit formation. See Pollak, 1976). Agents are assumed to follow essentially the same rules in reacting to these variables, up to some degree of variability (e.g. up to an affine transformation of the function f). The time subscript denotes the dynamic nature of the system.

This representation is consistent with a wide range of complex systems. For example, for fireflies, the independent variables include the time of the day (day or night; where flashing is restricted to night time), while the relative variables include the outside flash received from surrounding flies. For a bird flock, each bird is influenced by weather and regional geography as independent variables. But they are also influenced by nearby birds, if any. A merchant would set a price according to costs (independent variable), as well as his local neighbors' prices (relative variable). And so on.

This characterization allows the system to self-organize, as each unit or agent would adjust its behavior to independent variables in accordance to the behavior of its neighbors. As each agent adjusts to his neighbors, the whole group eventually synchronizes its behavior to the independent variables.

The independent variables are essentially common to all agents, as it is apparent from the above examples. This is essential for the system to organize and achieve global functioning. However, each unit or agent would be exposed to a subset of these variables. For example, each bird in a flock would look at a certain part of the region, and each fish in a school would sense a different part of the environment. But these different peaces of information integrate each other to form a whole. So we can view the vector $\mathbf{z}_i$ as different realizations of the same process or different locations of the same landscape. Accordingly, we require that there exists a function *F*, such that:

[2] $\mathbf{z}^* = F(\mathbf{z}_1,...,\mathbf{z}_i,...,\mathbf{z}_n)$.

The vector $\mathbf{z}^*$ is a consistent aggregate of variables $\mathbf{z}_i$. For example, in case of ants, $\mathbf{z}^*$ could be the coordinates of food place. Each ant would have a piece of information, $\mathbf{z}_i$, e.g. the direction towards the place from a certain point. However, all these directions collected from different ants, if consistent, would point to the same place, $\mathbf{z}^*$. Agents however need not know neither F nor $\mathbf{z}^*$. They know only $\mathbf{z}_i$ and act accordingly. But the structure of the system integrates this dispersed knowledge to reach self-organization. As Hayek (1945) points out, knowledge used by economic agents never exists in concentrated or integrated form, but as dispersed pieces of incomplete knowledge owned by different agents. "The problem is thus in no way solved if we can show that all of the facts, *if* they were known to a single mind … would uniquely determine the solution; instead, we must show how a solution is produced by the interactions of people, each of whom possesses only partial knowledge" (p. 530. See also Vriend, 2002). Accordingly, while the function *F* exists, it is not known to agents a priori, and the problem becomes how to coordinate the dispersed pieces of knowledge, $\mathbf{z}_i$, in order to achieve global order. While agents may not know the structure of *F*, they might be able to know that it exists. This is an area where deductive methods can complement inductive methods. Deduction is used to prove the existence of *F*, while induction is used to compute its value.

We assume agents react in the same manner to their neighbors (up to an affine transformation). If each responds fundamentally differently, their adjustment processes may not be coordinated, and thus the system may not self-organize.

Positive Feedback

The structure of relation [1] allows for positive feedback dynamics. The rise of x for any reason will raise the local relative variables for other agents, $\mathbf{x}$, causing x to rise again in response. Feedback mechanism is an essential feature of self-organization (e.g. Bonabeau et al., 1999), and can explain how the system may coordinate the behavior of its units without central control. Positive feedback however might lead to instability if not balanced properly. The presence of independent variables represents an essential mechanism for achieving such balance.

Edge of Chaos

It is insightful to examine how behavior of [1] would change if it did not balance these two types of variables. Consider the case where each agent responds dominantly to independent variables, but negligibly to relative ones. Then there will be no emergent behavior. Since each agent reacts to different (realizations of) independent variables, their behavior would be unsynchronized, and they become a disorganized collection of units.

In contrast, if each agent responds dominantly to relative variables, there will be an emergent structure, but the system may likely be chaotic. Given positive feedback, shocks to the behavior of units will make the whole group continuously react, and the reaction may never settle, as the change of the group would feed back the behavior of the unit. In social models, the positive feedback is sometimes called "social multiplier" (Becker and Murphy, 2000 pp. 14-15). It can explain fads and related information cascades (Bikhchandani et al., 1992).

While relative relations are important for adjustment of units to each other, independent variables are required for global order and functioning. In other words, relative adjustment describes the “self” part of “self-organization,” while independent variables are necessary for the “organization” part.

This discussion is consistent with the view that complexity lies at the “edge of chaos” discussed earlier. By including independent variables and relative variables, equation [1] reflects the dual characterization of complex systems.

The above model can be related to Kauffman’s *NK* network model, where small values of *K* makes the network dynamic but stable, i.e. in the phase of order at the edge of chaos. Accordingly, number of units in the vector **x** has to be relatively small in order to avoid chaotic behavior.

Diversity

Another way to look at system [1] is through diversity and similarity. The vector $\mathbf{z}_i$ reflects the diversity of the information of agents regarding the independent variables. This diversity is important as it allows agents to complement the knowledge and skills of each other to reach global optimum (Page, 2007). Several studies have shown that the more agents are heterogeneous in an economy, the more the regularity and stability of the *aggregate* economy (cited in Kirman, 1992 pp. 129-131). Further, diversity in networks has been found to be a crucial factor for their stability (Buchanan, 2002 pp. 146-148).

The vector $\mathbf{x}_{-i}$ reflects the similarity of each agent to its neighbors. This is required for coordinating their behavior, as mentioned earlier. A system of pure similarity becomes vulnerable to instability (this arises form the positive-feed back loop of the same variable, leading to instability and chaos). Thus, a complex system balances diversity and similarity, homogeneity and heterogeneity. In this manner it is able to be rich and innovative, meanwhile organized and stable.

Macro vs. Micro Behavior

For an outside observer, the whole system might appear behaving as a single entity responding to $\mathbf{z}^*$. An observer might therefore infer that:

$$[3a] \quad \overline{x}_t = g(\mathbf{z}^*_{t-1}).$$

That is, collective (or average) agents respond to aggregate independent variables directly. This would be the representative agent approach. But this tells us nothing of *how* did this relationship emerge in the first place. Ignoring the mechanism implies ignoring an important ingredient of the aggregate behavior. Since each unit reacts to its neighbors, and subsequently to its own past, aggregate behavior therefore would be also dependent on its own past. Thus a more proper specification of the system is:

$$[3b] \qquad \overline{x}_t = g(\mathbf{z}^*_{t-1}, \overline{x}_{t-1}).$$

The system becomes inherently dynamic. Thus collective behavior of the system cannot be fully explained by $\mathbf{z}^*$ alone. For example no endogenous cycles can arise from [3a]. But this arises naturally from [3b]. However, many distributional issues would appear irrelevant in [3], while they have strong implications on aggregate behavior if [1] is considered instead (see Kirman, 1992). Further, adopting equation [3] assumes availability of full information regarding $\mathbf{z}^*$ to each unit, and an unusual ability to figure out the response function g. Both, full information and the ability to calculate g, are obviously unwarranted. A dilemma therefore arises: How agents are able to coordinate in absence of these requirements? The complexity approach resolves this dilemma by looking at relation [1] instead of [3]. By taking relative behavior into account, neither full information nor perfect computational ability is needed. In other words, adopting the complexity approach allows richer behavior with fewer requirements. The examples given in the next section will show this in more detail.

III.6 Relative Behavior

Neoclassical theory assumes impersonal markets. Agents interact only through price signals (Kirman, 1997). Further, NT concentrates on studying the equilibrium state of the economy, but does not pay due attention to how this equilibrium is attained. It examines the properties of market clearing prices and resulting allocations, but ignores how agents trade with each other in order for prices to reach their market-clearing level.

As pointed out earlier, theory of complex systems provides mechanisms for self-organization that might help us understand how agents in the economy interact in a manner that produces emergent order. One important mechanism is relative behavior discussed earlier. That is, the behavior of each agent is influenced by that of his "neighbors" or close associates. This can propagate local behavior to the rest of the economy, and thus makes the economy behave as a single entity. Local interactions of agents might make the system respond much faster than uniform interactions (Young, 1998 pp. 98-99). Local interactions may account for much of widely observed macroeconomic properties, e.g. price rigidities and path dependence (Saint-Paul, 2005). Axtell (2005) compares Walrasian auctioneer with local interactions, and shows that the latter is much easier to compute, achieves Pareto optimality and global stability, but also path-dependent with wealth effects.

Relative behavior can have a variety of forms. An agent would choose, say, his consumption based not only on his own income (independent variable), but also on the consumption level of his neighbors or peers (relative variables). One prefers to conform to the group, at least in some respects, rather than being oddly different. Sympathy to others may also make agents prefer to behave in a manner that brings them closer to their associates. Adam Smith in *Theory of Moral Sentiments* noted that there are some principles in human nature "which interest him in the fortune of others, and render their happiness necessary to him, though he derives nothing from it except the pleasure of seeing it" (cited in Wilson, 1993 p. 31). This principle is assumed out from Neoclassical model of choice, where agents' behavior is determined solely by economic variables like income and prices.

Samuelson (2004) presents an evolutionary argument for developing preferences for relative consumption. Social interactions slowly attracted the attention of economists (Manski, 2000; see also Becker and Murphy, 2000; Durlauf and Young, 2001). In game theory, positive interactions are described as strategic complementarity, which characterizes coordination games with multiple equilibria (Cooper, 1999; see also Vives, 2005).

While Neoclassical theory considers only independent variables, an essential assumption of NT, perfect competition, is driven mainly through relative behavior, particularly imitation. Frank Knight (1935, p. 46) long time ago has pointed out that the "motive for business is to such a large extent that of emulation" (cited in Choi, 1993 p. 116). Even markets with very few agents may behave competitively in presence of imitation (Alexopoulos and Sapp, 2006; Camerer, 2003 p. 296). Despite the central role of competition in economic theory, NT is silent on how competition is actually achieved and the process behind it.

Imitation may play an important role in technology transfer and dissemination of innovation, as Baumol (1993, ch. 9). According to Richerson and Boyd (2005, p. 13), imitation allows the population to adapt in ways that outreach the abilities of any individual genius. It also serves to coordinate agents' behavior. Eshel, Samuelson, and Shaked (1998) show how imitation of successful players, in a local interaction model, allows altruist agents to survive when altruism is a strictly dominated strategy, as in the Prisoner's Dilemma game. Sornette (2003, pp. 121-133) argues that imitation is important for cooperation and thus self-organization. Bonabeau (2004) points that with increasing connectedness, imitation is more influential in our age than before.

Empirical research provides evidence on the prevalence of relative preferences. For example, in a survey by Solnik and Hemenway (1998), subjects were asked if they would prefer to earn an annual income of $50,000 while everyone else earns $25,000, or to earn $100,000 while others earn $200,000, when all other things are equal. Half of the respondents chose the first option. Frey and Stutzer (2002) cite other studies supporting this result. Frank (1985, 1999) provides extensive discussions on status and its economic implications. Bagwell and Bernheim (1996) cite further evidence on "Veblen effects" and show how it could arise in a signaling game. Herding behavior is well known in markets, especially financial markets (Shiller, 2000). Herding occurs when market participants' payoffs depend directly on the behavior of others (Drehmann et al., 2005). Informational cascades also result from interdependent decisions (Celen and Kariv, 2005).

Camerer (2003) surveys experimental evidence of imitation learning, and concludes: "These results … suggest imitation should be taken seriously as an empirical source of learning. However, imitation may also be a heuristic shortcut to more general types of learning" (p. 298). Models of reciprocity and inequity-aversion permit preferences to depend on consumption or payoffs of others (Sobel, 2005; Gintis et al., 2005). Preference for conformity is widely reported in psychological studies (e.g. Aronson, 1995, ch. 2), and supported by research in neuroscience (Goleman, 2006, pp. 9, 30-32, 40-43).

Regardless of the exact motives and incentives for individuals' decision to be influenced by that of others, relative behavior has an important role from a completely different angle: self-organization. This dimension allows the inclusion of others' choices into the decision function, creating feedback loops and thus system dynamics that differ markedly from those predicted by NT.

Types of Relative Behavior

Based on the above literature, relative or social behavior can be generally classified into two broad categories:

1. Similarity-seeking behavior. This includes various forms of imitation, conformity, equity, reciprocity, and altruism. These motives are reflected in a behavior of the decision maker similar in nature to that of a reference group or person.
2. Dissimilarity-seeking behavior. This includes innovation, differentiation, status games for positional goods, i.e. goods that improve the position or rank of the decision maker compared to the reference group.

Although the two types appear opposite to each other, it can be argued that similarity seeking is central to social behavior. It is not difficult to see that it is necessary for forming societies in the first place. Further, similarity serves as a "focal point" on which expectations could easily converge to, thus solving varieties of coordination games (see Schelling, 1960). Dissimilarity obviously cannot play this role.

Seeking dissimilarity on the other hand can be a good source of innovation and discovery. But it assumes a priori a minimum degree of similarity. People enjoy status over those who are close enough in order for the comparison to make sense, as Frank (1985, pp. 28-30) rightly points out.

The overall effect of status however depends crucially on the form it takes. Positional goods could be pecuniary or non-pecuniary. Non-pecuniary positional goods, like ranking in a hierarchy, can be traded for pecuniary reward. Frank (1985) shows that wages generally are not equal to marginal product of employees. The spread of wages is narrower than what Neoclassical theory predicts. The reason, he argues, is positional reward: Some employees may give up some of their marginal product in compensation for higher ranks. Others may choose the opposite: to accept lower ranks in compensation for a wage premium above their marginal product. The result is a mutually beneficial trade. More important, it may lead to *emergence of firms*. The trade would make the two agents able to produce more than the some of each alone, as Frank shows, so the whole is greater than the sum. Thus it is in the interest of the two to establish a firm with predefined hierarchy and production plan. Although there are other explanations for emergence of firms (e.g. increasing returns proposed by Axtell, 1999), the one based on rank is consistent with the role of relative behavior in complex systems. Further, trade of rank for wage premium can explain the source of increasing returns to cooperation, instead of being assumed a priori.

This trade however can arise only in presence of equity or similarity seeking behavior. That is, *if agents prefer to be similar, then dissimilarity in one respect has to be compensated for in another respect*. Trade therefore becomes mutually beneficial. It can take place because the two sides of the exchange are different: one is pecuniary and the other is not. Consequently, preference for non-pecuniary positional goods can improve the efficiency and productivity of the economy.

In contrast, preference for pecuniary positional goods might lead to inefficiency and waste of resources. This arises most clearly in the form of “conspicuous consumption” of Veblen (1899) or “demonstration effect” of Duesenberry (1949). Agents might consume more than others simply to feel they are better than them. If others follow the same strategy, they become engaged in a “game of status” (Hopkins and Kornienko, 2004) and “luxury fever” (Frank, 1999). Unfortunately, it is a zero-sum game, where all players end up with fewer resources and less satisfaction (Rayo and Becker, 2006).

Pecuniary status has the odd result that reducing wealth concentration will be undesirable for the less advantaged. Hopkins and Kornienko (2004) show how increasing the equality of wealth distribution makes agents more similar, and thus comparisons would be stronger. Less advantaged people therefore would feel worse. A similarly odd consequence is that corrective tax policy requires that marginal tax should be higher on middle class agents, where the effect of status is strongest because of strong similarities, but the rate should be lower for wealthy agents due to dispersed distribution at the top (Rayo and Becker, 2006).

Conspicuous consumption by design is driven mainly by relative variables, and much less by independent variables. Based on the earlier discussion of relation [1], the system therefore will be biased towards the phase of chaos more than that of complexity. Stabilizing the system requires primarily policies inducing agents to shift their attention from pecuniary to non-pecuniary status, and shall not be limited to fiscal or tax policies.

Complexity, Economics, and Social Sciences

Durlauf (2005) points that social interactions are properties of complex systems. From the previous discussions, it is not difficult to see why. It is surprising how the structure of complex systems complements behavioral and social characteristics. Relative behavior is a point at which hard sciences and social sciences meet each other. It is also a point where Neoclassical theory is clearly lacking. This would be a promising direction for cross-disciplinary research that might be fruitful to all related fields.

III.7 Simulation

Given the structure of complex systems, conventional techniques may not be suitable for studying their behavior. The interaction of different units, each with its own neighbors and to different independent variables, cannot be handled using "representative agent" models, nor with aggregate analytical representations. With interaction of different agents at the core of the system, a different tool is needed. Agent-based simulation appears to be more appropriate.

Agent-based Simulation

Simulation used to be performed using aggregate equations describing the whole system, and feeding these equations with numbers to see how the system behaves. Agent-based simulation (ABS) is different. It starts at the level of units comprising the system, characterizing the behavior of each, and how it is related to other units. The behavior of the whole system then can be examined through aggregating the behavior of individual units.

Before the 1990s, there was no simple programming language for this purpose. In early 1990s few simple languages were developed for this purpose. Subsequently, other languages and environments appeared, extending the abilities and power of carrying out agent-based simulations. The field is growing rapidly, especially in social sciences.

Agent-based simulation is used in a wide range of fields: statistics, physics, chemistry, medicine, engineering, economics, finance, political science, education, management science, etc.

The technique is quite useful, not only in understanding and modeling the phenomenon under investigation, but, more important, in policy implications and decision-making. Agent-based simulation is used by corporations and governmental agencies for a variety of issues and problems (Meyer and Davis, 2003; North and Macal, 2007).

How it Works?

An agent is an object that implements certain rules defined by the user. Different agents may implement different rules. As these agents interact with each other, aggregate behavior becomes easily observable and measurable. In many cases, an unpredictable macro-phenomenon emerges. Complexity at the macro-level could emerge from simple rules at the micro-level. This is one reason why agent-based simulation is increasingly attracting attention of researchers.

Agents could represent individuals (consumers, producers), institutions (banks, factories, farms), markets, cities, countries, etc. This makes the scope of analysis virtually unbounded.

Simulation as a Research Tool

Agent-based simulation can be used as a tool for scientific endeavor, in addition to experimentation and mathematical modeling. It is a type of experiment but "in silico." ABS does not replace other tools but it does enrich the repertoire of researchers in examining difficult questions. It is a research tool, and any tool is as good as the theory behind it. No tool whatsoever could replace good intuition, but good tools could help develop good theories.

ABS shares with mathematical modeling rigor and consistency, but falls short with respect to generality (Kollman et al., 1997; Foley, 2000). Deductive mathematical models can produce statements that apply to all instances within their domain. This is not the case for simulation, which essentially produces certain realizations of the world. But this might be an advantage, as it stimulates research in order to explore various settings and models and discover new patterns and regularities. The world is open, and thus deductive general statements are not very helpful for exploration. ABS however enjoys two advantages over deductive mathematical models (Wilensky, 2001): (1) It is more flexible and thus more realistic. Mathematical models achieve generality at the expense of flexibility. Many restrictive assumptions are made in order to keep the model tractable. But this makes the model less realistic and thus less insightful. (2) It is easier to understand and manipulate.

Further, mathematical models might not be computable, and therefore remain abstract constructs. As pointed out earlier, for complex systems, simulation becomes particularly important as it may not be feasible to characterize the behavior of the systems in advance.

Resources

There are now tens of papers and studies applying ABS in economics. One notable work is that of Epstein and Axtell (1996), where a society of agents is built, with the possibility of a wide range of social interactions, including trading and lending. Axelrod (1997) provides a good introduction to the subject. For an extensive list of works and references, including relevant software, visit the web site developed by Prof. Leigh Tesfatsion: www.econ.iastate.edu/tesfatsi/ace.htm.

Together with Ken Judd, Tesfatsion edited the recently published *Handbook of Computational Economics,* volume 2, which is devoted to agent-based computational economics. Gilbert and Troitzch (1999) and Gaylord and D' Andria (1998) provide several examples and applications of simulation in social sciences.

To the best of my knowledge, however, no work has been done in Islamic economics using ABS. The next section is devoted to this topic.

IV

ISLAMIC ECONOMICS IN A COMPLEX WORLD

Islamic economics is the study of Islamic principles concerning economic behavior. It includes the economic explanation of such principles, as well as their implementation and policy implications.

A brief outline of these principles includes:

- Material interest shall be balanced with spiritual and social interests.
- Time horizon is extended beyond this world to include the Hereafter.
- *Zakat* or obligatory charity is an essential duty.
- *Riba* or interest on loans is strictly prohibited.
- Gambling and wagering, or *gharar* in general, is also prohibited.

These principles are not peculiar to Islam, however. All Divine religions essentially share the same teachings. What is different in case of Islam is the supporting detailed regulations regarding trade, partnership, inheritance, etc, known as *Shari'ah*. These regulations obviously cannot be studied in isolation from the general principles.

Despite the substantial research done by researchers in this domain over the last four decades, the progress in developing a coherent theory of Islamic economics is below expectations. The reason by now should not be difficult to identify. Most of these efforts were based on, or influenced by, the Neoclassical approach. NT is concerned with equilibrium states, but is blind with respect to the process through which economic agents seek equilibrium. NT assumes choice to be path-independent, and thus excludes all non-economic factors from the economic decision. It is for this reason that economics appears to many outsiders as too selfish and materialist, as it ignores moral values and social aspects. Islamic principles, and all *Shari'ah* regulations, are equally concerned with the process as well as the equilibrium, final states. There is therefore an inherent incompatibility between the two. This is true even for conventional legal systems (see e.g. Parisi and Smith, 2005).

Values, Norms, and Law in a Complex World

The complexity worldview opens the door for new insights on why values and regulations are needed in economic life.

1. Since economic processes are path-dependent, then the means by which agents achieve their desires is important. This brings in the role of values, which dictate that ends do not justify means. In a path-dependent world, therefore, values have a fundamental role to play.
2. A complex system is irreducible, and thus individual behavior has to be coordinated with that of others to avoid the "fallacy of composition." A single agent

might benefit from hoarding his wealth, but if every one does the same, they all lose (e.g. Batten, 2000 pp. 81-84). Fallacy of composition arises when, inter alia, the relationship between the individual and the aggregate is nonlinear. In this case individual behavior has to be regulated to avoid adverse collective consequences. We already noted that the segregation game can be greatly modified, and the inadvertent segregation avoided, if simple constraints are imposed on individual agents' choices, as Schelling (2006) points out. Also, in car traffics, speed limits may greatly reduce the chances of jams (Gribbin, 2004 p. 159). This gives an insight into why *zakat* or charity is obligatory in Islamic economics: It is an effective measure against hoarding. We shall see later that *riba* or usury is yet another example of fallacy of composition.

3. One possible way to reconcile moral and legal rules with the Neoclassical approach is to view these rules as factors for "convexifying" the choice set or the economic landscape (compare Luna, 2005 pp. 225-226). Social norms and legal rules may help curbing positive feedback mechanisms in order to stabilize economic and social processes. An example is norms and regulations for curbing positional or arms race due to relative behavior (Frank and Cook, 1995 ch. 9; Frank, 1998). Further, in a world of increasing returns, where the rich naturally gets richer (Buchanan, 2002

ch. 7; Barabási, 2003 ch. 7), institutionalizing charity and philanthropy becomes of necessity to mitigate wealth concentration and counter the negative effects of increasing returns. Prohibition of *riba* and institutionalization of *zakat* can be seen as examples, as will be discussed shortly.

4. On a different level, Velupillai (2005*c*, 2007) argues that, if the economy is a complex system, i.e. a dynamical system capable of universal computing, then there is no effective procedure to systematically design an economic policy affecting the trajectory of the economy. In other words, a general theory for economic policy becomes impossible for a complex economy. This is not to say that there is no way to design a helpful policy for such an economy; it says that there is no general method (or algorithm) for finding and designing such policies. A "non-algorithmic step" must be taken in order to achieve desirable outcomes (2007, p. 478). "Justification for policy cannot be sought in mathematical formalisms. One must resort to poetry and classical political economy, i.e. rely on imagination and compassion, for the visions of policies that have to be carved out" (*ibid*, p. 479). This framework and results "make a case for an enlightened approach to policy, where poetry and prose may well be the better guides than one-dimensional mathematics" (*ibid*, p. 478).

In the light of this impossibility theorem, it can be argued that a Divine law becomes of great value, no less than that of "imagination and compassion," let alone "poetry," to design economic policy. In a complex world, one needs to resort to non-algorithmic sources of guidance. The Divine law is certainly the ultimate source for such guidance. The Divine law, it must be emphasized, is not ready-to-do recipes; considerable effort is needed to tailor it to continually changing human needs. But the principles or the "general method," fortunately, is well defined and decided.

Scope

This section builds on the previous discussions to evaluate certain Islamic principles of economic behavior. In particular, a structure similar to that in equation [1] is proposed, based on which three aspects of Islamic economics are examined: *Riba*, markup finance, and charity. We shall see that this structure provides new insights on the rationale of Islamic principles in this regard.

IV.1 Model

The analysis focuses on consumption. We examine a society of agents, where each earns an income y_i and decides on consumption c_i. Consumption obviously is affected by income, but we add one behavioral assumption: consumption is also affected by behavior of local neighbors. That is, we assume that:

[4] $$c_{i,t} = f(y_{i,t-1}, \overline{c}_{-i,t-1}),$$

where $\overline{c}_{-i}$ is average consumption of surrounding neighbors of agent *i*. This model has the same structure as [1], with relative variables appearing here in the form of simple average.

As discussed earlier, the inclusion of average local consumption is consistent with a variety of incentives for social conformity. But an important motivation for this formulation in this paper is the structure of complex systems, whereby relative variables represent a mechanism to achieve self-organization. In studies of social economics, the variable $\overline{c}_{-i}$ is considered as a form of "social capital" (Becker and Murphy, 2000 p. 9). It represents the accumulation of social behavior that affects individual's choice. The main assumption is that social capital has a complementary relationship to individual's choice, i.e. positive relationship.

We consider consumption of "non-positional" goods rather than conspicuous consumption or status. Accordingly, the system has no intrinsic tendency towards chaos. Unlike Duesenberry (1949) and related models (e.g. Harbaugh, 1996), no assumption is made regarding the shape or structure of the utility function of agents; relative consumption is simply assumed to affect consumption decisions. Further, agent's consumption is measured in absolute value, not in proportion to that of peers. The latter formulation is suitable for pecuniary conspicuous consumption, which is excluded from the present model.

Consumption Behavior

As agents get different incomes, they cannot have equal consumption. Agents with high income will enjoy high consumption, and vise versa. This means that average consumption for any given neighborhood will exceed available income for some agents. This creates a gap between desired consumption and available means. There are several possibilities in response to this gap:

One is that agents would move to localities with comparable consumption level whereby the gap is reduced. This results in segregation as in Schelling's model. This might explain demographic distribution of neighborhoods in large cities.

Another possibility would be to exchange labor services for additional income. If agents spend some time looking after their properties, say, then high-income agents may hire low-income agents for an agreed upon wage. This would be Pareto optimal for both, as low-income agents would earn additional income, while high-income agents would enjoy more leisure. Generally speaking, seeking similarity in one dimension necessarily creates heterogeneity in other dimensions. This can explain emergence of markets due to relative behavior.

A third possibility would be financing. This can take more than one form: interest-free lending, interest-bearing lending, markup financing, or simply through charity. High-income agents would donate some money to low-income ones. To simplify the analysis, we will examine only the latter two possibilities, financing and charity.

Charity

We assume first that an agent would set his consumption to the minimum of his income or that determined by [4]. That is:

[5] $$c_{i,t} = \min\{y_{i,t-1}, c^*_{i,t}\}, \text{ where } c^*_{i,t} = f(y_{i,t-1}, \overline{c}_{-i,t-1}).$$

In other words, an agent cannot live beyond his means. The dynamics arising from this condition are interesting.

Agents with low income will have their consumption constrained by their income. This drives the average consumption down, thus lowering consumption of neighbor agents. If high-income agents donate some of their wealth to their constrained neighbors, this would raise the latter's consumption level, leading to higher average consumption. The higher average consumption in turn allows high-income agents to improve their consumption level. Charity therefore may improve consumption of *both* the donor and the receiver. This stems from the presence of relative consumption in the consumption function. Unconstrained agents probably feel uncomfortable choosing a higher consumption level if their neighbors cannot share their behavior. By donating some of their wealth, unconstrained agents are able to avoid this tension, thus making every body better off. According to Gary Becker and Kevin Murphy (2000, p. 13), social capital restricts the individual's choice, so that a rise in income may not greatly affect agent's behavior compared to the pure individual model. In our case, consumption of high-income agents would be restricted by that of their neighbors, and thus charity would lead to higher consumption for the whole group.

Generally speaking, this result depends on the magnitude of relevant parameters. As long as the marginal impact of wealth is less than that of relative consumption, paying charity from wealth will improve consumption of both. However, there might be multiple donors and receivers, and thus the detailed dynamics of the impact of charity would be highly complicated, so it would be much easier to examine it through actual simulation.

Riba

Now suppose that lending is allowed. Unconstrained agents would lend constrained ones their needs to reach desired consumption, c_i^*, for a predetermined interest. How this would affect the economic behavior of agents?

A constrained agent would enjoy higher current consumption by borrowing, but future consumption may suffer. Since he or she has to pay interest, lender's income would rise, thus raising the latter's consumption. If the lender is sufficiently close, this would raise average consumption around the borrower, widening the consumption gap. The borrower thus needs to borrow more to finance the higher level. The cycle continues, and borrower's debt would rise, until it becomes impossible to repay, whereby bankruptcy is declared. Thus the boom in aggregate consumption would be followed by a bust when debtors become unable to keep up with it. *Riba* therefore does not solve the problem; it only makes it worse.

It is insightful to note how *riba* alters the structure of the system. Since *riba* allows agents to go beyond their budget constraints, the independent variables in function [4] become of less influence on behavior. This reinforces the positive feedback loop, as borrowing will raise average consumption, leading to additional borrowing, etc. This in turn will push the system towards the phase of chaos and away from the phase of complexity. As the choice of consumption level sidesteps income constraints, relative variables effectively determine the behavior of the system. This is a fundamental insight that complexity theory contributes to Islamic economics:

Interest-based lending allows the economic system to bypass independent variables, thus pushing the system towards the phase of chaos away from the phase of complexity.

This shows the logic of Islamic finance: In all modes of Islamic finance, including markup finance, debt is bounded by available resources. No mechanism exists in an Islamic economy whereby spending can consistently and systematically extend beyond economic means, as it is the case with interest-based lending or *riba*. Consequently, independent variables cannot be escaped, and the system is not allowed to move into the phase of chaos.

The mechanism of *riba* may help understand, at least in part, the phrase of the Qur'an describing usurers at the Day of Judgment: "Thos who eat *riba* never rise except as rises the one who the Satan 'smashes' him from (his) touch" (2:275). The word "smashes" is a translation of the Arabic word "يتخبطه", which implies that the Satan is causing the usurer to move aimlessly, continuously hitting walls or barriers. The description is vivid and has much in common with chaotic behavior. The phrase points to the connection between *riba,* growing levels of debt and economic instability, which is an established regularity (see e.g. Minsky, 1986; Chapra, 1986).

Budget Constraints

The requirement that consumption shall be bounded by real resources is the standard text-book assumption of economic behavior, as represented in the intertemporal budget constraint (IBC) and the No-Ponzi-game (NPG) condition (Blanchard and Fischer, 1989 pp. 48-50). Ponzi financing arises when fresh loans are used to pay interest on past debt. The NPG condition requires that, in the long run, the present value of debt would eventually vanish, which is equivalent to the transversality condition required for optimizing dynamic choice (Kamihigashi, 2006). Studies on sustainability of (government) debt develop econometric tests to examine the fulfillment of the IBC and NPG condition (see Afonso, 2005).

Despite the importance of the IBC and NPG conditions, it is not clear how they are actually enforced, as economists Oliver Blanchard and Stanley Fischer (1989, p. 84 n. 24) rightly note. The Maastricht Treaty, for example, requires that the annual budget deficit of E.U. members not to exceed 3% of respective GDP, and the ratio of public debt to GDP to be less than 60% (see www.ecb.int, 08.2007). While these measures are helpful, they are ad hoc and do not address the heart of the issue: How debt arises in the first place?

Interest Regulation

The same critique applies to interest-ceiling and usury laws, although they have been the rule rather than the exception in most countries throughout history (Homer and Sylla, 2005; www.usurylaw.com, 08.2007). These regulations are in general useful, as they prevent excessive costs of borrowing, the most recent form of which is "payday loans," whereby annual interest exceeds 500% (Frank, 2007). Prominent economists, like Adam Smith, John Maynard Keynes, and Joseph Stiglitz, used to be in favor of usury laws (Spiegel, 1998; Stiglitz, 2003; Keen, 2004). However, these laws do not address the root of the problem, which gives their critics a strong case in their debate. Critics argue that interest is just a price, and as it is the case with any price, it should not be regulated (Persky, 2007).

But this misrepresents the nature of interest; interest is not merely a price, it is the *rate of self-replication of debt.* An interest of *x*% means that *x*% of outstanding balance will replicate itself instantaneously. Interest therefore allows debt to grow independent of wealth, which leads to serious economic ills, not the least of which is Ponzi-financing, as discussed above. Interest thus reflects the *rate of divergence of debt from real wealth.*

Ideally, on-time payment of due installments shall save debtors from exploding debt levels. However, the mechanism of interest makes *any* deviation from payment on time accumulates as debt, and thus adds to accruing interest. This in turn increases the amount-due, which makes future payment on-time less likely and thus worsens the situation further. The process obviously cannot continue indefinitely, and must somehow stop, causing cyclical movements in the economy. The positive feedback mechanism of interest therefore can transform white-noise (i.i.d.) errors into cycles and nonlinear dynamics. This mechanism is excluded from text-book economics through the IBC and NPG conditions, as pointed out earlier. To be excluded in reality, however, interest must be somehow regulated. Usury laws (as currently applied), the Maastricht Treaty, and similar regulations, while helpful, are ad hoc rules that do not address the root of the matter.

Islamic regulations require full integration of debt financing with wealth creation. Debt is a claim against wealth, and thus the two must be governed by the same principles, as Nobel laureate scientist-economist Frederick Soddy (1933) argued long time ago. Since wealth cannot grow exponentially for an extended period of time, then debt cannot either. This requires that the rate of divergence between the two processes must be zero. Positive interest means debt growth can diverge from wealth creation, leading to instabilities and economic ills. According to University of Maryland economist Herman Daly (1996, p. 179):

> Since wealth cannot continually grow as fast as debt, the one-to-one relation between the two will at some point in time be broken—there must be some repudiation or cancellation of debt. *The positive feedback of compound interest must be offset by counter acting forces of debt repudiation*, such as inflation, bankruptcy, or confiscatory taxation, all of which breed violence. Conventional wisdom considers the latter processes pathological, but accepts compound interest as normal. Logic demands, however, that we either constrain compound interest, or accept as normal and necessary one or more of the counteracting mechanisms of debt repudiation. (Emphasis added.)

The divergence of debt growth from wealth creation is what makes the economy vulnerable to cycles and thus financially fragile, as economist Hyman Minsky (1982,

1986) had argued. A capitalist economy, i.e. one which relies on interest-bearing debt for financing, has an inherent tendency towards financial fragility. Since “profit opportunities are constrained by the growth of productivity, while credit is not so constrained,” competition and profit-seeking incentives pushes the economy towards speculative debt levels, and thus higher degrees of fragility (Dymski and Pollin, 1992 p. 40). The “thrust towards fragility” therefore is a characteristic feature of interest-based economies.

Interest-based lending is another example of the fallacy of composition. If every agent decides to live on interest from lending, the economy will collapse, as Soddy (1933, p. 87) rightly points out. Since people cannot live off the interest of their mutual indebtedness, it becomes clear that, to avoid the fallacy of composition, interest must be regulated (Daly, 1996 p. 179). It is noteworthy to mention that both, interest-based lending and hoarding, are examples of fallacies of composition which cause economic collapse, and both are prohibited in Islamic economics.

Relative Behavior and Regulations

If we take into account relative behavior, a new insight arises behind the prohibition of *riba*. It prevents agents from evading independent variables necessary for the stability of the economy. This is not the only case in which regulations are necessary to prevent relative behavior from taking over the system thus causing loss of wealth and productivity. Frank (1985, ch. 7) provides several examples, including safety, minimum wage, and overtime regulations. These laws appear inconsistent with free markets. But Frank argues that such laws become understandable if relative behavior is taken into account. For the minimum wage law, for example, laborers take into account the wage income they receive as well as that of their peers. This structure makes workers compete with each other by reducing the wage rate they accept hoping to obtain better income than their peers. But this competition leads eventually to lower income without changing their relative standing. All workers become worse off. A legal restriction on minimum wage therefore will be Pareto optimal.

A similar reasoning applies to overtime. Workers tend to compete with each other in working after hours, thus negatively affecting their health and overall productivity. Adam Smith pointed out that, when workers "are liberally paid by piece, are very apt to overwork themselves and to ruin their health and constitution in a few years" (cited in Laffont and Martimort, 2002 p. 9).

In these examples, a "price war" is launched that ends up in loss to all parties. This "war" arises because of relative considerations that fuel competition. It is in the interest of all parties therefore to institute a ceiling or restriction on the extent of the game. The case of usury or *riba* is in the same vein. Interest income causes consumption of lenders to rise, thereby causing their neighbors to try to catch up by further borrowing, which in turn causes higher income and thus higher consumption of lenders, etc. Borrowers are endlessly trying to catch up, but every move they take makes it even harder to reach their goal. Instituting a law regulating for-profit lending therefore will make borrowers better off. The case of one borrower who went deep in debt then filed for bankruptcy in 1996 helps clarifying this point. A teacher in New York has accumulated more than $27,000 of debt on a dozen of credit cards and other loans, even when her monthly payments equaled her monthly pay. When she was forced to file for bankruptcy after being denied additional credit, she lamented saying, “I wish somebody had cut me off 10 years earlier” (Frank, 1999 pp. 47-48).

It should be noted that there are some important differences between the case of interest and that of minimum wage and related issues. In the latter issues, relative behavior appears as relative differences, or positional status. The competition takes place between agents, but they end up at the same position with less income and wealth. In the case of interest, relative variables appear as levels rather than differences, which rules out the zero-sum nature of the positional game. Further, the competition is not between deficit agents themselves but between deficit and surplus units. Finally, the end result of the game is not for agents to stay at the same position as in the game of status; rather, deficit units end up worse than what they started with, while surplus units end up better off. In other words, the interest game starts with milder conditions on relative behavior, yet ends up in worse results. This shows that the rationale for interest regulations is stronger than those regarding minimum wage and similar issues. As pointed out earlier, usury laws and similar regulations do not address the heart of the problem. Islamic rules, in contrast, deal with it at a more fundamental level.

Markup Financing

Markup financing is sale with a deferred price. The deferred price usually is higher than the spot price, and the difference is the "markup" that reflects time-value of delay. At a first glance, it seems that markup financing is a loan with interest, and thus there is no genuine difference between the two. This conception arises from equating interest with time-value, a conclusion that is not warranted in Islamic economics. Muslim scholars were very clear that time does have value in exchange, and is therefore reflected in the sale price. The problem is not with time; it is with debt.

Interest is a mechanism for debt replication, as pointed out earlier. It allows debt to grow independent of real wealth. Refinancing of past loans causes exponential growth of debt, which inevitably leads to high instabilities and severe distortions of wealth distribution. To avoid these consequences, time-value must be integrated with real, value-creating, transactions, such that debt is always under control. This is done through markup financing.

Markup financing is extended only with a sale, i.e. with a real transaction. This guarantees that financing is embedded in value-creating activities. Debt therefore cannot grow independent of real wealth, and thus debt services cannot uncontrollably exceed real resources. Although the markup adds to the income of creditors, thus raising their consumption, the cycle cannot go on all the way to bankruptcy. The reason is that markup financing cannot be used to finance pre-existing debts; it can be used only for current consumption. As a result, spending cannot persistently extend beyond means. The simulation makes it clear how the two mechanisms actually lead to completely different consequences.

Delayed Payment

A logical consequence of markup financing arises with respect to delayed payments. If creditors want to make profits, and if no markup is allowed on delayed payments, as this is forbidden *riba*, it follows that creditors, if possible, will not allow for delayed payment to arise in the first place. This is done by constraining credit provided to consumers to be within their available resources. Restricting credit therefore becomes an incentive-compatible strategy for creditors. Accordingly, credit extension would be limited such that amount due may not exceed a certain percentage of agent's average income. In fact, this policy is observed in reality where monetary authorities restrict monthly installment to a predetermined portion of monthly pay (e.g. in Saudi Arabia; www.sama.gov.sa).

If, however, creditors were able to generate returns from delayed payments, there will be no economic difference between markup financing and interest-based lending, other than semantics and terminology. This shows how legal artifices might defeat the logic and objectives of the legal system, creating inefficiencies due to fruitless and unproductive formalities.

Interest-free lending

Suppose in our model that lending is allowed but without interest. Interest-free lending is a non-profit transaction, although the borrower has to repay the loan. Since the borrower does not pay interest to the lender, the lender's income does not rise, and thus his consumption level does not rise. This breaks the cycle of consumption-borrowing that arises with *riba*. Hence, interest-free lending would help close the gap of consumption without ruining borrowers through accelerating debt levels.

IV.2 Implementation

The above model is implemented using an agent-based environment. The one chosen is NetLogo, developed by Prof. Uri Wilensky at Northwestern University (Wilensky, 1999). It is a simple yet flexible programming environment for simulating agent-based models.

There are 1225 agents modeled as patches on a landscape. Each agent receives an income and decides his consumption accordingly.

Each period, every agent gets a random draw from his income distribution. Income is exogenous and is distributed normally with mean μ_i and standard deviation σ. The mean, μ_i, is distributed uniformly among agents.

Initial consumption is determined by initial income and wealth. Afterwards, each agent sets his consumption level as a weighted average of his income and wealth in addition to average consumption of his local neighbors:

[6] $c_{i,t} = \beta_1 y_{i,t-1} + \beta_2 w_{i,t-1}$, for $t = 1$, and
$c_{i,t} = (1-\lambda)(\beta_1 y_{i,t-1} + \beta_2 w_{i,t-1}) + \lambda \overline{c}_{-i,t-1}$, for $t > 1$.

β_1 is "marginal propensity to consume" out of income, β_2 is marginal propensity to consume out of wealth, while λ is the weight of relative consumption. If $\lambda = 0$ the model reduces to Ando and Modigliani consumption model (e.g. Hall and Taylor, 1997). Any surplus of income after consumption is determined will be saved. Accumulated savings are added to wealth. Since savings are used to lend other agents, wealth become illiquid and therefore cannot be used for consumption. Savings are deposited in a central agency that manages lending and payments. Although a central agency might not be in the spirit of an agent-based model, in real life financial management is done electronically and therefore can operate to a large extent centrally. This is mainly a simplifying assumption to focus solely on consumption behavior and its consequences, without transaction costs or frictions.

Financing

The central agency manages channeling funds from surplus units to deficit units. Debtors have to pay back in installments over a defined number of periods. If aggregate savings are less than total demand for loans (total deficits), funds are rationed based on the relative size of deficit to total deficit. An agent can be a lender and a borrower simultaneously.

Loans are registered to agent's debt, which is deducted from accumulated savings to obtain his current net-worth. Loans are scheduled to be repaid in a pre-determined number of periods, set to 60 periods. (A period in this model can represent one month, so 60 periods is equivalent to 5 years, which is quite common in real life.) Collected repayments are distributed to lenders based on their shares in accumulated surpluses, or wealth.

Payments of principal loans are not added to income of creditors, but reflect a change in the liquidity of wealth. Total funds available for lending equals total principal payments, plus total current surpluses, plus previous funds not lent out.

Bankruptcy occurs when due installment exceeds a certain threshold. This is set to 2 times mean income, μ_i. Unless the agent has positive wealth to reduce his outstanding debt, if amount due reaches that threshold, he is declared bankrupt. Outstanding debt becomes then a "bad debt," and his existing wealth is "confiscated" and transferred to creditors. Bankruptcy would reset all variables to zero, so the bankrupt agent is "out of the economy" or unemployed for a certain number of periods (set to 15 periods). After that, he joins the economy with newly generated income and wealth.

Interest and Markup

If interest is allowed, it is calculated based on gross outstanding debt of the agent. Outstanding debt consists of past debt (i.e. past loans), current loans, and interest past-due payments, minus principal payments.

If markup financing is allowed instead, then markup is calculated on current loans only. That is, markup is added on fresh consumption financing, not past debt. It might appear that a markup is equivalent to simple interest. But it is more than that: Simple interest is charged for loans, while markup is charged for consumption financing, not loans per se. A loan can be used to finance consumption, and can be used to repay an outstanding debt, whereby simple interest transforms into compound interest when outstanding debt includes past-due interest. This cannot happen in markup financing, as financing is extended only for consumption, not pure loans.

Since markup is not charged for past debt, creditors will not allow for delayed payments, as discussed earlier. Accordingly, amount due is restricted to 0.5 of mean income. If this threshold is reached, a debtor has to reduce his outstanding debt through his net-worth, or otherwise no further credit is extended. This mechanism automatically precludes the possibility of bankruptcy, since amount due cannot by design exceed average income.

Markup and interest are distributed to creditors according to their shares in total credit, as before. They are added to their income. Net-income represents the current draw of income, plus interest or markup, minus amount due. For creditors, principal payments are not added to income since they were lent out from savings. Only markup or interest is added to income.

Charity

To examine the impact of charity, we assume that no lending takes place. The only source for closing the consumption gap is charity. The agent therefore sets his consumption to the minimum of his income or that determined by equation [6]. That is:

[7] $c_{i,t} = \min\{y_{i,t-1}, c^*_{i,t}\}$,

where $c^*_{i,t} = (1-\lambda)(\beta_1 y_{i,t-1} + \beta_2 w_{i,t-1}) + \lambda \overline{c}_{-i,t-1}$.

Savings are not used to finance current consumption (akin to “locked up” savings). This helps accumulating wealth. Not any agent is eligible to receive charity. Only those with

(1) below average net-worth and (2) whose current income is less than $c^*_{i,t}$, can receive charity to cover their deficits.

Charity is deducted from above-average wealth via the "central agency." Collected charities are distributed to eligible agents in accordance with their needs, i.e. the size of their deficit. The share of agent's deficit to total deficit determines his share in collected charities.

Simulation is performed for three different ratios of charity: 2.5%, 5%, and 10%, in addition of course to the default of no charity.

Parameters

There are several methods for estimating marginal propensities to consume out of income and out of wealth; for a review see Altissimo et al. (2005) and Hall and Taylor (1997). Parameters are assumed to take a range of values instead of a single point. This accommodates the heterogeneity of agents and supports robustness of results.

- Marginal propensity to consume out of income $\beta_1 \sim \text{uni}(0.85 \pm 15\%)$.
- Marginal propensity to consume out of wealth $\beta_2 \sim \text{uni}(0.01 \pm 30\%)$.
- Weight of relative consumption $\lambda \sim \text{uni}(0.5 \pm 30\%)$.
- Income distribution $y_i \sim N(\mu_i, 15)$, where $\mu_i \sim \text{uni}(75 \pm 30\%)$.
- Interest = 0.5% of outstanding debt per period, or 6% per 12 periods.
- Markup = 0.5% of new consumption loans per period,

or 6% per 12 periods.

- Bankruptcy threshold = $2\mu_i$.
- Markup installment threshold = $0.5\mu_i$.
- Number of periods = 1500.
- Number of agents = 1225.
- Number of neighbors for each agent = 8.

IV.3 Results

Financing

The results include three models: interest-free lending, interest-based lending, and markup-based financing. As mentioned earlier, each model was run for 1500 periods, and repeated 50 times (each with a different random seed number). The averages of the 50 runs are summarized in Table 1.

Standard denotes the model with interest-free lending. *Std* denotes standard deviation scaled by the mean. *Gap* denotes the difference between the mean value of the upper half of the population and that of the lower half, scaled by the median. The last row represents number of agents with value below 50% of the maximum in the population. Net-income represents income plus agent's share in markup or interest, minus amount due.

Table 1
Summary Statistics of Major Variables

	Standard	*Markup*	*Interest*
		Consumption	
Mean	74.3	74.3	69.7
Median	74.0	74.4	64.7
Std	0.186	0.226	0.541
Gap	0.316	0.377	0.835
No. below .5 Max	127	240	1040
		Net-income	
Mean	64.6	64.1	64.6
Median	64.6	64.9	62.7
Std	0.294	0.344	0.887
Gap	0.470	0.551	1.361
No. below .5 Max	537	621	1114
		Net-worth	
Mean	1,985	2,152	2,398
Median	1,730	1767	39
Std	0.858	0.942	1.988
Gap	1.609	1.827	130.947
No. below .5 Max	1,103	1,152	1,183

Note that Net-income in the standard model does not include paid installments from borrowers. These are registered as changes in the components of wealth. If a loan is made, wealth is transformed from cash to credit. If principal is repaid, it is back from credit to cash. Only markup and interest are included in net-income. Net-worth represents wealth minus debt, bounded by zero from below.

Overall, interest-based model is much more concentrated than the other two models. Markup model is less concentrated than the interest model, but more so than the interest-free model.

Table 2
Disaggregated Mean Values

	Standard		*Markup*		*Interest*	
	Lower	Upper	Lower	Upper	Lower	Upper
Consumption	62.6	86.0	60.3	88.3	42.7	96.7
Net-income	49.5	79.8	46.2	81.9	21.9	107.2
Net-worth	595	3,376	539	3,765	2	4,797

Table 2 presents disaggregated means for the three models. Upper and Lower denote the upper half and the lower half of the population for each variable, respectively. Upper half values show monotonic increases across the three models, while the lower half shows monotonic decreases. But the interest-based model shows disproportionate reduction for the lower half. This is very likely due to increased number of bankruptcies resulting from excessive debt levels.

Table 3
Debt Levels and Components

	Standard	*Markup*	*Interest*
Gross-debt	592	809	1,261
m/r debt	0	187	1,080
m/r share	0	0.231	0.857
Bankruptcies	0	0	1,930
Confiscated wealth	0	6	1,572

Table 3 shows data on debt. Gross-debt includes debt due to principal plus debt due to markup (m) or interest (r). Both markup and interest models have higher debt levels per agent than the standard, interest-free model, although the interest model is 50% higher in gross debt. Further, the distribution of debt differs significantly. Markup debt represents only 23% of gross-debt, while interest debt represents 85%. In other words, most debt obligations are due to interest on past debt, not new loans. Not surprisingly, consumption of the lower half (mostly debtors) is about 30% lower than that in the markup model.

Table 4 shows size of loans and repayments, per agent, for the three models.

Table 4
Flow of Funds

	Standard	*Markup*	*Interest*
Acc. loans	10,551	11,137	11,485
Acc. repayment	9,969	13,677	23,430
Acc. surplus	2,440	2,595	10,459
Repayment per $	0.945	1.228	2.040
Turnover	4.32	4.29	1.10
Effective cost of finance	0%	0.47%	2.91%
Effective rate of return	0%	2.03%	3.20%

Surplus is the amount of income in excess of consumption. Accumulated surplus thus represents savings for each agent accumulated throughout the life of the model. Accumulated loans represents total amount of money borrowed per agent throughout the life of the simulation. Accumulated repayment represents total amount repaid per agent.

The ratio of accumulated repayments to accumulated loans represents how much paid per dollar of loans. In the standard model, 95 cents per dollar of loans were repaid by the end of simulation. This is mainly due to new loans advanced before old ones are fully repaid. For the markup model, for each dollar of loans 1.23 was repaid, and for the interest model, 2 dollars were repaid. From the shares of markup and interest in Table 3, we know that 23% of repayment is for markup, while for the interest model, 85% is for interest. Since repayment is distributed over 60 periods, this means that agents in the markup model are paying effectively 0.47% in markup per dollar of loan per period, while in the interest model they are paying 2.9% in effective interest. This is in contrast to the nominal, contractual cost of 0.5% for each per period. This shows an important result: *interest-based financing ends up costing much more than markup financing*, despite the fact that they start with identical contractual cost per dollar.

Despite the significant difference in cost of financing, the difference in return on surplus is not as much. Table 4 lists accumulated surpluses, which represent the source of loans to borrowers. Dividing markup or interest repayment per period by surpluses gives average rate of return to creditors. For the markup model, it is 2%, while for the interest-based model it is 3.2%. The markup model therefore achieves about two-thirds of the return of the interest-model, but for about one-fifth of the costs.

This result can be attributed to turnover rate of funds.

The bottom row in Table 4 shows the ratio of accumulated loans to accumulated surpluses. For the standard model, each dollar of surpluses was lent about 4.3 times, which is about the same rate for the markup model. For the interest-based model it is only 1.1 times. That is, *the interest-based model is the least efficient in utilizing funds.* The reason is not difficult to see. The compound-interest mechanism makes it easier for debtors to delay principal repayment, and thus for creditors to accumulate additional surpluses per loan. The same loan therefore generates increasing levels of returns to lenders. This will make it less desirable for them to collect the original loan and re-lend it again. Consequently, turnover rate becomes very low. In the other two models, delay cannot generate income, and thus turnover rate will be much higher.

Table 5
Wealth and Debt

	Standard	*Markup*	*Interest*
Wealth	2,440	2,590	2,452
Debt	592	622	183
Gross debt	592	809	1,261
Net wealth	1,848	1,968	2,269
Net of gross	1,848	1,782	1,191

Table 5 shows average wealth and debt levels at the end of the simulation. Wealth represents agent's share in the central agency's assets. These assets consist of accumulated surpluses (in cash), and claims against borrowers (credit). The shares are determined by the ratio of accumulated surpluses of each agent divided by that of the population. Debt denotes principal debt plus past due of markup or interest debt. This is in contrast to gross debt, which includes in addition to principal, entire obligations of markup or interest, not only past due. Net wealth is wealth minus debt. Net-worth is simply the maximum of net-wealth or zero.

It should be noted that when net-wealth is aggregated over all agents, the result is simply cash assets, because credit and debt cancel each other out. Thus net-wealth represents available cash or liquid assets. When full markup or interest obligations are accounted for, we get the last row in Table 5.

The markup model achieved the highest level of wealth, i.e. the highest level of cash and credit per agent. Debt levels for the standard and markup models are comparable, but it is much lower for the interest model. The reason is that debt includes only principal debt plus past due interest. Since turnover rate is very low in the interest model, size of principal debt is much smaller than in the other two models. Accordingly, net-wealth is higher in the interest model than in the other two. However, if gross debt is considered, the interest model becomes the lowest in terms of net assets, while the standard and markup models achieve similar levels. If only net wealth of gross debt is available for investment, this means that the interest model will have the lowest investment and, subsequently, growth rates. This is a potential area for future investigation.

Dynamics

The above results describe the models at the end of the simulation. The figures below show the time evolution of the major variables for a typical run of these models. Figures 1 and 2 show average consumption and net-income of the three models, respectively.

Consumption is highly cyclical in the interest-based model, consistent with the role of interest in creating positive feedback loop leading to large number of bankruptcies. The cycles apparently cause consumption level to be about 8% less than the standard and the markup models. Consumption behavior in the markup model is very similar to that of the standard model. Recall that consumption here is assumed to be non-conspicuous, thus higher consumption overall implies higher welfare.

Figure 2 shows net-income. The standard and markup models have essentially similar patterns, while the interest-based model is highly cyclical.

Figure 1: Consumption

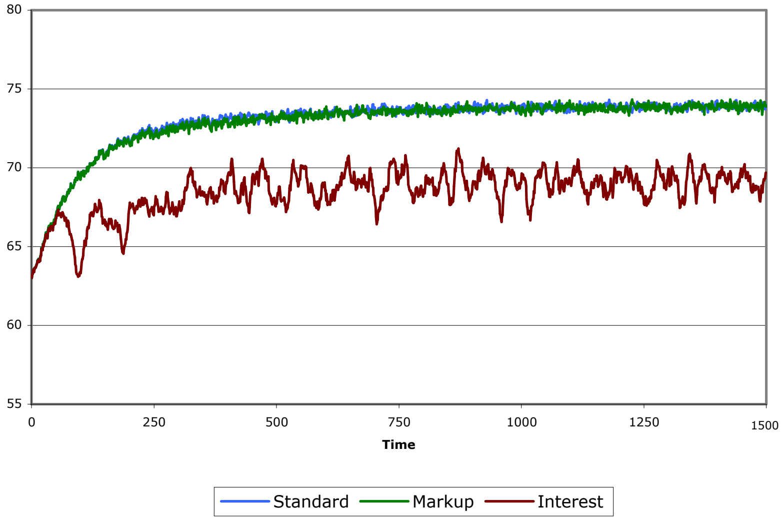
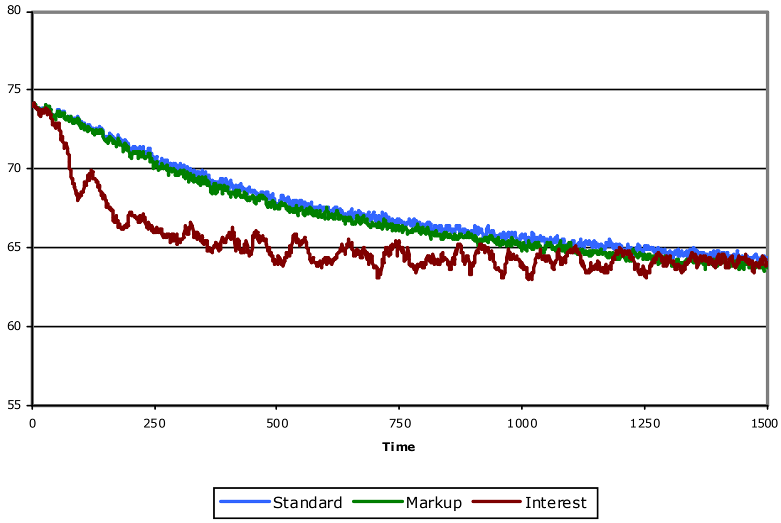


Figure 2: Net Income



(Graph is smoothed exponentially)

Figure 3: Lorenz Curve

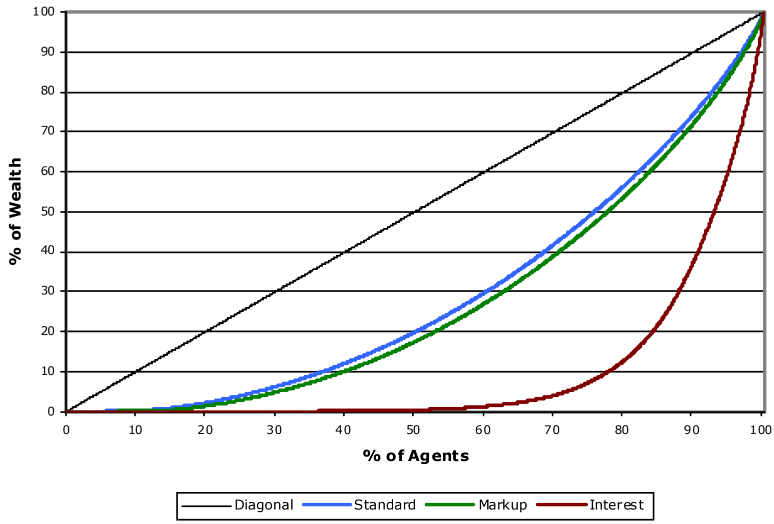


Table 6
Wealth Distribution, %

% of Agents	*Standard*	*Markup*	*Interest*
10	0.4	0.2	0.0
20	2.3	1.4	0.0
30	6.3	4.9	0.1
40	12	10	0.2
50	20	18	0.5
60	30	27	1.4
70	42	39	4.2
80	57	54	13
90	75	72	38

Wealth Distribution

Figure 3 shows Lorenz curve for the three models at the end of the simulation. The graph lists percentage of agents on the *x*-axis, and the corresponding percentage of aggregate wealth on the *y*-axis.

The graph shows that 70% of agents own 42% of wealth in the standard model, 39% of wealth in the markup model, and only 4.2% of wealth in the interest model (see Table 6). 80% of agents own 57% of net-worth in the standard model, 54% in the markup model, and 13% in the interest model. The top 10% of agents own 25%, 28%, and 62% of wealth in the three models, respectively. Wealth in the interest model is more than twice as concentrated in the hands of the upper segment as the other two models.

Summary of Financing Models

The above results show that different financing modes have dramatically different economic impacts. The results also provide insights that were not easily deducible:

1. Markup financing is fundamentally different from interest or *riba* financing. Despite some apparent similarities, they have starkly different impacts on economic variables. Most of the previous research on Islamic economics focused on profit sharing as “the” alternative financing instrument to interest. Although profit sharing is important and superior to other modes, markup financing nonetheless does

serve the goals of Islamic economics, particularly with respect to consumption, where profit sharing is not applicable.

2. Interest is not merely a price; it is a mechanism for debt growth. This is not the case for markup financing. Markup restricts debt to actual consumption, thus controlling the growth of debt to that of available resources. Interest in contrast allows debt to grow exponentially. Debt growth in this case is controlled not by interest but through bankruptcy.
3. We have seen that delayed payments are treated quite differently in the two models. In the interest model, they represent a source of income to lenders. This leads to very low turnover of funds, explosion of debt and consequently to economic cycles. The markup model does not allow for generating profits from these obligations. This puts an incentive to creditors not to extend credit beyond a level that would permit for delay to arise in the first place. This can be contrasted to some legal artifices that allow creditors in practice to gain from delay. Not only this contradicts the principles and logic of *Shari'ah*, but also makes markup financing economically indistinguishable from interest financing.
4. The interest model demonstrates several undesirable results. These include: cycles and

instability, wealth concentration, low fund utilization and thus high inefficiency, and high costs of borrowing. In contrast, the markup model shows stability, high efficiency, less concentration of wealth, and relatively low costs of financing.

5. The markup model is slightly more concentrated than the standard model, but it shows higher savings and liquidity. Although not modeled at this stage, higher savings potentially promote higher investment and higher economic growth.

Charity

The assumption of relative behavior also predicts that charity, i.e. transfers from high net-worth agents to low net-worth ones, might improve consumption of *both*, donors and receivers. The results below are obtained from simulations with similar parameters as before, except that no lending of any kind is allowed. This assures that results are purely due to charity as such. The interaction of charity with financing is certainly a potential area for future research.

Table 7 summarizes statistics of consumption at different charity structures. There is an overall increase in average and median consumption under all structures.

Minimum consumption has increased notably, while standard deviation and gap decreased notably also.

Table 7
Consumption Statistics under Charity

	$z = 0$	$z = 2.5\%$	$z = 5\%$	$z = 10\%$
Mean	74.0	78.1	79.0	78.9
Median	72.9	76.4	77.3	77.1
Max	120.4	120.9	121.1	120.6
Min	31.8	43.4	43.6	44.0
Std	0.223	0.174	0.165	0.165
Gap	0.373	0.288	0.272	0.272
No below .5 max	276	94	64	62

Consumption by Category

	$z = 0$	$z = 2.5\%$	$z = 5\%$	$z = 10\%$
Donors	84.8*	85.0	85.1	84.9
Receivers	63.6*	71.5	73.3	73.2

* Potential donors and receivers.

Number of agents with consumption below 50% of the maximum level has dropped significantly. Overall, charity was effective in reducing inequality in consumption and raising its aggregate level.

The Table shows that consumption overall rises with charity rate up to 5%; afterwards it declines slightly. That is, higher rates do not monotonically correspond to higher mean or median consumption.

Table 7 also compares consumption of both donors and receivers. Consumption of receivers has increased substantially, while that of donors increased only marginally. The increase for the 2.5% and 5% rates however is statistically significant at the 5% level (test statistics are not reported).

Improved consumption of donors arises from the small marginal impact of wealth, $(1-\lambda)\beta_2$ (around .005), compared with the marginal impact of relative behavior, λ (around .5). Thus by donating from wealth, the negative impact on consumption is much smaller, up to a point, than the positive impact of relative behavior.

Overall, results confirm the impact of charity in presence of relative behavior. Both donors and receivers are materially better off with charity, not only receivers. Note that this result differs from that obtained from the assumption of concave utility function, with diminishing marginal utility. With diminishing marginal utility, donors suffer less utility than that gained by receivers. Thus net aggregate utility would be higher. Here, *both* donors and receivers enjoy higher consumption. No assumption is made regarding the shape of the utility function. The relative behavior assumption thus reaches stronger results with less stringent, and more realistic, conditions.

IV.4 Extensions for Future Research

The above model is one application of the structure of complex systems as formulated in equation [1]. But there are other useful applications.

Suppose we want to model the behavior of an investor in a financial market. He shall purchase an amount of asset x based on two factors: its (intrinsic) return, r, and the decision of his peers or reference group, $\bar{x}$. This would have the same structure of [1] above:

[9] $x_{i,t} = f(r_t, \bar{x}_{-i,t-1})$.

As before, $\bar{x}$ is the relative variable, while r is the independent variable. As long as return is exogenous and is not dominated by relative behavior, model [9] shall be away from the phase of chaos. But what if r becomes determined primarily by $\bar{x}$? This would happen if: (1) returns were generated through price increases driven by increasing demand, and (2) peers are sufficiently large to affect demand and consequently returns.

The mechanism however may start from a small number of peers. As $\bar{x}$ rises for any reason, x also rises. This causes $\bar{x}$ of other groups to rise, leading in turn to additional rise in x, and so forth. As the reaction spreads among investors, the range of the reference group also extends.

In financial markets, the widespread of financial data might make the reference group for an investor effectively the majority of market participants. As Bonabeau (2004) argues, mass media can extend imitation beyond the close group of neighbors of friends.

Accordingly, the effect of peers would be sufficient to push the price up, and thus feeds back to demand. The system therefore becomes:

$$x_{i,t} = f(r(\overline{x}_{-i,t-1}), \overline{x}_{-i,t-1}).$$

In this case the system would be predominantly relative: Higher demand for the asset creates higher returns, which induces further demand, etc. It becomes a Ponzi scheme, where *investment creates its own return.* This would happen in financial markets in case of bubbles (Shiller, 2000).

Investors push the price of assets up, thus generating higher returns, leading to more investment, leading to even higher returns, and so on. Note that without relative behavior, peers' effect would not be sufficient to drive prices up. Peers affect each agent, thus creating network externalities that may transform the market to a Ponzi scheme.

This appears to be a promising line for future research.

V

CONCLUSION

This paper suggests a different approach for studying and analyzing economic behavior. Complexity theory provides an alternative paradigm to the Neoclassical framework widely adopted in economic studies. The new paradigm calls for a different methodology than the one used by the mainstream: agent-based simulation allows for exploring rich and highly complex problems in an intuitive and systematic manner.

From an Islamic point of view, the alternative theory and methodology appear more suitable to the problems and challenges facing Islamic economics. The applications discussed in the paper provide examples of how radically different results could arise from innocent assumptions not easily addressed through the conventional approach.

In particular, relative behavior appears to be a thread linking psychological, sociological, economic, and scientific aspects together. Self-organization requires relative behavior, which in turn has been widely documented in behavioral and sociological studies. The impact of relative behavior on economic analysis and policy recommendations is substantial, as discussed in detail in the literature. From an Islamic point view, usury or *riba* have a radically different impact in presence of relative considerations, giving another rationale for its legal prohibition. *Riba* allows agents to evade independent variables governing the economic system, thereby making the economy dominated by relative behavior, and pushing the system away from the phase of complexity towards the phase of chaos. Markup financing in contrast does not suffer these consequences. Finally, charity appears to have a greater positive impact in a complex economy, reinforcing the old wisdom.

Extending the logic of complex systems to financial markets might bring new insights on how the market might be transformed into a zero-sum, Ponzi system. These concepts deserve further investigations, and might well lead to fruitful research.

APPENDIX

NetLogo (v 3.1.4) Code
(RC Model 8.4.4)

```
globals
        [ seed-number time bankrupt acc-bankrupt consumption-ag consumption-md net-income-md wealth-ag net-income-ag net-worth-md net-worth-ag var-c var-y var-nw total-debt total-amount-due total-surplus total-deficit total-payment total-interest-due loan-share total-wealth total-net-worth total-interest-payment total-interest-past-due total-markup-payment total-markup-past-due loan-funds z-funds in-flow z-share eligible-deficit total-loan out-flow acc-c-wealth total-principal-payment total-acc-loan wealth-md wealth-ma var-w consumption-gap net-income-gap net-worth-gap total-acc-surplus total-acc-payment total-acc-principal-payment total-acc-markup-payment total-acc-interest-payment capital total-cash total-credit total-a-share total-c-share factor total-c-wealth total-net-wealth total-fresh-surplus total-donation total-charity ]

patches-own
       [ probability consumption income mean-income net-income p-income wealth donation class debt amount-due interest-c past-due interest-due interest-payment interest-past-due interest-share markup-payment markup-due markup-share markup-c markup-past-due credit surplus net-surplus loan default donor surplus-share  c-1 c-2 c-star avg-consumption payment interest-d installment-due principal-payment deficit net-worth gap charity d mpc mpc-w net-wealth principal-debt markup-debt interest-debt gross-debt no-of-loans acc-payment acc-loan acc-interest-payment acc-markup-payment acc-principal-payment acc-surplus acc-past-due c-share a-share net-share adj-share c-wealth adj-wealth fresh-surplus limit-loan ]

to setup
  ca
  set-random-seed
  setup-patches
end

to set-random-seed
   ifelse fix-random-seed
     [ let input-seed-number user-input "Type a seed number"
       set seed-number read-from-string input-seed-number
       random-seed seed-number ]
     [ set seed-number new-seed ]
   print "Seed number = " + seed-number
   print "Start at " + date-and-time
end

to setup-patches
  random-seed seed-number
  ask patches [
      set mean-income avg-income + (random  (2 * std-avg-income * avg-income)) - (std-avg-income * avg-income)
      set mpc income-propensity + (random-float (2 * std-mpc * income-propensity)) - (std-mpc * income-propensity)
          if mpc >= 1 [set mpc .99]
      set mpc-w wealth-propensity + (random-float (2 * std-mpc-w * wealth-propensity)) - (std-mpc-w * wealth-propensity)
      set consumption mpc * mean-income
      set pcolor scale-color brown (consumption) 1 139
      set d relativity + (random-float (2 * std-r * relativity) ) - (std-r * relativity)
          if d >= 1 [set d .9]
      ;set up shares
      set surplus 10
      set acc-surplus surplus
      set default 0
      set limit-loan false
    ]
  set capital sum values-from patches [acc-surplus]
```

```
  random-seed seed-number
end

to set-consumption
   ask patches [
       if default = 0 [
          ifelse gap >= 0
             [ set consumption c-star
               set loan 0
               set charity 0 ]

             ;else, if gap < 0, then:
             [ ifelse net-worth < net-worth-ag
                 [ set charity z-share * deficit
                   set donation 0 ]
                 [ set charity 0 ]; end of second ifesle
               set loan loan-share * (deficit - charity)
               set consumption (p-income + loan + charity) ]; end of first else.
          ; check markup condition
          if limit-loan = true
             [ set loan 0
               set consumption (p-income + charity)
               set limit-loan false ]
          set pcolor scale-color brown (consumption) 1 139
          ] ]
end




to generate-income
    ask patches [
          if default = 0
              [ set income abs( random-normal mean-income (std * mean-income) )
                set net-income ( income + interest-c + markup-c - amount-due )
                ifelse net-income < 0
                    [ set past-due abs(net-income)
                      set payment amount-due - past-due
                      ]
                    [ set payment amount-due
                      set past-due 0 ]
                set p-income max (list net-income 0)

             ]
        ]
end


to cal-payments
    ask patches [
        set interest-payment interest-share * payment
        set interest-past-due interest-share * past-due
        set markup-payment markup-share * payment
        set markup-past-due markup-share * past-due
        set principal-payment payment - interest-payment - markup-payment
        set interest-c surplus-share * total-interest-payment
        set markup-c surplus-share * total-markup-payment

        ]
    set total-payment sum values-from patches [payment]
    set total-principal-payment sum values-from patches [principal-payment]
    set total-markup-payment sum values-from patches [markup-payment]
    set total-interest-payment sum values-from patches [interest-payment]
    set total-interest-past-due sum values-from patches [interest-past-due]
    set total-markup-past-due sum values-from patches [markup-past-due]
    set total-acc-payment total-acc-payment + total-payment
    set  total-acc-principal-payment  total-acc-principal-payment  +  total-principal-
payment
    set total-acc-markup-payment total-acc-markup-payment + total-markup-payment
    set   total-acc-interest-payment   total-acc-interest-payment   +   total-interest-
payment
end


to cal-c-star
  ask patches [
     set avg-consumption mean values-from neighbors [consumption]
```

```
     set c-1 (1 - d) * ( (mpc * p-income) + (mpc-w * net-worth) )
     set c-2 d * avg-consumption
     set c-star c-1 + c-2
     ]
end


to cal-deficit-surplus
   ask patches [
       if default = 0 [
         set gap p-income - c-star
         ifelse gap >= 0
           [ set surplus gap
             set deficit 0
             ]
           [ set deficit abs(gap)
             set surplus 0
             ]
        set acc-surplus acc-surplus + surplus + fresh-surplus

          ]
      ]
   set total-deficit sum values-from patches [deficit]
   set total-surplus sum values-from patches [surplus]
   set total-fresh-surplus sum values-from patches [fresh-surplus]
   set in-flow in-flow + total-surplus + total-principal-payment
   set capital capital + total-surplus + total-fresh-surplus
   set out-flow out-flow + total-loan
end



to cal-donations
    ask patches [
        ifelse net-worth >= net-worth-ag
            [ set donor 1
              set donation (z / 1200) * net-worth
              set charity 0 ]
            [ set donation 0
              ifelse deficit > 0
                [ set donor -1 ]
                [ set donor 0 ] ]
                ]

    ; calculate charity
    set total-donation sum values-from patches [donation]
    set total-charity sum values-from patches [charity]
    set z-funds z-funds + total-donation - total-charity
    set  eligible-deficit  sum  values-from  patches  with  [net-worth  <  net-worth-ag]
[deficit]
    if eligible-deficit = 0 [set eligible-deficit 1]
    set z-share z-funds / eligible-deficit
    if z-share > 1 [set z-share 1]
end



to cal-loan-share
   set loan-funds loan-funds + total-surplus + total-principal-payment - total-loan
       if loan-funds < 0
         [set loan-funds 0
          user-message "negative loan-funds"]
   set total-cash loan-funds ; identity
   let total-deficit-1 max (list total-deficit 1)
   set loan-share min (list (loan-funds / total-deficit-1) 1)
   if allow-lending = false [ set loan-share 0 ]
end



to cal-debt
   if m > 0 [ set r 0 ]
   if r > 0 [ set m 0 ]
   ask patches [
     if default = 0 [
       set principal-debt principal-debt + loan - principal-payment ;
           if principal-debt < 0 [ set principal-debt 0]
```

```
       set markup-debt markup-debt + (loan-period * ( m / 1200 ) * loan) - markup-
payment
           if markup-debt < 0 [set markup-debt 0]
       set interest-debt interest-debt + (loan-period * ( r / 1200 ) * debt) -
interest-payment
           if interest-debt < 0 [set interest-debt 0]
       set gross-debt principal-debt + interest-debt + markup-debt
       set debt principal-debt + markup-past-due + interest-past-due
           if debt < 0 [set debt 0]
       set acc-payment acc-payment + payment
       if (markup-debt > 0 and interest-debt > 0) [user-message "warning: m & r >
0"]; just to check

 ; calculate installment and interest:
       set amount-due gross-debt / loan-period
       set interest-due interest-debt / loan-period
       set markup-due markup-debt / loan-period
       let gross-debt-1 max (list gross-debt 1)
       set interest-share interest-debt / gross-debt-1
       set markup-share markup-debt / gross-debt-1
        ] ; end of if
     ] ; end of ask.

    set total-amount-due sum values-from patches [amount-due]
    set total-debt sum values-from patches [debt]
    set total-credit total-debt ; identity
    set total-loan sum values-from patches [loan]
end


to cal-surplus-shares
   ask patches [
       if default = 0 [ set surplus-share acc-surplus / capital ]
       ]
end


to adjust-shares
   if total-c-wealth > 0 [
      ask patches [
          set c-share c-wealth / total-wealth
          set net-share (wealth - c-wealth) / total-wealth
          ifelse c-wealth > 0
              [ set a-share 0
                set adj-share net-share ]
              ; else:
              [ set a-share net-share  ] ; end of else
               ] ; end of ask

      set total-a-share sum values-from patches [a-share]
      set total-c-share sum values-from patches [c-share]
      set factor (total-a-share + total-c-share) / total-a-share
      ask patches [
          if a-share > 0 [ set adj-share a-share * factor ]
          set acc-surplus adj-share * capital
          set surplus-share adj-share
        ] ; end of ask
      ] ; end of if total-c-wealth > 0
end


to cal-wealth
    ask patches [
        set wealth surplus-share * (total-cash + total-credit)
        set net-wealth wealth - debt
        set net-worth max (list (net-wealth - donation) 0)
        set fresh-surplus 0
        ]
    set total-wealth sum values-from patches [wealth]
    set total-net-worth sum values-from patches [net-wealth]
end


to check-bankruptcy ;;patches-procedure
   ask patches [
       if default = 0 [
          if amount-due > 2 * mean-income
             [ ifelse net-worth > 0
```

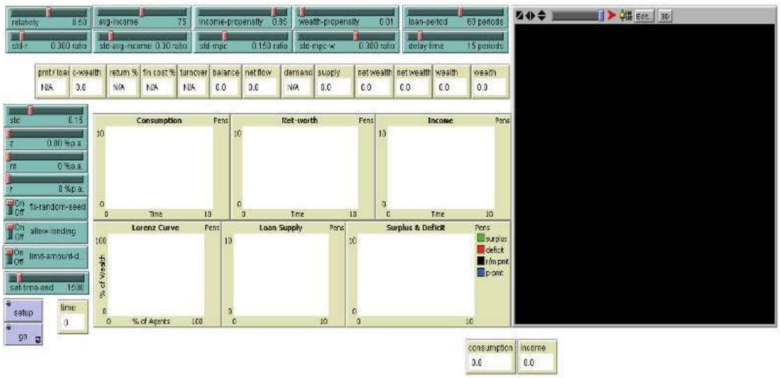
```
                [ set c-wealth debt
                  set debt 0
                  set principal-debt 0
                  set markup-debt 0
                  set interest-debt 0
                  ]
              ; else, if net-worth <= 0
              [ set c-wealth wealth
                 declare-bankruptcy ] ; end of else
             ] ; end of if amount-due > 2 * mean-income
           ] ; end of if default = 0
          ] ; end of ask
end

to update-bankruptcy
   ask patches [
       if default > 0
          [ ifelse default = delay-time + 1
              [ set default 0
                set income abs(random-normal mean-income std)
                set consumption mpc * income
                set fresh-surplus 10
                set pcolor scale-color brown (consumption) 1 139
                ]
              ; else
              [ declare-bankruptcy ] ; end of else
          ] ; end of if default > 0
       ] ; end of ask



       ; update counting
       let past-bankrupt bankrupt
       set bankrupt count patches with [default > 0]
       let d-bankrupt max (list (bankrupt - past-bankrupt) 0)
       set acc-bankrupt acc-bankrupt + d-bankrupt

 end



to check-markup-limit
   if limit-amount-due = true [
      ask patches [
          if amount-due >= .5 * mean-income [
              if m > 0
                  [ ifelse wealth > 0.1 * gross-debt
                      [ set c-wealth 0.1 * gross-debt
                        set principal-debt principal-debt - ( (1 - markup-share) * c-
wealth ) ; reduce principal-debt by its share
                            if principal-debt < 0 [set principal-debt 0]
                        set markup-debt markup-debt - ( markup-share * c-wealth ) ;
reduce markup-debt by its share
                            if markup-debt < 0 [set markup-debt 0]
                        ;update debt
                        set debt principal-debt + markup-past-due
                        set limit-loan false
                        ]

                 ; else, if wealth <= 0.1 * gross-debt, then:
                 [ set limit-loan true ]
                 ] ; end of ifelse
                    ] ]; end of ask.
        ] ; end of markup finance condition
end

to cal-c-wealth
   set total-c-wealth sum values-from patches [c-wealth]
   set acc-c-wealth acc-c-wealth + total-c-wealth
end

to update-loans
   ask patches [
          set acc-loan acc-loan + loan
          if loan > 0 [ set no-of-loans no-of-loans + 1]
          ]
end
```

```
to declare-bankruptcy
          set default default + 1
          set pcolor red
          set debt 0
          set principal-debt 0
          set gross-debt 0
          set markup-debt 0
          set interest-debt 0
          set consumption 0
          set income 0
          set net-income 0
          set loan 0
          set amount-due 0
          set past-due 0
          set interest-due 0
          set interest-c 0
          set interest-payment 0
          set interest-past-due 0
          set principal-payment 0
          set markup-due 0
          set markup-c 0
          set markup-past-due 0
          set markup-payment 0
          set payment 0
          set credit 0
          set wealth 0
          set net-wealth 0
          set net-worth 0
          set surplus 0
          set deficit 0
          set gap 0
          set acc-surplus 0
          set surplus-share 0
          set fresh-surplus 0
end


to update-net-wealth
   if total-c-wealth > 0 [
      set total-debt sum values-from patches [debt]
      set total-credit total-debt
      ask patches [
          set wealth surplus-share * (total-cash + total-credit)
          set net-wealth wealth - debt
          set net-worth max (list net-wealth 0)
          set c-wealth 0
          set net-share 0
          set adj-share 0
          ]
      set total-wealth sum values-from patches [wealth]
      ]
end



to decide-consumption
    check-bankruptcy
    check-markup-limit
    cal-c-wealth
    adjust-shares
    update-net-wealth
    update-bankruptcy
    generate-income
    cal-payments
    cal-c-star
    cal-deficit-surplus
    cal-donations
    cal-loan-share
    set-consumption
    update-loans
    cal-debt
    cal-surplus-shares
    cal-wealth
end
```

```
to draw-lorenz-curve  ; taken from Models Library of NetLogo
  set-current-plot "Lorenz Curve"
  clear-plot

  ;; draw a straight line from lower left to upper right
  set-current-plot-pen "equal"
  plot 0
  plot 100

  set-current-plot-pen "lorenz"
  set-plot-pen-interval 100 / 1225
  plot 0

  let sorted-wealths sort values-from patches [wealth]
  let total-wealth-g sum sorted-wealths
  let wealth-sum-so-far 0
  let index 0



  ;; now actually plot the Lorenz curve

  repeat 1225 [

    set wealth-sum-so-far (wealth-sum-so-far + item index sorted-wealths)
    let wealth-dist (wealth-sum-so-far / total-wealth-g) * 100
    plot wealth-dist
    set index (index + 1)
    ]

end

to do-plots
      set-current-plot "Income"
      plot net-income-ag

      set-current-plot "Consumption"
          set-current-plot-pen "default"
          plot consumption-ag
          set-current-plot-pen "max-consumption"
          plot max values-from patches [consumption] / 2

      set-current-plot "Surplus & Deficit"
        set-current-plot-pen "surplus"
        plot total-surplus / 1225
        set-current-plot-pen "deficit"
        plot total-deficit / 1225
        set-current-plot-pen "p-pmt"
        plot total-principal-payment / 1225
        set-current-plot-pen "r/m pmt"
        plot (total-interest-payment + total-markup-payment) / 1225

      set-current-plot "Net-worth"
      plot net-worth-ag

      set-current-plot "Loan Supply"
      plot loan-funds / 1225

      draw-lorenz-curve
end


to cal-aggregates

      set consumption-md median values-from patches [consumption]
      set consumption-ag (mean values-from patches [consumption])
      set consumption-gap (mean values-from patches with [consumption > consumption-
md][consumption]  -  mean  values-from  patches  with  [consumption  <  consumption-
md][consumption]) / consumption-md


      set net-income-md median values-from patches [net-income]
      set net-income-ag mean values-from patches [net-income]
      set  net-income-gap  (mean  values-from  patches  with  [net-income  >  net-income-
md][net-income]  -  mean  values-from  patches  with  [net-income  <  net-income-md][net-
income]) / net-income-md
```

```
      set net-worth-md median values-from patches [net-worth]
      set net-worth-ag mean values-from patches [net-worth]
      set  net-worth-gap  (mean  values-from  patches  with  [net-worth  >  net-worth-
md][net-worth] - mean values-from patches with [net-worth < net-worth-md][net-worth])
/ net-worth-md


      set wealth-md median values-from patches [wealth]
      set wealth-ag mean values-from patches [wealth]

      set var-c (standard-deviation values-from patches [consumption]) / consumption-
ag
      set var-y (standard-deviation values-from patches [net-income]) / net-income-ag
      set var-nw (standard-deviation values-from patches [net-worth]) / net-worth-ag
      set var-w (standard-deviation values-from patches [wealth]) / wealth-ag

end



to go
  set time time + 1
  decide-consumption
  cal-aggregates
  do-plots
  if time = set-time-end
    [ print "End at " + date-and-time
      stop ]
end
```

NetLogo Interface:



REFERENCES

Abraham, R. (2002) "The Genesis of Complexity," Visual Math Institute. URL: www.vismath.org.

Afonso, A. (2005) "Fiscal Sustainability: The Unpleasant European Case," *FinanzArchiv: Public Finance Analysis*, vol. 61, pp. 19-44.

Alexopoulos, M. and S. Sapp (2006) "Exploring the Behavior of Economic Agents: The Role of Relative Preferences," *Economic Bulletin*, vol. 12, pp. 1-7.

Altissimo, F., E. Georgiou, T. Sastre, M. Valderrama, G. Sterne, M. Stocker, M. Weth, K. Whelan, and A. Willman (2005) *Wealth and Asset Price Effects on Economic Activity*, European Central Bank, Occasional paper no. 29.

Anderson, P.W., K.J. Arrow, and D. Pines, eds. (1988) *The Economy as an Evolving Complex System*, Addison-Wesley Publishing.

Aragones, E., I. Gilboa, A. Postlewaite, and D. Schmeidler (2005) "Fact-free Learning," *American Economic Review*, vol. 95, pp. 1355-68.

Aronson, E. (1995) *The Social Animal*, W.H. Freeman & Co.

Arrow, K. (1986) "Rationality of Self and Others in an Economic System," in R. Hogarth and M. Reder, eds., pp. 201-15.

Arrow, K. (1988) "Workshop on the Economy as an Evolving Complex System: Summary," in Anderson et al., eds., pp. 275-81.

Arrow, K. (1994) "Methodological Individualism and Social Knowledge," *American Economic Review*, vol. 84, pp. 1-9.

Arthur, W.B. (1988) "Self-reinforcing Mechanisms in Economics," in Anderson et al., eds., pp. 9-31.

Arthur, W.B. (1990) "Positive Feedbacks in the Economy," *Scientific American*, vol. 262, pp. 92-6.

Arthur, W.B. (1994) "Inductive Reasoning and Bounded Rationality," *American Economic Review*, vol. 84, no. 2, pp. 406-11.

Arthur, W.B. (1996) "Increasing returns and the New World of

Business," *Harvard Business Review*, vol. 74, pp. 100-9.

Arthur, W.B. (1999) "The End of Certainty in Economics," in Clippinger, J.H., ed., *The Biology of Business*, Jossey-Bass Publishers, pp. 31-46.

Arthur, W.B., S. Durlauf, and D. Lane, eds. (1997) *The Economy as an Evolving Complex System II*, Westview Press.

Auyang, S.Y. (1998) *Foundations of Complex-system Theories in Economics, Evolutionary Biology, and Statistical Physics*, Cambridge University Press.

Axelrod, R. (1984) *Evolution of Cooperation*, Basic Books.

Axelrod, R. (1997) *The Complexity of Cooperation: Agent-based Models of Competition and Cooperation*, Princeton University Press.

Axtell, R. (1999) "The Emergence of Firms in a Population of Agents: Local Increasing Returns, Unstable Nash Equilibria, and Power Law Distributions," Center on Social and Economic Dynamics, Brooking Institution, Washington, D.C., Working Paper no. 3.

Axtell, R. (2005) "The Complexity of Exchange," *Economic Journal*, vol. 115, pp. F193-F210.

Bagwell, L., and B. Bernheim (1996) "Veblen Effects in a Theory of Conspicuous Consumption," *American Economic Review*, vol. 86, pp. 349-73.

Bak, P. (1996) *How Nature Works: The Science of Self-organized Criticality*, Springer-Verlag.

Bak, P., K. Chen, J. Sheinkman, and M. Woodford (1993) "Aggregate Fluctuations from Independent Sectoral Shocks," *Ricerche Economiche*, vol. 47, pp. 3-30.

Barabási, A. (2003) *Linked*, Plume, Penguin Group.

Barry, N. (1982) "The Tradition of Spontaneous Order," *Literature of Liberty*, vol. 5, pp. 7-58. URL: www.econlib.org.

Batten, D. (2000) *Discovering Artificial Economics*, Westview Press.

Baum, E. (1997) "Toward a Model of Intelligence as an Economy of Idiots," NEC Research Institute. URL:

www.neci.nj.nec.com:80/homepages/eric/eric.html.

Baum, E. (1998) "Manifesto for an Evolutionary Economics of Intelligence," in C. Bishop, ed., *Neural Networks and Machine Learning*, Springer-Verlag, pp. 285-344.

Baumol, W.J. (1993) *Entrepreneurship, Management, and the Structure of Payoffs*, MIT Press.

Becker, G., and K. Murphy (2000) *Social Economics: Market Behavior in a Social Environment*, Belknap Press of Harvard University Press.

Beinhocker, E.D. (2006) *The Origin of Wealth: Evolution, Complexity, and the Radical Remaking of Economics*, Harvard Business School Press.

Ben-Ner, A., and L. Putterman, eds. (1998) *Economics, Values, and Organizations*, Cambridge University Press.

Besanko, D., D. Dranove, M. Shanley, and S. Schaefer (2004) *Economics of Strategy*, 3rd ed., Wiley.

Bikhchandani, S., D. Hirshleifer, and I. Welch (1992) "A Theory of Fads, Fashion, Custom, and Cultural Change as Information Cascades," *Journal of Political Economy*, vol. 100, pp. 992-1026.

Blanchard, O., and S. Fischer (1989) *Lectures on Macroeconomics*, MIT Press.

Bonabeau E. and C. Meyer (2001) "Swarm Intelligence: A Whole New Way to Think About Business," *Harvard Business Review*, May, pp. 107-114.

Bonabeau, E, M. Dorigo, and G. Theraulaz (1999) *Swarm Intelligence: From Natural to Artificial Systems*, Oxford University Press.

Bonabeau, E. (2004) "The Perils of the Imitation Age," *Harvard Business Review*, June, pp. 45-54.

Brock, W.A. (2000) "Some Santa Fe Scenery," in D. Colander, ed., pp. 29-49.

Brooks, R. (1991) "Intelligence without Reason," MIT Artificial Intelligence Laboratory, Memo no. 1293.

Buchanan, M. (2002) *Nexus: Small Worlds and the Ground Breaking Science of Networks*, W.W. Norton.

Camazine, S. J-L. Deneubourg, N.R. Franks, J. Sneyd, G. Theraulaz, and E. Bonabeau (2001) *Self-Organization in Biological Systems*, Princeton University Press.

Camerer, C. (2003) *Behavioral Game Theory*, Princeton University Press.

Camerer, C., G. Loewenstein, and M. Rabin, eds. (2004) *Advances in Behavioral Economics*, Princeton University Press.

Celen, B., and S. Kariv (2005) "Distinguishing Informational Cascades from Herd Behavior in the Laboratory," *American Economic Review*, vol. 94, pp. 484-498.

Chaitin, G. (1998) *Limits to Mathematics*, Springer-Verlag.

Chaitin, G. (2002) "On the Intelligibility of the Universe and Notions of Simplicity, Complexity, and Irreducibility," German Philosophy Association. URL: www.cs.auckland.ac.nz/CDMTCS/Chaitin.

Chapra, U. (1986) *Towards a Just Monetary System*, The Islamic Foundation.

Choi, Y.B. (1993) *Paradigms and Conventions: Uncertainty, Decision Making, and Entrepreneurship*, University of Michigan Press.

Colander, D., ed. (2000) *The Complexity Vision and the Teaching of Economics*, Edward Elgar.

Colander, D., R. Holt, and J.B. Rosser (2003) *The Changing Face of Economics: Conversations with Cutting Edge Economists*, University of Michigan Press.

Cooper, R. (1999) *Coordination Games*, Cambridge University Press.

Daly, H. (1996) *Beyond Growth: The Economics of Sustainable Development*, Beacon Press, Ch. 12. Reprinted from Daly, H. (1980) "The Economic Thought of Frederick Soddy," *History of Political Economy*, vol. 12, pp. 469-88.

David, P. (2005) "Path Dependence in Economic Processes: Implications for Policy Analysis in Dynamical System Context," in K. Dopfer, ed., pp. 151-194.

Deaton, A. and J. Muelbauer (1980) *Economics and Consumer Behavior*, Cambridge University Press.

Debreu, G. (1959) *Theory of Value*, Yale University Press.

Debreu, G. (1991) "The Mathematization of Economic Theory," *American Economic Review*, vol. 81, pp. 1-7.

Dixit, A. and R. Pindyck (1994) *Investment Under Uncertainty*, Princeton University Press.

Dopfer, K. (2005) "Evolutionary Economics: A Theoretical Framework", in K. Dopfer, ed., pp. 3-55.

Dopfer, K., ed. (2005) *The Evolutionary Foundations of Economics*, Cambridge University Press.

Dore, M.H.I., and J.B Rosser, Jr. (2006) "Do Nonlinear Dynamics in Economics Amount to Kuhnian Paradigm Shift?", memo, James Madison University, URL: cob.jmu.edu/rosserjb.

Dosi, G., L. Marengo, and G. Fagiolo (2005) "Learning in Evolutionary Environments," in K. Dopfer, ed., pp. 255-338.

Drehmann, M., J. Oechssler, and A. Roider "Herding and Contrarion Behavior in Financial Markets: An Internet Experiment," *American Economic Review*, vol. 95, pp. 1403-26.

Duesenberry, J. S. (1949) *Income, Saving, and the Theory of Consumer Behavior*, Harvard University Press.

Durlauf, S. (2005) "Complexity and Empirical Economics," *Economic Journal*, vol. 115, pp. F225-43.

Durlauf, S., and H.P. Young, eds. (2001) *Social Dynamics*, MIT Press.

Dymski, G. and R. Pollin (1992) "Hyman Minsky as Hedgehog: The Power of the Wall Street Paradigm," in S. Fazzari and D. Papadmitriou, eds., *Financial Conditions and Macroeconomics Performance: Essays in Honor of Hyman P. Minsky*, M.E. Sharpe Inc, pp. 27-61.

Eatwell, J., M. Milgate, and P. Newman, eds. (1998) *The New Palgrave Dictionary of Economics*, Palgrave Publishers.

El Diwany, T. (2003) *The Problem with Interest*, 2nd ed., Kreatoc Ltd.

Epstein, J. (2006) *Generative Social Science: Studies in Agent-based Computational Modeling*, Princeton University Press.

Epstein, J. and R. Axtell (1996) *Growing Artificial Societies*, MIT Press.

Eshel, I., L. Samuelson, and A. Shaked (1998) "Altruists, Egoists, and Hooligans in a Local Interaction Model," *American Economic Review*, vol. 88, pp. 157-79.

Flake, G. (1998) *The Computational Beauty of Nature: Computer Explorations of Fractals, Chaos, Complex Systems, and Adaptation*, MIT Press.

Foley, D. (1998) "Introduction," in P. Albin, *Barriers and Bounds to Rationality*, edited with an introduction by D. Foley, Princeton University press.

Foley, D. (2000) "Complexity and Economic Education," in D. Colander, ed., pp. 167-73.

Foley, D. (2003) *Unholy Trinity: Labor, Capital, and Land in the New Economy*, Routledge.

Foley, D. (2005) "The Complexity Vision in Economics," presented at Workshop on Computable Economics, University of Ireland, Galway, March 21-25.

Foster, D.P., and H.P. Young (2001) "On the Impossibility of Predicting the Behavior of Rational Agents," *Proceedings of the National Academy of Science*, vol. 98, pp. 12848-53

Frank, R. (1985) *Choosing the Right Pond: Human Behavior and the Quest for Status*, Oxford University Press.

Frank, R. (1998) "Social Norms as Positional Arms Control Agreements," in A. Ben-Ner and L. Putterman, eds., pp. 275-295.

Frank, R. (1999) *Luxury Fever*, Princeton University Press.

Frank, R. (2007) "Payday Loans Are a Scourge, but Should Wrath Be Aimed at the Lenders?" *The New York Times*, January, 18.

Frank, R. and P. Cook (1995) *The Winner-Take-All Society*, Penguin Books.

Fredkin, E. (2000) *Introduction to Digital Philosophy*, URL: www.digitalphilosophy.org.

Freeman, C. (1998) "Innovation," in Eatwell et al., eds., vol. 2, pp. 858-

860.

Frey, B. and A. Stutzer (2002) "What Can Economists Learn from Happiness Research?" *Journal of Economic Literature*, vol. 40, pp. 402-435.

Galbraith, J. K. (1994) "Keynes, Einstein, and Scientific Revolution," *The American Prospect*, Issue 12.01.94. URL: www.prospect.org.

Gaylord, R., and L. D' Andria (1998) *Simulating Society: A Mathematica Toolkit for Modeling Socioeconomic Behavior*, Springer TELOS.

Georgescu-Roegen, N. (1971) *The Entropy Law and Economic Processes*, Harvard University Press.

Gigerenzer, G. (2004) "Is the Mind Irrational or Ecologically Rational?" in F. Parisi and V. Smith, eds., pp. 37-67.

Gigerenzer, G., P. Todd, and the ABC Research Group (1999) *Simple Heuristics that Make Us Smart*, Oxford University Press.

Gilbert, N., and K. Troitzsch (1999) *Simulation for the Social Scientist*, Open University Press.

Gintis, H., S. Bowles, R. Boyd, and E. Fehr, eds. (2005) *Moral Sentiments and Material Incentives: The Foundations of Cooperation in Economic Life*, MIT Press.

Glaeser, E., and J. Scheinkman (1998) "Neither a Borrower nor a Lender Be: An Economic Analysis of Interest Restrictions and Usury Laws," *Journal of Law and Economics*, vol. 41, pp. 1-36.

Gleick, J. (1987) *Chaos*, Viking Penguin.

Goldstein, R. (2005) *Incompleteness: The Proof and Paradox of Kurt Gödel*, W.W. Norton.

Goleman, D. (2006) *Social Intelligence*, Bantam Books.

Goodwin, R. (1947) "Dynamical Coupling with Especial Reference to Markets Having Production Lags," *Econometrica*, vol. 15, pp. 181-204.

Gribbin, J. (2004) *Deep Simplicity: Bringing Order to Chaos and Complexity*, Random House.

Hall, R., and J. Taylor (1997) *Macroeconomics*, 5th ed., W.W. Norton.

Hands, D.W. (2006) "Integrability, Rationalizability, and Path-Dependency in the History of Demand Theory," *History of Political Economy*, vol. 38, Supp. 1, pp. 153-85.

Harbaugh, R. (1996) "Falling Behind the Joneses: Relative Consumption and the Growth-Saving Paradox," *Economics Letters*, vol. 53, pp. 297-304.

Hargadon, A. (2003) *How Breakthroughs Happen*, Harvard Business School Press.

Hawking, S. (1996) *A Brief History of Time*, updated and expanded edition, Bantam Books.

Hayek, F. (1945) "The Use of Knowledge in Society," *American Economic Review*, vol. 35, pp. 519-30.

Heal, G.M. (1998) "The Economics of Increasing Returns," Columbia Business School, Working Paper PW-97-20, Columbia University.

Heiner, R. (1983) "The Origin of Predictable Behavior," *American Economic Review*, vol. 73, no. 4, pp. 560-95.

Hildenbrand, W., and A.P. Kirman (1988) *Equilibrium Analysis*, North-Holland.

Hogarth, R.M., and M.W. Reder, eds. (1986) *Rational Choice: The Contrast Between Economics and Psychology*, University of Chicago Press. The material originally appeared in *Journal of Business*, 1986, vol. 59, supplement.

Holland, J.H. (1988) "The Global Economy as an Adaptive Process," in Anderson et al., eds., pp. 117-124.

Holland, J.H. (1995) *Hidden Order*, Basic Books.

Holland, J.H. (1999) *Emergence: From Chaos to Order*, Perseus Books.

Holland, J.H., K.J. Holyoak, R.E. Nisbett, and P.R. Thagard (1986) *Induction: Processes of Inference, Learning and Discovery*, MIT Press.

Homer, S., and R. Sylla (2005) *A History of Interest Rates*, 4th ed., Wiley Finance.

Hopkins, E., and T. Kornienko (2004) "Running to Keep in the Same Place: Consumer Choice as a Game of Status," *American Economic*

Review, vol. 94, pp. 1085-107.

Huberman, B. and T. Hogg (1995) "Distributed Computation as an Economic System," *Journal of Economic Perspectives*, vol. 9, pp. 141-52.

Jehle, G. A. (1991) *Advanced Microeconomic Theory*, Prentice Hall.

Kamihigashi, T. (2006) "Transversality Conditions and Dynamic Economic Behavior," Kobe University, Japan. URL: www.rieb.kobe-u.ac.jp.

Kauffman, S. (1993) *The Origins of Order: Self-organization and Selection in Evolution*, Oxford University Press.

Kauffman, S. (1995) *At Home in the Universe: The Search for Laws of Self-Organization and Complexity*, Oxford University Press.

Kauffman, S. (2000) *Investigations*, Oxford University Press.

Ke, J. (2004) "Self-Organization and Language Evolution: System, Population, and Evolution," Ph.D. dissertation, City University of Hong Kong.

Keen, S. (2004) *Debunking Economics: The Naked Emperor of Social Sciences*, Zed Books.

Kennedy, J. and R. Eberhart (2001) *Swarm Intelligence*, Morgan Kaufman Publishers.

Kirman, A. (1997) "The Economy as an Interactive System," in W.B. Arthur et al., eds., pp. 491-531.

Kirman, A. (1992) "Whom or What Does the Representative Individual Represent?" *Journal of Economic Perspectives*, vol. 6, pp. 117-36.

Knight, F. (1935) *Ethics of Competition*, Allen Unwin.

Kollman, K., J. Miller, and S. Page (1997) "Computational Political Economy," in W.B. Arthur et al., eds., pp. 461-90.

Koppl, R. (2001) "Teaching Complexity: An Austrian Approach," in D. Colander, ed., pp. 137-46.

Koppl, R. and J.B. Rosser (2002) "All That I Have to Say Has Already Crossed Your Mind," *Metroeconomica*, vol. 53, pp. 339-60.

Krugman, P. (1996) *The Self-Organizing Economy*, Blackwell Publisher.

Laffont, J. and D. Martimort (2002) *The Theory of Incentives: The Principal-Agent Model*, Princeton University Press.

LeBaron, B. (2006) "Agent-based Computational Finance," in L. Tesfatsion and K. Judd, eds., pp. 1187-233.

Lee, C. (2005) "Emergence and Universal Computation," in K. Velupillai, ed. (2005*d*) pp. 198-217.

Lewis, A. (1992) "On Turing Degrees of Walrasian Models and a General Impossibility Result in the Theory of Decision Making," *Mathematical Social Sciences*, vol. 24, pp. 141-71.

Lucas, R.E. (1986) "Adaptive Behavior in Economic Theory," in R. Hogarth and M. Reder, eds., pp. 217-42.

Luna, F. (2005) "Research and Development in Computable Production Functions," in Velupillai, ed. (2005*d*) pp. 219-32.

Manski, F. (2000) "Economic Analysis of Social Interactions," *Journal of Economic Perspectives*, vol. 14, pp. 115-36.

Markose, S. (2002) "The New Evolutionary Computational Paradigm of Complex Adaptive Systems," in Shu-Heng Chen, ed. *Genetic Algorithms and Genetic Programming in Computational Finance*, Kluwer Academic Publishers.

Markose, S. (2005) "Computability and Evolutionary Complexity: Markets as Complex Adaptive Systems (CAS)," *Economic Journal*, vol. 115, pp. F159-F192.

Martens, B. (2000) "Towards a Generalized Coase Theorem: A Theory of The Emergence of Social and Institutional Structures Under Imperfect Information," in W.A. Barnett, C. Chiarella, S. Keen, R. Marks, and H. Schnabl, eds., *Commerce, Complexity, and Evolution*, Proceedings of the 12^{th} International Symposium in Economic Theory and Econometrics, Cambridge University Press.

Meyer, C. and S. Davis (2003) *It's Alive: The Coming Convergence of Information, Biology and Business*, Crown Business.

Miller, J., and S. Page (2007) *Complex Adaptive Systems: An Introduction to Computational Models of Social Life*, Princeton University Press.

Miller, M.S., and K.E. Drexler (1988) "Markets and Computation:

Agoric Open Systems," in B. Huberman, ed., *The Ecology of Computation*, North Holland, pp. 51-76.

Minsky, H. (1982) *Can "It" Happen Again?* M.E. Sharpe Inc.

Minsky, H. (1986) *Stabilizing an Unstable Economy*, Yale University Press.

Mirowski, P. (1989) *More Heat than Light: Economics as Social Physics, Physics as Nature's Economics*, Cambridge University Press.

Newman, P. (1998) "Convexity," in Eatwell et al., vol. 1, pp. 645-7.

North, D. (2005) *Understanding the Process of Economic Change*, Princeton University Press.

North, M. and C. Macal (2007) *Managing Complexity: Discovering Strategic Solutions with Agent-based Modeling and Simulations*, Oxford University Press.

Page, S. (2007) *The Difference: How the Power of Diversity Creates Better Groups, Firms, Schools, and Societies*, Princeton University Press.

Parisi, F., and V. Smith, eds. (2005) *The Law and Economics of Irrational Behavior*, Stanford University Press.

Penrose, R. (1989) *The Emperor's New Mind*, Oxford University Press.

Perelman, M. (1996) *The End of Economics*, Routledge.

Persky, J. (2007) "From Usury to Interest," *Journal of Economic Perspectives*, vol. 21, pp. 227-36.

Pollak, R. (1976) "Interdependent Preferences," *American Economic Review*, vol. 66, pp. 309-20.

Popper, K. (1957) *Poverty of Historicism*, Beacon Press.

Prasad, K. (1991) "Computability and Randomness of Nash Equilibrium in Infinite Games," *Journal of Mathematical Economics*, vol. 20, pp. 429-42.

Prigogine, I. (1997) *The End of Certainty*, Free Press.

Prigogine, I. (2005) "The Rediscovery of Value and the Opening of Economics," in K. Dopfer, ed., pp. 61-9.

Puffert, D. (2003) "Path Dependence," in R. Whaples, ed., *EH.Net Encyclopedia*. URL: eh.net/encyclopedia/article/puffert.path.dependence.

Rayo, L., and G.S. Becker (2006) "Peer Comparisons and Consumer Debt," *University of Chicago Law Review*, vol. 73, pp. 231-48.

Resnick, M. (1994) *Turtles, Termites, and Traffic Jams*, MIT Press.

Reynolds, C. (2001) *Boids*, URL: www.red3d.com/cwr/boids.

Richerson, P. and R. Boyd (2005) *Not by Genes Alone: How Culture Transformed Human Evolution*, University of Chicago Press.

Rosser, J.B. (1999) "On the Complexities of Complex Economic Dynamics," *Journal of Economic Perspectives*, vol. 13, no. 4, pp. 169-92.

Rothschild, M. (2000) "Complexity, Business, and Biological Metaphors," in D. Colander, ed., pp. 285-96.

Rubinstein, A. (1998) *Modeling Bounded Rationality*, MIT Press.

Ruelle, D. (1988) "Can Nonlinear Dynamics Help Economists?" in Anderson et al., pp. 195-204.

Rust, J. (1997) "Dealing with the Complexity of Economic Calculations," Yale University, Working paper.

Saint-Paul, G. (2005) "Some Evolutionary Foundations for Price Level Rigidity," *American Economic Review*, vol. 95, pp. 765-79.

Samuelson, L. (2004) "Information-based Relative Consumption Effects," *Econometrica*, vol. 72, pp. 93-118.

Samuelson, P. (1947) *Foundations of Economic Analysis*, Harvard University Press.

Sangalli, A. (1998) *The Importance of Being Fuzzy, and Other Insights from the Border between Math and Computers*, Princeton University Press.

Sawyer, R. (2005) *Social Emergence: Societies as Complex Systems*, Cambridge University Press.

Schelling, T. (1960) *The Strategy of Conflict*, Harvard University Press.

Schelling, T. (1978) *Micromotives and Macrobehavior*, W.W. Norton.

Schelling, T. (2006) "Some Fun, Thirty-Five Years Ago," in L. Tesfatsion and K. Judd, eds., pp. 1639-44.

Sen, A. (1997) "Maximization and the Act of Choice," *Econometrica*, vol. 65, pp. 745-79.

Shiller, R. (2000) *Irrational Exuberance*, Princeton University Press.

Silberberg, E. (1990) *The Structure of Economics: A Mathematical Analysis*, McGraw Hill.

Simon, H. (1957) *Models of Man: Social and Rational*, Wiley.

Simon, H. (1978) "Rationality as Process and as Product of Thought," *American Economic Review*, vol. 68, pp. 1-16.

Simon, H. (1986) "Rationality in Psychology and Economics," in R. Hogarth and M. Reder, eds., pp. 25-40.

Skyrms, B. (1996) *Evolution of the Social Contract*, Cambridge University Press.

Smith, E. and D. Foley (2005) "Classical Thermodynamics and Economic General Equilibrium Theory," New School University, Center for Economic Policy Analysis, Working paper.

Smith, V. (2003) "Constructivist and Ecological Rationality in Economics," *American Economic Review*, vol. 93, pp. 465-508.

Sobel, J. (2005) "Interdependent Preferences and Reciprocity," *Journal of Economic Literature*, vol. 43, pp. 392-436.

Soddy, F. (1933) *Wealth, Virtual Wealth, and Debt*, 2nd ed., E.P. Dutton.

Sornette, D. (2003) *Why Stock Markets Crash: Critical Events in Complex Financial Systems*, Princeton University Press.

Spiegel, H. (1998) "Usury," in Eatwell et al., eds. vol. 4, pp. 769-70.

Sterman, J. (2000) *Business Dynamics: Systems Thinking for a Complex World*, McGraw-Hill. URL: web.mit.edu/jsterman/www/.

Stiglitz, J. (2001) "Information and the Change in the Paradigm in Economics," URL: nobelprize.org/economics/laureates.

Stiglitz, J. (2003) "Ethics, Market and Government Failure, and Globalization," *The Governance of Globalization*, The proceedings of the Ninth Plenary Session of the Pontifical Academy of Social Sciences, Acta 9, Edmund Malinvaud and Louis Sabourin, eds., Casina Pio IV, 2-6 May. URL: www2.gsb.columbia.edu/faculty/jstiglitz/.

Strogatz, S. (2003) *Sync: The Emerging Science of Spontaneous Order*, Theia.

Sugden, R. (1989) "Spontaneous Order," *Journal of Economic Perspectives*, vol. 3, pp. 85-97.

Surowiecki, J. (2004) *The Wisdom of Crowds*, Doubleday.

Takayama, A. (1993) *Analytical Methods in Economics*, University of Michigan Press.

Tesfatsion, L., and K. Judd (2006) *Handbook of Computational Economics, Volume 2*, Elsevier.

Varian, H. (1992) *Microeconomic Analysis*, 3rd ed., W.W. Norton.

Veblen, T. (1899) *The Theory of the Leisure Class*, MacMillan.

Velupillai, K. (2000) *Computable Economics*, Oxford University Press.

Velupillai, K. (2003) "Essays on Computable Economics, Methodology, and the Philosophy of Science," Department of Economics, University of Trento, Italy, Discussion Paper no. 8.

Velupillai, K. (2005*a*) "A Primer on the Tools and Concepts of Computable Economics," in K. Velupillai, ed. (2005*d*) pp. 148-97.

Velupillai, K. (2005*b*) "The Unreasonable Ineffectiveness of Mathematics in Economics," *Cambridge Journal of Economics*, vol. 29, pp. 849-72.

Velupillai, K. (2005*c*) "The Impossibility of an *Effective Theory* of Policy in a Complex Economy," Department of Economics, University of Trento, Italy, Discussion Paper no. 14.

Velupillai, K., ed. (2005*d*) *Computability, Complexity, and Constructivity in Economic Analysis*, Blackwell Publishing.

Velupillai, K. (2007) "Variations on the Theme of Conning in Mathematical Economics." *Journal of Economic Surveys*, vol. 21, pp. 466-505.

Velupillai, K. (2008) "Uncomputability and Undecidability in Economic Theory," presented at the Workshop on Physics and Computation, Vienna, August 25-28.

Vives, X. (2005) "Complementarities and Games: New Developments," *Journal of Economic Literature*, vol. 43, pp. 437-79.

Vriend, N. (2002) "Was Hayek an Ace?" *Southern Economic Journal*, vol. 68, pp. 811-40.

Waldrop, M.M. (1992) *Complexity: The Emerging Science at the Edge of Order and Chaos*, Simon and Schuster.

Weintraub, E.R. (2002) *How Economics Became a Mathematical Science*, Duke University Press.

Wilensky, U. (1999) *NetLogo*, URL: ccl.northwestern.edu/netlogo/.

Wilensky, U. (2001) "Modeling Nature's Emergent Patterns with Multi-agent Languages," Proceedings of EuroLogo, Linz, Austria.

Williams, G.P. (1997) *Chaos Theory Tamed*, Joseph Henry Press.

Wilson, J.Q. (1993) *The Moral Sense*, Free Press.

Young, H.P. (1998) *Individual Strategy and Social Structure: An Evolutionary Theory of Institutions*, Princeton University Press.

Arabic References

[1] **عيون الأخبار،** محمد بن عبد الله بن قتيبة، دار الكتب العلمية، ١٤٢٤هـ، ٢٠٠٣م.

[2] **مجموع فتاوى ابن تيمية،** أحمد بن عبد الحليم بن تيمية، جمع عبد الرحمن بن قاسم، الطبعة السعودية، بدون تاريخ.

والحمد لله رب العالمين

ABOUT THE AUTHOR

The author obtained his Bachelor's degree in Science from King Saud University, Riyadh, Saudi Arabia, in 1987. He obtained his Master's degree from Southern Illinois University in Carbondale, USA, in 1990, and in 1995 obtained his Ph.D. from Washington University in St. Louis, Missouri, USA, both in Economics. He then joined Al Rajhi Bank, Riyadh, as a senior consultant, and in 1998 became Manager of Research & Development in the Shari'ah Group at the Bank. He joined IDB Group in December, 2004, and currently he is Deputy Director of Islamic Research and Training Institute.

ABOUT THE BOOK

Complexity theory provides a starkly different worldview from Neoclassical theory. With recent advances in agent-based simulation, there are great opportunities to examine how the economy behaves within a complex environment and, more important, how Islamic principles affect such behavior.

Results show that, in a complex setting, interest-based lending leads to severe instability and wealth concentration. Compared with mark-up financing, it is much more costly and highly inefficient. Mark-up financing, in contrast, allows for highly stable dynamics, with low costs of financing and high efficiency of fund utilization. In terms of stability and efficiency, mark-up finance is indistinguishable from interest-free lending. Finally, simulation results show that wealth-based charity improves both mean and median consumption. Further, up to a certain rate, charity improves consumption of donors in addition to that of receivers.

The recent advances in complexity theory and agent-based simulation might be very helpful in assisting future research in Islamic economics and finance.

Topics

I. Introduction
II. The Neoclassical Paradigm
III. Characterizing Complex Systems
IV. Islamic Economics in a Complex World
V. Conclusion