TRANSFORMATIONS IN SCIENCE AND A CHANGING LANDSCAPE FOR SOCIO-ECONOMICS

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Abstract

This paper argues that a new scientific framework (Science II) has been slowly emerging and is rivaling the Descartes-Newtonian perspective (Science I) which was dominant for several hundred years. The Science II framework places a great deal of emphasis on evolution, dynamism, chance, and/or pattern recognition. As a cause and effect of the new perspective, scholars in the physical, biological, and social sciences are increasingly addressing common problems and are borrowing insights from and interacting with each other. The framework of Science II has enormous potential for social, biological, and physical scientists to focus on problems which should be of fundamental interest to socio-economists. The paper focuses on five problem areas and/or methods in which the interests of socio-economists and natural scientists are converging within the framework of Science II: self-organizing processes, complex networks, power-law distributions, the general binding problem and multi-level analysis.

Keywords:

Inequality, economic governance, complex networks, power-law distributions, multi-level analysis, interdisciplinarity, path dependency, scientific paradigms

JEL Classification:

A14 sociology of economics, D002 institutional design, D85 network formation and analysis, P0 general economic systems, P16 political economy, Y80 related disciplines

1. Introduction

For several hundred years, the dominant framework shaping Western science has been the Descartes-Newtonian "paradigm." Historically, this framework—with its own epistemology—has been powerful in shaping the thinking of both natural and social scientists. An alternative view of explaining reality has slowly been emerging, and the influence of this new perspective is rapidly diffusing. In the following discussion, we focus on these two scientific perspectives, especially the more recent one, and suggest that it has considerable potential for enriching the field of socio-economics and for assisting socio-economists to understand the connections between their research endeavors and those in other social and natural sciences.

The current status of socio-economics can be crudely summarized as follows: socio-economics has been quite strong in empirical and comparative analyses and in its relentless criticism of the neoclassical paradigm. However, socio-economics has remained relatively weak in developing a comprehensive theoretical alternative to the dominant neo-classical framework. We suggest that the emerging alternative perspective for conducting science heightens the potential for an enriched socio-economic research agenda.

Despite the strong theoretical commitment to interdisciplinarity in the socio-economic research agenda, borrowing knowledge from other disciplines has remained as difficult for socio-economists as for those in most other scientific fields.[1] Learning from other disciplines confronts two different types of errors. Using terminology from statistical test-theory, borrowing from other disciplines can produce α-type errors by accepting analogies, methods or models from other disciplines which turn out to be highly questionable and generate no cognitive value, let alone surplus value. On the other hand, learning from other disciplines may also generate β-type errors by rejecting highly appropriate and very fruitful analogies, models or methods from fields outside one's own domains. Socio-economists, like those in most other scientific fields, very seldom commit α-type errors, but like those in most other scientific fields, have a high propensity for β-type errors. A principal reason for this error is usually the outdated mapping of scientific fields and the overall complexity of the scientific landscape. Yet, using perspectives and concepts which are rapidly developing in both the social and natural sciences, socio-economists have the potential to uncover new models and concepts with which to engage in theory construction independent of the classical Descartian-Newtonian paradigm and to assist in advancing the theoretical insights of their natural science colleagues. In short, we are at a moment in the history of science when there is potential for serious convergence of interests among social and natural scientists.

2. The Rivalry of Two Scientific Perspectives

A fundamental re-organization and re-configuration of scientific knowledge is presently well underway. For several hundred years, much of western science was influenced by a fundamental distinction, a leading metaphor and a dominant paradigm. The core paradigm was based on the *Principia Mathematica* by Isaac Newton. The fundamental distinction and leading metaphor for the Newtonian paradigm had been proposed by René Descartes in his *Meditationes de Prima Philosophia*, in which he offered two ontological kingdoms, *res extensa* for the natural world, and the other for mental substances (*res cogitans*). Descartian dualism paved the way for separating science into two fundamentally different cultures, operating on two sets of principles. With increasing differentiation of scientific disciplines, philosophers and scientists such as Wilhelm Dilthey (1881), Max Weber (1905), C.P. Snow (1959), and many others elaborated on the high cognitive distances between the natural and the human sciences.

For Descartes, the dominant metaphor for the natural world was the machine (see Part IV of his *Discourse on Method*). While his metaphor was originally presented as a way of understanding living things, it eventually became generalized as a view about the entire world, as a description of how the world operates and as a prescription for how to study it. Accepting his mechanistic view, scholars have often adopted a simplified view of the world, of the relation of parts to wholes, of causes to effects, and have frequently developed strategies for manipulating and predicting world events. Borrowing the machine metaphor, scholars have extended the metaphor to that of engineer, watch-maker, designer, or social planner.

Turning more specifically to the cognitive organization of the Newton-Descartes paradigm—to what we term Science I—its characteristic features can be captured by a hierarchy of levels in the scientific domains and in the socio-natural universe (see Table 1). The leading epistemological vision within the Science I paradigm lies in its heavy emphasis on reductionism: societies are believed to be built up from individuals, individuals from cells and their neural organization, cells from molecules, molecules from atoms, etc. An epistemological assumption was that the behavior of large interactive systems could be understood by analyzing the elements separately and studying the microscopic mechanisms individually. Moreover, the dominant theory in the Newton-Descartes perspective lay in the identification and clustering of universal laws.

Table 1 Differences between Science I and Science II
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Such a mentality suggests that we can understand the interactions among variables and that only a relatively few variables need be manipulated in order to change nature or a society. This view approaches the world as made up of variables, linked by differential equations that are described like laws of motion, subject to noise and random variation. There is a widely shared view that we can easily design new institutions; even transfer them or various practices from one society to another. Policy makers draw up complex plans for altering national economies or for nation and state building of entire societies; natural scientists talk about genetic engineering. Even though the visions are often grand, the mentality has been that of the engineer with an emphasis on efficiency and redundancy: design projects as simply as possible and keep interactions among the necessary parts to a minimum. When the engineering mentality shapes policy or designs projects, logic is expected to prevail, but for failsafe purposes, designers usually include some redundancy (i.e., the performance of the same function by similar elements). In very complex and sophisticated projects, there is some feedback modeling or other elements from control theory, but at all stages of the design, irrelevancy is to be avoided. Each part is designed to complement other parts.

Contrary to the Cartesian design, a massive re-configuration of science has been slowly emerging for approximately 150 years, starting with the Darwinian Revolution in the middle of the nineteenth century, accelerating from the 1950s onward toward a new science regime labeled herein Science II. The newer framework is not grounded on engineering and clockwork metaphors but is primarily concerned with an effort to comprehend both the natural and the social world in terms of evolution, complex adaptive systems which tend to be self organizing and spontaneous. Whereas a view of the world shaped by the influence of Newton and Descartes is comparatively tidy and predictable, the new scientific configuration emphasizes the complexity and unpredictability of the world, open to many more possibilities than were previously realized (Kauffman, 1993; Bak, 1997; Prigogine and Stengers, 1997; Crouch, 2005).

The new perspective became increasingly widespread after physicists and computer scientists began to demonstrate in the 1960s and 1970s that even simple equations can produce results which are complex, surprising, and unpredictable. Advances in genetics, neurosciences, computer science, and other fields have led to a conception of science which increasingly emphasizes the important role of chance in explaining phenomena (Edelman, 1987). The cherished notions of general laws or axioms have been recast within the Science II world by notions like pattern formation and/or pattern recognition (Barabási, 2002). Over the past two decades, specialists in discipline after discipline have increasingly recognized that the world is far more complex than experts had hitherto recognized. In the words of economist Brian Arthur, more and more scientists realize “that logic and philosophy are messy, that language is messy, that chemical kinetics is messy, that physics is messy and finally that the economy is messy” (1992: 329; also see Lewin, 1993). The emerging perspective, rapidly diffusing across academic disciplines, suggests that the world does not change in predictable ways (Sornette, 2000; Mayr, 1991; Wallerstein, 2004; Bak, 1997; Arthur et al., 1997). Self organization is a dominant process in much of reality. Uncertainty is a basic epistemological assumption. Practitioners of Science II think in terms of probabilities. Physical and social phenomena are always evolving, but no one can predict the path of the future. Systems have an inherently nonlinear dynamic quality. The games in which actors are engaged are ever changing, and even in the same game, the rules keep evolving. There is a great deal of co-evolution in the world, in which very small changes can have both big and long-term consequences. Science II analysts often engage in case studies over long periods of time and report a great deal of contingency and chance in explaining outputs.[2]

Two scientists whose work very much inspired and embodied the Science II paradigm were Charles Darwin, perhaps the greatest biologist and historian ever; and Ilya Prigogine, a physicist and Nobel laureate during the later part of the twentieth century. Unlike the emphasis on static equilibrium and universal laws in the Descartes-Newtonian paradigm, Darwin and Prigogine emphasized the importance of dynamic analysis, the uniqueness of historical events, the irreversibility of social and natural processes, and the difficulty of making successful predictions in complex systems. Both understood the importance of retrospective (i.e., historical) analysis in order to understand reality. In the Science II framework, scientists search for regularities within systems, but unlike neo-classical analysts, they view systems as tending to move far from an equilibrium. Because a system is always changing, at some point it evolves into what appears to be a new system. Science II rejects the idea that reality can be explained with determinism, linearity, and certainty. Darwin and Prigogine's methodological and theoretical frameworks argued that historical analysis was central to scientific understanding (Prigogine and Stengers, 1997; Wallerstein, 2004: Chapters Three and Four). Prigogine's work advanced the idea that systems with a large number of interacting parts have adaptive self-organizing internal structures (Waldrop, 1992; Sornette, 2000). The works of Darwin, Prigogine, and others (e.g., John Von Neumann) have had enormous impact not only on the field of socio-economics but also on biology, geology, meteorology, and computer science. A central tenet of complex systems analysis is the understanding that large-scale collective behaviors result from repeated nonlinear interactions among constituent parts, whereby wholes tend to be much more than the sum of their parts. Increasingly analysts maintain that such systems are not susceptible to mathematical analysis, but must be understood by letting them evolve—either in time or with simulation analysis. In short, the evolution of complex systems is inherently unpredictable (Newman et al., 2006; Sornette, 2003: 15–17; Chaitin, 1987; Pines, 1986; von Neumann, 1966, Mayr, 1991; Wolfram, 2002).

Numerous Science II analysts have observed that in many social and biological systems, some of the same functions are performed by similar structures (a world with a great deal of redundancy). Physicists and others point out that many systems are characterized by degeneracy—situations characterized by physical scientists in which elements which are structurally different can lead to the same output (Edelman and Gally, 2001). Similarly, more and more socio-economists are recognizing that at different moments in the same society, the same type structure can be associated with a different output or performance, and on the other hand that across societies, different structures are associated with the same output or performance. Interesting examples in recent socio-economic analysis pertain to the German and American economies which had relatively stable but different structures over the last twenty-five years. In some decades, one set of structures had much better performance than the other, but over time the performance situation reversed, suggesting how the same performance can stem from different structures (Crouch, 2005; O'Sullivan, 2005).

Table I identifies some of the cognitive structure of the new science regime, and emphasizes in an ideal-typical manner some of the basic differences between Science I and II. In contrast to Science I, one finds in Science II a nested structure of science which is neither hierarchical nor reductionist, an epistemological search for complex interdisciplinary pattern construction across different scientific domains. However, requirements for scientific explanation are much weaker than with the Descartes-Newtonian paradigm.

Despite the prominence we give to Science II, we are not suggesting that the Science I perspective is no longer valid for scientific investigations. To the contrary. To address many problems, the Science I perspective will continue to be very valuable, while for others Science II will be highly useful. Our argument is that at present, Science II has considerable promise for the advancement of a socio-economic research agenda.

3. Socio-Economics in the Framework of Science II

For several reasons, the potential for major theoretical advance in socio-economics has increased dramatically in recent decades. First, the cognitive distance in Science II between the natural sciences and socio-economics is diminishing, suggesting that socio-economists have the potential to contribute to and borrow from theoretical insights and models developed in a large variety of other fields. While socio-economics has had limited success in the area of theory construction, it has considerable potential to adapt to the rapidly developing new methods, models, tools, and other building blocks necessary for pattern recognition and pattern formation. Second, the stock of available models and mechanisms within the Science II framework is characterized by a steep increase in complexity and is focused predominantly on process dynamics and evolutionary perspectives which are quite compatible with socio-economists' interests in societal change and long term trends. Third, the interaction and communication among analysts in various fields of science is rapidly increasing due to the emergence of commonly shared information and communication technologies within the Science II framework.

For example, socio-economics during the last decade has moved much closer to many conceptual issues high on the agenda of the life sciences. This is suggested by Colin Crouch's recent book *Capitalist Diversity and Change: Recombinant Governance and Institutional Entrepreneurs* (2005). Elsewhere, Robert Boyer (2005: 43) focused on "hybridization" and "endometabolism" as driving forces for institutional change. Significantly, terms like "recombinant" and "endometabolism" have been deeply embedded within the life-sciences for years. Other socio-economists have also incorporated life-science perspectives into their writings—concepts such as self-organization, self-assembly, emergence, co-evolution, path-dependency, bifurcations, punctuated equilibrium, and multi-level analysis come to mind.

Within the field of socio-economics, we should reflect on whether the range of our current interdisciplinary interests is broad enough. Might we enhance our insights for a richer research program if we broadened our interdisciplinary perspectives and attempted to understand how certain key issues which are highly relevant for socio-economics—such as self-organizing processes, complex networks, power-law distributions, binding theory, and multi-level analysis—have been used by scientists in fields outside the broad domains of the social sciences? In our own research, we are struck by the degree to which scientists in many fields—not just socio-economics—are wrestling with similar problems, a theme discussed at some length below. It is important that scientists recognize that when they are addressing common problems, they can derive substantial benefits by engaging in mutual interactions.

3.1 Common Metaphors

As we interact with natural scientists, we should recognize that many advances in knowledge have historically occurred by individuals thinking metaphorically across different scientific domains. We offer three recent examples, but could easily suggest many others. In 1999, Günter Blobel was awarded the Nobel Prize in Physiology or Medicine for his work in cell biology, built metaphorically on the idea of a postal system within human cells engaged in sending and receiving messages. In 2003, Roderick MacKinnon received the Nobel Prize in Chemistry for demonstrating how materials are transferred across cell membranes by structures resembling the architecture of water channels. And a few years earlier, John Walker in Cambridge (U.K.) received the Nobel Prize in Chemistry for analyzing movement within cells, a process which he characterized as similar to a transport system in a modern economy (see the Nobel laureates' descriptions of their work at http://nobelprize.org). We are optimistic that if we strive to think in common metaphors and attempt to borrow insights from our colleagues in other fields, we too are likely to have richer perspectives. But even though metaphorical thinking is an important tool in theory construction, "metaphors are never complete, precise, or literal mappings" (Hodgson, 1999: 68). Useful tools for developing new insights, metaphors can be a vehicle by which ideas and models from one field may be transferred to another. After a metaphor provides a new insight, we must then engage in rigorous and deep thinking in order to refine our new perspective. Metaphors have remarkably rich allusive power but can neither be proved nor disproved. By engaging in metaphorical thinking, however, we enhance our potential to increase the range of our understanding of the world (Edelman, 2006: 58–59; Brown, 2003; Maasen and Weingart, 2000).

Highly creative and productive scholarship involves a trade-off between range and specificity. By enhancing the range of our knowledge, we increase the prospects of recognizing new patterns and of developing new insights about the world but at the expense of in-depth understanding. High creativity emerges as a result of permissibility in broad thinking, but it usually requires integrating knowledge from diverse fields but with great investment in being rigorous and acquiring great depth in specific areas (Edelman, 2006; Hollingsworth, 2007).

3.2. Shared Methods and Models

We should be aware of an increasing number of common, cross-disciplinary methods and models within Science II. However, the transfer of models and methods are not restricted to a one-way flow from the natural to the social sciences or vice versa. There are a variety of flows from the social sciences to natural science which immediately come to mind. The ideas of *The*

Theory of Games and Economic Behavior by John von Neumann and Oskar Morgenstern (1944), originally conceived as a radical revolution for economic theory, rapidly diffused into the biological and other sciences in the form of game theory (Lewontin, 1961). Mitman (1992) brilliantly demonstrated how entomologists analyzing the social behavior of insects borrowed models from social scientists who studied social cooperation and business associations.

Some socio-economists are working to integrate evolutionary neuroscience into the discipline of economics, in an effort to understand human sociability from the standpoint of physiology. There is also a burgeoning literature in the related field of neuroeconomics which is having a "revolutionary" impact on long-held assumptions of economists about human decision making (Cory, 2006; Levine, 2006; Wilson, 2006; Lynne, 2006; Cohen, 2005; Camerer et al., 2005; Cassidy, 2006). Entire new institutes and research programs are emerging which focus on problems of common interest to both natural and social scientists. One of the most visible has been the Santa Fe Institute in New Mexico, involving some of the world's most prominent physicists, biologists, sociologists, economists, and anthropologists, several of whom are Nobel laureates (Hollingsworth and Müller, 2007; Waldrop, 1992).

4. Examples of Socio-Economists and Natural Scientists Working on Common Problems

As researchers in different fields become more cognizant that they are working on similar types of problems, they enhance their potential for mutual learning. There are many examples we could provide, but for illustrative purposes, we will briefly discuss five major, but interrelated areas in which the scholarship of socio-economists is hardly distinguishable from the work of their colleagues in the natural sciences. Some of the most important recent contributions to socio-economics are being made by individuals who were trained in the physical sciences. Each of these five, interrelated problem areas is at the frontiers of research in both the natural and social sciences. They are (1) self-organizing processes, (2) the structure and dynamics of complex networks, (3) power-law distributions for understanding rare events, (4) the binding problem, or what might also be called processes of integration and disintegration, and (5) multi-level analysis. There are considerable differences in the way that various disciplines address these processes/methods, and much additional research needs to be done before we have a thorough comprehension of any one of them. But we enhance our potential for advancing our understanding of these issues in any one field by studying how each of these problems is currently being addressed by our colleagues in many other disciplines.

4.1 Self-organizing Processes

These processes generally occur in open, complex systems, without being guided by some central agent. Research programs designed to understand self-organizing processes are well underway in such diverse fields as sociology, political science, economics, anthropology, psychology, history, physics, biology, chemistry, meteorology, and earth sciences. Invariably, the models employed are non-linear in nature. Hardly any scientist in these fields is able to make successful predictions about the future, as self-organizing processes are understood best by retrospective analysis (Prigogine and Stengers, 1997; for an exception, see Wolfram, 2002). Various sociologists and economists have elaborated on self-organizing processes by confronting the underlying mechanisms which permit spontaneous order and self-organizing processes? Social scientists who eloquently addressed this problem but in fundamentally different ways include Adam Smith, Thomas Malthus, Karl Marx, Nikokai Kondratiev, Joseph Schumpeter, Friedrich von Hayek, Ferdinand Braudel, Immanuel Wallerstein, and Jon Elster. In self-organizing processes, the emergence of macro socio-economic structures results from collective and dynamic interactions among large assemblages of individuals operating at the micro level of societies. Thus macro and micro phenomena are constantly evolving together. Self organization processes are evolutionary in that the impact of a central organizer or planner has only modest or no influence on emergent processes. Indeed, “control” tends to be distributed over large numbers of interacting parts of an entire system. Causes and effects operate in a somewhat nonlinear manner: small causes can have huge effects or large factors can have small effects. Because of its general characteristics, analysts have limited ability to make predictions about a system’s behavior (Holland, 1996; Kauffman, 1993; Nicolis and Prigogine, 1977; von Foerster and Zopf, 1962; Heylighen, 2003).

When one explores the literature about self-organizing processes and spontaneous order, it quickly becomes apparent that the increased specialization within sub-disciplines has discouraged many scholars from thinking about this subject (Barry, 1982). Scholars who work on self-organizing processes are generally those who cross disciplines, study problems over lengthy time periods, and include such contemporary social scientists as economic geographers, historians, and sociologists (Pred, 1966; Saxenian, 1994; Krugman, 1996; Sabel and Zeitlin, 1985, 2003; Morowitz, 2002; Diamond, 2005). Their writings have demonstrated that such varied subjects as the location and growth of cities, economic sectors in specific locations, and the rise and decline of empires occur in self-organizing and spontaneous ordering processes.

While those who study self-organizing processes are represented in many disciplines, this type of issue is frequently addressed in various sub-specialties of an interdisciplinary nature: a few specialized areas deserving brief mention encompass such complex subjects as (a) self-organized criticality, (b) radical innovations, and (c) path dependency.

(a) The study of self-organized criticality originally emerged from the inspiration of Per Bak (1997), a Danish physicist working in the United States in the 1980s. In his writings, he (interacting with economists, sociologists, historians, geologists, biologists, and meteorologists) began to develop and validate a theory that many complex systems naturally evolve to a critical state in which a minor event starts a chain reaction which has huge consequences. Sornette (2003), Mandelbrot and Hudson (2004), Arthur (1994), and others have demonstrated with vast quantities of data that self-organized criticality models yield great insights for understanding stock market crashes, the collapse of empires and states, the emergence of plagues and global epidemics, as well as other extreme events with large social consequences (Diamond, 2005; Tainter, 1990; Hollingsworth and Müller, 2007; McNeill, 1976; Kolata, 1999). Similarly, Kauffman (1993) has demonstrated that many biological systems can be understood by applying models of self-organized criticality.

(b) Many of our retrospective studies of the occurrence of radical innovations suggest that they are not planned but emerge in self-organizing, unpredictable processes in complex environments. These findings tend to be born out whether one is studying radical organizational innovations, technological innovations, or innovations in basic and/or applied science (Freeman and Soete, 1997; Schumpeter, 1934; Saxenian, 1994; Hollingsworth et al., forthcoming 2008; Hage and Hollingsworth, 2000; Rosenberg, 1975; Dosi, 1982; Powell et al., 2005).

(c) Path dependency is another concept which may profitably be analyzed under the broad category of self-organizing processes. While there are various approaches to the study of path dependent processes, the one which is most broadly employed across disciplines is that suggesting that historical processes are self reinforcing (David, 2000; Nelson and Winter, 1982). While many writing about path dependency have emphasized how processes are self reinforcing, a number of scholars have nevertheless focused on the role of actors who influence paths at critical junctures. Relatedly, Thelen (2004) and others (Pierson, 2000; Crouch, 2005) have demonstrated that historical processes often undergo abrupt change. Historically, some of these appear to have been revolutionary in nature (Mahoney, 2000). Indeed, paleontologists and biologists have employed the concept punctuated equilibrium to demonstrate that during most historical periods stasis has been dominant but occasionally there have been gigantic events or processes which fundamentally altered the geographical and historical landscape. Indeed, the concept punctuated equilibrium has had considerable utility in numerous scientific disciplines—including several in the social sciences (Somit and Peterson, 1992).

Although many models and explanations of self-organizing processes are employed by scholars in numerous fields, socio-economists and others need to recognize that much of this work needs additional research which will address two fundamental problems: (1) the relative importance of endogenous and exogenous explanations, and (2) the problem of control. There is a tendency in most literature on self-organizing processes to explain extreme events as due to endogenous factors of a system and to minimize or even ignore the response of the system to an external shock (Reiter, 2003). However, as Sornette (2007) observes, "most natural and social systems are continuously subjected to external stimulations….It is not clear….if a large event is due to a strong exogenous shock, to the internal dynamics of the system organizing in response to the continuous flow of small solicitations, or maybe a combination of both" (for further discussion in socio-economics, see O'Sullivan, 2007; Thelen, 2003: 209; Streeck and Thelen, 2005: 1). Obviously, an understanding of this problem is fundamental for comprehending the nature of change in complex systems.

The relationship between external forces and the spontaneous internal fluctuations is an unsettled problem in every field of science, and one which sociologists, historians, physicists, and biologists continue to wrestle (Ruelle, 2004). Within socio-economics, Schumpeter (1934) was very explicit in dismissing the role of external shocks. In our own day, the tension between endogeneity and exogeneity was elegantly addressed by Romer's endogenous growth theory (Romer, 1996).

Some scholars have suggested that one reason our theoretical understanding of the processes of self organization and spontaneous order is underdeveloped is the tendency for humans to overestimate the degree to which they are in control of their destiny, a trait that a number of biologists have suggested is evolutionarily adaptive. As Sornette (2007) observes, "the exercise of governmental authority, the managing of the economy, the regulation of financial markets, the management of corporations, and the attempt to master natural resources, control natural forces, and influence environmental factors all arise from this quest" (also see Satinover and Sornette, 2007). A dominant figure in developing the research on "illusion of control" has been the distinguished Harvard psychologist Langer (1975) whose empirical studies have demonstrated that there is a tendency for individuals to believe that they control events over which they have no influence. This research as well as that of others has suggested that individuals appear to be biologically adapted to underestimate the role of chance in interpreting either their immediate environment or larger social forces. Until we have a better understanding of the research on the issues of "illusion of control," our perspectives on the larger issues of self-organizing processes and related issues (self-organized criticality, radical innovations, path dependency, endogeneity versus exogeneity) are likely to remain under-theorized, and our empirical analysis are subject to being specious findings (Langer and Roth, 1975; Presson and Benass, 1996; Goodman and Irwin, 1996; Kahai et al., 1998).

4.2 The Structure of Complex Networks

Complementing interdisciplinary work on self-organizing processes is another body of research involving a number of academic fields: the study of complex networks. Those specializing in the study of complex networks find that complex network architecture has a high degree of similarity, whether one is analyzing the social world, biological cells, neural connections in the human brain, epidemics, the Internet, or languages. It is no exaggeration to suggest that the study of complex networks has done more to bring a convergence of interests of social, physical, and biological scientists than any other area of research in the history of modern science (Barabási, 2002, 2007; Barabási and Oltvai, 2004; Newman et al., 2006).

Of course the study of networks is not new. Scholars have long been aware that networks are pervasive throughout nature and society. However, a new science of networks has emerged. In this paper, we call attention to two broad classes of networks—those with a structure which is somewhat democratic or egalitarian and those which have an aristocratic structure. Despite the variety of shapes of networks, until approximately 15 years ago, most network analysts studied the more egalitarian type of network and assumed that a network had a fixed number of nodes which were randomly connected to each other. In short, much of the older literature characterized nodes in a network as having a normal (Gaussian) distribution. Thus, in an egalitarian type network, most nodes have essentially the same number of links. Most of the older work on networks (also called random networks) was essentially descriptive and static and tended to focus on individual members of networks and their interactions with other network members, while underemphasizing the collective or macro structure of an entire network.

The new science of networks focuses on the structures and processes of entire networks, analyzes the evolution and continuous change of networks and the outcomes and effectiveness of networks. Moreover, the new research on networks engages in longitudinal studies of individual networks as well as comparisons of networks in the social world with those in the biological and physical worlds. A primary goal of the new science is to simplify our understanding of how things are connected to each other and how their connections evolve. A dominant theme in the recent work is that most aristocratic-type networks were not developed by designers or engineers but were unplanned and very decentralized and emerged from a self-organizing collection of interacting parts (Powell et al., 2005; Uzzi and Spiro, 2005; Watts, 2003; Provan et al., 2007; Barabási, 2002).

In contrast to earlier students of networks, analysts of aristocratic-type networks are holistic in their thinking and assume that nothing happens in isolation: most things are linked to everything else. Aristocratic-type networks have a characteristic signature: there is a high degree of local clustering but at a more macro level there is only a short distance between any two nodes. Those studying aristocratic-type networks clearly subscribe to the Science II framework, methodologically are anti-reductionist in their research strategies, and believe that the structure of networks is the key to understanding much of the world.

The recent work on aristocratic-type networks emphasizes their scale-free nature—that some network nodes have a large number of links to other nodes, while most nodes have very few links to other nodes. In short, there is great inequality in the way that nodes are connected to each other. Inegalitarian or scale-free networks are characteristic of large transportation systems. For example, there are a few major hubs—airports such as Chicago O'Hare, London Heathrow, Frankfurt International—each having links with hundreds of smaller airports. But each smaller airport is linked to relatively few other airports. Similarly, in the global network of banks, there are a few major banks in New York, London, Frankfurt, and Tokyo linked to many other banks, while throughout the world there are thousands of small banks, each with few links to other banks. It is the architecture of these kinds of networks which has been of greatest interest to social scientists engaged in the new science of networks (Watts, 1999, 2003, 2004; Sornette, 2003). However, there are egalitarian type networks in which each node has only a few links to other nodes, but none has numerous links to others. Terrorist networks tend to be of an egalitarian type, and these also are attracting attention of researchers.

In the social sciences, the foundation for the study of aristocratic-type networks was prepared many years ago by several scholars working independently of one another. There was Robert Merton's famous paper "The Matthew Effect in Science" (Merton, 1968), Herbert Simon's celebrated work "The Gibrat Principle," (Simon and Bonini, 1958), and Derek John de Solla Price's argument about cumulative advantage in science. Merton developed his paper from a quotation from the Gospel of Matthew in the New Testament "For unto every one that hath shall be given, and he shall have abundance; but from him that hath not shall be taken away even that which he hath." Merton's argument was that rewards in science are distributed in a self-organizing but very inegalitarian manner. Those who already have rewards continue to receive more and more, while those who are unrecognized—even if deserving—remain unrecognized. In Merton's thinking, each scientist was part of the architecture of a complex network. His analysis was a variant on Pareto's "law" (1896) established some years earlier: the rich tend to get richer, generally at the expense of the poor. Similarly, Herbert Simon (1955), a future Nobel laureate, and an honorary fellow of the Society for the Advancement of Socio-Economics, demonstrated that business firms grow in a more or less self-organizing fashion but their probability of further growth is proportional to their current size. About the same time that Simon was publishing his work, the economic historian Kuznets (1965) was writing a series of papers, for which he would later receive the Nobel award in economics, demonstrating a complementary set of findings about the inequality of income with longitudinal studies both within and across countries. Price (1976) laid the foundation for the study of networks in the citation of scientific papers and was one of the first to demonstrate that the pattern of citing scientific papers had an aristocratic-type network structure. He demonstrated that papers receive citations in proportion to the number they already have, a phenomenon he labeled as the process of "cumulative advantage" (Price, 1976; Newman et al., 2006).

The new science of networks has been heavily based on three underlying concepts: that of growth, preferential attachment, and re-wiring. The phenomena of growth and preferential attachment are so common across all kinds of aristocratic-type (e.g., scale free) networks that analysts tend to view these as micro rules which generate highly ordered macro-behaviors across a variety of heterogeneous domains. The key idea of preferential attachment is that small differences in ability or even luck tend to get locked in and lead to large inequalities over time. Once an entity becomes large—regardless of how it occurred—it is likely to grow even larger (Arthur, 1994; David, 2000). The principle that the rich get richer is the underlying driving force behind the self-organizing evolution of such networks. If one node has many more links than any other, it is far more likely to continue growing new links with other nodes. The older nodes have distinct advantages over more recently established nodes. Similarly, urban geographers have observed that there is a rank ordering of cities whereby large cities are more likely to attract new arrivals than small cities, thus exacerbating their differences in size (Pred, 1966).

In addressing the issues of growth and preferential attachment, there was no intention in the work of Merton, Simon, Price, and Kuznets to deny the importance of historical specificity in the phenomena they were addressing. Indeed, each of these studies was based on rich historical analysis. Nevertheless, the idea was that regardless of the specific reasons for initial success in a particular space or time, the successful were more likely to continue reaping more rewards than the less successful. The rich have many ways of getting richer, some deserved and others not, but as far as the resulting statistical distribution is concerned, the significant thing is that they continue to prosper relative to others in the network (Watts, 2003: 109–111; Barabási, 2002). While the processes of growth and preferential attachment tend to be common across complex networks, there is slowly emerging a literature—especially in sociology—which addresses the issue of why there is variation in the specific norms or rules which determine the type of preferential attachments which emerge in specific networks in a particular time and space (Kogut, 2000; Powell et al., 2005; White, 2002; Provan et al., 2007).[3]

Specific networks are subject to change or collapse due to internal and external conditions. Internal network mechanisms may become overloaded, as nodes cannot integrate and exchange new information. External conditions may so change the environment for an aristocratic network that it becomes overwhelmed and previous patterns of growth and preferential attachment cease to be relevant. Some of these changes may be so extreme that they destroy the nodes with the most attached links, especially if they are tightly linked to each other. This, of course, would mean that the shape of a network would be profoundly changed.

Meantime, some recent analysts have demonstrated that there is often a self-organizing process of re-wiring among complex networks, a process that allows for flexibility in networks by permitting the removal of links connected to certain nodes and replacing them with new links, essentially amounting to a re-shuffling of node connections based on the principle of preferential attachment. This kind of activity facilitates the creation of new markets, technologies, behavior, and/or institutions—the result being the continuing emergence of novelty (Schintler et al., 2005; Arthur et al., 1997: 1–14).

Despite their flexibility, complex networks are vulnerable to attack or collapse, in that at times they experience "tipping" or cut-off points, which can have very widespread ramifications. These are the points at which the collective organization of an entire network changes, at which time the network structure may collapse. "Tipping points" are critical states of change related to node relationships and their distribution within an entire complex network (Watts, 2003).

Examples of how change might or might not lead to a "tipping point" can be found in the history of financial institutions. If a single bank is linked to only a few other banks, perhaps because of its small capitalization or its rural location, its failure will not resound throughout the network. However, the failure of several large financial institutions, each with links to many other banks, can induce so much turbulence in an extensive financial system that an entire network could collapse. The failure of one or more large financial institutions could represent a "tipping point," destroying the whole system. It is with these insights that analysts in the new science of networks are able to have a better understanding of "crashes" in stock markets going all the back to the "tulip mania" in the seventeenth century, even the crashes that happen on the Internet, the contagion effects of fads in fashion, book publishing, the media, the spread of disease. At present, a major issue of interest to analysts of networks is to understand the fragility of specific networks in many different scientific domains. And the intense interaction among social scientists, biologists, and physical scientists on these subjects is indeed impressive

(Sornette, 2003; Pastor-Satorras and Vespignani, 2001, 2004; Vega-Redondo, 2007; Barabási, 2007).

4.3 Power-law Distribution

The extensive research on the new science of networks reminds us that the world is extraordinarily complex, very dynamic, and extremely inegalitarian. Each individual, group, and/or network is unique, and yet there is a great deal of commonality in the overall architecture of networks and their constituent parts, and one of our tasks as socio-economists is to understand that architecture.

Scientists long believed that most phenomena in the social and natural world followed a bell-shaped curve, also known as a Gaussian curve. Observations, which were random, were believed to be distributed in a bell-shaped pattern. Most social scientists have long assumed that most things fall within a normal distribution, with a well defined average. A bell-shaped curve has a sharp peak, which rapidly tapers off on each side. This kind of curve is so widespread that scientists have tended to refer to it as a "normal distribution." Most observations were assumed to be independent of each other. A common example of a bell-shaped curve would be the distribution of the heights of males in a given population. Most males would be between five and six feet tall and there would be a peak value, with people scattered on either side of the peak. It is unimaginable that some might be twenty or thirty feet tall. Clearly, many phenomena are best described with a bell-shaped curve. Bell-shaped distributions are so common that many analysts in some social science fields do not even closely analyze their data in order to discern whether there might be "non-normal distributions." However, astute observers have long realized that distributions do not always follow a normal curve. Many distributions and patterns are non-linear, and there are many types of non-linear distributions. With the emergence of Science II, analysts across different disciplines began to observe that the phenomena in self-organizing processes often have power-law distributions.

Until almost 15 years ago, unless one were a physicist or mathematician, power laws were unfamiliar—despite the fact that they had been used to describe a variety of social phenomena for well over a half century (Zipf, 1949). But increasingly, many kinds of social phenomena can best be described by a power-law distribution instead of a bell-shaped curve.

As we observe in Figure 1.1, power-law distributions do not have a peak at their average value. Rather, the distribution begins at its maximum value and then decreases toward zero. Power-law distributions are very different from normal distributions, suggesting the likelihood of extreme cases—or rare events—in the upper value range of the variable in question as well as a clear asymmetry between a small number of high values and a large number of low values. Thus, in the example in Figure 1.1, there are very few individuals with extreme wealth, while most individuals have very little wealth.

Figure 1 Examples of power-law distributions
About Here

Analysts generally portray a power-law distribution as shown in Figure 1.2. A distinguishing feature of a power-law distribution is that when plotted on a double logarithmic scale, it appears as a straight line with a negative slope (see Figure 1.2). The key factor in a power-law distribution is a quantity generally referred to as an exponent, which essentially describes how the distribution changes as a function of the underlying variable. The power-law distribution has no cutoff value (Watts, 2003: 104–107; 2004: 250). A power-law distribution is found in networks with few highly connected hubs or nodes holding together a large number of small nodes. In this sense, the network has no scale or is "scale free" (a term rooted in the statistical physics literature). Scale-free networks are dominated by hubs, whereas egalitarian-type networks have no hubs. It is in networks with power-law distributions that "extreme" events are observed, quite unlike the situation with "normal" distributions (Barabási, 2002; Barabási and Oltvai, 2004).

Analysts in the new science of networks have discovered that power-law distributions are quite pervasive in both the social and natural worlds. A few examples in the social world include the distribution of the intensity of wars from 1916 to 1990, the distribution of income and wealth within countries, the distribution of the sizes of cities, the number of citations received by scientific papers, the distribution of major scientific discoveries across organizations over time, the distribution of the times that words appear in a text, and the distribution of the size of firms within and across industries, power grids and transportation systems across countries and over time, and "crashes" in financial markets (Mandelbrot and Hudson, 2004; Sornette 2000: 89ff; Newman, 2005; Zipf, 1949).

A metaphorical example of a power-law distribution is the "Pareto Law" whereby twenty percent of the population in many capitalist societies owns eighty percent or more of the wealth. Similarly, urban geographers who study the rank ordering of cities point out that a few cities have very large populations, with eight to fifteen million inhabitants, while many others have only a few thousand. Again, this is a power-law-type distribution. Power-law distributions in networks, in contrast to normal distributions, are characterized by a small number of nodes with many connections and a large number of nodes with few or no links.

Scholars have found a distinctive architecture in the distribution of other social phenomena as well as much in the natural world—e.g., earthquakes, the networks in which neural cells are connected, the cellular metabolic networks of dozens of different organisms. In short, fundamentally different systems in the social and natural world have some of the same architectural design, especially if they are part of an aristocratic-type (scale-free) network.

4.4 General Binding Problem

One of the most common issues confronting scientists in many fields is what is known as "the General Binding Problem." This is concerned with why different types of phenomena are attracted to each other, how strongly and for what duration they are attracted, and what consequences ensue. Over the decades, both natural and social scientists have addressed this problem as they have studied complex networks, leading to increased communication across fundamentally different disciplines as scientists from such disparate fields as sociology, physics, and chemistry increasingly interact with one another. Contemporary examples are Harrison White and Duncan Watts, two prominent sociologists at Columbia University who have Ph.D.s in the natural sciences but derived many of their key sociological insights from physics and mathematics. However, sociologists have a long and distinguished tradition of studying the general binding problems of social cohesion and solidarity (Durkheim, [1893] 1984) and more recently with the work based on network node connectivity (Moody and White, 2003).

In the field of socio-economics, the general binding problem has been raised in recent years not only in the study of complex networks but also under the guise of complementarity. Colin Crouch, former President of the Society for the Advancement of Socio-Economics, observed that socio-economists and natural scientists were wrestling with the general binding problem when he pointed out that much of the literature on economic governance uses some of the reasoning in which chemists and biologists have engaged when they have employed the concept "complementarity" (Crouch, 2004; Crouch et al., 2005). In Crouch's discussion, complementarity exists when two or more dissimilar actors/agents (e.g., firms, institutions, macromolecules, etc.) are parts of a relationship due to underlying logic or rules, non-random in nature, a relationship constantly threatened by instability.

The individual from whom some theorists on socio-economic governance (Hollingsworth and Boyer, 1997) derived considerable insight and inspiration on the general binding problem was Caltech chemist and Nobel laureate Linus Pauling—certainly the most creative scientist to emerge in the U.S. and probably the most important chemist of the twentieth century. Just as theorists of economic governance have been interested in the logic by which a particular type of market coheres to or is associated with a particular type of state, associative system, etc., Pauling throughout much of his career addressed a comparable problem—attempting to understand the logic with which atoms of particular molecules would bond to each other, why particular molecules were either loosely or tightly coupled, and with what consequences. Thus, some socio-economists and Pauling have been addressing the same theoretical problem: Why are different phenomena attracted to each other, how strong and for what duration is the attraction, and with what consequences? Addressing this problem, Granovetter (1973) wrote one of the most frequently cited papers in sociology during the latter half of the twentieth century; significantly, he had the key insights for his paper as a student in a chemistry course.

Pauling's most significant contribution to chemistry was his theory of chemical bonds and complementarity. His approach to how bonding is expressed in terms of complementarity was first introduced into the chemistry literature in 1940 in a very significant paper co-authored with a young German physicist, Max Delbrück (later also a Caltech professor and Nobel laureate). They wrote that "in order to achieve maximum stability, two molecules must have complementary surfaces, like die and coin" (Pauling and Delbrück, 1940). The idea that atoms from dissimilar molecules would be attracted to each other became a key component of bonding and complementarity in modern chemistry and biology. Later, Delbrück became a mentor to James D. Watson, and the logic of the Pauling-Delbrück 1940 paper about bonding and complementarity provided one of the key insights for Crick and Watson to solve the structure of DNA, one of the most important scientific discoveries of the last century (Watson, 1968).

The history of several academic fields could be written around the effort to understand why phenomena with differences as well as similarities are attracted to each other (Moody and White, 2003).[4] One example of binding among mutually exclusive elements is found in the history of twentieth century immunology. Many scientists suggested that antigens and antibodies are attracted to each other like a lock and a key. It was in the antigen-antibody reactions that complementarity often received the most attention. For example, biologists long argued that an antigen and antibody were attracted to each other because there was a "complementarity" in the way that their shapes fit or complemented one another—in much the same way that a lock fits or complements the key for which it has been designed. The antigen in the metaphor was the lock and the antibody the key (Serafini, 1989: 99–100).

Jerne's research—for which he was awarded a Nobel Prize in 1984—is especially suggestive for socio-economists who address the problem of why particular governance structures are attracted to one another. Just as there is not a precise, one-to-one relationship between any particular type of state, market, or associative structure, so Jerne found that an antibody does not have to fit precisely to the antigen to have an "affinity." In short, "a key doesn't have to fit 100 percent to open a lock." The same key can fit multiple locks. (Söderqvist, 2003: 177; Jerne, 1993). Similarly only particular kinds of state structures are attracted to particular kinds of markets. In nature, there are no perfect fits between antigen and antibodies; in the social sciences we also find that there is no perfect fit among different governance structures.

But is there some underlying logic as to how different governance structures are attracted to each other, or is the process by which governance structures fit together in particular societies simply a result of chance? The work of various scholars studying the socio-economics of capitalism includes analyses of why different institutional arrangements (e.g., forms of governance) bond to each other (Hollingsworth and Boyer, 1997; Hollingsworth et al., 1994; Whitley, 1998). This scholarship argues that there are a number of institutional arrangements/modes of governance (markets, types of hierarchies, networks, associations, state structures, communities, and clans) for coordinating relationships among various economic actors. Though each of these seven governance modes has its own distinctive logic, none exists in a pure or ideal form. Each is found only in some kind of combination relationship with other modes of governance. Governance modes may be mutually exclusive from one another, but they exist in relationship with each other in often-unstable configurations.

Moreover, there are many types of each of the above seven different modes of governance. For example, Boyer (1997) demonstrated that there are many types of markets, and hereafter it should be obvious that it makes no sense for anyone to suggest that an economy is coordinated by a “pure market,” the “free market,” etc. And it is hardly necessary to argue that there are many kinds of states. Because each type of governance may exist in combination with many other types, the possible combinations of governance structures is very large, although extraordinarily small in comparison to the combinations which computational biologists are facing (Kitano, 2002; Hood, 2003). Because the problems faced by scholars in these fields are quite similar, social scientists should be very attentive to the biologists’ methods and strategies.

There are several critical theoretical issues about the binding of different governance arrangements which socio-economists should address: (1) What is the logic by which one type of governance is *attracted* to another or repelled?[5] (2) What is the logic by which governance configurations are *tightly coupled* or bonded in some societies, while elsewhere they are *loosely coupled*? This problem relates to why there is variation in the coherence of governance structures, both within and across societies—a theme prominently discussed in some of the varieties of capitalism literature as well as in the literature on governance of different sectors in the same country (Campbell et al., 1991; Herrigel, 1996, 2005; O'Sullivan, 2005).

Even though scientists in different fields work on common problems and can derive insights from one another, scientific explanations are essentially specific to the phenomenon to be explained. As Bunge (2003: 22) observes "there are no all-encompassing explanations because there are no one-size-fits-all mechanisms." However, there seem to be a few common processes which socio-economics shares with a number of other fields of science in studying the general bonding problem (Moody and White, 2003; Moody, 2004). For example, bonds are strongest among entities in smaller systems. Physicists and chemists have demonstrated that bonds are very strong when nuclear forces give rise to small systems, whereas bonds holding super-molecules in biology are much weaker. Similarly, in the socio-economic world, in small societies which are relatively homogeneous in ethnicity and religion, the bonds holding a society together tend to be relatively strong. On the other hand, in societies which are larger and have a great deal of ethnic, religious, and linguistic diversity, the bonds holding the parts of the society together are much weaker (Hanneman and Hollingsworth, 1984; Granovetter, 1973; White, 2002; Axelrod, 1997).

Concerned with how the constituent parts of societies emerge and bond together, some scholars have long focused on the processes of nation and state building (Hollingsworth, 1971; Grew, 1978). Some have studied the processes of mergers and acquisitions of firms (Williamson, 1985). Others have written about the conditions under which capitalists and workers organize and how they relate to each other (Schmitter and Streeck, 1981; Streeck, 1992; Offe and Wiesenthal, 1980). How nodes of networks are connected to each other has become a major research issue among those who study complex networks—for sociologists as well as for physicists (Powell et al., 2005; Uzzi and Spiro, 2005; Moody, 2004; Kogut, 2000; Padgett and Ansell, 1993; Newman, et al., 2006).

Theorizing about how bonds hold phenomena together is only one side of the coin. The binding problem also concerns the process by which things come apart, and this concern cuts across many disciplines. Physicists and chemists have long been fascinated with the process by which solids break down. One of the leading areas of biological research is research on the mechanisms of aging and death—the process by which parts of cells become dysfunctional and lead to cell death. In the social sciences, scholars have long been fascinated with the breakdown of empires and states—e.g., the downfall of the Roman Empire, the collapse of the old regime in France, the collapse of the Austro-Hungarian and Ottoman Empires, the downfall of the British Empire, the disintegration of the Soviet Union and Yugoslavia (Kennedy, 1987; Beissinger, 2002).

4.5 Multi-level Analysis

To understand why societies come together or break apart requires a multi-level form of analysis—micro, meso, or macro research strategies which attempt to explain how individuals and institutions relate to one another (Hollingsworth et al., 2002). In many fields of science, a major concern in recent decades has been to overcome the tendency to engage in micro-reductionism, extreme forms of micro level analysis. From the seventeenth century to recent decades, micro-reductionism was the dominant scientific strategy for understanding reality. If reality resembled a machine, it followed that in order to understand the machine it made good sense to deconstruct it into its component parts. For such reductionists, reality was to be understood only at the level of parts—e.g., protons, electrons, atoms, molecules in the natural sciences or individuals in the social sciences. In the social sciences, extreme micro-reductionism has often been characterized as methodological individualism (Hodgson, 2007).

However, wise investigators are reductionists only to obtain points of entry to complex systems. They are very much aware that parts or individuals are embedded in complex environments. As scientists in more recent years have become more sophisticated, they have engaged in a great deal of thought about interactions across different levels. Hence, in biology, a scientist may be a specialist in molecular biology but, at the same time, very concerned with phenomena from subatomic particles to atoms as well as phenomena above the molecular level such as cell biology, systems biology, whole-organism biology, population biology, and even the global environment. Physical scientists also work at multiple levels. But the logic of doing multi-level analysis and of moving beyond extreme reductionism is similar in both. Although most scientists become specialists at one level of analysis, E. O. Wilson of Harvard and Nobel laureate Gerald Edelman are good examples of understanding how phenomena at one level are constrained by or interact with phenomena at other levels (Wilson, 1998; Edelman, 1987).

Similarly, the social sciences in recent years have been increasingly involved in multi-level analysis. Table 2 presents two different approaches by social scientists using multi-level analysis—one for spatial arrangements within political systems and the other for individuals and structures in entire social systems (see Table 2). The table also suggests how physical and biological scientists also work at multiple levels. Regardless of the field of science, analysts are increasingly viewing the world as a network of interacting components. Reality may be approached from the bottom up, or from the top to the bottom. Most scientists, whether social scientists or natural scientists, center their research on only one level; very few systematically conduct research at multiple levels. In most fields, all levels are constantly interacting with one another, and thus, there are clear benefits of relating one's specialized research to a larger system. In some respects, one of the major goals of a socio-economics research agenda should be to understand how levels interact with one another. Economies have many levels of interaction. Units at any level can serve as building blocks for structuring behaviors at any other level. In short, there are many kinds of interactions and channels of communication across levels.[6]

Table 2 Examples of multi-level analysis

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Whether in the social or the natural world, entities at each level have their own logic (i.e., rules which constrain their behavior). No level exists out of relationship with each other level. Thus in the social sciences, analysts cannot understand human behavior out of its context any more than the cell biologist can understand the behavior of a cell totally abstracted from its environment. Natural as well as social scientists tend to become specialized at only one level. But in the future, we must all attempt to have a better understanding of how each level is linked with each other level, with positive and negative feedback among levels.

The biological and social worlds in some respects operate similarly. The different levels do not fit together because there was some designer with specific purpose. As Wolfgang Streeck has observed (2002) with respect to the social world, when there is institutional coherence and complementarity, it is often because we as observers happen to recognize distinct patterns. Both rationalism and functionalism grossly exaggerate the capacity of actors to know what they are doing before they have done it. In short, the emergence of biological and social systems constitutes a long term evolutionary process, with each level interacting with a larger environment and resulting whole. At any moment in history, the total complexity of a system contains the resources and legacies of its past. Pre-existing complexes are very rarely completely wiped out. All systems—biological and social—consist of multiple levels of history with their multiple logics. However, the cumulative effect of small changes in the alternation of phenomena at any particular level can have big effects at any other level (also see Campbell and Pedersen, 2001; Bak, 1997; Kauffman, 1993).

5. Concluding Observations

There is a general lack of theoretical consensus among socio-economists about their subject matter. Because there is great fragmentation within their field, socio-economists—like their colleagues in many other disciplines—often find it difficult to become interested in the work of others in the same field. Socio-economics is a highly clustered network, the boundaries of socio-economics are highly permeable, and this trait could well turn into a strength. High permeability of fields offers the potential for cross-disciplinary collaboration. Scholars specializing in distinct problems and methods but in different disciplines have the potential to transfer their interests to highly permeable fields. Hence, one of the great strengths of socio-economics is its potential to promote collaboration among those who work in differentiated research areas, but having wide-ranging and complimentary interests (Moody, 2004: 215–217; Abbot, 2001; Collins, 2001).

In recent years, two significant and interrelated changes have been occurring which offer socio-economists new prospects to expand their theoretical perspectives on the world. First, the decline in the dominance of Science I and the increasing importance of Science II have provided new opportunities for understanding the world, especially because our new theoretical frameworks play an important role not only in influencing the problems we pose about the universe but also in how we go about solving those problems. Science II suggests that much of the world is dynamic and complex with large numbers of micro-level interactions which lead to the emergence of macro-level patterns of behavior. Practitioners of a Science II outlook are increasingly sympathetic to a "holistic," multi-level effort to understand the world rather than one which insists on taking a top-down, reductionist approach in search of universal laws which can only explain micro-level phenomena.

Second, the study of complex networks has emerged as a significant tool for facilitating social, biological, and physical scientists to collaborate in studying problems of a complementarity nature. We have discussed five common problems and processes which socio-economists share with many of their colleagues in the social as well as the natural sciences: self-organizing processes, aristocratic-type networks, power-law distributions, the binding problem, and multi- level analysis. But among these particular problem areas, the one which intersects most often with the others is the analysis of networks. However, it is useful to emphasize the centrality of social networks for a socio-economics agenda.

The study of aristocratic-type networks is one of the most rapidly expanding fields of research in the social, biological, and physical sciences. Because of the importance of such networks in multiple areas of science, we are at a moment in the history of modern science when there is high potential for serious interaction between socio-economists and the other sciences.

Despite variation in subject matter, the overall performance of networks—irrespective of the specific domain—is shaped by a common architecture with a high degree of similarity.

In all networks, there is an assembly of elements (nodes) connected to one another by links. In multiple sciences, scholars have discovered that networks have a natural tendency to self organize themselves into a similar but highly concentrated architecture: a few nodes become extremely concentrated, while others have little or no concentration (Barabási, 2002, 2007).

Aristocratic-type networks tend to start from an initial configuration with a small number of components, but grow in the course of their evolution—in a self-organizing process—into very large networks. "Starting from a small nucleus of nodes, the number of nodes increases throughout the history of the network by the subsequent addition of new nodes" (Albert and Barabási, 2002: 71). In short, these networks tend to be open, to grow, and to self evolve; existing nodes as well as new nodes tend to bind with each other in a non-random way—often called preferential attachment. New bonds tend to occur to already highly connected nodes rather than to weakly connected components. In the social science literature, the process of preferential attachment has been identified as a key factor in such different domains as migration processes, the growth of cities, industrial districts, scientific communities, business firms, citation indices, the world wide web, the clustering of innovations, the spread of ideas, the emergence of social movements, railway and airport networks, as well as research and development collaborations.

One of the most intriguing aspects of the new science of networks lies in the fact that several micro rules (i.e., openness, growth, and preferential attachment) tend to generate highly ordered macro-behaviors across a wide variety of domains. In addition, the generic features of such networks include several other characteristics: (1) power-law distributions, (2) a degree of randomness which leads to different evolutionary histories despite identical initial configurations and identical micro-rules. Phrased differently, most complex networks combine a certain degree of micro-variability with macro-features such as a power-law distribution. (3) Most complex networks tend to be quite robust. Many nodes which are loosely linked to the overall network structure can fail, but the overall structure of a complex network has a high degree of error-tolerance. However, an attack on central components of a complex network can lead to a complete breakdown of an entire network. Significantly, social scientists, biologists, neuroscientists, epidemiologists, and others have engaged in a great deal of recent interdisciplinary discussion about how to repair attacks on connections in a network system.[7]

Many of the novel recent advances in socio-economics have been made by those who have the study of aristocratic-type networks as central to their concern. Significantly, the recent theoretical advances about such networks focused heavily on those traits that can be analyzed statistically (the distribution of connectivity, the average distance between nodes, self-organizing processes, etc.). Accordingly, the methods used to make advances in this research area have had strong links to the field of statistical physics. Indeed, many of the leaders in this area of socio-economics have been either physicists (Barabási, 2002, 2007; Newman et al., 2006) or sociologists heavily engaged with the physics community (Powell et al., 2005; Uzzi and Spiro, 2005; Watts, 2003). This observation is relevant to many of the themes of this paper: socio-economics is becoming a truly interdisciplinary field, and scholars addressing certain kinds of problems at the frontiers of the field must be willing to borrow concepts, methods, and insights from many disparate fields. For certain kinds of problems, we should continue to expect the convergence of interest of researchers—regardless of the discipline from which one was originally trained (Vega-Redondo, 2007: 10).

We hope, returning to a terminology introduced at the beginning of this paper, that in the course of our explorations and searches for common models and methods across different disciplines that we will commit no serious α-type errors. We believe that in the process of emphasizing the importance of complex networks to a socio-economics agenda that in this subject area we have helped to eliminate the potential for large β-type errors. As we undertake the active transfer of the ever-expanding stock of common problems, metaphors, methods, and/or models among natural and social scientists as part of their normal socio-economic research strategies, we should substantially advance our understanding of social reality. In this way we should contribute to diminishing the cultural divide between the natural and human sciences which C. P. Snow and others have found so frustrating during the last half-century.

Endnotes

[1] Much of this perspective about socio-economics is derived from an examination of the papers in the *Journal of Socio-Economics* and *Socio-Economic Review* and from the writings of the leading participants in the annual meetings of the Society for the Advancement of Socio-Economics (SASE). Thus far, socio-economics is interdisciplinary in that it borrows methods and insights from economics, sociology, psychology, and other fields. This paper is an effort to point the direction to more effective bridge building between socio-economics and other fields.

[2] Science I and Science II should in no way be confused with the concepts Mode I and II which Helga Nowotny and her colleagues discuss in *Re-Thinking Science: Knowledge and the Public in an Age of Uncertainty* (2001).

[3] To date, one of the most sophisticated studies on the theoretical process of growth and preferential attachment in aristocratic networks is that by Powell et al. (2005). This study, along

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with Padgett and Ansell (1993) on the rise of the Medici during the Renaissance in Florence are among the few studies which analyze the rules and norms which shape the emergence and stability of specific types of preferences in aristocratic-type networks over extended periods of time.

[4] Historically, complementarity as used by scholars in most fields does not address phenomena having similarities. Bonding and complementarity theory generally involves interconnectivity of fundamentally different components. Throughout the twentieth century a critical puzzle for many scholars has been how mutually exclusive and dissimilar phenomena are attracted to each other.

[5] It is not as though this is a neglected research problem in the social sciences. Wolfgang Streeck's (1992) work on the associations of workers and business interests is certainly noteworthy in this respect. This is also an important theme in many of the essays in Streeck and Yamamura (2001).

[6] For elaboration of these ideas, see Boyer and Hollingsworth, 1997; Arthur, Durlauf and Lane, 1997, especially 1–14.

[7] Interestingly, the literature on counterterrorism and the maintenance of robustness of the world's banking system borrows on research about the robustness and vulnerability of complex networks in both the natural and social sciences (Vega-Redondo, 2007; Taleb, 2007).

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Table 1 Differences between Science I and Science II

	Science I	**Science II**
Leading Fields of Science	Classical Physics	Evolutionary Biology and the Sciences of Complexity
Theoretical Goal	General, Universal Laws	Pattern Formation and Pattern Recognition
Theory Structures	Axiomatic, Reductionist	Phenomena Nested in Multiple Levels of Reality Simultaneously
Forecasting Capacities or Ability to Make Predictions	High	Low
Complexity	Low	High
Ontology	Dualism (*res extensa/res cogitans*)	Monism, with a Highly Complex Architecture
Perspective on Change	Emphasizes Static, Linear Phenomena in a State of Equilibrium	Emphasizes Dynamism, Openness of System, Operating Far from Equilibrium
Distribution of Phenomena	Emphasis on Normal Distributions, Phenomena Which are Distributed Like a Bell-shaped Curve	Emphasis on Rare or Extreme Events; Sensitive to Phenomena with Power Law Distributions
Micro-Macro Distinctions	Micro and Macro Level Processes are Viewed as Separate and Distinctive	Little Distinction: Macro Phenomena Emerge from the Collective Micro Level Behavior
Potential for Interdisciplinary Research	Low	High
Leading Metaphors	Clocks	Complex Networks, Living Cells, Clouds
Cognitive Distances between the Social Science and the Natural Sciences	High	Medium
Inspirational Scientists	René Descartes, Isaac Newton, Adam Smith	Charles Darwin, Ilya Prigogine, Gerald M. Edelman

Table 2 Examples of multi-level analysis*

Natural Sciences		**Social Sciences**	
Physical Science	*Biological Science*	*Spatial Analysis*	*Structural Analysis*
Cosmos, Galaxies, Stars	Environment	Global	Rules, Norms, Habits, Conventions, etc. (Institutions)
Earth	Organisms	Transnational Regions (e.g., European Union)	Institutional Arrangements (Markets, Hierarchies, States, etc.) and Institutional Sectors (Financial, Educational, Business, Research Systems, etc.)
Subsystems of Earth	Tissues	Nation State	Organizations, Firms
Molecules	Cells	Subnational Region	Small Groups, Families
Atoms	Molecules	Local Level	Individuals
Particles	Atoms		

* It is assumed that each level influences all levels below it, and that there is feedback among all levels. We do not mean to suggest that the phenomena in the rows of the table are somehow similar to one another.

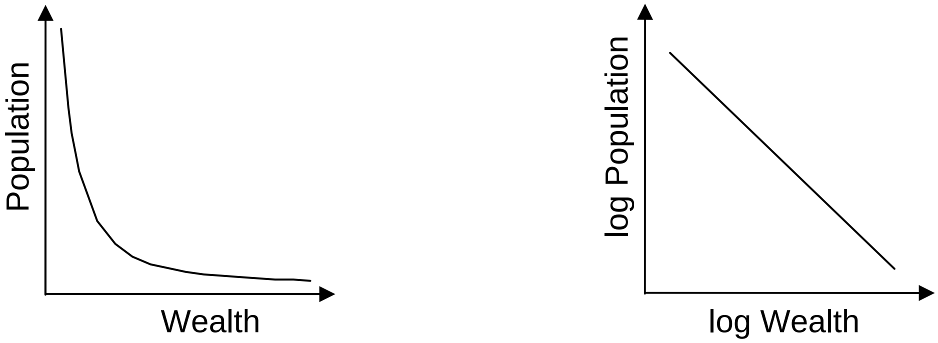

Figure 1.1
Power-Law Distribution

Figure 1.2
Power-Law Distribution
on a log-log Plot

Figure 1 Examples of power-law distributions