Foundations of "New" Social Science:
Institutional Legitimacy from Philosophy, Complexity Science, Postmodernism, and Agent-based Modeling

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This version is missing a section on agent modeling, but I have run out of time and all of you attending the Sackler Colloquium probably know more about agent-based modeling than I anyway!
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Since the death of positivism in the 1970s, philosophers have turned their attention to scientific realism, evolutionary epistemology, and the Semantic Conception of Theories. Building on these trends, Campbellian Realism allows social scientists to accept real-world phenomena as criterion variables against which theories may be tested without denying the reality of individual interpretation and social construction. The Semantic Conception reduces the importance of axioms, but reaffirms the role of models and experiments. In addition, philosophers now see models as "autonomous agents" that exert independent influence on the development of a science, in addition to theory and data. The inappropriate molding effects of mathematical models on social behavior modeling are noted. Complexity science offers a "new" normal science epistemology focusing on order-creation by self-organizing heterogeneous agents—and featuring agent-based models. The more responsible core of postmodernism builds on the idea that agents operate in a constantly changing web of interconnections among other agents. The connectionist agent-based models of complexity science draw on the same conception of social ontology as do postmodernists. The recent trends in philosophy of science, the notion of models as autonomous agents, the new normal science epistemology from complexity science, connectionist postmodernist ontology, and use of agent-based in place of mathematical models combine to provide foundations for a "new" social science centered on formal modeling not requiring the mathematical assumptions of agent homogeneity and equilibrium conditions. Together these foundations give "new" social science a level of institutional legitimacy in scientific circles that current social science approaches lack.

1 INTRODUCTION

The last time I looked, a theoretical model could predict the charge on an electron (really an average) out to the 12th decimal place and an experimenter could produce a real-world number out to the 12th decimal place—and they agreed at the 7th decimal place. Recent theories of genetic structure coupled with lab experiments now single out genes that cause things like sickle-cell anemia. These outcomes look like science in action and are treated as such. There is rock-hard institutional legitimacy within universities and among user communities around the world given to the physics of atomic particles, genetic bases of health and illness, theories expressed as axiom-based mathematical equations, and experiments. It has been so for a century. John Casti (2001), a mathematician, shows up at the Marschak Colloquium at UCLA, advocating agent-based modeling in social science and an elderly gentleman asks, "So, where is the universal solution?" Which is to ask, Where is the science? Agent modelers show up at our Dean's office asking for funding with computer screens in which agents dance on multicolor grids and GUIs (graphical user interfaces) produce charts that seem to grow magically from left to right, with multiple lines dancing up and down, as time progresses. Our Dean looks at the computer screen and his facial expression asks, Where is the science? No funds are forthcoming.

A recent citation search compared 5400 social science journals against the 100 natural science disciplines covered by INSPEC (over 4000 journals) and Web of Science (over 5700 journals) Indexes (Henrickson 2002). It shows keywords *comput** and *simulat** peak at around 18,500 in the natural sciences while they peak at 250 in economics and around 125 in sociology. For the keyword, *nonlinear*, citations peak at 18,000 in natural science, at roughly 180 in economics, and near 40 in sociology. How can it be that sciences founded on the mathematical linear determinism of classical physics have moved more quickly toward the use of nonlinear computer models than economics and sociology—where the agents doing the science are no different than the social actors that ARE the Brownian Motion?

Writ large, social sciences appear to seek improved scientific legitimacy by copying the century old linear deterministic modeling of classical physics—with economics in the lead (Mirowski 1989, Hinterberger 1994)—at the same time natural sciences strongly rooted in linear determinism are trending toward nonlinear computational formalisms (McKelvey 1997, Henrickson 2002). The postmodernist solution takes note of the heterogeneous-agent ontology of social phenomena, calling for abandoning classical normal science epistemology and its assumptions of homogeneous agent behavior, linear determinism, and equilibrium. Postmodernists seem unaware of the "*new*" *normal science* alternative being unraveled by complexity scientists who assume, and then model, autonomous heterogeneous agent behavior, and from this model, study how supra-agent structures are created (Kauffman 1993, 2000, Cowan 1994). Social scientists need to thank postmodernists for constantly reminding us about the reality of heterogeneous social agent behavior. But they need to stop listening to postmodernists at this point and study the epistemology of "new" normal science instead, specifically the order-creation aspects of complexity science (Kauffman 1993, Mainzer 1997, McKelvey 1999a, 2001d, e). Finally social scientists need to take note of the *other* nonpostmodernist postpositivisms that give legitimacy: *scientific realism*, *evolutionary epistemology*, and the model-centered science of the *Semantic Conception* (Suppe 1989, Azevedo 1997, McKelvey 1999c, 2000b, 2001c).

In what follows I begin by describing recent trends in philosophy of science, starting with Suppe's (1977) epitaph for positivism. Next I present the most recent view of the role of models in science espoused by Morgan and Morrison (2000) and colleagues. Then I outline complexity science, emphasizing its order-creation core, as a means of framing the elements of "new" normal science concerns and epistemology—a theme starting with Mainzer (1997) and resting on foundational theories by other leading theorists including Ilya Prigogine, Ross Ashby, Jack Cohen, Edward Lorenz, Hermann Haken, Murray Gell-Mann, Stewart Kauffman, Stanley Salthe, and Ian Stewart. My connection of postmodernist ontology with "new" normal science ontology comes next (Cilliers 1998). Finally, I use this logic chain to establish the institutional legitimacy of agent-based social science modeling and its rightful claim at the center of "new" Social Science.

2 POST-POSITIVIST PHILOSOPHY OF SCIENCE

Nothing seems to me less likely than that a scientist or mathematician who reads me should be seriously influenced in the way he works. (Wittgenstein, quoted by Weinberg, 1993, p. 167.)

The insights of philosophers have occasionally benefited physicists…by protecting them from the preconceptions of other philosophers….

We should not expect [philosophy of science] to provide scientists with any useful guidance…. (Weinberg, 1993, pp. 166–167.)

While philosophy originally came before science, since Newton at least, philosophers have been following along behind with their *reconstructed logic* (Kaplan 1964) of how good science works. But there is normal science and then there is social science. Like philosophy of science, social science always seems to *follow* older normal science epistemology—but searching for institutional legitimacy rather than reconstructed logic. At the end of the 20th century, however, (1) normal science is leading efforts to base science and epistemology directly on the study of heterogeneous agents, thanks to complexity science; and (2) philosophy of science is also taking great strides to get out from under the classical physicists' view of science. Social science lags—especially the modeling side—mostly still taking its epistemological lessons from classical physics. At this time, useful lessons for enhancing social science legitimacy are emerging from both normal science and philosophy of science. I start with the latter.

Though Suppe (1977) wrote the epitaph on positivism and relativism, a positivist legacy remains, details of which are discussed by Suppe and McKelvey (1999c). The idea that theories can be unequivocally verified in search for a universal unequivocal "Truth" is gone. The idea that "correspondence rules" can unequivocally connect theory terms to observation terms is gone. The role of axioms as a basis of universal Truth absent empirical tests is negated. The importance of models and experiments is reaffirmed.

Though the "postpositivism" term is often used to refer to movements such as relativism, poststructuralism, critical theory, postmodernism, and the like, another trail of postpositivisms is shown in Figure 1. In addition to a more fluid view of the interrelation of theory and observation terms, scientific realism and Semantic Conception of Theories have further developed since 1977. Together these lead to a reaffirmation of a realist, model-centered epistemology. This is the new message from philosophy to social science on which I now focus.

>>> Insert Figure 1 about here <<<

2.1 Realism

From the positivist legacy a *model-centered evolutionary realist epistemology* has emerged. Elsewhere (McKelvey 1999c), I argue that model-centered *realism* accounts to the legacy of positivism and evolutionary realism accounts to the dynamics of science highlighted by relativism, all under the label *Campbellian Realism*. Campbell's view may be summarized into a tripartite framework that replaces the historical relativism of Kuhn (1962) and Feyerabend (1975) for the purpose of framing a dynamic realist epistemology. First, much of the literature from Lorenz (1941) forward has focused on the selectionist evolution of the human brain, our cognitive capabilities, and our visual senses (Campbell, 1974, 1988), concluding that these capabilities do indeed give us accurate information about the world we live in (reviewed by Azevedo, 1997).

Second, Campbell (1991, 1994) draws on the hermeneuticists' coherence theory in a selectionist fashion to argue that over time members of a scientific community (as a tribe) attach increased scientific validity to an entity as the meanings given to that entity increasingly cohere across members. This process is based on hermeneuticists' use of coherence theory to attach meaning to terms (Hendrickx, 1999). This is a version of the social constructionist process of knowledge validation that defines Bhaskar's use of transcendental idealism and the sociology of knowledge components in his scientific realist account. The coherentist approach selectively winnows out the worst of the theories and thus approaches a more probable truth.

Third, Campbell (1988, 1991) and Bhaskar (1975) combine scientific realism with semantic relativism. Nola (1988) separates relativism into three kinds:

1. "Ontological relativism is the view that what exists, whether it be ordinary objects, facts, the entities postulated in science, etc., exists only relative to some relativizer, whether that be a person, a theory or whatever" (1988, p. 11)—[*ontologically nihilistic*].
2. Epistemological relativisms may allege that (1) what is known or believed is relativized to individuals, cultures, or frameworks; (2) what is perceived is relative to some incommensurable paradigm; (3) there is no general theory of scientific method, form of inquiry, rules of reasoning or evidence that has privileged status. Instead they are variable with respect to times, persons, cultures, and frameworks (1988, pp. 16–18)—

[*epistemologically nihilistic*].

3. Semantic relativism holds that truth and falsity are "…relativizable to a host of items from individuals to cultures and frameworks. What is relativized is variously sentences, statements, judgements or beliefs" (1988, p. 14)—[*semantically weak*].

Nola observes that Kuhn and Feyerabend espouse both semantic and epistemological relativism. Relativisms[1] familiar to social scientists range across all three kinds, that is, from ontological nihilism to semantic. Campbell clearly considers himself a semantic relativist in addition to being an ontological realist (Campbell and Paller 1989). This produces an ontologically strong relativist dynamic epistemology. In this view the coherence process within a scientific community continually develops in the context of selectionist testing for ontological validity. The socially constructed coherence enhanced theories of a scientific community are tested against real-world phenomena (the criterion variable against which semantic variances are eventually narrowed and resolved), with a winnowing out of the less ontologically correct theoretical entities. This process, consistent with the strong version of scientific realism proposed by de Regt (1994), does not guarantee error free "Truth" (Laudan 1981) but it does move science in the direction of increased verisimilitude (truthlikeness).

Campbellian realism is crucial because elements of positivism and relativism remain in social science. Campbell's epistemology folds into a single epistemology: (1) dealing with metaphysical terms, (2) objectivist empirical investigation, (3) recognition of socially constructed meanings of terms, and (4) a dynamic process by which a multiparadigm discipline might reduce to fewer but more significant theories.

Campbell defines a *critical, hypothetical, corrigible, scientific realist selectionist evolutionary* epistemology as follows: (McKelvey 1999c, p. 403)

1. A scientific realist postpositivist epistemology that maintains the goal of objectivity in science without excluding metaphysical terms and entities.
2. A selectionist evolutionary epistemology governing the winnowing out of less probable theories, terms, and beliefs in the search for increased verisimilitude may do so without the danger of systematically replacing metaphysical terms with OPERATIONAL TERMS.
3. A postrelativist epistemology that incorporates the dynamics of science without abandoning the goal of objectivity.
4. An objectivist selectionist evolutionary epistemology that includes as part of its path toward increased verisimilitude the inclusion of, but also the winnowing out of the more fallible, individual interpretations and social constructions of the meanings of theory terms comprising theories purporting to explain an objective external reality.

[1] Includes ontologically and/or epistemologically nihilistic subjectivist *postpositivisms* such as ethnomethodology, historicism, radical humanism, phenomenology, semioticism, literary explicationism, hermeneuticism, critical theory, and postmodernism, all of which are "post" positivist and in which subjective and cultural forces dominate ontological reality. Lincoln and Guba (1985, p. 7) use the term "*naturalism*" to encompass a similar set of postpositivist paradigms.

The epistemological directions of Campbellian realism have strong foundations in the scientific realist and evolutionary epistemology communities (see Azevedo, 1997). *The one singular advantage of realist method is its empirically based, self-correcting approach to the discovery of truth* (Holton, 1993). While philosophers never seem to agree exactly on anything, nevertheless, broad consensus does exist that these statements reflect what is best about current philosophy of science.

To date evolutionary realism has amassed a considerable body of literature, as reviewed by Hooker (1987, 1995) and Azevedo (1997). Along with Campbell, and Lawson's (1997) realist treatment of economics, Azevedo stands as principal proponent of realist *social* science. Key elements of her "*mapping model of knowledge*" are shown in Table 1. Though it might seem that the Campbellian Realist approach is more model-centered than hers, nothing is more central in Azevedo's analysis than the mapping model—making her epistemology just as model-centered as mine (and Read's 1990). Furthermore, both of us emphasize isolated idealized structures. Her analysis greatly elaborates the initial social constructionist applications of realism to social science by Bhaskar (1975) and Campbell (1991, 1994) and accounts for heterogeneous agent behavior as well.

>>> Insert Table 1 about here <<<

2.2 The New "Model-Centered" Epistemology

In my development of Campbellian Realism (McKelvey 1999c) I show, that model-centeredness is a key element of scientific realism, but I do not develop the argument. In this section, I flesh out the development of a model-centered social science by defining the semantic conception and close with a scale of scientific excellence based on model-centering. As Cartwright put it initially: "The route from theory to reality is from theory to model, and then from model to phenomenological law" (1983, p. 4; my italics). The shift from Cartwright's earlier view of models as passive reflections of theory and data to models as autonomous agents mediating between theory and phenomena reaches fullest expression in Cartwright (2000), Morgan and Morrison (2000), Morrison (2000), Morrison and Morgan (2000), as they extend the semantic conception. I discuss this further in Section 3.

Models may be iconic or formal. Most social science lives in the shadow of economics departments dominated by economists trained in the context of theoretical (mathematical) economics. Because of the axiomatic roots of theoretical economics, I discuss the axiomatic conception in epistemology and economists' dependence on it. Then I turn to the semantic conception, its rejection of the axiomatic definition of science, and its replacement program.

2.2.1 THE AXIOMATIC SYNTACTIC TRADITION

Axioms are defined as self-evident truths comprised of primitive syntactical terms. Thus, in Newton's second law,

$F = ma$, most any person can appreciate the reality of force—how hard something hits something else, mass—how heavy something is, and acceleration—whether an object is changing its current state of motion. And the three terms, force, mass, and acceleration cannot be decomposed into smaller physical entities defined by physicists—they are primitive terms this sense (Mirowski, 1989, p. 223). A formal syntactic language system starts with primitives—basic terms, definitions, and formation rules (e.g., specifying the correct structure of an equation) and syntax—in $F = ma$ the syntax includes F, m, a, = and × (implicit in the adjoining of *ma*). An axiomatic formal language system includes definitions of what is an axiom, the syntax, and transformation rules whereby other syntactical statements are deduced from the axioms. Finally, a formal language system also includes a set of rules governing the connection of the syntax to real phenomena by such things as measures, indicators, operational definitions, and correspondence rules all of which contribute to syntactic meaning.

The science of analytical mechanics (Lanczos, 1970) is the classical physics example of theories being governed by an axiomatic syntactic formalized language. It began with the three laws of motion and the law of gravitational attraction (Thompson, 1989, p. 32–33):

1. Every entity remains at rest or in uniform motion unless acted upon by an external unbalanced force;
2. Force equals mass times acceleration ($F = ma$);
3. For every action there is an equal and opposite reaction;
4. The gravitational force of attraction between two bodies equals the gravitational constant ($G = 6.66\times10^{-s}$ dyne cm.^{2}/gm.^{2}) times the product of their masses (m_1m_2) divided by the square of the distance between them (d^2), that is, $F = G(m_1m_2/d^2)$.

During the 22 decades between Newton's *Principia* (circa 1687) and initial acceptance of quantum and relativity theory, physicists and eventually philosophers discovered that the syntax of these basic axioms and derived equations led to explanations of Kepler's laws of planetary motion, Galileo's law of free fall, heat/energy (thermodynamic) laws, electromagnetic force (Maxwell's equations), and thence into economics (Mirowski, 1989). Based on the work of Pareto, Cournot, Walras, and Bertrand, economics was already translating physicists' thermodynamics into a mathematicized economics by 1900. By the time logical positivism was established by the Vienna Circle circa 1907 (Ayer, 1959; Hanfling, 1981), science and philosophy of science believed that a common axiomatic syntax underlay much of known science—it connected theories as far removed from each other as motion, heat, electromagnetism, and economics to a common set of primitives. Over the course of the 20th century, as other sciences became more formalized, positivists took the view that any "true" science ultimately reduced to this axiomatic syntax (Nagel, 1961; Hempel, 1965)—the origin of the "Unity of Science" movement (Neurath and Cohen, 1973; Hanfling, 1981).

Now, the axiomatic requirement increasingly strikes many scientists as more straight-jacket than paragon of good science. After quantum/relativity theories, even in physics Newtonian mechanics came to be seen as a study of an isolated idealized simplified physical world of point masses, pure vacuums, ideal gases, frictionless surfaces, linear one-way causal flows, and deterministic reductionism (Suppe, 1989, p. 65–68; Gell-Mann, 1994). But biology continued to be thought—by some—as amenable to axiomatic syntax even into the 1970s (Williams, 1970, 1973; Ruse, 1973). In fact, most formal theories in modern biology are not the result of axiomatic syntactic thinking. Biological phenomena do not reduce to axioms. For example, the Hardy-Weinberg "law," the key axiom in the axiomatic treatments of Williams and Ruse is:

$$p = \frac{AA + 1/2\,Aa}{N},$$

where p = gene frequency, A & a are two alleles or states of a gene, and N = number of individuals. It is taken as prerequisite to other deterministic and stochastic derivations. But instead of being a fundamental axiom of evolutionary theory, it is now held that this "law," like all the rest of biological phenomena is a result of evolution, not a causal axiom (Beatty, 1981, p. 404–405).

The so-called axioms of economics also suffer from the same logical flaw as the Hardy-Weinberg law. Economic transactions appear to be represented by what Mirowski refers to as the "heat axioms." Thus, Mirowski shows that a utility gradient in Lagrangian form,

$$\mathbf{P} = \text{grad } U = \left[\frac{\partial U}{\partial x}\ \frac{\partial U}{\partial x}\ \frac{\partial U}{\partial z}\right] = \left\{P_x, P_y, P_z\right\},$$

is of the same form as the basic expression of a force field gradient,

$$\mathbf{F} = \text{grad } U = \left[\frac{\partial U}{\partial x}\ \frac{\partial U}{\partial y}\ \frac{\partial U}{\partial z}\right] = \left\{X, Y, Z\right\}.$$

As Mirowski (1989: 30–33) shows, this expression derives from the axiom $F = ma$. Suppose that, analogous to the potential or kinetic energy of planetary motion defined by the root axiom $F = ma$, an individual's movement through commodity space (analogous to a rock moving through physical space) is $U = ip$, (where i = an individual, p = change in preference). The problem is that Newton's axiom is part of the causal explanation of planetary motion, but the economists' axiom could be taken as the *result* of the evolution of a free market capitalist economy (steered by Alan Greenspan?), not as its root cause. Parallel to a Newtonian equivalent of an isolated physical system where axioms based on point masses and pure vacuums, etc., are effective, the axiom, $U = ip$, works quite well in an isolated idealized capitalist economy—but as we have discovered recently—not in Russia. This "axiom" is not a self-evident expression that follows an axiomatic syntax common to all "real" sciences. It is the result of how economists think an economy *ought* to behave, not how economic systems *actually* behave universally. Economists are notorious for letting *ought* dominate over *is* (Redman, 1991). Orthodox economic theory still is defined by axiomatic syntax (Blaug, 1980; Hausman, 1992). Sporadic axiomatic attempts in linguistics (Chomsky, 1965), various behavioral and social sciences, and even in organization theory (Hage, 1965) have all failed. So much so that following the Kuhnian revolution the many social scientists took historical relativism as license to emphasize the various "alternative" relativist postpositivisms (Hunt, 1991).

In logical positivism, formal syntax is "interpreted" or given semantic meaning via correspondence rules (C-rules). For positivists, theoretical language, V_T , expressed in the syntax of axiomaticized formal models becomes isomorphic to observation language, V_O, as follows (Suppe, 1977, p. 16):

> The terms in V_T are given an explicit definition in terms of V_O by correspondence rules *C*—that is, for every term '*F*' in V_T, there must be given a definition for it of the following form: for any x, $Fx \equiv Ox$.

Thus, given appropriate C-rules, scientists are to assume V_T in an "identity" relation with V_O.

In the axiomatic conception of science one assumes that formalized mathematical statements of fundamental laws reduce back to a basic set of axioms and that the correspondence rule procedure is what attaches discipline-specific semantic interpretations to the common underlying axiomatic syntax. The advantage of this view is that there seems to be a common platform to science and a rigor of analysis results. This conception eventually died for three reasons: (1) Axiomatic formalization and correspondence rules, as key elements of logical positivism, proved untenable and were abandoned; (2) Newer 20th century sciences did not appear to have any common axiomatic roots and were not easily amenable to the closed-system approach of Newtonian mechanics; and (3) Parallel to the demise of the Received View, the semantic conception of theories developed as an alternative approach for attaching meaning to syntax.

2.2.2 Essential Elements of the Semantic Conception

Parallel to the fall of The Received View (Putnam's (1962) term combining logical positivism and logical empiricism) and its axiomatic conception, and starting with Beth's (1961) seminal work dating back to the Second World War, we see the emergence of the semantic conception of theories, Suppes (1961), Suppe (1977, 1989), van Fraassen (1970), and Giere (1979, 1988). Cartwright's (1983) "simulacrum account" follows, as does the work of Beatty (1987), Lloyd (1988), and Thompson (1989) in biology; Read (1990) in anthropology. Suppe (1989, p. 3) says, "The Semantic Conception of Theories today probably is the philosophical analysis of the nature of theories most widely held among philosophers of science." Lambert and Brittan (1987, pp. 145–146) say, "No clear objections…to the semantic view have yet emerged." I present four key aspects:

From Axioms to Phase-Spaces. Following Suppe, I will use *phase-space* instead of Lloyd and Thompson's state-space or Suppes' set-theory. A phase-space is defined as a space enveloping the full range of each dimension used to describe an entity. Thus, one might have a regression model in which variables such as size (employees), gross sales, capitalization, production capacity, age, and performance define each firm in an industry and each variable might range from near zero to whatever number defines the upper limit on each dimension. These dimensions form the axes of an n-dimensional Cartesian phase-space. Phase-spaces are defined by their dimensions and by all possible configurations across time as well. They may be defined with or without identifying underlying axioms—the formalized statements of the theory are not defined by how well they trace back to the axioms but rather by how well they define phase-spaces across various state transitions. *In the semantic conception, the quality of a science is measured by how well it explains the dynamics of phase-spaces—not by reduction back to axioms*. Suppe (1977, p. 228) recognizes that in social science a theory may be "qualitative" with nonmeasurable parameters, whereas Giere (1979) says theory *is* the model (which for him is stated in set-theoretic terms—a logical formalism). Nothing precludes "improvements" such as symbolic/syntactic representation, set-theoretic logic, symbolic logic, mathematical proofs, or foundational axioms.

Isolated Idealized Structures. Semantic conception epistemologists observe that scientific theories never represent or explain the full complexity of some phenomenon. A theory may *claim* to provide a generalized description of the target phenomena, say, the behavior of a firm, but no theory ever includes so many variables and statements that it effectively accomplishes this. A theory (1) "does not attempt to describe all aspects of the phenomena in its intended scope; rather it abstracts certain parameters from the phenomena and attempts to describe the phenomena in terms of just these abstracted parameters" (Suppe, 1977, p. 223); (2) assumes that the phenomena behave according to the selected parameters included in the theory; and (3) is typically specified in terms of its several parameters with the full knowledge that no empirical study or experiment could successfully and completely control all the complexities that might affect the designated parameters. Suppe (1977, p. 223–224) says theories invariably explain *isolated idealized systems* (his terms). And most importantly, "if the theory is adequate it will provide an accurate characterization of what the phenomenon *would have been* had it been an isolated system…." Using her mapping metaphor, Azevedo (1997) explains that no map ever attempts to depict the full complexity of the target area—it might focus only on rivers, roads, geographic contours, arable land, or minerals, and so forth—seeking instead to satisfy the specific interests of the map maker and its potential users. Similarly for a theory. A theory usually predicts the progression of the idealized phase-space over time, predicting shifts from one abstraction to another under the assumed idealized conditions.

Classic examples given are the use of point masses, ideal gasses, pure elements and vacuums, frictionless slopes, and assumed uniform behavior of atoms, molecules, genes, and rational actors. Laboratory experiments are always carried out in the context of closed systems whereby many of the complexities of real-world phenomena are ignored—manipulating one variable, controlling some variables, assuming others are randomized, and ignoring the rest. They are isolated from the complexity of the real world and the systems represented are idealized. Idealization also could be in terms of the limited number of dimensions, the assumed absence of effects of the many variables not included, or the mathematical formalization syntax, the unmentioned auxiliary hypotheses relating to theories of experiment, data, and measurement.

Model-Centered Science and Bifurcated Adequacy Tests. Models comprise the core of the semantic conception. Figure 2a portrays the *axiomatic conception*: (1) Theory is developed from its axiomatic base; (2) Semantic interpretation is added to make it meaningful in, say, physics, thermodynamics, or economics; (3) Theory is used to make and test predictions about the phenomena; and (4) Theory is defined as empirically and ontologically adequate if it both reduces to the axioms and is instrumentally reliable in predicting empirical results. Figure 2b depicts the *social science approach*: (1) Theory is induced after an investigator has gained an appreciation of some aspect of social behavior; (2) An iconic model is often added to give a pictorial view of the interrelation of the variables, show hypothesized path coefficients, or possibly a regression model is formulated; (3) The model develops in parallel with the theory as the latter is tested for empirical adequacy by seeing whether effects predicted by the theory can be discovered in the real-world. Figure 2c illustrates the *semantic conception*: (1) Theory, model, and phenomena are viewed as independent entities; (2) Science is bifurcated into two not unrelated activities, analytical and ontological adequacy (see also Read 1990). My view of models as centered between theory and phenomena sets them up as autonomous agents, consistent with Morrison (2000), Cartwright (2000), and others in Morgan and Morrison (2000)—though I see model autonomy as coming more directly from the semantic conception than do Morrison or Cartwright.

>>> Insert Figure 2 about here <<<

Analytical Adequacy focuses on the theory–model link. It is important to emphasize that in the semantic conception "theory" is always expressed via a model. "Theory" does not attempt to use its "If *A*, then *B*" epistemology to explain "real-world" behavior. It only explains "model" behavior. It does its testing in the isolated idealized world of the model. "Theory" is not considered a failure because it does not become elaborated and fully tested against all the complex effects characterizing the real-world phenomena. A mathematical or computational model is used to structure up aspects of interest within the full complexity of the real-world phenomena and defined as *"within the scope"* of the theory, and as Azevedo (1997) notes, according to the theoretician's interests. Then the model is used to test the "If *A*, then *B*" propositions of the theory to consider how a social system—as modeled—might behave under various possibly occurring conditions. Thus, a model would not attempt to portray all aspects of, say, school systems—only those within the scope of the theory being developed. And, if the theory did not predict *all* aspects of these systems' behaviors under the various relevant real-world conditions it would not be considered a failure.

Ontological Adequacy focuses on the model–phenomena link. Developing a model's ontological adequacy runs parallel with improving the theory–model relationship. How well does the model *represent* real-world phenomena? How well does an idealized wind-tunnel model of an airplane wing represent the behavior of a full sized wing in a storm? How well does a drug shown to work on "idealized" lab rats work on people of different ages, weights, and physiologies? How well might a computational model from biology, such as Kauffman's (1993) *NK* model that, Levinthal (1997), Baum (1999), McKelvey (1999a, b), Yuan and McKelvey (2001) and Rivkin (2000) apply to firms, actually represent coevolutionary competition in, for example, the laptop computer industry? In this case it involves identifying various coevolutionary structures, that is, behaviors, that exist in industry and building these effects into the model as dimensions of the phase-space. If each dimension in the model—called model-substructures—adequately represents an equivalent behavioral effect in the real world, the model is deemed ontologically adequate (McKelvey, 2001c).

Theories as Families of Models. A difficulty encountered with the axiomatic conception is the belief that *only one* theory–model conception should build from the underlying axioms. In this sense, only one model can "truly" represent reality in a rigorous science. Given this, a discipline such as evolutionary biology fails as a science. Instead of a single axiomatically rooted theory, as proposed by Williams (1970) and defended by Rosenberg (1985), evolutionary theory is a *family of theories* including theories explaining the processes of (1) variation; (2) natural selection; (3) heredity; and (4) a taxonomic theory of species (Thompson, 1989, Ch. 1). Even in physics, the theory of light is still represented by two models: wave and particle. More broadly, in other mature sciences there are competing theories/models about the age of the universe, the surface of the planet Venus, whether dinosaurs were cold or warm blooded, the cause of deep earthquakes, the effect of ozone depletion in the upper atmosphere, and so on.

Since the semantic conception does not require axiomatic reduction, it tolerates multiple theories and models. Thus, "truth" is not defined in terms of reduction to a single model. Set-theoretical, mathematical, and computational models are considered equal contenders to more formally represent real-world phenomena. In physics both wave and particle models are accepted because they both produce highly reliable predictions. That they represent different theoretical explanations is not a failure. Each is an isolated idealized system representing different aspects of real-world phenomena. In evolutionary theory there is no single "theory" of evolution. In fact, there are even lesser families of theories (multiple models) *within* the main families. All social sciences also consist of various families of theories, each having families of competing models within it. Under the semantic conception, social sciences may progress toward improved analytical and ontological adequacy with families of models and without an axiomatic base.

2.2.3 A Guttman Scale of Effective Science

So far I have identified four nonrelativist postpositivisms that remain credible within the present-day philosophy of science community: the *Legacy* of positivism, *Scientific Realism*, *Selectionist Evolutionary Epistemology*, and the *Semantic Conception*. As a simple means of (1) summarizing the most important elements of these four literatures; and (2) showing how well social science measures up in terms of the institutional legitimacy standards inherent in *these* postpositivisms, I distil seven criteria essential to the pursuit of effective science (Figure 3):

>>> Insert Figure 3 about here <<<

The list appears as a Guttman scale. It goes from easiest to most difficult. To be institutionally legitimate and effective, current epistemology holds that theories in social science must be accountable to these criteria. Existing strong sciences such as physics, chemistry, and biology meet all of them. Many, if not most, social science theory applications to social phenomena do not meet any but the first and second. This could be why social science has so such modest institutional legitimacy from scientific, philosophical, and even user communities.

1. Avoidance of Metaphysical Terms.

This criterion *could* have been the most difficult for social science to meet. If we were to hold to the "avoid metaphysical entities at all costs" standard of the positivists, social science would fail even this minimal standard since even the basic entity, the social system, is hard to put one's hands on—that is, gain direct knowing about. Scientific realists, and especially Aronson, Harré and Way (1994), remove this problem by virtue of their "principle of epistemic invariance." They argue that the "metaphysicalness" of terms is independent of scientific progress toward truth. The search and truth-testing process of science is defined as fallibilist with "probabilistic" results. Given this, it is less important to know for sure whether the fallibility lies (1) with fully *metaphysical* terms (e.g., "corporate strategy"), eventually detectable terms (e.g., "idiosyncratic resources"), or as measurement error with regard to observation terms (e.g., "# of company cars"), or (2) the probability that the explanation or model differs from real-world phenomena (discussed in McKelvey 2001c). Whatever the reason, empirical findings are only true with some probability and selective elimination of any error improves the probability. Since metaphysicalness has been taken off the table as a standard by the scientific realists, it is one standard social science meets, if only by default.

2. Nomic Necessity.

Nomic necessity holds that one kind of protection against attempting to explain a possible accidental regularity occurs when rational logic can point to a strong relation between an underlying structure—force—that, if present, produces the result—if force *A*, then regularity *B*. Consider the "discovery" that "…legitimization affects rates of [organizational] founding and mortality…" (Hannan and Carroll, 1992, p. 33). Is this an accidental regularity? The posited causal proposition is "If legitimacy, then growth." But, there is no widely agreed upon underlying causal structure, mechanism, or process that explains the observed regularity (Zucker, 1989). Thus, if legitimacy is removed, do (most) growing firms disappear? Since there are many firms with no legitimacy that have grown rapidly because of a good product, the proposition seems false (Baum and Oliver, 1992; and Hybels, Ryan and Barley, 1994).

A different aspect of the theory of population dynamics, however, is clearly not an accidental regularity. In a niche having defined resources, a population of firms will grow almost exponentially when the population is small relative to the resources available, and growth will approach zero as the population reaches the carrying capacity of the niche (Hannan and Freeman, 1989). This proposition explains changes in population growth by identifying an underlying causal mechanism—the difference between resources used and resources available—formalized as the Lotka-Volterra logistic growth model: $dN/dt = rN(K - N/K)$.

In this case, the law came to sociology before the discovery of the hypothesized organizational regularities since it was imported from theoretical ecology (Levins, 1968) by Hannan and Freeman (1977), hence the prospect of an accidental regularity is reduced. The model expresses the underlying causal mechanism and it is presumed that if the variables are measured and their relationship over time is as the model predicts then the underlying mechanism is *mostly likely* present—truth always being a probability and fallible.

3. Bifurcated Model-Centered Science.

My use of "model-centeredness" has two meanings: (1) Are theories mathematically or computationally formalized? and (2) Are models the center of bifurcated scientific activities—the theory–model link and the model–phenomena link? A casual review of most social science journals I am familiar with appears to indicate that social science in general is a long way from routinely formalizing the meaning of a theoretical explanation, as is common in physics and economics. And few data-based empirical studies in social science have the mission of empirically testing the real-world fit of a formalized model—they mostly try to test unformalized hypotheses directly on the full complexity of the real world.

4. Experiments.

Witchcraft, shamanism, astrology, and the like, are notorious for attaching *post hoc* explanations to apparent regularities that are frequently accidental—"disaster struck in '38 after the planets were lined up thus and so." Though nomic necessity is a necessary condition, using experiments to test the propositions reflecting the law (law-like relation) in question is critically important. Meeting nomic necessity by specifying underlying causal mechanisms is only half the problem, as has been discovered with the "legitimacy explanation" in population ecology. The *post hoc* use of "legitimacy" is an example of sticking an explanation to an accidental regularity absent the correct underlying causal mechanism. Cartwright (1983) goes so far as to say that even in physics all theories are attached to causal findings—like stamps to an envelope. Lalonde (1986) showed that the belief of many econometricians—that econometrics substitutes for experiments (including even the 2-stage model leading to Heckman's Nobel Prize)—is false. The only recourse is to set up an experiment, take away cause *A* and see if regularity *B* also disappears—add *A* back in and see if *B* also reappears. In my area of research, organization theory and strategy are fields particularly vulnerable to pinning theories to accidental regularities. Given that lab studies of all but the smallest social systems are borderline impossible, naturally occurring quasi-experiments (Cook and Campbell 1979) and computational experiments offer constructive substitutes.

5. Separation of Analytical and Ontological Tests.

This standard augments the nomic necessity, model-centeredness, and analytical results criteria by separating theory-testing from model-testing. In mature sciences theorizing and experimenting are usually done by different scientists. This assumes that most people are unlikely state-of-the-art on both. Thus, if we are to have an effective science applied to social systems, we should eventually see two separate activities: (1) Theoreticians working on the theory–model link, using mathematical or computational model development, with analytical tests carried out via the theory–model link; and (2) Empiricists linking model-substructures to real-world structures. It is possible that some researchers would be able to compare model analytic results with real-world quasi-experimental results, as do many papers in the *American Economic Review*. Without evidence that both of these activities are being pursued independently, as per Figure 2c, social science will remain with questionable institutional legitimacy. The prevailing social science tendency toward attempting only direct theory–phenomena adequacy tests follows a mistaken view of how effective sciences progress.

6. Verisimilitude via Selection.

I ranked this standard here because the selection process happens only over time. For selection to produce any movement toward less fallible truth there need to have been numerous trials of theories of varying quality, accompanied by tests of both analytical and ontological adequacy. So, not only do all of the previous standards have to have been met, they have to have been met across an extensive mosaic of trial-and-error learning adhering to separate analytical and ontological adequacy tests. Population ecology meets this standard quite well. As the Baum (1996) review indicates, there is a 20 year history of theory–model and model–phenomena studies with a steady inclination over the years to refine the adequacy of both links by the systematic removal of the more fallible theories and/or model ideas and the introduction and further testing of new ideas. The lack of contrived experiments has already been noted—though quasi-experiments are evident when population regulation dynamics are shown to readjust after a technological or deregulation discontinuity (Tushman and Anderson 1986, Baum, Korn and Kotha 1995).

7. Instrumental Reliability.

A glass will fall to earth every time I let go. This is 100% reliability. Four hundred years ago Kepler, using Tyco Brahe's primitive (pretelescope) instruments, created astronomical tables that improved the reliability of predicting the locations of planets to within ±1′ compared to the up to 5° of error in the Ptolemaic/Copernican tables. Classical physics achieves success because its theories have high instrumental reliability, meaning that they have high analytical adequacy—every time a proposition is tested in a properly constructed test situation the theories predict correctly and reliably. It also has high ontological adequacy because its formal models contain structures or phase-space dimensions that very accurately represent real-world phenomena "within the scope" of various theories used by engineers and scientists for many of their studies. Idealizations of models in classical physics have high isomorphism with the physical systems about which scientists and engineers are able to collect data. But, as Gell-Mann (1994) observes, laws in modern physics are no longer exact but probabilistic. *The more accurate physicists' measures, the more probabilistic their laws!*

It seems unlikely that social science will ever be able to make individual event predictions. Even if social science moves out from under its archaic view of research—that theories are tested by looking directly to real-world phenomena—it still will suffer in instrumental reliability compared to the natural sciences. The "*isolated idealized systems*" of natural science are more easily isolated and idealized, with lower loss of reliability, than those studied by social scientists. Natural scientists' lab experiments more reliably test nomic-based propositions and their lab experiments also have much higher ontological representative accuracy. In other words, their "closed systems" are less different from their "open systems" than is true for socio-economic systems. Consequently natural science theories will usually produce higher instrumental reliability.

The instrumental reliability standard is truly a tough one for social science. The good news is that the semantic conception makes this standard easier to achieve. Our chances improve if we split analytical adequacy from ontological adequacy. By having some research focus only on the predictive aspects of a theory–model link, the chances improve of finding models that test propositions with higher analytical instrumental reliability—the complexities of uncontrolled real-world phenomena are absent. By having other research activities focus only on comparing *model-structures* and *processes* across the model–phenomena link, ontological instrumental reliability will also improve. In these activities, reliability hinges on the isomorphism of the structures causing both model and real-world behavior, not on whether predictions occur with high probability. Thus, in the semantic conception instrumental reliability now rests on the joint probability of two elements: (1) *predictive analytic reliability*; and (2) *model-structure reliability*, each of which is higher by itself.

Of course, instrumental reliability is no guarantee of improved verisimilitude in transcendental realism. The semantic conception protects against this with the bifurcation above. Instrumental reliability does not guarantee "predictive analytical reliability" tests of theoretical relationships about transcendental causes based on nomic necessity. If this part fails the truth-test fails. However, this does not negate the "success" and legitimacy of a science resulting from reliable instrumental operational-level event predictions even though the theory may be false. Ideally, analytic adequacy eventually catches up and replaces false theories in this circumstance.

If a science is not based on nomic necessity and centered around (preferably) formalized computational or mathematical models it has little chance of moving up the Guttman scale. Such is the message of late 20th century (postpositivist) philosophy of normal science. This message tells us very clearly that in order for social science to improve its institutional illegitimacy it must become model-centered. The nonlinearity of much of our phenomena makes model-centeredness even more essential, as Contractor et al. (2000) observe.

3 MOLDING EFFECTS OF MODELS ON SOCIAL SCIENCE

3.1 MODELS AS AUTONOMOUS AGENTS: THE MOLDING EFFECT

There can be little doubt that mathematical models have dominated science since Newton. Further, mathematically constrained language (logical discourse), since the Vienna Circle circa 1907, has come to define good science in the image of classical physics. Indeed, mathematics is good for a variety of things in science—shown in Table 2.

>>> Insert Table 2 about here <<<

More broadly, math plays two roles in science. In logical positivism (which morphed into logical empiricism; Suppe 1977), math supplied the logical rigor aimed at assuring the truth integrity of analytical (theoretical) statements. As Read (1990) observes, the use of math for finding "numbers" actually is less important in science than its use in testing for rigorous thinking. But, as is wonderfully evident in the various chapters in the Morgan and Morrison (2000) anthology, math is also used as an efficient substitute for iconic models in building up a "working" model valuable for understanding not only how an aspect of the phenomena under study behaves (the empirical roots of a model) and/or for better understanding the interrelation of the various elements comprising a transcendental realist explanatory theory (the theoretical roots).

Traditionally, a model has been treated as a more or less accurate "mirroring" of theory or phenomena—as a billiard ball model might mirror atoms or a barometer might mirror prediction of business cycles (van den Bogaard 2000). In this role it is a sort of "catalyst" that speeds up the course of science but without altering the chemistry of the ingredients, as it were. Morgan and Morrison et al. take dead aim at this view, however. It is perhaps best illustrated in a figure supplied by Boumans (2000, p. 93). He observes that Cartwright, in her classic 1983 book, and Morgan (1988) "…conceive models as instruments to bridge the gap between theory and data" (p. 93). Boumans (and van den Bogaard who also looks at early business cycle models) both give ample evidence that many ingredients influence the final nature of a model. Boumans' depiction is reproduced as Figure 4. Cartwright (2000) and Morgan (2000) concur with the new perspective. The Boumans/van den Bogaard analyses are based on business cycle models by Kalecki, Frisch and Tinbergen in the 1930s and Lukas (1972) that clearly illustrate the warping resulting from "mathematical molding" for mostly tractability reasons (Boumans p. 90) and the influence of the various nontheory and nondata ingredients.

>>> Insert Figure 4 about here <<<

Models as autonomous agents, thus, gain their independence both from (1) *math molding* and (2) influence by all the other ingredients. Since the other ingredients could reasonably influence agent-based models as well as math models—as formal, symbol-based models, and since math models dominate formal modeling in social science (mostly in economics)—I now focus only on the molding effects of math models rooted in classical physics. As is clearly evident from the construction of the four previously mentioned business cycle models, Mirowsky's

(1989) broad discussion (not included here), and Read's (1990) analysis (below), the math molding effect is pervasive.

The molding effect of math as an autonomous model/agent—as developed in classical physics (and economics, since its math model emulates the math model of classical physics) makes two heroic assumptions: First, to use the math model, classical physics takes the "instrumentally convenient" *homogeneity assumption* at the lower bound.[2] This makes the math more tractable. Though Brown (of Brownian Motion) recognized heterogeneous agents, Boltzmann set up the continuation of the instrumental homogeneity assumption by introducing the instrumentally convenient statistical mechanics method based on the *averaging* (across heterogeneous agents) *assumption*. Second, classical physics principally studies phenomena under the governance of the 1st Law of Thermodynamics, and within this Law, the *equilibrium assumption*. Economics mostly emulates this as well (Mirowski 1989). Here the math model acts as an accounting methodology describing the translation of order from one form to another and presumes all phenomena vary around some kind of equilibrium.

3.2 MATH'S MOLDING EFFECTS ON SOCIOCULTURAL ANALYSIS

Read's (1990) analysis of the applications of math modeling in archaeology provides further illustration of how the classical physics roots of math modeling and the needs of tractability give rise to assumptions that are demonstrably antithetical to a correct understanding, modeling, and theorizing of human social behavior. Though his analysis is ostensibly about archaeology, it applies generally to sociocultural systems. Most telling are assumptions throughout his paper that combine to show just how much social phenomena have to be warped to fit the tractability constraints of the rate studies framed within math molding process of calculus. These are listed in Table 3. They focus on universality, stability, equilibrium, external forces, determinism, global dynamics at the expense of individual dynamics, and so on.

>>> Insert Table 3 about here <<<

Given the molding effect of all these assumptions it is especially instructive to quote Read, the mathematician, worrying about equilibrium-based mathematical applications to archaeology and sociocultural systems.

1. In linking "empirically defined relationships with mathematically defined relationships…[and] the symbolic with the empirical domain…a number of deep issues…arise…. These issues relate, in particular, to the ability of human systems to change and modify themselves according to goals which change through time, on the one hand, and the common assumption of relative stability of the structure of …[theoretical] models used to express formal properties of systems, on the other hand…. A major challenge facing effective—mathematical—modeling of the human systems considered by archaeologists is to develop models that can take into account this capacity for self-modification according to internally constructed and defined goals." (p. 13)
2. "In part, the difficulty is conceptual and stems from reifying the society as an entity that responds to forces acting upon it, much as a physical object responds in its movements to forces acting upon it. For the physical object, the effects of forces on motion are well known and a particular situation can, in principle, be examined through the appropriate application of mathematical representation of these effects along with suitable information on boundary and initial conditions. It is far from evident that a similar framework applies to whole societies." (p. 22)
3. "The linkage between conceptual structure [such as kinship terminology] and behavior is, evidently, complex and non-deterministic, yet constrained by external conditions. It clearly has aspects open to manipulation by individuals or subgroups…but such manipulation is also constrained by publicly accepted conceptual structures such as kinship termfinology, marriage rules, and the like. This self-evaluation capacity, coupled with the ability of the actors in the situation to affect the societal means of reproduction, including both material and ideational dimensions, makes modeling of societies difficult and hard to reduce, assuming it is possible, to deterministic models. When models incorporate parameters whose values are fixed, a non-reflective system that does not incorporate self-modification is implicitly presumed." (p. 22)
4. "Dynamic structural modeling is a powerful framework for analyzing the properties of systems, but does not, in and of itself, provide the means for analyzing the properties of systems that are self-reflective and capable of both affecting and defining how they are going to change, as is true of human systems." (p. 27)
5. "Perhaps because culture, except in its material products, is not directly observable in archaeological data, and perhaps because the things observable are directly the result of individual behavior, there has been much emphasis on purported 'laws' of behavior as the foundation for the explanatory arguments that archaeologists are trying to develop. This, I argue, is not likely to succeed. To the extent that there *are* 'laws' affecting human behavior, they must be due to properties of the mind that are the consequence of selection acting on genetic information. As a consequence, 'laws' of behavior are inevitably of a different character than laws of physics such as $F = ma$. The latter, apparently, is fundamental to the universe itself; behavioral 'laws' such as 'rational decision making' are true only to the extent to which there has been selection for a mind that processes and acts upon information in this manner…. Without virtually isomorphic mapping from genetic information to properties of the mind, searching for universal laws of behavior as a means to develop explanatory models of human systems in analogy with the role that physical laws have played in physics in developing explanatory models of the universe is a chimera." (p. 28)

Common throughout these statements are observations about "the ability of [reified] human systems to change and modify themselves," be "self-reflective," respond passively to "forces acting" from outside, "manipulation by subgroups," "self-evaluation," "self-reflection," "affecting and defining how they are going to change," and the "chimera" of searching for "behavioral laws" reflecting the effects of external forces.

3.3 MOLDING EFFECTS ON ECONOMIC ANALYSIS

The previous "attack" on the homogeneity and equilibrium assumptions in Orthodox Economics occurred when Nelson and Winter (1982) tried to shift the

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[2] Given a hierarchy of sciences, say, physics, chemistry, biology, psychology, economics, sociology, etc., I use "lower bound" to refer to the lower boundary of a science or discipline. Sciences traditionally make the homogeneity assumption at the lower bound. Thus, economists studying aggregate economic phenomena assume firms are all the same or all actors are rational; psychologists used to assume that human physiology was homogeneous; biologists assume water molecules are all the same; classical physicists assumed electrons had the same charge, etc. Needless to say, as sciences progress, the lower bound homogeneity assumption gets challenged.

exemplar science from physics to biology. They argue that Orthodoxy takes a static view of order-creation in economies, preferring instead to develop the mathematics of thermodynamics in studying the resolution of supply/demand imbalances within a broader equilibrium context. Also, Orthodoxy takes a static or instantaneous conception of maximization and equilibrium. Nelson and Winter introduce Darwinian selection as a dynamic process over time, substituting routines for genes, search for mutation, and selection via economic competition.

Rosenberg (1994) observes that Nelson and Winter's book failed because Orthodoxy still holds to energy conservation mathematics (the 1st Law of Thermodynamics), the prediction advantages of thermodynamic equilibrium, and the latter framework's roots in the axioms of Newton's orbital mechanics, as Mirowski (1989) reports. Also, whatever weakness in predictive power orthodoxy has, Nelson and Winter's approach failed to improve it. Therefore, economists had no reason to abandon Orthodoxy since, following physicists, they emphasize predictive science. Rosenberg goes on to note that biologists have discovered that the mathematics of economic theory actually fits biology better than economics, especially because gene frequency analysis meets the equilibrium stability requirement for mathematical prediction (p. 398). He notes in addition that two other critical assumptions of mathematical economics, infinite population size and omniscient agents hold better in biology than in economics.

In parallel, Hinterberger (1994) critiques economic orthodoxy and its reliance on the equilibrium assumption from different perspective. In his view, a closer look at both competitive contexts and economic actors uncovers four forces working to disallow the equilibrium assumption:

1. Rapid changes in the competitive context of firms does not allow the kinds of extended equilibria seen in biology and classical physics;
2. There is more and more evidence that the future is best characterized by "disorder, instability, diversity, disequilibrium, and nonlinearity" (p. 37);
3. Firms are likely to experience changing basins of attraction—that is, the effects of different equilibrium tendencies;
4. Agent actions coevolve to create higher level structures that then become the selection contexts for subsequent agent behaviors.

Hinterberger's critique comes from the perspective of complexity science. This angle is pursued in much more depth in the Santa Fe Institute anthology edited by Arthur, Durlauf, and Lane (1997). They note the following characteristics of economies, all of which defeat the kind of equilibrium essential to predictive mathematics—shown in Table 4. They describe economies in terms of autonomous, heterogeneous, coevolving, adaptive, agents who create novel adaptive solutions, and supervening structures in nonequilibrium situations. Despite the book's focus on *The Economy as an Evolving Complex System*, after reviewing all the chapters, most of which rely on mathematical modeling, the editors ask, "…In what way do equilibrium calculations provide insight into emergence?" (p. 12) Clearly, most of the chapters miss the essential character of complex adaptive systems stylized in the Table. Despite the Santa Fe Institute's commitment to studying nonlinear autonomous heterogeneous agent behaviors, equilibrium molding still lingers.

>>> Insert Table 4 about here <<<

4 ORDER-CREATION BEFORE THE 1st LAW

4.1 FAST MOTION SCIENCE

The foregoing critiques have at their heart the question whether order-creation in the phenomena studied moves fast or slow relative to the equilibrium assumptions by the classic mathematical sciences studying 1st Law energy translations. Orbital mechanics stay in equilibrium long enough—billions of years, more or less—that the equilibrium assumption works very well. It works well in the biosphere, too, but mainly because we take a slow motion view of the tail end of biological evolution. Taking a longer view and speeding it up, we discover that bioevolution occurs in a very thin layer sandwiched between two giant Bénard (1901) cells[3]—one in the atmosphere (Lorenz 1963) and one in the earth's geology of lava plumes and tectonic plate sinks, speculated about by Salthe (1993, p. 107) and wonderfully analyzed and depicted in an artist's rendition in Gurnis (2001). The first creates the climate on the earth's surface via heat, deserts, wind, storms, rain, floods, and so on. The second is the engine creating the biosphere's geological context—rising and sinking continents, plate subductions, ocean trenches, volcanoes, mountain ranges, rivers, lakes, valleys, shifting landscapes, and ultimately the biological punctuations analyzed by Eldredge and Gould (1972). Sped up, *order* in the biosphere results more from the joint effects of both giant Bénard processes than it does from Darwinian gradualism. Darwinian gradualist selection, as introduced into social science, thus, reflects only the relatively static, most recent frame in what is really a 3.8 billion year movie. But note that the *punctuated equilibrium* theory proposed by Eldredge and Gould (1972) fits with the Bénard-type self-organization process and see application in social science via the work of Tushman and colleagues.[4]

As noted previously, following the view of "models as autonomous agents" given by Morgan and Morrison (2000), math models now affect the course of social science modeling as much as do theory or data. Figure 5 is a rather fanciful depiction showing the math model's increasing disconnection from modern social science phenomena, represented by the *line*. As a rough estimate,

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[3] Consisting of a fluid between hot and cold surfaces; at some critical point in the temperature gradient between the plates, circular bulk movements of molecules will occur so as to reduce the temperature differential—an example of self-organization (Haken 1977).

[4] Tushman and Romanelli, Tushman and Anderson (1986), Tushman and Rosenkopf (1992).

the Y axis represents the rate at which various phenomena erode away from equilibrium—not wobble around some central tendency—but are permanently re-ordered. The X axis is a sort of log scale, except that it drops by three magnitudes per mark—thus, billions (planetary orbits) to millions (species) to thousands (socio/cultural/economic structures) of years, to changes within a few years (school systems, firms), and finally erosions occurring in less than one year (single heterogeneous agents ranging from particles to molecules to biomolecules, to microbes, to human agents). Many readers probably would say that the *line* misrepresents the rate of equilibrium erosion—preferring instead the *curve*.

>>> Insert Figure 5 about here <<<

4.2 THEORIES OF ORDER-CREATION

What causes order-creation *before* 1st Law equilibria take hold? And, if new order is caused, what causes it to emerge one way and not another? Complexity science is about what causes order (Mainzer 1997). Quantum entanglement[5] as the precursor to emergent order is much discussed in physics (Gell-Mann 1994). And the primordial pool existing before the origin of life is much discussed in biology (Kauffman 1993). As already noted, the Darwin/Wallace theory of natural selection (Darwin 1859) explains speciation in the biological world. Durkheim (1893) and Spencer (1898) also defined order as the emergence of kinds, specifically, social entities. Half a century later, however, Sommerhoff (1950), Ashby (1956, 1962), and Rothstein (1958) defined order not in terms of entities but rather in terms of the connections among them. In fact, order doesn't exist without both.

Particularly for the biological and social worlds, Ashby long ago made two observations. Order (organization), he said, exists between two entities, *A* and *B*, only if this relation is "conditioned" by a third entity, *C* (1962, p. 255). If *C* is viewed as the "environment" which is external to the relation between *A* and *B*, it follows that environmental constraints are what cause order (Ashby 1956). This, then, gives rise to his "*Law of Requisite Variety*" (1956). It holds that for a biological or social entity to be efficaciously adaptive, the variety of its internal order must match the variety of the environmental constraints. Interestingly, he also observes that order does not emerge when the environmental constraints are chaotic (1956, pp. 131–132). In sum, order-creation is always a function of context.

Within 1st Law energy translations, we observe a stock of energy (a tension) in one kind of ordered structure flowing at some rate and quantity into another. If there are enough agents (particles/molecules) such as in the flow of a river, there is no concern as to what motivates each of the billions of agents—attention focuses on the flow rate past a measuring point. Self-organization theorists, however, focus on what motivates individual agents to begin to shift from a disordered, disequilibrium state to produce some kind of collective, higher-level order (Cowan 1994). And, once this happens, there is quickly interest in how the higher level affects agent behaviors, and from here interest focuses on coevolution: how lower level agents affect higher level order and respectively how that order alters lower level agent behaviors. In fast-motion sciences, and particularly in social science where agents' order-creation rates are—in terms of Figure 5—within the few-year and intra-year ranges, self-organization questions and analyses may easily dominate, though not necessarily make meaningless, slow-motion science questions.

And, of course, as the number of agents studied drops from billions to, say, the few hundreds of dotcom firms, or the couple firms in the petroleum industry, or the few top administrators at the Federal Reserve, analysis of coevolutionary agent behaviors and order-creation surely dominates the equilibrium methods of slow-motion science.

Complexity science's emergent-order explanations could vary across the physical, biological, and social worlds. Since they are hierarchical—in that social entities are composed of biological entities that are composed of physical entities—the issue of upward vs. downward causality also arises. Natural selection is the traditional way of explaining how order appears out of the primordial probabilistic soup—the *selectionist* explanation. Leading writers about biology, such as Salthe (1993), Rosenberg (1994), Eldredge (1996), Ulanowicz (1996), Depew (1998), Weber (1998), Conrad (1998), and Kauffman (2000) now argue that Darwinian theory is, itself, equilibrium bound and not adequate for explaining most biological dynamics. Underlying this change in perspective is a shift to the study of how heterogeneous agents create order in the context of geological and atmospheric dynamics. Implicit in this change is a change from the slow-motion science of Newtonian classical physics—and its mathematics—to the fast-motion science necessary to see agent-level order-creation dynamics in action.

To better understand the course of emergent order and fast-motion dynamics in bioeconomics, I have reviewed a number of well established theories about causes of emergent order in physics and biology, some of which have been extended into the econosphere (McKelvey 2001d). I consider explanations of how "*order*" (what Gell-Mann calls *coarse-graining*) emerges from the fine-grained structure of entanglement pools and higher-level networks, with special focus on the views of Prigogine (1955), Ashby (1962), Lorenz (1963), Haken (1977), Kelso and colleagues (1992), Salthe (1993), Cohen and Stewart (1994), Gell-Mann (1994), Mainzer (1997),

[5] Think of *quantum entanglement* as the interdependence of two particles or entities such that neither one can behave or be understood independently, and decoherence as the negation of the entanglement effect. For an application of entanglement and correlated interdependency histories at a human scale, see McKelvey (forthcoming).

Omnès (1999), and Kauffman (2000).

This review produces a set of premises pertaining to order-creation that is not the result of variations around some equilibrium-driven central tendency:

Bottom-Up Coarse-Graining

Gell-Mann's Premise: *Contextual effects lead some correlated histories in the fine-grained structure to surface as the basis of probabilistic effects while the remaining histories are washed out—their effects remaining randomized.*

Mainzer's Premise: *Initially tiny quantum chaotic effects can accumulate to cause coarse-graining in atoms (even without contextual stimulation), and subsequently in higher-level natural phenomena.*

Omnès's Premise: *Externally imposed energy flows (with some reference to energy differentials) cause emergent coarse-grained structure from entanglement pools—still seen as a reductionist, bottom-up causal process.*

Haken's Premise: *At the instability point forced by the 1st critical value, R_{c1}, and, thus, after most degrees of freedom in complex systems are enslaved by a very few remaining variables (the order parameters), self-organization is driven by variance in the external forces acting on the control parameter, R.* [6]

Top-Down Coarse-Graining

Order-Creation

Cohen & Stewart's Premise: *Laws of nature are coarse grained patterns—conditioned by context—that collapse an underlying sea of chaos (the fine-grained entanglement pool), thereby creating new order.*

Prigogine's Premise: *Tension resulting from the entropy differential between a high-order state and a more entropic state causes dissipative structures to self-organize, thereby causing order-creation.*

Lorenz's Premise: *The region of emergent complexity (self-organization of autonomous heterogeneous agents) is sandwiched between two critical values (the Rayleigh numbers, R_{c1} & R_{c2}) along the Reynolds energy gradient (R).*

Kelso, et al.'s premise: *Control parameters, R_i, externally influenced, create $R > R_c$ with the result that degrees of freedom are enslaved, order parameters appear, and a phase transition (instability) appears, resulting in similar patterns of complexity emerging even though underlying generative mechanisms show high variance.*

Order-Creation & Extinction

Salthe's Premise: *The material (geological & atmospheric) context of the biosphere creates the entropy production potential that gives rise to dissipative structures that themselves progress through immaturity, mature, and senescent stages of their own entropy production—that in turn creates irreversible order-creation conditions for lower scale dissipative structures, and so on in downward hierarchical progression.* (His proposed new law of thermodynamics).

Extinction

Kauffman's Premise: *Given that (unspecified) conditions are in place that drive bioeconomic phenomena toward the dynamical edge of chaos, the power law effects of self-organized criticality come into effect leading to extinction events, thereby preventing the overwhelming triumph of nonergodicity into the "adjacent possible."* (His "candidate 4th law" of thermodynamics.)

The generative mechanisms (processes) implied by the premises separate into two broad categories of causal force: bottom-up and top-down. First, the bottom-up rule holds that the *effects of context* are focused onto a few order-parameters remaining after the effects of most other degrees of freedom are negated. Neither the summing-over effect or the contextual effect can independently cause coarse-graining. And since both are involved as necessary conditions, but neither is sufficient, we have what Churchman and Ackoff (1950) long ago termed a *co-producer* situation.

Downward causality divides into three sets. Cohen & Stewart, Prigogine, and Lorenz focus on an order-creation rule. Salthe includes both creation and extinction rules. Kauffman suggests a basic power-law based extinction rule. Order-creation is clearly seen as emergent when *R*, the measure of energy or entropy flow, is $R_{c1} < R < R_{c2}$—the tension produced by the difference between a highly ordered system and a more entropic system lies between the 1st and 2nd critical values of *R*. Salthe and Kauffman recognize that no causal model is complete without a damping mechanism. As Kauffman notes, since the bio- and econospheres are not totally ordered everywhere, some force acts to attenuate the unending proliferation of dissipative structures. Extinction does this very well.

One could argue that for more than 4 decades Prigogine has been working on what could be viewed as the **0th law of thermodynamics**.[7] This idea has carried over into the European complexity science community (Prigogine 1955, 1962, Haken 1977, Nicolis and Prigogine 1989, Stauffer 1987a, b, Cramer 1993, Mainzer 1997), but is not evident in much of the work associated with the Santa Fe Institute (Pines 1988, Nadel and Stein 1992, 1995; Cowan, Pines, and Meltzer 1994, Morowitz and Singer 1995, Arthur, Durlauf, and Lane 1997, Kohler and Gumerman 2000) though it does show up in Kauffman 1993, 2000)[8]. The work by Kelso and colleagues (in the

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[6] Mainzer (1997, p. 58), as does Haken (1983, p. 254) incorrectly terms *R* the Rayleigh number. *R*, is really the Reynolds number—a measure of the rate of fluid flow. In a Bénard cell *R* is a direct function of the heat differential. In fluid dynamics, at a specific level of *R*, fluid flow becomes turbulent. This "critical value" of *R* is termed the Rayleigh number, R_c (Lagerstrom, 1996). Laminar flow scientists have one critical value, R_c that separates laminar from turbulent flows. Lorenz and complexity scientists have created two R_cs. The 1st separates the region of emergent complexity from laminar flow or conduction and the 2nd separates the region of emergent complexity from deterministic chaos—the so-called "edge of chaos."

[7] Physicists always cringe when social scientists start tampering with their terms, as I am now doing with thermodynamics. But since natural scientists themselves have spread the use of "thermodynamics" into social science—specifically Prigogine, Haken (1996), Mainzer, Salthe, Kauffman, among many others—it would appear they have opened the door to social scientists.

[8] Goldstein (1993) manages to write a paper about "nonlinear dynamics of pattern formation" in which he talks about "dissipative dynamics" and the Rayleigh dissipation function" without ever mentioning the work of Prigogine or Haken, for example. Even more surprising is the omission of Prigogine and Haken's work in a 148 page chapter by Tagg (1995) about instabilities in fluid flows brought on by changes in the Reynolds number and in which he even cites Bénard's original (1901) paper. Most egregious is a paper by Bennett (1988) in which he discusses irreversible self-organization resulting from dissipation in the context of the 2nd Law of Thermodynamics, without citing Prigogine, though he does cite van Kampen's (1962) paper on the statistical mechanics of irreversible processes—the subject of Prigogine's (1962) book. A recent exception is a paper by te Boekhorst and Hemelrijk (2000), who happen to be at the University of Zurich.

Santa Fe Proceedings volume edited by Mittenthal and Baskin 1992) is a notable exception.

But, if an order-creation law actually exists across the physical, biological, and social worlds, I also show that it has not been coherently defined or broadly agreed to as yet (McKelvey 2001d). As my review indicates, it spreads across at least ten initial insights (the premises) about when and what kind of force precipitates order-creation by heterogeneous agents. There is disagreement about whether the force is up-ward or down-ward. There is actually more agreement across the bio- and econospheres than there is going up and down between the quantum and atomic levels of matter. There is not total agreement that an energy or tension differential located within the 1st and 2nd critical values of R is the key requirement—but no one explicitly disagrees with this view. This view—externally originating tension differentials, with $R_{c1} > R > R_{c2}$, initiating order-creation activities by agents—is, of course, Prigogine's basic thesis. And, it all goes back to Bénard (1901).

My summary premise of Kelso, Bing, and Schöner's (1992) six concluding points (p. 433) on the dynamics of order-creation appears to come closest to a possible 0th law of thermodynamics:

> *Control parameters, R_i, externally influenced, create $R > R_c$ with the result that degrees of freedom are enslaved, order parameters appear, and a phase transition (instability) appears, resulting in similar patterns of complexity emerging even though underlying generative mechanisms show high variance.*

It is cumbersome compared to "energy conservation" or "entropy production"—the 1st and 2nd Laws, respectively, though "$R_{c1} > R > R_{c2}$" could be a good match. A one-sentence version says:

Adaptive tension R, positioned between R_{c1} and R_{c2}, produces self-organization.

Is the Bénard process, as an "*order-creation engine activating agents*," something that social scientists should pay attention to? The 1st Law of Thermodynamics essentially says that, given existing structure, energy is conserved. The 2nd Law says that over time, order induced by higher energy states dissolves into randomness. The 0th law is clearly central to complexity science (Nicolis and Prigogine 1989, Cramer 1993, Mainzer 1997, Kauffman 2000)—How does energy (or McKelvey's adaptive tension, 2001b) transform into order? The Bénard process energy-differential "cause" appears to apply to weather, fluid dynamics, various chemical materials, the geology of the Earth, and various biological phenomena. This is at the core of much of physical and biological complexity science. To what extent can this definition of the 0th "law" be applied to broader physical phenomena, to biological phenomena, and to social science?

Durlauf (1997, p. 33) says, "A key import of the rise of new classical economics has been to change the primitive constituents of aggregate economic models: while Keynesian models employed aggregate structural relationships as primitives, in new classical models individual agents are the primitives so that all aggregate relationships are emergent." In Durlauf's view agent behavior has become the basis of new classical economics. Similarly for economists and other social scientists who are using agent-based models—such as Axlerod and Bennett 1993), Arthur (1995), Arthur et al. (1997), Kollman, Miller, and Page (1997), Read (1998), Macy (1999), Tesfatsion (1999), White (1999), Bonacich (2000), Zak and Park (2000), Cederman (2001), LeBaron (forthcoming), and the many others who are now studying intrafirm social behavior, reported in anthologies such as Masuch and Warglien (1992), Carley and Prietula (1994), and Prietula, Carley, and Gasser (1998), Ilgen and Hulin (2000). These scholars explicitly model the actions of agents and so their models might reasonably be expected to explore engines such as the Bénard process that could position economic complexity in the "emergent complexity" region between Cramer's "Newtonian" and "chaotic" regions. They are also very clearly *not* assuming underlying equilibrium dynamics. They are in the best position to put the 0th law idea to test. These and other agent modelers have produced quite a number of findings by now that demonstrate that agent-based research aids the explanation of economic systems—as well as narrower (stock) market, intrafirm, firm, and industry behaviors.

5 PARALLELS BETWEEN CONNECTIONIST MODELING AND POSTMODERNISM

Postmodernism appears very much against positivism and normal science in general (Holton 1993, Norris 1997, Gross, Levitt and Lewis 1996, Gross and Levitt 1998, Koertge 1998, Sokal and Bricmont 1998) and surely has a "lunatic fringe" I find abhorrent. But, as I will demonstrate here, it has at its core a process of sociolinguistic order-creation that is isomorphic to processes in agent-based modeling, and therefore the more considered and responsible core of postmodernism, when connected with agent-based modeling, provides an additional platform of institutional legitimacy for social science. In short, its ontology is on target but its trashing of normal science epistemology is based on archaic rhetoric.

Sarup (1993) attributes the origin of the term, postmodernism to the artists and art critics of New York in the 1960s. From there it was taken up by French theorists such as Baudrillard, Derrida, Foucault, Lyotard and Saussure. Subsequently the theme was picked up by those in the "Science, Technology, and Society Studies…feminists and Marxists of every strip, ethnomethodologists, deconstructionists, sociologists of knowledge, and critical theorists" Koertge (1998, p. 3). From Koertge's perspective, some key elements of postmodernism are (pp. 3–4):

- "…Content and results [of science]…shaped by…local historical and cultural context;"
- "…Products of scientific inquiry, the so-called laws of nature, must always be viewed as social constructions. Their validity depends on the consensus of 'experts' in just the same way as the legitimacy of a pope

depends on a council of cardinals;"

- "…Scientific knowledge is just 'one story among many'."
- "…The best way to appraise scientific claims is through a process of political evaluation…. The key question about a scientific result should not be how well tested the claim is but, rather, Cui bono?"
- "…The results of scientific inquiry are profoundly and importantly shaped by the ideological agendas of powerful elites."
- "…Euroscience is not objectively superior to the various ethnosciences and shamanisms described by anthropologists or invented by Afrocentrists."
- "…Science is characterized chiefly by its complicity in all the most negative and oppressive aspects of modern history: increasingly destructive warfare, environmental disasters, racism, sexism, eugenics, exploitation, alienation, and imperialism."

A comprehensive view of postmodernism is elusive because its literature is massive and exceedingly diverse (Sarup 1993, Alvesson and Deetz 1996, Cilliers 1998). But if a "grand narrative" were framed it would be self-refuting since postpositivism emphasizes localized language games searching for instabilities (Lyotard 1984). Further, it interweaves effects of politics, technology, language, culture, capitalism, science, and positivist/relativist epistemology as society has moved from the Industrial Revolution through the 20th century (Sarup 1993). Even so, Alvesson and Deetz boil postmodernism down to the following points (1996, p. 205):

- Reality, or "'natural' objects," can never have meaning that is less transient than the meaning of texts that are locally and "discursively produced," often from the perspective of creating instability and novelty rather than permanency.
- "Fragmented identities" dominate, resulting in subjective and localized production of text. Meanings created by autonomous individuals dominate over objective "essential" truths proposed by collectives (of people).
- The "indecidabilities of language take precedence over language as a mirror of reality."
- "Multiple voices and local politics" are favored over meanings imposed by elite collectives in the form of "grand narratives…theoretical frameworks and large-scale political projects."
- The impossibility of separating political power from processes of knowledge production undermines the presumed objectivity and truth of knowledge so produced—it loses its "sense of innocence and neutrality."
- The "real world" increasingly appears as "simulacra"—models, simulations, computer images, and so forth—that "take precedence in contemporary social order."
- Research aims at "resistance and indeterminacy where irony and play are preferred" as opposed to "rationality, predictability and order."

The key insight underlying my claim that postmodernism does in fact offer institutional legitimacy to social science when the latter is viewed as mostly aiming at order-creation and heterogeneous agent behavior comes from a wonderful book by Paul Cilliers (1998)—*Complexity and Postmodernism.* Paul spent ten years of his life as a neural network computational modeler, after which he became a Lecturer in Philosophy in South Africa. He draws principally from Saussure, Derrida, and Lyotard. He interprets postmodernism from the perspective of a neural net modeler, emphasizing connections among agents rather than attributes of the agents themselves. This perspective comes from modern conceptions of how brains and (distributed) intelligence function. In the connectionist perspective—and as in neural net models—brain functioning is not in the neurons, nor "in the network" but rather "*is* the network" (Fuster 1995, p. 11). Distributed intelligence also characterizes firms, and many other social systems (McKelvey 2000a).

Cilliers (p. 6) first sets out ten attributes of complex adaptive systems (shown in italics) and later connects these attributes to key elements of postmodern society (pp. 119–123)—to which I add additional postmodernist themes:

1. "*Complex systems consist of a large number of elements.*" Postmodernists' focus on individuality, fragmented identities, and localized discourse.
2. "*The elements in a complex system interact dynamically.*" Postmodernists emphasize that no agent is isolated; their subjectivity is an intertwined "weave" of texture in which they are de-centered in favor of constant influxes of meaning from their network of connections.
3. "*The level of interaction is fairly rich*." Postmodernists view agents as subject to a constant flow and alteration of meanings applied to texts they are using at any given time. This in increasing in modern society. Texts imposed on any given agent are, needless to say, richly diverse in variety, content, and interpreted meanings.
4. "*Interactions are nonlinear*." Postmodernists hold that interactions of multiple voices and local interactions lead to change in meanings of texts, that is, emergent meanings. Given that texts and their variety and meaning do not flow evenly, that social interaction is not predictably systematic, that power and influence are not evenly distributed, and that none of the foregoing are stable over time, it follows that textual meaning flows and interpretations, and consequent emergent new meanings and concomitant social interactions are nonlinear and potentially could show large change outcomes from small beginnings.
5. "*The interactions are fairly short range.*" Postmodernists emphasize "local determination" (Lyotard 1984) and the "multiplicity of local "discourses'" (Cilliers p. 121). Though long range interactions and influences on textual meaning are not precluded, most agents are seen to respond to locally available information. Locally determined, socially constructed group level meanings, however, inevitably seep out to influence other groups and the agents within them.
6. "*There are loops in the interconnections*." Postmodernists translate this into reflexivity. Local agent interactions may form group level coherence and common meanings. These then, *reflexively*, supervene back down to influence the lower-level agents Lawson 1985). This fuels their view that meanings—interpretations of terms—are constantly in flux—"they are contingent and provisional, pertaining to a certain context and a certain time-frame." Local level interpretations are subject to the potentially greater influence of power-elites emerging to control the higher-level collectivities and their interpretation of meanings.
7. "*Complex systems are open systems.*" If there is any implicit pervasive subtext in postmodernism it is that agents, groups of agents, and groups of groups, etc., are all subject to outside influences on their interpretations of meanings. Postmodernists see modern societies—the modern condition—as increasingly subject to globalization and complication of influence networks. Cooper and Burrell (1988) note that "knowledge and discourse have to be 'constructed' from a 'chameleonic' world" (quote in Hassard and Parker 1993, p. 10).
8. "*Complex systems operate under conditions far from equilibrium.*" McKelvey (2001b) translates Prigogine's concept of "far from equilibrium" into *adaptive tension*. In postmodern society the mass media provide local agents, and groups of virtually any size, constant information about countless disparities in values, culture, economics—the human condition in general. These disparities set up adaptive tensions generating energy and information flows (what Salthe, 1993, refers to as "infodynamics") that create conditions: (1) for social self-organization and increasing complexity (McKelvey 2001a); (2) novelty, and economic change away from equilibrium (McKelvey 2001d, e)—Schumpeter's *creative destruction*; that (3) lead to rapid technological

change, scientific advancement and new knowledge, which in turn reflex back to create more disparity and nonlinearity.

9. "*Complex systems have histories.*" By viewing agents as *not* self-directing, Derrida "de-centers" agents by locating them in a system of interconnections among strata (Hassard and Parker 1993, p. 15). Postmodernists see history as individually and locally interpreted. Therefore, though systems have histories—the economists' path dependencies—histories do not appear as grand narratives uniformly interpreted across agents.

10. "*Individual elements are ignorant of the behavior of the whole system in which they are embedded.*" This shows up most clearly in postmodernists' view that "attempts to discover the genuine order of things are both naïve and mistaken" (Hassard and Parker 1993, p. 12). Agents are not equally well connected with all other parts of a larger system. In addition, agents have fragmented identities and localized production of textual meanings. Any agent's view of a larger system is at least in part colored by the localized interpretations of other interconnected agents. Even if information about the whole system is available it is always subject to localized interpretations. These are compounded by reflexivity effects.

Hassard and Parker's postmodernist framework (1993, pp. 11–15) highlights five elements foreshadowing Cilliers' merging of connectionist modeling and postmodernism. *Representation*: "Language which is produced by the empirical process does not equate with an increasingly accurate correspondence with reality. Instead, it represents a process of professional self-justification" (p. 12)—a local agent or group level supervening effect. *Reflexivity*: Grand narratives and broad scientific "truths" cannot be disentangled from local agent interpretations. Nor are agent interpretations independent of interpretations espoused by higher level social constructions. *Writing* is seen as "an autonomous self-propelling force that lies beyond the intentions of the individual actor." (Cooper 1989, p. 486). '*Difference*': A knowledge "concept is never present in and of itself…every concept is inscribed in a chain or in a system within which it refers to" other concepts (Derrida 1982, p. 11; quoted in Hassard and Parker, p. 14). *De-centering*: Agents are seen as no longer self-directing but instead embedded in a system of interrelations among different sociostructural levels (Derrida 1978)—agents are a convenient location for the throughput of discourses (Hassard and Parker, p. 15). The latter notion is not unlike the view that biological phenotypes are simply temporary repositories for the genetic code of a species (McKelvey 1982) or Fuster's view that intelligence "*is* the network."

As noted previously, Postmodernism is notorious for its anti-science views. Many of these anti-science interpretations may be written off as localized interpretations totally off the mark. In the evolutionary epistemological terms of Campbellian Realism, they will be quickly winnowed out of epistemological discourse. It is also true that much of postmodernist rhetoric is based on the positivists' reconstructions of epistemology based on classical physicists' linear deterministic equilibrium analyses of phenomena governed by the 1st Law. As such, its rhetoric is archaic—it is based on a reconstruction of science practice (*logic-in-use* in Kaplan's, 1964, terms) that never existed, and in any event, has since been discredited (Suppe 1977). The core of postmodernism I have described here does, however, support a strong interconnection between "new" normal science—as reflected in complexity science—and postmodernism: Both rest on parallel views of socially connected, autonomous, heterogeneous, human agents. The ten points above, drawn from Cilliers' analysis, give evidence of this.

6 CONCLUSION: AGENT-BASED MODELS AS "PHILOSOPHICALLY CORRECT"

The title of this paper, "Foundations of "new" Social Science," sounds pretentious. But consider:

1. *Model-Centered Science*. Toward the end of the 20th century, philosophers moved away from positivism to adopt a more probabilistic view of truth statements, the scientific realist view that transcendental causal processes can be uncovered and explained without running afoul of metaphysical term issue that so worried the positivists. Campbell's contribution is to recognize that real-world phenomena may act as external criterion variables against which theories may be tested without social scientists having to reject individual interpretationist tendencies and social construction. Regarding the Semantic Conception it is worth repeating that Suppe (1989, p. 3) says, "[It] today probably is the philosophical analysis of the nature of theories most widely held among philosophers of science." As outlined in this paper, models are the central feature of the Semantic Conception as is the bifurcation of scientific activity into tests of the theory–model relationship and the model–phenomena link. In this view, theory papers should end with a (preferably) formalized model and empirical papers should start by aiming to test the ontological adequacy of one. ***Most social science papers are not so oriented.***

2. *Math Molding Effects.* The message from the Morgan and Morrison (2000) chapters speaks to the autonomous influence of models on science—in addition to theory and data. Math models are surely are the dominant autonomous modeling influences in modern science. Read (1990) points to the fundamental molding effect of math models on social science and also points to their fundamental limitation, saying, "…A major challenge facing effective—mathematical—modeling…is to develop models that can take into account…[agents'] capacity for self-modification according to internally constructed and defined goals." (p. 13) Basically, the assumptions required for tractable mathematics steer models away from the most important aspects of human behavior. To the extent that there are formal models in social science they tend to be math models—a clear implication to be drawn from Henrickson's (2002) citation survey. ***Few social scientists use models immune to the molding effects of the math model.***

3. *Order-Creation Science.* Complexity science is a recent development in natural science now spreading into social science (Cowan, Pines and Meltzer 1994, Merry 1995, Mainzer 1997, Byrne 1998, Axlerod and Cohen

2000). But the primary message from Mainzer's book is that complexity science is really focusing on the processes of order-creation by heterogeneous coevolving autonomous agents—he traces the story from quantum physics, to biology, to neural behavior, to AI, and finally to social systems. McKelvey (2001d) develops this theme further in a search for a basic theory or order-creation ranging from physics to economics (see also Salthe 1993, Kauffman 1993, 2000; McKelvey 2001e). As McKelvey observes, formal modeling in social science—and principally in economics—uses math born primarily in the context of classical physicists' study of orbital mechanics and Newton's 1st Law (energy conservation). Of most interest in social science is order-creation *before* the equilibrium constraints of the 1st Law—and there are very few formal models of "pre 1st Law" dynamics. Because math calls for equilibrium assumptions, and is essentially deterministic, most formal models in social science, by definition, cannot study order-creation. The use of formal math models, thus, precludes the study of how heterogeneous, autonomous agents create order. Needless to say, once the formal modeling of order-creation in social science is well established, the empirical corroboration of instances where societies become locked in equilibrium and somehow do not create new order becomes much more interesting—modern hunting-and-gathering societies being a case in point. ***Very few social scientists have followed the complexity scientists redefinition of normal science to focus more directly on order-creation by heterogeneous autonomous agents, using agent-based computational models.***

4. *Postmodernism's Connectionist Core.* While postmodernism is anathema to normal scientists (Gross, Levitt and Lewis 1996, Norris 1997, Gross and Levitt 1998, Koertge 1998, Sokal and Bricmont 1998) we do need to give relativists and postmodernists credit for reminding us that "We ARE the Brownian Motion!" Most natural scientists are separated from their "agents" by vast differences in size and/or distance and barriers. Social scientists are agents doing their science right at the agent level. Most sciences do not have this luxury. But it also means a fundamental difference. We are face to face with stochastic heterogeneous agents and their interconnections. Social scientists should be first in line to want a scientific modeling epistemology designed for studying order-creation by agents. Instead, we draw our formal modeling technology from sciences vastly separated from their agents, and by tradition and instrumental convenience, comfortable with their homogeneity and equilibrium assumptions. This simply does not make sense, except when viewed in the light of weak sciences trying to bolster their institutional legitimacy by copying established sciences. Unfortunately, many postmodernists base their anti-science rhetoric on an abandoned epistemology and ignore a "new" normal science ontological view very much parallel to its own. As Cilliers (1998) argues, at its core, postmodernism zeros in on the web of interconnections among agents that give rise to localized scientific textual meanings. In fact, its ontology parallels that of complexity scientists. The third lesson from complexity science is that natural scientists have begun finding ways to practice normal science without assuming away the order-creation activities of heterogeneous autonomous agents. ***There is no reason, now, why social scientists cannot combine "new" normal science epistemology with postmodernist ontology. Yet very few have done so.***

5. *Legitimacy.* Given the connectionist parallels between complexity science and postmodernist views of human agents, we may conclude that their ontological views are essentially isomorphic. Complexity science ontology has emerged from the foundational classic and quantum physics and biology, as briefly described in Section 3. And surely there can be no doubt that postmodernist ontology has emerged from an analysis of the human condition and human agents. It follows that an epistemology based on complexity science and its agent-based modeling approaches may reasonably be applied to social science ontology as reflected in the agent-based ontology of postmodernism. **"New" Social Science Epistemology**, rather than having to build institutional legitimacy by mirroring classic physics, its lower-bound homogeneity assumption and its equilibrium-centered math model, can instead draw legitimacy from other sources:

1. Campbellian realism, coupled with the *model-centered science* of the Semantic Conception, bases scientific legitimacy on theories aimed at explaining transcendental causal mechanisms or processes, the insertion of models as an essential element of sound epistemology, and the use of real-world phenomena as the criterion variable leading to a winnowing out of less plausible social constructions and individual interpretations;

2. The more responsible core of postmodernism, as described here, sets forth an ontology that emphasizes meaning- and order-creation based on the changing interconnections among autonomous, heterogeneous social agents—this *connectionist-based, social agent-based ontology* from postmodernism offers social science second basis of improved legitimacy;

3. The "new" normal science emerging from complexity science, centered around emergent order-creation and complexity from the interactions of autonomous heterogeneous agents, has developed an *agent- and model-centered epistemology* that couples with the ontological legitimacy emerging from postmodernism. This offers a third basis of improved legitimacy;

4. Model-centered science is a two edged sword. On the one hand, formalized models are reaffirmed as a critical element in the already legitimate sciences and receive added legitimacy from the Semantic Conception in philosophy of science. On the other, the more we learn about *models as autonomous agents*—that offer a third influence on the course of science, in addition to theory and data—the more we see the problematic molding effects math models have on social science. In short, math models are mostly inconsistent with the new agent- and model-centered epistemology. The more the math model's molding effects are realized, and the more that it is also realized that they require assuming away both the core postmodernist ontology and "new" normal science ontology, the more the legitimacy an alternative formal modeling approach—such as agent-based modeling—is increased. This offers a fourth basis of improved legitimacy.

5. In a classic paper, Cronbach (1957) divided research into two essential technologies: *experiments* and *correlations*. Since then we have added math modeling. Hulin and Ilgen (2000) title their book, *Computational Modeling of Behavior in Organizations: The Third Scientific Discipline*, to highlight their idea that computational modeling gives social scientists a third essential technology in addition to Cronbach's two. As Henrickson's (2002) journal survey shows, nonlinear

computational models are rapidly on the increase in the natural sciences. Rounding out the social scientists research tool bag and finding a technology that fits well with social phenomena surely adds a fifth basis of improved legitimacy.

Agent-based models offer a platform for model-centered science that rests on the five legitimacy bases described in the previous points: Agent-based models support a *model-centered social science* that rests on strongly legitimated connectionist, autonomous, heterogeneous agent-based ontology and epistemology. **Yet very few social scientists have connected the use of agent-based models with the five bases of legitimacy I have just identified.**

The parallels between the agent-behavior assumptions of "new" normal science and agent-based models is striking—not least because of their coevolutionary development over the past decades. This is, again, an example of the model-as-autonomous-agent in action. The Arthur-Durlauf-Lane description of complex adaptive systems is in terms of autonomous, heterogeneous, coevolving, adaptive, agents who create novel adaptive solutions, supervening structures in nonequilibrium situations. This sentence also describes agent-based models. None of these descriptors can be associated with math-based models.

There can be little doubt that agent-based modeling *should* emerge as the preferred modeling approach and that future, significant, social science contributions will emerge more quickly if science-based beliefs are based on findings that are the joint result of both agent-modeling and subsequent empirical corroboration. Each of the five bases of legitimacy that support my use of the word, *should*, rest on solid ontological and epistemological arguments. That is, based on both analytical and ontological adequacy, where "analytical" is mostly based on agent-based models and "ontological" is based mostly on the *heterogeneous agent* and "*before the 1st Law*" phenomena.

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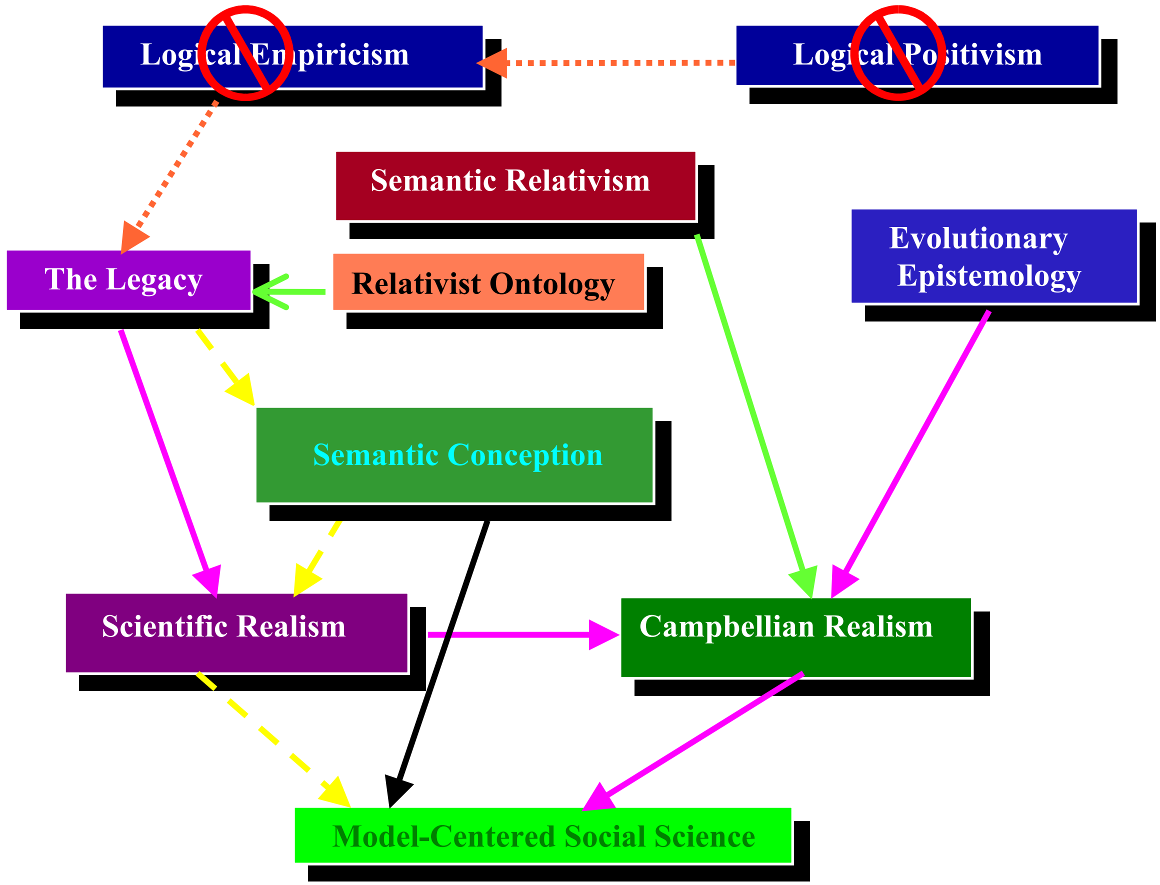
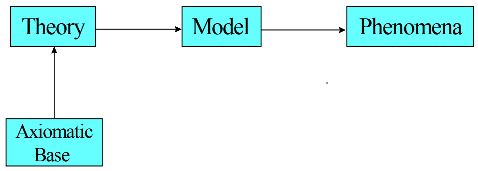


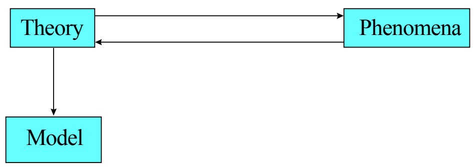
Figure 1 The Map

Figure 2 Conceptions of the Axiom-Theory–model–phenomena Relationship

2a Axiomatic Conception



2b Organization Science Conception



2c Semantic Conception

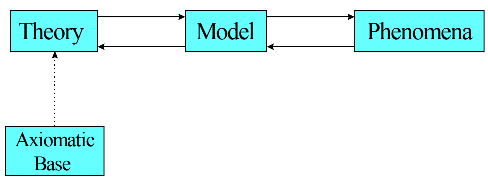


Figure 3 Guttman Scale of Effective Science

Highest Scientific Standard

1. Instrumental Reliability
2. Verisimilitude via Selection
3. Separation of Analytical and Ontological Tests
4. Experiments
5. Model-Centeredness
6. Nomic Necessity
7. Avoidance of Metaphysical Terms

Minimal Scientific Standard

Figure 4 Boumans's (2000) Depiction of "Ingredients" in Model Building

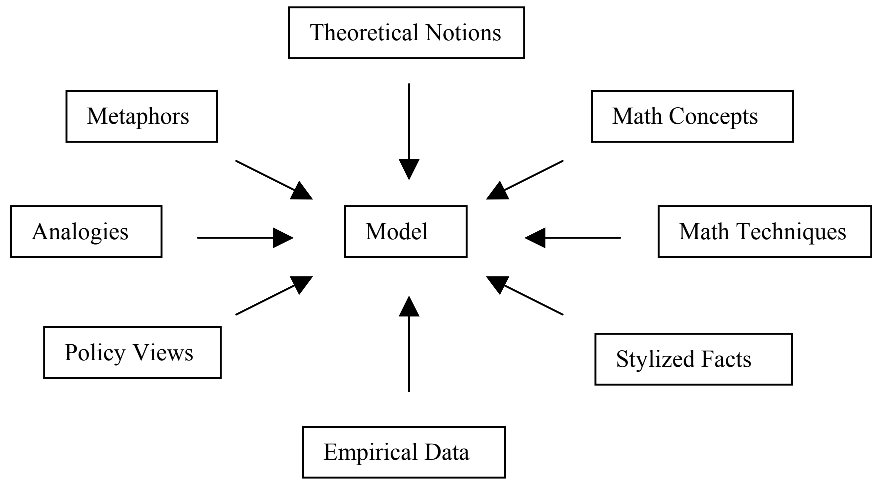


Figure 5 Rate of Change Away from Precondition Parameters

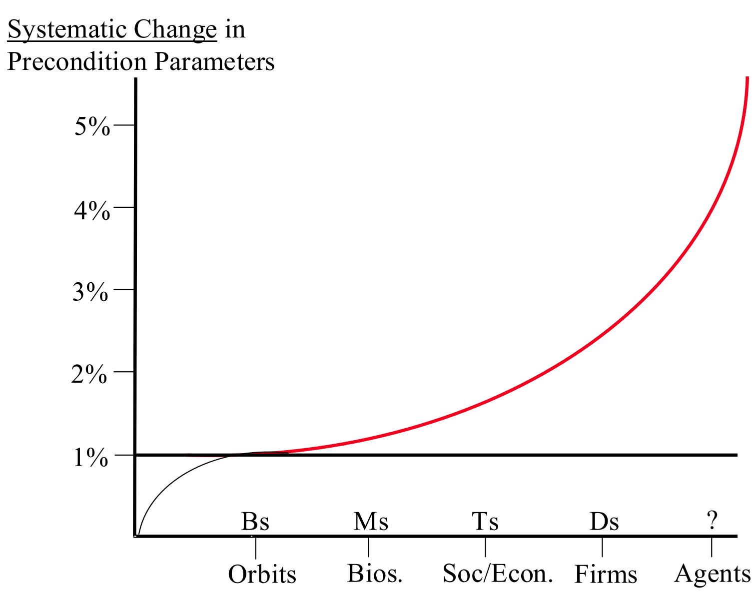


Table 1. Key Elements from Azevedo's *Mapping Model of Knowledge* (1997)

1-	Realism holds "that there is a real world existing independently of our attempts to know it."
2-	"The realist adopts a fallibilist approach to science" and truth.
3-	The rise of postmodernism is based on the "inadequacies of positivism."
4-	"Postmodernists show a profound ignorance of contemporary realism and a reluctance to engage in serious debate."
5-	"[H]umans are products of biological evolution…[that] have evolved perceptual and cognitive mechanisms…. Natural selection would not have left us with grossly misleading perceptual and cognitive mechanisms."
6-	"Valid beliefs, therefore, are achieved as a result of social processes rather than despite them."
7-	Being "scientific is tied up with the nature of the structure and the norms of the institution of science…that distinguish science from other belief production and maintenance institutions" such as religion.
8-	The "validity of theories is both relative to the interests that guide theory creation and a function of the reality that they represent."
9-	[T]heories, like maps, are valid insofar as they are reliable guides to action and decision making."
10-	"Causal analysis is the basis of validity."
11-	"Explanations in terms of composition, structure, and function are as much a part of science as are causal explanations.
12-	"[M]entalist explanations [based on meanings, motives, and reasons] turn out to be interpretative functional analyses.…[and] have a loose, but nonetheless specified, relationship with the [causal] transition theories they explain.…leaving the way open for a naturalist [realist] approach to the social sciences."
13-	"[K]nowing a complex reality actually demands the use of multiple perspectives."
14-	"The reality of some entity, property, or process is held to be established when it appears invariant across at least two…independent theories." (pp. 255–269)

Table 2. What Math is Good For

1.	Finding numbers;
2.	Accounting for energy translations governed by the 1st law;
3.	Testing theoretical logic by showing deduced consequences following from a theory's structural properties (initial state parameters);
4.	More compact expressions of complicated interrelations;
5.	Projecting results into the future or past (across time);
6.	Tracing new reasoning back to foundational axioms;
7.	Testing and exploring linear and especially nonlinear relations among theory elements/parameters/variables; and
8.	Theory- and data-based model building—substituting math for mechanical or other iconic models.

Table 3. Mathematical Assumptions Mentioned by Read (1990)

Applications of mathematics assume:

1. That universal processes exist (p. 38);
2. That linear relationships prevail (p. 39);
3. The structural stability of a model's form (p. 40);
4. Constancy of parameter values over time (p. 45);
5. There is some set of state variables that fully describe system at t_1 (p. 46);
6. Analysis consists of determining stability and equilibrium properties (p. 47);
7. That there is an equilibrium solution (p. 48);
8. That social systems respond to external forces as physical objects respond to forces of motion;
   That social rules are deterministic as opposed to being the result of evolved agent behavior;
   That state parameters are not subject to modification by agents (p. 49);
9. That external constraints are stable over time;
   That social systems inevitably drive toward stable equilibrium (p. 51);
10. In Linear Programming:
    - That maximization of utility functions characterizes human behavior (p. 51);
    - That people minimize cost functions (p. 51);
    - That individual decision making leads to optimal solutions (p. 51);
    - That the effects of individual dynamics on global dynamics can be ignored (p. 51);
    - That systems that survive are the optimal ones (p. 51);
    - That functions are continuous fixed marginal costs (p. 51);
    - That solutions based on averaging are valid (p. 52);
    - When using changing marginal costs, that subjects track the differences (p. 53);
    - That two basic assumptions hold: a) substitutability of resources and b) constancy of parameters (p.54).

Table 4. Key Elements of Economies as Complex Adaptive Systems*

1. *Dispersed Interaction*—dispersed, possibly heterogeneous, agents active in parallel;
2. *No Global Controller or Cause*—coevolution of agent interactions;
3. *Many Levels of Organization*—agents at lower levels create contexts at higher levels;
4. *Continual Adaptation*—agents revise their adaptive behavior continually;
5. *Perpetual Novelty*—by changing in ways that allow them to depend on new resources, agents coevolve with resource changes to occupy new habitats;
6. *Out-of-Equilibrium Dynamics*—economies operate "far from equilibrium," meaning that economies are induced by the pressure of trade imbalances, individual to individual, firm to firm, country to country, etc.

*Arthur, Durlauf, and Lane (1997)