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Toward a complexity science of entrepreneurship

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Abstract

Darwinian selectionist theory is characterized as equilibrium bound. Complexity science focuses on order creation, hence is a better platform for a science of entrepreneurship. "Self-organization biologists" study order creation in the context of all four Aristotelian causes: *material*, *formal*, *final*, and *efficient*, whereas normal science rests only on *efficient* cause. Mohr's process theory and Siggelkow's narrative about entrepreneurship rest on all four, standing as good representations of postmodernist ontology. Since modern epistemology still calls for model-centered science, agent models are proposed as an alternative to mathematics as a means of applying modern normal science standards to research on entrepreneurship—all without downgrading thick, postmodernist descriptions of complex causality.

Keywords: Order creation; Entrepreneurship; Causality

1. Executive summary

Should CEOs pay attention to research findings about entrepreneurship published in mediums such as the *Journal of Business Venturing*? Apparently, they do not. Pfeffer and Fong (2002) find that executives pay little attention to research by academics, preferring instead to listen to consultants. Does either of these sources offer advice that executives should take seriously enough to put into practice? Is there any truth to what they say?

Many articles in this journal are econometric analyses based on time-series data. This means that a very few variables are used to predict theorized outcomes. These are known as "thin" descriptions of entrepreneurial behavior. Alternatively, there are "thick" descriptions

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of entrepreneurial practice, such as a recent analysis by Siggelkow (2002) of the start-up of The Vanguard Group. Here, one researcher describes the rich interactions of many events, but only in one firm, at one point in time. Thin descriptions are untrustworthy because many causal effects are ignored. Thick descriptions are untrustworthy because they are not necessarily generalizable to any other entrepreneurial setting. Science is poorly served by either approach. In addition, good science is "model-centered," which is to say theories are based on formalized models. These serve to keep scientists honest by forcing them to zero in on the most critical variables—so as not to bury managers with theories so complex that they are opaque and/or useless.

Since Isaac Newton, science has essentially copied the physicists' focus on studying phenomena under conditions of equilibrium. They assume that all the causal elements, that is, *agents*, such as particles and biomolecules, are homogeneous. Economists are particularly notorious for using physicists' scientific methods (and copying their emphasis on mathematics) for studying social behavior, all the while assuming that people and firms are homogeneous. Thick-description scientists say this is nonsense, but the thin-description researchers continue to make these assumptions—even in this journal.

In this article, I suggest that a new kind of research, called *heterogeneous agent-based computational modeling*, offers a way to combine both thin- and thick-description research. Agent models allow scientists to capture much more of the complex causality present in typical entrepreneurial settings. They also allow scientists to use the formalized methods of good science likely to produce theories about effective entrepreneurial practices having higher truth value.

Agent models are the method of choice by many complexity scientists—the newest form of modern science. Unlike traditional scientists, who conduct research under conditions of equilibrium, complexity scientists focus on the study of *order creation*. Since creation of new economic order in the form of new firms is what entrepreneurs do, complexity science makes much more sense as the preferred kind of science for entrepreneurial research.

Complexity scientists study nonlinear outcomes resulting from (1) rapid phase transitions caused by adaptive tensions and (2) coevolutionary (positive feedback) processes set in motion by seemingly inconsequential instigating events. Sixty years ago, Schumpeter (1942) turned our attention to the critical effect that phase transitions have on the creation of new economic order. He called it "creative destruction." Finally, good science has caught up with Schumpeter—except that the focus is not on destruction of old order but more specifically on how to create new economic entities, such as firms. Taking cues from Schumpeter and complexity science, I suggest several ways in which researchers may use agent models to develop more truthful theories about entrepreneurship without assuming away the complex causality invariably driving most entrepreneurial decisions.

2. Introduction

The reliance on evolutionary theory to explain entrepreneurial "start-up" behavior, and more generally novelty creation dynamics—Schumpeter's (1942) *creative destruc-*

tion—in the econosphere is not as useful as heretofore thought. Consider the following syllogism:

- ✓ Evolutionary theory is now best interpreted as an equilibrium theory rather that an order-creation theory.
- ✓ Population ecology is assuredly an equilibrium theory.
- ✓ Entrepreneurship is, by definition, an activity focusing on new order creation rather than on equilibrium.
- ✓ Therefore, evolutionary theory and population ecology are inappropriate to the study of entrepreneurship.

By 1982 several significant works had appeared arguing that the study of socioeconomic dynamics would be better served if theory and research were enlightened by evolutionary and ecological lessons from biology (Kaufmann, 1975; Hannan and Freeman, 1977; Aldrich, 1979; Weick, 1979; McKelvey, 1982; Nelson and Winter, 1982). This theory is held to explain the appearance of novelty and order in bio- and econospheres. This paradigm has prevailed for two decades in organization science, with the most recent book-length example being Aldrich (1999).

Recently, however, some biologists have come to see selectionist evolutionary theory as describing an equilibrium process rather than explaining the appearance of new order in the biosphere. Kauffman (1993), Salthe (1993), Depew and Weber (1995), and Van de Vijver et al. (1998) exemplify this view. They point, instead, to self-organization by heterogeneous bioagents that are caught between two giant Bénard (1901) convection cells—one in the earth and one in the atmosphere (McKelvey, 2003c).

This view of new order creation rests on two theories of the underlying order-creation generative mechanisms. A mostly European school, based on Prigogine's (1955) work on the emergence of dissipative structures (new kinds of order), emphasizes phase transition effects, instigated by externally imposing energy differentials, as the cause of order creation. An American school, centered around the Santa Fe Institute Studies in the Sciences of Complexity (Lewin, 1999), emerges from chaos theory (Gleick, 1987). In this view, order creation results from nonlinear dynamics set in motion by coevolutionary interaction among heterogeneous agents. The coevolutionary process is, in turn, started by small instigating events not unlike the fabled butterfly effect in chaos theory. They model these processes using heterogeneous, agent-based modeling, computational simulation methods.

"Self-organization biologists" also offer another stream of thought, some of which appears in the work of Salthe (1993), Matsuno and Salthe (1995), Van de Vijver (1998), Juarrero (1998), and Kampis (1998). They argue that causal theories about order creation should draw on all four Aristotelian causes: *material*, *final*, *formal*, and *efficient*. This counters traditional statements on scientific epistemology, rooted as they are in Newtonian physics, logical positivism, and the mathematization of theories. Traditional science focuses only on *efficient* cause.

Based on these trends, I argue that the study of entrepreneurial start-ups is off the track without an epistemology that incorporates all four Aristotelian causes and heterogeneous, agent-based modeling. Here is another syllogism:

✓ Entrepreneurial research requires theories drawing on all four Aristotelian causes.
✓ Traditional model-centered science draws only on *efficient* cause.
✓ Math models and modern empirical methods focus mainly, if not only, on *efficient* cause.
✓ Therefore, current epistemology is ill suited to the study of entrepreneurship.

Based on this syllogism, I conclude that the only way to study order creation, while at the same time living up to the core elements of sound epistemology, is to integrate thick-description, postmodernist, process-based research with the use of heterogeneous agent models. I illustrate this using Siggelkow's (2002) description of entrepreneurship at The Vanguard Group.

I begin with a short review of why evolutionary theory describes equilibrium processes rather than order-creation processes. Then, I give a brief review of the European and American schools of complexity science, both of which focus on self-organizing agents as the basis of new order creation. I also use complexity science as an exemplar of a modern normal science that has found a way to connect model-centered epistemology with the localized, connectionist, ontological view of organizational postpositivists and postmodernists. Next, I show just how much a typical narrative about the entrepreneurial process is laden with all four Aristotelian causes, using Siggelkow's case study. Finally, I argue that agent-based models are the only way of creating generalizable, empirically validated statements about entrepreneurial dynamics.

3. Equilibrium-bound evolutionary theory

Nelson and Winter (1982) look to Darwinian evolutionary theory for a dynamic perspective useful for explaining the origin of order in economic systems; so too, do Aldrich (1979, 1999) and McKelvey (1982, 1994). Leading writers about biology, such as Salthe (1993), Rosenberg (1994), Depew (1998), Weber (1998), and Kauffman (2000), now argue that Darwinian theory is, itself, equilibrium bound and not adequate for explaining the origin of order. Underlying this change in perspective is a shift to the study of how heterogeneous bioagents create order in the context of geological and atmospheric dynamics (McKelvey, 2003c).

Campbell brought Darwinian selectionist theory into social science (Campbell, 1965; McKelvey and Baum, 1999). Nelson and Winter (1982) offer the most comprehensive treatment in economics; Aldrich (1979) and McKelvey (1982) do so in organization science. The essentials are (1) genes replicate with error, (2) variants are differentially selected, altering gene frequencies in populations, (3) populations have differential survival rates, given existing niches, and (4) coevolution of niche emergence and genetic variance. Economic orthodoxy develops the mathematics of thermodynamics to study the resolution of supply/demand imbalances within a broader equilibrium context. It also takes a static, 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 fails because orthodoxy still holds to energy conservation mathematics (the first 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) discusses at considerable length. Hinterberger (1994) critiques orthodoxy's reliance on the equilibrium assumption from a different perspective. In his view, a closer look at both competitive contexts and socioeconomic actors uncovers four forces working to disallow the equilibrium assumption:

1. Rapid changes in the competitive context of firms do 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 equilibria.
4. Agents coevolve to create higher level structures that become the selection contexts for subsequent agent behaviors.

Hinterberger's critique comes from the perspective of complexity science. Also from this view, Arthur et al. (1997, pp. 3–4) note that the following characteristics of economies counter the equilibrium assumption essential to predictive mathematics:

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; and
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.

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) The answer is, of course, they do not. What is missing? Arthur et al.'s elements of complex adaptive systems are what are missing: *agents*, *nonlinearities*, *hierarchy*, *coevolution*, *far-from-equilibrium*, and *self-organization*.

This becomes evident once we use research methods allowing a *fast-motion* view of socioeconomic phenomena. The fast-paced technology and market changes in the modern knowledge economy—that drive entrepreneurship—suggest such an analytical time shift for socioeconomic research methods is long over due. The methods of economics are based on the methods of physics, which in turn are based on very slow-motion, new order-creation events—planetary orbits and atomic processes have remained essentially unchanged for billions of years.

Bar-Yam (1997) divides degrees of freedom into *fast*, *slow*, and *dynamic* time scales. On a human time scale, applications of thermodynamics to the phenomena of classical physics and economics assume that *slow processes are fixed* and *fast processes are in equilibrium*, leaving thermodynamic processes as *dynamic*. Bar-Yam says, “Slow processes establish the [broader] framework in which thermodynamics can be applied” (p. 90). Now, suppose we speed up slow motion physical processes so that they appear dynamic at the human time scale—say to a rate of roughly 1 year for every 3 seconds. Then about a billion years go by per century. It is like looking at a 3.8-billion-year-movie in fast motion. At this speed, we see the dynamic effects geological changes have on biological order—the processes of Darwinian evolution go by so fast they appear in equilibrium (elaborated in McKelvey, 2003c)!

If the classical physics, equilibrium-influenced methods of socioeconomic research are viewed through the lens of fast-motion science, evolutionary analysis shifts into Bar-Yam’s fast motion degrees of freedom. Thus, changes attributed to selection “dynamics” slip into equilibrium. By this logic, since evolutionary analysis is equilibrium-bound, it is ill suited for research focusing on entrepreneurship. Following Van de Vijver et al., dynamic analysis, therefore, must focus on agents’ self-organization rather than Darwinian selection.

The first law of thermodynamics has been *the* defining dynamic of science—but it focuses on *order translation*, not *order creation*. Elsewhere, I review the complexity scientists’ search for the zeroth law of thermodynamics, focusing on the root question in complexity science: What causes order *before* first law equilibria take hold? (McKelvey, 2003c). How and when does order creation occur? *Post-equilibrium* science studies only time-reversible, *post* first law energy translations—how, why, and at what rate energy translates from one kind of order to another (Prigogine, 1955, 1997). It invariably assumes equilibrium. *Pre-equilibrium* science focuses on the order-creation characteristics of complex adaptive systems. Entrepreneurial research needs to be based on pre-equilibrium science! Stacey (1995), Lichtenstein (1999, 2000, 2001), and Bruyat and Julien (2001) also argue or demonstrate that complexity science is the preferred platform for effective entrepreneurial research.

4. The complexity science engines of order creation

The complexity science view of the origin of order in biology is that self-organization—pre first law processes—explains more order in the biosphere than Darwinian selection (Kauffman, 1993, 2000; Salthe, 1993; the many authors in Van de Vijver et al., 1998). Two engines of order creation are apparent in complexity science.

4.1. European school

Europeans (Prigogine, 1955, 1997; Haken, 1983; Nicolis and Prigogine, 1989; Cramer, 1993; Kaye, 1993; Mainzer, 1997, among others) draw mostly from the physical sciences, emphasize mathematics, and view imposing energy differentials leading to phase transitions as the cause of order creation. A phase transition occurs because an imposing energy differential, what I term *adaptive tension* (McKelvey, in press), exceeds what is called the first critical value, R_{c1}, which defines the lower bound of the region of emergent complexity.

Elsewhere, I have reviewed a number of theories about causes of emergent order in physics and biology, some of which have been extended into the econosphere (McKelvey, 2003c). Kelso et al. (1992) offer the best synthesis of the European school:

> Control parameters, R_i, externally influenced, create $R > R_{c1}$ with the result that a phase transition (instability) approaches, degrees of freedom are enslaved, and order parameters appear, resulting in similar patterns of order emerging although underlying generative mechanisms show high variance.[1]

This "zeroth law," the *order-creation law*, summarizes the European school's view. They focus on the Bénard energy-differential process that applies to weather, fluid dynamics, various chemical materials, the geology of the earth and, subsequently, to various biological phenomena.

Equilibrium thinking and the first law are endemic in evolutionary theory applications to economics and organization science. Equilibrium thinking, central tendencies, and the use of energy dynamics in independent variables to predict outcome variables are also endemic to organization science empirical methods, whether regression or econometric analyses. However, there now is a shift from the homogeneous agents of physics and mathematics to heterogeneous, self-organizing agents. As 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 this statement, the zeroth law is brought in more directly.

Besanko et al. (2000) summarize Schumpeter's (1942) thesis as follows:

> Schumpeter considered capitalism to be an evolutionary process that unfolded in a characteristic pattern. Any market has periods of comparative quite, when firms that have developed superior products, technologies, or organizational capabilities earn positive economic profits. These quiet periods are punctuated by fundamental "*shocks*" or "*discontinuities*" that destroy old sources of advantage and replace them with new ones. The entrepreneurs who exploit the opportunities these shocks create achieve positive profits during the next period of comparative quiet. Schumpeter called this evolutionary process creative destruction. (p. 485; italics and underlines supplied)

[1] It is rather ironic, however, that the most complete statement of the European view is in the only paper I have found among the many Santa Fe Institute publications that focuses on the critical values and phase transitions!

Remarkably, in 1942, Schumpeter wrote about replacing evolution with phase transitions—well before Prigogine (1955), and replacing gradualist evolution with punctuated equilibrium long before Maruyama (1963) or Eldredge and Gould (1972)!

The application of the zeroth law in socioeconomics rests with Haken's control parameters, the first two words in the Kelso et al.'s statement. The R_i adaptive tensions (McKelvey, 2003c, in press) can appear in many different forms, from Jack Welch's famous phrase, "Be #1 or 2 in your industry in market share or you will be fixed, sold, or closed" (Tichy and Sherman, 1994, p. 108; somewhat paraphrased), to narrower tension statements aimed at technology, market, cost, or other adaptive tensions. Schumpeter observes (quote above) that entrepreneurs are particularly apt at uncovering tensions in the marketplace. The applied implication of the zeroth law is that entrepreneurial activity is a function of (1) *control parameters*, (2) *adaptive tension*, and (3) *phase transitions* motivating (4) *agents' self-organization*. Take away any of these and order creation (read: entrepreneurship) stops.

4.2. American school

What sets off bursts of nonlinear order creation via coevolution? Americans draw from the life and social sciences and chaos theory, emphasize heterogeneous agent computational simulation models, and see large nonlinear effects stemming from mutually causal or coevolutionary agent interactions instigated by small initiating events.

The American complexity literature focuses on coevolution, power laws, and *small* instigating effects. Gleick (1987) details chaos theory, its focus on the so-called butterfly effect (the fabled story of a butterfly flapping its wings in Brazil causing a storm in North America), and aperiodic behavior ever since the founding paper by Lorenz (1963). Bak (1996) reports on his discovery of *self-organized criticality*—a power law event—in which small initial events can lead to complexity cascades of avalanche proportions. Arthur (1990, 2000) focuses on positive feedbacks stemming from initially small instigation events. Casti (1994) and Brock (2000) continue the emphasis on power laws. The rest of the Santa Fe story is told in Lewin (1999). In their vision, coevolution is the "engine" of complex system adaptation. American complexity scientists tend to focus on R_{c2}—the "edge of chaos" (Lewin, 1999; Kauffman, 1993, 2000; Brown and Eisenhardt, 1998), which defines the upper bound of the region of emergent complexity. What happens at R_{c1} is better understood; what happens at R_{c2} is more obscure. The "edge of chaos," long a Santa Fe reference point (Lewin, 1999), is now in disrepute, however (Horgan, 1996, p. 197).

It is not hard to find evidence of coevolutionary behavior in organizations. The earliest discoveries date back to Roethlisberger and Dixon (1939) and Homans (1950)—both dealing with the mutual influence of agents (members of informal groups), the subsequent development of groups, and the emergence of strong group norms that feed back to sanction agent behavior. Much of the discussion by March and Sutton (1997) focuses on the problems arising from the use of simple linear models for measuring performance—problems all due to coevolutionary behavior of firms and agents within them. In a recent study of advanced manufacturing technology (AMT), Lewis and Grimes (1999) use a multiparadigm (postmodernist) approach. They study AMT from all of the four paradigms identified by Burrell and Morgan (1979). With each lens, that is, no matter which lens they use, they find evidence of coevolutionary behavior within firms. Many of the articles in the *Organization Science* special issue on coevolution (Lewin and Volberda, 1999) report out evidence of micro-coevolutionary behavior in organizations. Finally, a number of very recent studies of organization change show much evidence of coevolution between organization and environment and within organizations as well (Erakovic, 2002; Meyer and Gaba, 2002; Kaminska-Labbe and Thomas, 2002; Morlacchi, 2002; Siggelkow, 2002).

In a truly classic paper, Maruyama (1963) discusses *mutual causal* processes mostly with respect to biological coevolution. He also distinguishes between the "deviation-counter-acting" negative feedback most familiar to general systems theorists (Buckley, 1968) and "deviation-amplifying" *positive-feedback* processes (Milsum, 1968). Boulding (1968) and Arthur (1990, 2000) focus on "positive feedbacks" in economies. Negative-feedback control systems, such as thermostats, are most familiar to us. Positive-feedback effects emerge when a microphone is placed near a speaker, resulting in a high-pitched squeal. Mutual causal or coevolutionary processes are inherently nonlinear—large-scale effects may be instigated by very small initiating events, as noted by Maruyama (1963), Gleick (1987), and Ormerod (1998).

To overcome the boiled-frog effect,[2] both European and American perspectives are important. Phase transitions are often required to overcome the threshold-gate effects characteristic of most human agents. This, in turn, requires the adaptive tension driver to rise above R_{c1}. Once these stronger than normal instigation effects overcome the threshold gates, then, assuming the other requirements are present (heterogeneous, adaptive learning agents, and so forth), coevolution starts. Neither seems both necessary and sufficient by itself, especially in social settings. Phase transition and coevolution are *coproducers*, to use Churchman and Ackoff's (1950) term. It seems clear that entrepreneurial *initiating* events, as Schumpeter figured out 60 years ago, fit with the European school. Consequently, research about entrepreneurial activity is better based on the nascent zeroth law than on Darwinian theory. As I argue above, the latter has nothing to do with the initial entrepreneurial event—which is about order creation, not equilibrium. Once the initial event has taken place, then, following the American school, entrepreneurship is about managing the dynamics of coevolution. I develop this topic elsewhere (McKelvey, 2002a).

5. Complexity science legitimates postmodernism

Complexity science does more than simply steer our thinking away from evolutionary theory and toward the zeroth law and coevolutionary dynamics. Pfeffer (1993) correctly documents and laments the miniscule epistemological and other kinds of organization

[2] A frog dropped into boiling water will jump right out; a frog put in cold water, which is slowly brought to a boil, will not jump out, cooking to death instead. This is why the European complexity scientists worry so much about critical values and consequent phase transitions—it takes significant shocks to get systems out of unresponsive states.

science legitimacy relative to other sciences. McKelvey (2003a) takes the Kuhn (1962) position that organization science is a collection of prescience "fields," and thus not a science at all—yet. Organizational postpositivists and postmodernists correctly argue that organizational ontology is not amenable to traditional, and still prevailing, physics-based research epistemologies. At its extreme, this produces an antiscience mentality (Holton, 1993; Koertge, 1998).

Complexity science is best seen as a *modern* "normal" science—practiced by natural and life scientists as well as some social scientists. It has originated a "logic-in-use" (Kaplan, 1964) based on a reading of physical, biological, and economic ontology signifying localization, connectionism, and self-organized, emergent order creation, rather than the linear prediction empirics—and associated positivist epistemology—of classical physics. As such, it holds the same ontological view as postpositivists and postmodernists. It follows that complexity science offers a legitimizing "reconstructed logic" (Kaplan, 1964) that integrates the practices of organization scientists following either normal science or postmodern dictums.

5.1. Organizational postmodernist (postpositivist) ontology

Many key tenants of postmodernism have been present for some time in organization studies. They have been identified and elucidated by organizational *postpositivists* who take a closer, richer, thicker, more subjective view of organizational phenomena, coming to appreciate its fundamentally complex, idiosyncratic, and multi- and mutually causal nature (Berger and Luckmann, 1967; Silverman, 1970; Geertz, 1973; Lincoln, 1985). They conclude that the prevalence of idiosyncratic phenomena precludes the use of conventional positivist methods, calling instead for subjective, richly descriptive, natural history style case analyses (see also Van Maanen, 1988; Eisenhardt, 1989; Calás and Smircich, 1999; Langley, 1999; Pentland, 1999).

Sarup (1993) attributes the origin of the term *postmodernism* to the artists and art critics of New York in the 1960s. Alvesson and Deetz (1996, p. 205) emphasize the following aspects:

1. Reality, or "'natural' objects," cannot have meaning 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.
2. "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).
3. The "indecidabilities of language take precedence over language as a mirror of reality."
4. "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."
5. 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."

6. The "real world" increasingly appears as "simulacra"—models, simulations, computer images, and so forth—that "take precedence in contemporary social order."
7. Research aims at "resistance and indeterminacy where irony and play are preferred [as opposed to]. . .rationality, predictability and order."

5.2. Connectionism in complexity science and postmodernism

The primary analysis underlying my claim that postmodernism does in fact fit with the "modern, normal science of complexity" comes from Cilliers' (1998) book—*Complexity and Postmodernism*. He draws principally from poststructuralists like de Saussure (1974), Derrida (1978), and Lyotard (1984). He interprets postmodernism from the perspective of a neural network 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, in press).

Cilliers (1998, p. 6) first sets out 10 attributes of complex adaptive systems, and then makes his foundational argument as follows (p. 37):

- Complexity is best characterized as arising through large-scale, nonlinear interaction.
- Since it is based on a system of relationships, the poststructural inquiry into the nature of language helps us to theorize about the dynamics of the interaction in complex systems.
- Connectionist networks share the characteristics of complex systems, including those aspects described by a poststructural theory of language.

These points link the poststructuralist *responsible core* of postmodernism and complexity science together by virtue of their common focus on connectionism. From this platform, Cilliers connects his 10 attributes of complex adaptive systems (shown in italics) to key elements of postmodernists' characterizations of current society (pp. 119–123)—to which I add additional postmodernist themes. The centrality of interacting agents is obviously essential to both.

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 decentered 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.
4. "*Interactions are nonlinear.*" Postmodernists hold that localized interactions of multiple voices lead to change in meanings of texts, that is, emergent meanings. Furthermore, 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, 1998, p. 121).
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).
7. "*Complex systems are open systems.*" A pervasive subtext in postmodernism is that agents, groups of agents, and groups of groups, etc., are all subject to outside influences on their interpretations of meanings.
8. "*Complex systems operate under conditions far from equilibrium.*" In postmodern society, the mass media provide local agents, and groups of virtually any size, constant information about countless disparities in values, culture, economics—about the human condition in general.
9. "*Complex systems have histories.*" By viewing agents as *not* self-directing, Derrida "decenters" 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.
10. "*Individual elements are ignorant of the behavior of the whole system in which they are embedded.*" This compares with the 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. An agent's view of a larger system is at least in part colored by the localized interpretations. Reflexivity compounds all these effects.

The foregoing demonstrates that the poststructuralist core of postmodernism strongly supports 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.

6. Aristotelian causes vs. traditional science

Having integrated a modern normal science stemming from complexity science with postmodernist ontology, recognized that both attend to order creation, and having carved out space and legitimacy for models of the heterogeneous agent kind, my next question is: What kind of causal analysis best fits order-creation science—and more specifically, entrepreneurial research? Needless to say, I have argued against whatever causal thinking lies at the heart of evolutionary—selectionist thinking—it analyzes the longer-term results of entrepreneurship, not the "entrepreneurial act" itself. In this section, I will argue that virtually *all* traditional science-based theories and empirical analyses draw on Aristotle's *efficient* cause. Mostly, traditional science is also "reductionist" in nature—meaning that behaviors of *parts* are used to explain the behavior of the *whole*. It is also "time-series" based—meaning that antecedent variables are used to predict and/or explain outcome or dependent variables later. These are all very simple hierarchy- or time-linear views of causality. I will argue that entrepreneurial research will benefit from analyses that appreciate the coevolution of six kinds of causality: all four of Aristotle's causes (*material*, *final*, *formal*, and *efficient*), as well as bottom-up and top-down causality. The latter are well known. I begin with Aristotle's causes and then move into what I think is a more accurate and suitable interpretation of Mohr's (1982) *process theory* as compared to what has appeared recently in Elsbach et al. (1999) special issue on theory development—specifically articles by Langley and Pentland.

Classical physics and neoclassical economics draw, first, on Aristotle's *efficient* cause.[3] *Efficient* cause occurs when energy perturbations of one kind cause energy perturbations of another kind. In classical physics, this view begins with Newton's laws of motion, the study of planetary dynamics, and the discovery of the first law of thermodynamics—the energy conservation law. Under this law, time is reversible (Prigogine, 1955, 1997). Translations of order can go forward or backward, with mathematics acting as a means of accounting for the order-translation process, holding energy constant. Newtonian science, via the application of the first law, extends into thermodynamics, electromagnetism, and electrodynamics. It also extends to neoclassical economics, as noted earlier (Mirowski, 1989). The use of *efficient* cause and the energy-conservation dynamics of the first law also give physics its much envied predictive ability.

Matsuno and Salthe (1995), Salthe (1998), and Van de Vijver (1998), among others (see Van de Vijver et al., 1998) argue that, in the complexity perspective, dynamics are *not* governed by Aristotelian *efficient* cause. Given this, they focus on local rather than global dynamics. They abandon the idea that there are global energy dynamics that, via *efficient* cause, cause changes in local phenomena. Instead they emphasize Aristotle's *material* cause.[4] "Local descriptions of dynamics put priority on concrete particulars, while global consistency becomes secondary and derived—a consequence in a subsequent record of an integration of preceding, uncertain local dynamics and individuations" (Matsuno and Salthe, 1995, p. 312). Local dynamics dominate global dynamics. "From the point of view of any single local situation, the global is almost (but of course not fully) epiphenomenal" (p. 315). Van de Vijver points out that this perspective is based on the view that people can have only limited insights into the outcomes of nonlinear systems dynamics (a postmodernist statement for

[3] Aristotle's comments on the four causes appear in his book, *Physics*, which is published in Barnes' (1995) work.

[4] Aristotle looked at causes from the perspective of building a house. A grass hut and igloo differ because each is constructed of different locally available materials—*material* cause. Cheops' pyramid and Eiffel's Tower differ because their vision of what should be built was different—*final* cause. Their organizational means of accomplishment (getting the job done on time, under cost, and consistent with the vision; use of hierarchy and technology, motivation of workers, etc.), were also different—*formal* cause. Their use of force and energy differed as well; flowing river and strong backs to get stones to the site vs. use of fire to form cast-iron girders and wheels to transport them—*efficient* cause. The latter is the only one that survived into Newtonian, physics-based sciences.

sure). In addition, she notes that complex systems are "continuously evolving" [really continuously coevolving] and, thus, "can only be grasped locally, hence partially and inadequately" (p. 250). This, she says, means that complex systems follow from *material* causes. *Material* causality means that systems emerge from the materials at hand, as opposed to *efficient* causes, which are the result of energy dynamics—that is, energy changes of one kind cause energy changes of other kinds.

7. Mohr's process theory joined with agent modeling

One way to talk about the interaction of the Aristotelian causes in organizations is in terms of process theory as it unfolds in a specific, well-told, narrative about entrepreneurship—in this instance, Siggelkow's (2002) Vanguard Group case.

7.1. Mohr's process theory

In the *Academy of Management Review*'s (1999) special issue, two papers focus on Mohr's (1982) process theory (Langley, 1999; Pentland, 1999). Both emphasize *process* as sequences of events. Like the poststructuralists and postmodernists, they emphasize "narrative," more in-depth qualitative inductive discoveries, along with Weick's (1995) *sensemaking*. Neither author takes up the problem of discerning the truth content, reliability and validity, or justification of the "sense" that has been made from narrative analysis. Although I believe my analysis is more in keeping with Mohr's depictions of variance and process theories and my focus on agent-based models very much more in keeping with his five examples of process theories, this is not to say that Langley and Pentland are inordinately inconsistent with my interpretation. The fundamental difference, however, between Mohr and Langley and Pentland is that the narrative approach is inevitably about the past, with no mechanism for testing the application of the emergent theory as it applies to order creation into the future. Mohr's process theory replaces Aristotle's *efficient* cause with "the operation of the laws of chance" (p. 51) as processes unfold into the future. Narratives from the past vs. order creation into the future is not a trivial difference.

Mohr says, "variance theory rests ultimately on a belief in the metaphysical notion of *efficient* causality" (p. 51), that is, a change in variable *a* couples with a change in variable *b*. Scientific realists would like to discover that *a* is a *truthful* indicator of a process causing *b*. Positivists—to the extent that they are instrumentalists[5]—settle for finding out whether a change in *a* simply predicts a change in *b*. For variance theorists, Mohr notes that random processes are seen as error, but in process theory "random processes are explanation" (p. 52)—although he also recognizes that in process theory there still could be random error due to missing variables, faulty measures, or other still hidden causes. He says, "without external

[5] The logical positivists' *instrumental* view treats antecedent variables simply as predictors, without any attribution about underlying (metaphysical) causal generative mechanisms, or claims about *truthful* theory, being associated with them.

forces and probabilistic processes, alleged, tentative, or incipient process theories are anemic." External forces instigate a "compelling flow of action.... [with] emphasis still on the future." In this sense, *efficient* cause is still in Mohr's framework. The externally imposed tension driving the flow of events seems missing in the Langley and Pentland analyses. Finally, Mohr's (pp. 52–54) emphasis is on a "series of occurrences of events rather than a set of relations among variables."

Langley (1999, p. 693) observes that Mohr keeps events separate from variables but, in contrast, in her process theory diagram she mixes events and variables. She shows a "Strategy 1" (variable) giving rise to a "box" within which are a sequence of *events*, *activities*, and *choices* (her terms) that give rise to another variable, "Strategy 2." Taking an instrumental predictive view, one could easily treat the box as a hidden (and not required to be known) black box with, as a result, variable *a* (Strategy 1) predicting variable *b* (Strategy 2)—no cause assigned. This would surely be inconsistent with Mohr. Adding in a little Aristotle: (1) Strategy 1 could be a mixture of all four causes, none of which is necessary and sufficient; (2) it could be the *efficient* cause of traditional science—more energy into the Strategy 1 variable produces a better outcome on the Strategy 2 variable; or (3) it also could be a *final* cause (see Mohr, 1982, pp. 58+)—such as sustained economic rents. Thus, competition effects, such as Porter's (1980) five drivers, set up the external tension that, then, drives the flow of sequences inside the box. This, coupled with an intrabox process based on the interplay of *material*, *final*, and *efficient* causes, with some probability, produces Strategy 2 (which is actually one of several possible Strategy 2s). If the sequence of events produces a hierarchy and institutional structure of some kind, (4) a top-down *formal* cause could enter in as well—although bottom-up *formal* cause from agents is not precluded. Given the apparent interaction of Aristotelian causes in organizational phenomena, the fundamental problem becomes: How to translate Mohr's process model—and its interacting Aristotelian causes—into a framework for entrepreneurial research having modern epistemological legitimacy?

The narrative approach to process research typically follows guidelines, such as those of Eisenhardt (1989) and develops a sampling of narrative event histories of the kind proposed by Langley (1999) and Pentland (1999). It is possible that even a quasi-experiment (Cook and Campbell, 1979) could be set up using multiple narratives. Thus, one subsample could contain variable *P*, while in another subsample it is missing. Theorized outcome differences, O_j, could be proposed and evaluated. Needless to say, collecting this many narrative histories is difficult and time consuming, and many input and moderating variables still could remain uncontrolled. Several recent studies of radical organization change are good examples of this approach (Newman and Nollen, 1998; Erakovic, 2002; Kaminska-Labbe and Thomas, 2002; Siggelkow, 2002). They are also examples of the interplay of the four kinds of causality.

7.2. Heterogeneous agent-based modeling

Mohr's model begs for agent modeling. Mohr lists five process models: (1) *Contraction of malaria*, (2) *Mendelian segregation*, (3) *Diffusion*, (4) *Garbage-can model of organizational choice*, and (5) *Darwinian evolution—the origin of species* (pp. 47–51). These easily translate into agent models. All but "Garbage-can model of organizational choice" originate in biology. All agents have some individual attribute assigned via random draw. All conduct searches and contact other agents subject to some process also controlled by a random draw. Outcomes are the result of individual agent attributes, search results, larger system attributes, and environmental constraints. The garbage-can process was set up as an agent-based model in the original article (Cohen et al., 1972). Models 2 and 5 have already been set up numerous times as genetic algorithms (Holland, 1995; Mitchell, 1996). Models 1 and 3 are diffusion models and have been set up as agent models as well.

The use of agent-based models in social science has increased over the past decade.[6] Agents can be at any level of analysis: atomic particles, molecules, genes, species, people, firms, and so on. The distinguishing feature is that the agents are not uniform. Instead, they are probabilistically idiosyncratic. Therefore, at the level of human behavior, they fit the postmodernists' ontological assumptions. Using heterogeneous agent-based models is the best way to marry postmodernist ontology with model-centered science and the current epistemological standards of assumptions of effective modern sciences—specifically, complexity science (McKelvey, 2002b, 2003b; Henrickson and McKelvey, 2002). There are no homogeneity or equilibrium assumptions. Agents may change the nature of their attributes and capabilities along with other kinds of learning. They may also create network groupings or other higher-level structures—new order.

Agent-based models allow one to run experiments involving all four Aristotelian causes. *Material* cause is defined in terms of agent rules, kinds of agents, their search space possibilities, level of initial connectivity, and so forth—the ingredients at hand in the agents' simulated world from which order creation emerges. *Final* cause is defined in terms of the *agents' objectives*, such as more learning, higher fitness, more wealth, lower cost, more or less differentiation, and so on, and/or *system objectives*, which could be the same or different from agent objectives. *Efficient* cause is defined in terms of the external forces that drive the flow of the event sequences in the emergent macro structure(s). These take the form of niche resources (such as the sugar in Sugarscape; Epstein and Axtell, 1996), resource constraints (limitation of sugar at some locations in the search grid), adaptive tensions, or energy differentials (these are rules agents have that determine when they will activate and decide, say, to copy the fitness of some neighboring agent). It is possible that *efficient* and *final* causes could coincide—agents could have the goal of altering an outcome variable, such as performance, that is also subject to *efficient* cause. In models consisting of more than one level, or in models where there are emergent higher levels (agents form groups, followed by hierarchy and institutional structure), *formal* cause occurs when the higher levels evolve to the point where they initiate operational means of accomplishment that in turn feedback to influence agents' behaviors. Of course, the lower-level agents may also initiate methods of accomplishment as well.

Elsewhere (McKelvey, 2002b), I have used the study by Contractor et al. (2000) as a good example demonstrating two of the elements that improve the justification-logic credentials of agent-based modeling. First, this paper is particularly notable because each of its 10 agent

[6] For example, see Masuch and Warglien (1992), Carley and Prietula (1994), Epstein and Axtell (1996), Prietula et al. (1998), and Ilgen and Hulin (2000).

rules is grounded in an existing body of empirical research. The findings of each body of research, clouded as they are by errors and statistics, are reduced to idealized, stylized facts that then become agent rules. The second justification approach in the Contractor et al. study is that the model parallels a real-world human experiment. Their results focus on the degree to which the composite model and each of the 10 agent rules predict the outcome of the experiment—some do; some do not. Another approach, with a much more sophisticated simulation model, is one by LeBaron (2000, 2001). In this study, LeBaron shows that the baseline model "is capable of quantitatively replicating many features of actual financial markets" (p. 19). Here the emphasis is mostly on matching model outcome results to real-world data rather than basing agent rules on stylized facts. A more sophisticated match between agent model and human experiment is one designed by Carley (1996). In this study, the agent model and people were given the same task. While the results do offer a test of model vs. real-world data, the comparison also suggests many analytical insights about organization design and employee training that emerge only from the juxtaposition of the two different methods.

The problem with the "justification logic" used by Contractor et al., LeBaron, and Carley is that the emergent outcome events and sequences, that is, the emergent order creation, is reduced to predictable *efficient* cause variables just as what Langley's process approach does. For Contractor et al., the predicted variable is the mean quantity of communication among all networked dyads of agents. For LeBaron (2001), the predicted variables are amount of returns, volatility, amount of excess kurtosis, number of large market moves. For Carley, the predicted variable is error rate. Thus, for the justification tests they are back to predicting *efficient* cause variables with the other Aristotelian causes, intervening sequences, and events black boxed.

8. Modeling entrepreneurial dynamics

Suppose we divide entrepreneurial activity into two distinct phases: (1) the *initial start-up phase* and (2) the *BVSR managerial phase* (blind variation, selection, and retention; McKelvey and Baum, 1999). This paper is about the first phase. Ideally, the function of the BVSR process is most effective when there is an appropriate amount of random blind variation. On the other hand, much of the advice-giving to entrepreneurs very early in the initial start-up phase is aimed at reducing blind variation. If this advice is poorly founded, *both* early and later stages of the overall entrepreneurial venture are weakened. The first phase is where the greatest entrepreneurial risk is focused, although this is not to say there is not risk in the later managerial phases—but it is more managerial rather than entrepreneurial.

To remind, my argument early on in this paper is that bioevolutionary theory is about equilibrium, not order creation. Since entrepreneurship, dating all the way back to Schumpeter (1942), is about phase transition (his *creative destruction*, which I term *order creation*), evolutionary theory is essentially irrelevant. Population ecology is even more irrelevant, being very much a short-term perspective. In it, species are fixed and niches are fixed. The long-term study of changes in species and niches is traditionally the focus of evolutionary theory (although this is now in question—as noted earlier). Population ecology is about equilibrium, not order creation—it is about existing species repopulating a vacant niche (*r* conditions) and then equilibrium—that is, population regulation (*k* conditions).

Admittedly, the biological side of these theories is more equilibrium centered than the organization science side. Thus, in the latter, it is necessary to point out that applications of evolutionary theory and population ecology are often about (1) new forms coevolving with new niche formation, (2) the population new niches, and *then* (3) equilibrium. This because our dynamics are already of the fast-motion type—we do not need to speed up the movie; we do not need "fast-motion science," to see nonequilibrium dynamics. *Still*, our use of evolutionary and population ecology theories and research methods are about *second-phase* dynamics. They are not, and cannot be, about *first-phase* dynamics. Genetics is about order creation; evolutionary theory is about what happens *after* blind variation. Population ecology is about what happens after a species is created, not about its creation. Entrepreneurship is about creating blind variation and before selectionist evolution and population ecology. So, how to study order-creation processes?

8.1. Siggelkow's narrative

To begin, in a recent study, Siggelkow (2002) presents a multiperiod narrative describing the initial entrepreneurial process and subsequent change over time of an organization's core elements. He reports out very elaborate diagrams of "The Vanguard Group's" organizational systems in the years 1974, 1977, 1978, and 1997. Embedded in the descriptions are elements of various extant theories purporting to describe organizational evolution, specifically, quantum evolution (Miller and Friesen, 1984), and punctuated equilibrium (Romanelli and Tushman, 1994). Siggelkow says, "At the end of each such defined period, the organization replaces all (or almost all) of its core elements and creates an entire new set of core elements" (p. 154). He concludes by noting the limitations of "a single case study" and addresses the question of "why firms add (or do not add) new core elements." He suggests, "one possible factor is the volatility of the environment" (p. 157). All four Aristotelian causes are apparent. He does not reduce the richness of the emergent structure to one or more outcome variables. In this respect, he avoids what Langley, Contractor et al., LeBaron, and Carley do—black-box the emergent structure in favor of input and output variables linked by *efficient* cause.

8.2. Rising above locality, time, and researcher idiosyncrasies

Thick-description (Geertz, 1973) narratives of the Siggelkow kind paint a causal picture full of Aristotelian causes and the ebb and flow of top-down and bottom-up causality. Organization scientists struggle with Geertz's thin- vs. thick-research dimension. Thin-description research has large samples but invariably narrows causality down to one direction and only *efficient* cause. Thick-description narratives frequently uncover much more complicated causal plot lines, but they suffer from locality, time, and researcher specific limitations—the justification logic underlying their claims for generalizability is absent. Without this, there is not much point in reading the story other than for historical interest—something happened in one place, at one time, as recorded by one observer. What license do we have to offer advice to future entrepreneurs, given this? Eisenhardt (1989) offers a multicase sampling approach. This is an improvement, but is still weak on justification logic and subject to researcher bias.

Given the ‘‘thin’’ look of current nonnarrative entrepreneurial research, as compared to the causal complexity evident in the Vanguard case and the coevolution papers cited earlier, agent models offer one way of integrating the two research styles. All of the causal ingredients, as I have argued above, can be introduced into, explored and studied, winnowed out, consolidated, reduced to more elegant theory, and so on, by the use of agent modeling methods. Very briefly, I suggest 10 steps that researchers could take to bridge across the advantages of both thin- and thick-description research methods, that is, bridging across existing narrative and existing empirical approaches:

1. Focus on ways to bridge from the richness of Siggelkow-type narratives to more elegant multicausal theories.
2. Develop entrepreneurship oriented order-creation theories incorporating all six causes—focusing on start-up order creation as well as order creation after the start-up phase.
3. Develop entrepreneurship theories allowing for the coevolution of causes.
4. Develop theory direction-and-application questions that extend theorizing from narrative(s) to more generalizable forms.
5. Translate theories into model form—translate causes into agent rules, create agent activation and interaction regimens, time and space effects, etc.
6. Draw on stylized facts as much as possible.
7. Set up model procedures to explore the theory direction-and-application questions: How to simplify causes? What are coevolving cause effects over time? What can be managed? What can be empirically researched? What aspects are specific and/or generalizable?
8. Set up baseline-model outcomes that may be compared with real-world experiments and time-series effects.
9. Use models to develop simplified theories that can then be tried out by entrepreneurs or tested empirically on the assumption that elements of the theories have already been tried out by entrepreneurs.
10. Cycle through all of the foregoing steps, taking into account the coevolution of (1) theory–model link, (2) model–phenomena link, and (3) coevolution of the various model parts, as described in McKelvey (2002a,b).

More specifically, suppose we were to set up a research approach relying on agent-based modeling as a way to improve the generalizability of Siggelkow’s findings? Consider:

1. *Material* cause elements of the theory are reduced to stylized facts as they pertain to various initializing elements in the model—the organizing materials at hand. The process of using an agent model simulation is useful for reducing an error-prone, low variance-

explained body of prior research to idealized, stylized facts that later can be altered as necessary to improve their representation of extant research and reality. In the Vanguard case, these would be the "materials" at hand that would serve to give character to the firm: its environment, people and entities it deals with, and other elements and conditions that would affect agent rules at the time of creation and at each subsequent phase transition. Example start-up *material* causes are elements, such as mutual structure, selling and marketing activities, investors, networks, relation with Wellington management, management fee structure, customer base, competitors, employees, skills, and so on.

2. *Final* cause would materialize in terms of those rules pertaining to agents' purposeful objectives for themselves and/or for the firm as a whole. These also should follow from stylized facts. Example start-up *final* causes are goals, purposes, and strategies, such as low cost, asset growth, long-term performance, missionary zeal, high-quality service, and so on. Agent/employee goals are things like, focus on reducing costs (encouraged by incentives), unwillingness to do Wall Street-style trading, pursuit of the "noble goal" of putting shareholder interest first, long-term employment, learning how to make telephone calls to customers, and the like.
3. *Efficient* cause is accounted for by introducing contextual forces—such as the environmental volatility variable Siggelkow mentions—along with relevant others. These could range from the insignificant instigation variables that set off complexity cascades (the American approach) or environmental punctuations above the first critical value (the European approach). Note that in this example *final* cause does not "cause" the outcome, per se, but rather activates the agents or otherwise affects how they define their rules. External forces could turn agent rules on or off, make agents more sensitive to some *material* and *formal* causes, change their interaction and mutual influence patterns and rates, alter their threshold gates, and so on. Example start-up *efficient* causes reflect some of the *final* causes: rate of change measures, cost measures, asset growth, cost of management, quality measures, lower wage costs, customer satisfaction, industry rankings, and so forth.
4. *Formal* causes are the means by which the *final* and *efficient* cause "ends" are achieved. They can be designed into the model, follow from stylized facts, or be left to emerge. In most existing models *formal* cause, for example in the form of group initiated means or group task agendas, is mostly a designed feature. However, it should not be long before models exist where means-of-accomplishment activities become emergent. If designed, *formal* cause, too, may be based on stylized facts. If it is emergent, at an interim stage it is an outcome structure that itself can be compared with stylized facts. Example *formal* cause activities are hiring recent college graduates to lower cost, managing funds internally and inexpensively, no short-term trading, running operations separate from Wellington Management Company, candid communication, moderate wages, no perks, focus on fixed-income funds, and so forth.
5. By way of justification logic, one advantage of agent models is that various aspects of the four causes can be turned on or off as needed to understand how the theory seems to be working. Designing a model where they all run all the time would not clarify much of anything.

8.3. Dealing with multi- and equifinality

The general system theorist, von Bertalanffy (1968), introduced the idea of *equifinality*. Equifinality implies that systems starting from initially different circumstances (*material* cause) end up similar. Under conditions of negative feedback, goal-seeking systems (responding to *final* cause) end up in similar states, although initial conditions, Aristotle's *material* causes, were different, and although they are open to environmental—*efficient* cause—forces. Given the latter effect, many researchers end up choosing variance theory over process theory—*efficient* cause variables can predict outcome measures of equifinality. In doing this they ignore the basic thrust of Mohr's process theory—and all of biology—which shows that the combination of causes can produce *multifinality*—different, equally viable outcomes emerge even given similar *material*, *final*, *formal*, and *efficient* causes (Salthe, 1993).

Multifinality results when organisms may be characterized as showing different solutions to similar imposed niche problems. If entrepreneurs produce complete equifinality at Phase 1, then there is no blind variation with which to begin the BVSR second phase. BVSR obviously benefits from multifinality in the first phase. One of the problems with early start-up descriptions, such as Siggelkow's, is that, in this case, the Vanguard story may be just one instance of a multifinal first phase. Presumably, all the different investment funds began with a variety of Aristotelian cause dynamics in place. If one is doing research for the purpose of turning some of the blind variation into educated guesses, drawing too heavily from one, or even a few narratives could inadvertently produce an artificial equifinality when in fact a variety of Phase 1 solutions are equally effective—given the information at hand.

Process narratives of the Langley/Pentland/Siggelkow variety, based on one or a few case studies, fall short because they offer no generalizable results—whether equifinality or multifinality is present. The variance model falls short because its *efficient* cause equation can hide multifinality—a fundamentally important deficiency if results are being used for normative application—*one solution is implied when many are equally viable*, including novel possibilities that may have more future "*exploration*" value than present "*exploitation*" value, as March (1991) might put it. The Eisenhardt multicase approach falls short if the sampling of cases suggests multifinality—no clear pattern is apparent; but, if the sampling is sequential and in the context of similar *efficient* and *final* causes—and thus trends toward equifinality—it could support the substitution of the variance model for justification purposes.

Agent models offer a means of more justifiably abstracting effective, elegant theories without doing away with multifinality inappropriately or too quickly. Agent models may also help to more justifiably smooth the transition from multifinality to equifinality by allowing the exploration of the interaction dynamics of the various causes. Thus, researchers (1) could begin with agent models that generate multifinality samples, (2) find abstracted solutions cutting across the multifinality variances, and then (3) model these abstracted, potentially equifinality solutions under different environmental conditions to test how much generality they have and more specifically, identify conditions where they do or do not hold true. Baseline versions of the models could be empirically or experimentally tested, or the more specific examples of abstracted, equifinality theory solutions could then be empirically or experimentally tested. One way to avoid the alternatives of (1) no generalization vs. (2) reduction to some kind of *efficient* cause outcome variable is to model all four causes as they create multifinal emergent structures.

Some issues in using agent models to improve generalizing from narrative descriptions are:

- *Multifinality:* Finding ways to abstract down to commonalities appearing under conditions of multifinality. A model could be used to generate all kinds of multifinality—based on the use of various causes. Then, use the model to find abstractions that cut across the multifinality-created differences. Abstractions could then be empirically tested via experiment or time-series data. Can the abstractions be reduced to *efficient* cause variables? Or does initial start-up multifinality disappears only after selection effects? *Issue:* Can we find common, well founded lessons for start-up entrepreneurs or is it inevitable that we have blind variation followed by Darwinian selection? Can we see initial entrepreneurial multifinality or does equifinality set in even before market tests? To what extent does the VC stage cut down on, or foster multifinality?
- *Equifinality:* Are there conditions where equifinality appears at the start-up phase—before the market-based SR process begins? Are there lessons for entrepreneurs that, right at the initial start-up phase, call for a reduction of variance on *material*, *formal*, and *final* causes? What are the causal conditions of *early* equifinality? Is it possible? Desirable? *Issue:* How much blind variation is it wise to get rid of at the initial start-up phase? If we want to max out on blind variation, we should stop giving advice to entrepreneurs—meaning that entrepreneurship-oriented MBA programs are misguided. Or, is it best to offer some steps (educated guesses?) toward early equifinality? How much of this is appropriate?
- *Efficient cause:* Is the focus on all the other causes a tempest in a teapot? Use the model to find ways of finding *efficient* cause outcome variables that remain stable despite (some) changes in *material* and *final* causes. Under what conditions does *efficient* cause become a good or bad "summary" of the other cause effects? Presumably, *efficient* and *formal* causes are directly related. Boils down to finding out to what extent variance on *material* and *final* causes effects *formal* and *efficient* causes.
- *Top-down vs. bottom-up:* In the Vanguard narrative, it is often unclear as to how much of what we see is bottom-up vs. top-down-caused outcomes. How much is directly the CEO–entrepreneur effect and how much is a bottom-up corporate brain (social capital-based) effect? How much is the top-down/bottom-up ebb and flow (changes in causal dominance over time) due to *material* and *final* causes? A detailed analysis of top-down control vs. bottom-up autonomy effects appears in a recent eleven-year study of the entrepreneurial phases in the rapid growth of a global cosmetics firm (Thomas et al., 2003).

More specifically, one could take two additional modeling steps:

- First, let an agent model create a *multifinality sample*—a set of varying emergent structures that respond equally effectively to some set of niche constraints—which is what Mohr's process model examples are doing. Then, using available positional and relational network description algebras that abstract down to common structural elements (see Pattison, 1993; Wasserman and Faust, 1994, for block modeling methods), an abstract description of the sample may be developed. The *composite description abstraction(s)* might then be evaluated with respect to one or more outcome (*efficient* cause-generated) variables.

In this way, the multicausal, multifinality characteristic of the model's order-creation outcomes is preserved while at the same time the *composite description abstraction* is connected to, say, performance variables. This is not simply to say "Find the 'average' of the varying emergent structures." I think a composite that is built from an abstracted reassembly of modal relations and nodes would be better. Each mode represents a network relation or position that appears more than once in the model's "multifinality sample" as an apparent emergent adaptive solution. Quite possibly, no single emergent model solution contains all of the mode-indicated adaptive properties. There could be several contenders.

- Second, as a further justification, *composite description abstractions* may be statistically compared to a parallel abstraction based on one or more real-world narratives, such as Siggelkow's, a real-world quasi-experiment, or lab experiment, using goodness-of-fit models of the kind described in Pattison or Wasserman and Faust.

To return to the Vanguard case, the theories mentioned by Siggelkow, such as quantum evolution, punctuated equilibrium, and the like, could be translated into the *material* and *final* cause agent rules. He has already mentioned environmental volatility as a possible *efficient* cause; there could be others. Since it is an entrepreneur-founded firm, there are, right at the outset, *formal* cause forces in the form of top-down organizing, motivating, and other operational activities. There could be bottom-up formal causes as well, that are instigated by lower-level agents. Some of the *formal* causes could be inserted as initial design features of the model. With increased programming sophistication, additional ones could be of the emergent kind. The model would be used to generate any number of multifinality samples. These would differ depending on which rules are being used, etc. The multifinality samples would then be reduced to composite description abstractions based on network modes emerging across the multifinality samples. Siggelkow already has some network centrality measures. For the *first* justification procedure, these can be reduced to one or more *efficient* cause outcome variables—primarily low cost in Vanguard's case. For the *second* justification procedure, Siggelkow already has a head start. He could construct a baseline model designed to predict one or more of the periodic network configurations presented in his article. Having done this he could then alter the rules of the model in an attempt to get it to produce the Liz Claiborne network configuration (Siggelkow, 2001).

9. Conclusion

In entrepreneurial research, especially, the division of research into that explicitly aimed at early order creation in the initial start-up phase, as opposed to that aimed at studying after-the-fact selection processes, seems critical to producing effective knowledge that is useful to start-up entrepreneurs. Since there is the likelihood that advice given to entrepreneurs early on lowers the blind variation rate (possibly changing blind variation into educated guesses, but we cannot be sure), there is reason to worry about the quality of this advice.

I began the paper by pointing out that if the study of biological order creation is put into fast motion, it seems clear that the dynamics of order creation are the result of geological events and Darwinian selection is largely a fine-tuning process toward equilibrium within a context of existing species and stable niches. Biological population ecology is a discipline even more completely within the framework of existing species and niches—population ecology is even more short term than the time horizon of Darwinian selection. The new look at biological order-creation dynamics suggests that evolutionary theory is a poor choice of theoretical approaches to apply to the study of entrepreneurship. At best, it is useful after much of the initial start-up decision effects are over. And yet, this special issue is mostly about evolutionary and population ecology theory and research being applied to the study of entrepreneurship. *The lesson from biology is that most of the true order-creation action is over before these theory and research approaches become relevant*.

Order creation has become the central focus of complexity science. It is really *order-creation science*. Calling it ‘‘complexity science’’ is like calling thermodynamics ‘‘hot science’’—that is, naming it after one extreme of the outcome variable. The real concern is about the study of order-creation dynamics. My brief review separates order-creation science into two schools, European and American. The former focuses on the effects of imposed energy differentials (adaptive tension) on the production of phase transitions. These are important for overcoming the boiled frog, or threshold gate, problem. The American school focuses on nonlinearities stemming from the coevolution of interacting, heterogeneous agents that are set in motion by small instigation effects—the butterfly effects of chaos theory. The American school, in particular, is also noteworthy because it reflects the development of a ‘‘normal’’ science that is based on a localized, connectionist ontology similar to that which postmodernists have concluded is a better representation of social ontology. In short, the European school puts Bénard’s critical values and phase transition effects at the origin of order creation. The American school legitimizes the postmodernists’ ontology and offers heterogeneous agent computational models as a means of pursuing model-centered science on the postmodernists’ representation of social ontology.

One of the lessons from thick-description narratives, of the postmodern kind, and the reemphasis of process theory of the Mohr kind, is that complex causality results (Thomas et al., 2003). Studied carefully, narratives, such as Siggelkow’s (2002) Vanguard case, illustrate the coevolving role of six kinds of causality: the four Aristotelian causes (*material*, *final*, *formal*, and *efficient*) coupled with the ebb and flow dynamics of top-down and bottom-up causality. The traditional science approach is to quickly rush to the use *efficient* cause as a quick summary cause variable, ignoring the other Aristotelian causes and usually the coevolution of top-down and bottom-up causes as well.

The rich narratives by which we learn about all the ins, outs, ups, and downs of start-up phase entrepreneurial activities are locality, time, and researcher specific. Agent modeling allows us to explore complex-causality dynamics for the purpose of creating more generalizable theories—that also have more scientific legitimacy and practical credibility. Agent models allow us to unravel some of the causal complexity long ago mentioned by general systems theorists, that is, multifinality and equifinality. I conclude with comments on how this might be accomplished.

In sum, entrepreneurial research would be advanced more quickly if it, at the least, balanced its focus on theoretical ideas other than those stemming from traditional equilibrium-based research findings, or even methods lifted from bioevolution and bioecology. The latter are also equilibrium bound. Entrepreneurship is about order creation not equilibrium. It is time to put more emphasis on helping entrepreneurs, at the initial start-up phase, deal with adaptive tensions, critical values, phase transitions, and coevolving causalities. While blind variation is an essential ingredient of Campbell's BVSR process (Campbell, 1965; McKelvey and Baum, 1999), the question is: How blind? Although blind variation is essential, theories that better improve entrepreneurs' educated guesses at the initial start-up phase seem better advised than simply maximizing out on blind variation—or trying to minimize it. I suggest a variety of theory and modeling approaches for doing this that are consistent with modern normal science epistemology, as represented by complexity science.

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