Toward a social capital theory of technology-based new ventures as complex adaptive systems

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RESEARCH

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Abstract

Purpose – Technology-based new ventures (TNVs) – which rely on entrepreneurial activities based on science and technology applications in newly created organizations to be successful – are important to current economic growth and innovation. Past research has looked at the importance of networks and social capital to TNV performance. Yet these studies rarely provide theoretical predictions of the attributes of network ties. This paper aims to bring TNV theory up to date with respect to twenty-first century adaptation and complexity conditions.

Design/methodology/approach – The paper draws on new developments in complexity science (specifically scalability and scale-free theories) and long-standing first principles of efficacious adaptation to develop TNV-relevant theory offering an alternative perspective on the impact of network ties on the performance of TNV.

Findings – It is argued that TNVs can achieve superior performance by developing and building moderate numbers of short-term (and thereby weak) network ties. The theorizing calls for a new research agenda pertaining to TNVs, which are delineated. The paper also develops four propositions as part of setting forth an agenda for future research.

Originality/value – The paper updates the entrepreneurship and social network literatures by reshaping them with respect to the nonlinear order-creation dynamics of complexity theory and scale-free dynamics of econophysics. It focuses on the aspects of network theory that are especially likely to set in motion the complex adaptive systems dynamics essential to TNV performance. Therefore, the conceptual framework contributes to TNVs as a guide to achieving higher performance, effectiveness, and longevity in a rapidly changing world.

Keywords Social capital, Complexity theory, Business enterprise, Adaptability

Paper type Conceptual paper

1. Introduction

Technology-based new ventures (TNVs) are fundamentally important to economic growth and innovation, not least because they often commercialize scientific, technological, and engineering advances into new businesses. The importance of TNVs is obvious, but their paths to sustainability are not. New ventures, whether technology-based or not, suffer from the liabilities of newness (Stinchcombe, 1965; Aldrich and Auster, 1986) and smallness (Hannan and Freeman, 1984). They lack resources (Stevenson, 1999) and encounter constantly changing technologies (Forbes, 1995). TNVs face idiosyncratic challenges in making timely and correct decisions in
nonlinear (dynamical) environments (Stevenson and Gumport, 1985; Brown and Eisenhardt, 1997). These constraints inhibit their survival and growth.

Many researchers subscribe to the view that network ties, and their consequent social capital, counter the factors that constrain new venture and TNV performance (Aldrich et al., 1987; Bamford et al., 2006; Lin et al., 2006). Received wisdom suggests that building a stable set of long-term network ties can improve new venture performance because these ties create trust (Nahapiet and Ghoshal, 1998; Adler and Kwon, 2002) and provide the firm with higher quality information (Nahapiet and Ghoshal, 1998). Prior research has considered the structure and content of ties, learning and resource-based reasons for developing ties (Florin et al., 2003), the effects of strong and weak ties (Granovetter, 1973), and bridging weak ties (Burt, 1992)[1]. But the theories and methods of extant network analysis literature are static and linear (Wasserman and Faust, 1994) and ill-suited to the nonlinear nature of TNV dynamics.

We propose an alternative analysis of social network ties better suited to contemporary TNV dynamics. It is based on complexity science—a discipline originating in physics and biology that is increasingly popular for explaining managerial and organizational dynamics (Maguire et al., 2006). Specifically, we draw on theories that explain how complex systems adapt to changing technological and competitive environments (Kaufman, 1993; McKelvey, 1999), how network configurations can change dramatically over time (Barabási, 2002), and how the same causal dynamics apply to multilevel systems through power laws and scale-free dynamics (Newman et al., 2006). We explain scale-free dynamics and apply this concept to firms (Andriani and McKelvey, 2007b).

We use complex adaptive systems (CAS) theories of emergent new order creation to explain how TNV entrepreneurs can better mobilize their resources and develop strategies to meet the demands of seven well known first principles of efficacious adaptation (McKelvey, 2004a). These principles include Fisher's (1930) genetic variance, Ashby's (1956) requisite variety, Maruyama's (1963) deviation amplification, and Simon's (1962) near decomposability. We also draw on several scale-free theories from biology and econophysics (Newman, 2005), recognizing that effective adaptation is required throughout all levels of a multilevel firm.

We advance the literature on social network analysis and entrepreneurship in three ways. First, we employ complexity theory and econophysics to bring a nonlinear dynamical perspective to network theory. There is some literature relating complexity theory to social network analysis (Frank and Faerbach, 1999; McKelvey, 1999; Morel and Ramanujam, 1999), but the lens of complexity science has rarely been applied to entrepreneurship, with the exception of Lichtenstein (2000a, b, 2003) and McKelvey (2004c). And virtually nothing has been done that relates complexity science to TNVs.

Second, the field of entrepreneurship is still developing its own unified theory (Bull and Willard, 1993). We build on McKenzie and van Winkelen (2004) and Thomas et al. (2005) to suggest a new theoretical framework for TNVs aimed at improving one pole of a duality by focusing on the opposite. Thus, we propose that TNVs can achieve stability through instability, gain strength through weakness, reach long-term goals with short-term plans, obtain predictability with disorder, and nurture directed creativity with chaos.

Third, we update current perspectives on social network analysis (Wasserman and Faust, 1994), with the nonlinear order creation dynamics of complexity theory (Casti, 1994; McKelvey, 2004b) and scale-free dynamics of econophysics (West and Deering, 1995;
Mantegna and Stanley, 2000). Finally, we zero in on those aspects of network theory that are especially likely to set in motion the CAS dynamics essential to TNV performance.

This paper proceeds as follows. First, we set up the problem by showing that network-based social capital theory is out of touch with the dynamic competitive environment in which TNVs exist. Next, we develop a theory of TNV adaptation centering on CAS, principles of adaptation, and scale-free theories. We then set forth several propositions about the structure and dynamics of networks required for CAS to function effectively.

2. The challenges facing TNVs
Technological entrepreneurship is “a hybrid of scientist/engineer and businessperson” (Phan and Foo, 2004, p. 1). We limit our analysis to the impact of network tie dynamics on TNV performance in the first eight years of a firm’s life. This is consistent with the traditional definition of a new venture (McDougall et al., 1994). TNVs face several unique challenges. They suffer the liability of newness (Stinchcombe, 1965); they operate in high-velocity environments under extreme time pressure (Eisenhardt, 1990); they exist in conditions of technological change and uncertainty (Li and Atuahene-Gima, 2002). TNVs have limited resources (Barney, 1991; McDougall et al., 1994; Stevenson, 1999), but they have to constantly develop the next generation of products, services, and business processes to stay competitive (Tushman and O’Reilly, 1996; Autio et al., 2000). They shape and redefine their own competitive arena (Hayton, 2005) and often work toward radical and incremental innovation (Nambisan, 2002). Ultimately, TNVs aim to achieve an efficacious rate of risk and return (Zahra, 1993).

The challenges of technological entrepreneurship are well recognized in the literature and there is general agreement that network ties can transform these challenges into entrepreneurial opportunities (Aldrich and Zimmer, 1986; Eisenhardt and Schoonhoven, 1996; Nahapiet and Ghoshal, 1998; Adler and Kwon, 2002). Indeed, these network ties spread across the life and activities of the new venture; for example, through inter-firm alliances, mergers, and acquisitions (Ahuja, 2000; Yli-Renko et al., 2001). However, little work has been done to understand exactly which attributes of network ties might resolve the challenges faced by TNVs.

3. TNVS need an updated theory of entrepreneurial social capital
Most of the entrepreneurship literature adopts a static and linear approach (Low and MacMillan, 1988; Chandler and Lyon, 2001; van de Ven and Engleman, 2004). However, entrepreneurship itself is dynamic and nonlinear. Its related development and activities cannot be fully captured by a static view. For example, scholars find that 80 percent of empirical entrepreneurship studies published from 1989 to 1999 were cross-sectional (Chandler and Lyon, 2001) – specifically, 233 of 291 studies in the top academic journals. Therefore, researchers (Shane and Venkataraman, 2000; Davidsson and Wiklund, 2001) have called for a more dynamic approach.

This paper responds to the call by using a dynamical theory to explain a dynamical context. That is, we use complexity theory to show that we need to update existing entrepreneurial social capital theory if we are to understand the characteristics of TNVs operating in nonequilibrium, nonlinear environments.
Changes in the nature of network ties can produce different impacts on performance of firms (Lu and Beamish, 2006). Changes in tie attributes can require different levels of resources. This could also have impact on firm performance (Hoang and Antoncic, 2003). The extant literature on social networks rarely considers the attributes that are most likely to contribute to TNV success based on asset parsimony (Hambrecht and MacMillan, 1984; Stevenson and Gumpert, 1985). Though there are well-documented studies linking network ties and small firms (Minguzzi and Passaro, 2001) and early-stage entrepreneurship (Davidsson and Honig, 2003; Lechner et al., 2006), there is little literature focusing on the dynamical context of TNVs and different requirements of network-tie attributes pertaining to this context. Other researchers have found that managing networks and ties can have on a positive impact on firm performance (Jarillo, 1988; Starr and MacMillan, 1990; Zhao and Aram, 1995). But these studies tend to focus on the structure, governance, and content of ties (Hoang and Antoncic, 2003); and the strength (Granovetter, 1973; Ardichvili and Cardozo, 2000; Perry-Smith and Shalley, 2003), as well as range, and depth of ties (Zhao and Aram, 1995). There is very little research on the two key attributes of network ties that can make a real difference to firm performance – the duration and/or strength, and number of, ties – as we argue below.

4. Defining social capital, networks and ties
Social capital is gaining popularity in management research as a key foundation of a firm’s success (Inkpen and Tsang, 2005), although there is still widespread uncertainty about its meaning and effects (Koka and Prescott, 2002). Bourdieu (1986, p. 248) defines social capital as “the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance or recognition.” Inkpen and Tsang (2005) treat social capital resources set within the network of relationships possessed by an individual or organization. This latter definition accommodates both private and public perspectives of social capital and deems networks of relationships as highly valuable resources. A network tie between two individuals or organizations (e.g. customer and vendor) yields social capital for both parties.

In the social network literature, actors are embedded within interconnected network relationships that both enhance and inhibit behavior. This view differs from extant perspectives that have examined individual actors only. Researchers in social network analysis focus on relational and structural patterns of interaction (Brass et al., 2004). They define a network as a set of nodes and the ties between nodes. Further, they describe nodes as actors – individuals, work units, or organizations – and ties represent the relationships, or lack of them, between nodes. We build on Brass et al.’s definition of networks and ties and operationalize ties in the limited context of TNVs.

Brass et al. reviewed research on the antecedents and consequences of networks at the interpersonal, interunit, and interorganizational levels. They note a shift in organizational network research from simple binary considerations (e.g. the existence or non-existence of a relationship) to more comprehensive distinctions (e.g. the strength and content of a relationship). Brass et al. also show that this level of detail is needed to make theoretical predictions. Cross and Cummings (2004) study network characteristics and performance and called for further research on theoretical mechanisms and sophisticated models of performance. They state that different network profiles might be associated with dimensions of performance. In particular,
they call for studies examining the theoretical importance of tie characteristics. Our work builds on this notion; we focus on the effects of two specific kinds of ties – short-term (weak) ties (2) and moderate number of ties – and then analyze their role in CAS and TNV adaptation.

Network relationships tend to strengthen over time as the parties make frequent contact, reap the rewards of earlier collaborations, and freely share valuable knowledge (Inkpen and Tsang, 2005). But as ties become more numerous and more permanent, the novelty and entrepreneurial advantage of short-term ties give way to negative "groupthink" (Janis, 1972) and strong tie effects (Granovetter, 1973, 1985; Perry-Smith and Shalley, 2003). In other words, as people in a group or firm lose their heterogeneity they become more clone-like, think more alike, and novelty becomes more elusive.

This phenomenon has been recognized in the complexity literature as Kauffman’s (1993) “complexity catastrophe” effect (McKelvey, 1999). Kauffman finds that adaptive movements toward improved fitness are best achieved with moderate numbers of ties, at all levels in biology. Maguire et al. (2006) list 24 different organizational applications of complexity catastrophe theory, all showing the benefits of moderate numbers of ties among agents. What is a “moderate number” depends in part on the total size of people that could potentially be networked. The various computational models used to research this effect suggest that “moderate” means that people have from 3 to 8 links. If they have fewer, they lose the novelty advantage of short-term ties; if they have more, they tend to get bogged down in networking and have increased probability of connecting with naysayers.

Given these findings, it seems likely that TNVs are better off with short-term ties and a moderate number of ties, but this issue has been overlooked in the extant entrepreneurial literature. TNVs need to use their limited resources to build maximum productivity and develop the most innovative ideas and products. Being locked into the wrong tie relationships early on may impose tangible and intangible costs that impair a TNV’s ability to innovate. And developing and maintaining ties draws valuable resources away from other productive activities.

We propose that a moderate number of short-term ties is important for achieving superior TNV performance. The extant literature offers little guidance about the kinds of networks that TNVs should develop to adapt to the dynamic nature of their competitive challenges. We aim to fill this gap by drawing on complexity theory to build an updated entrepreneurial social capital theory based on number and duration of ties.

5. TNVs as complex adaptive systems
TNVs exist in dynamic, nonequilibrium, nonlinear competitive environments – i.e. dynamical environments. Complexity scientists have established that only CAS are able to adapt, survive, and grow under these conditions (Kauffman, 1993; Holland, 1995; McKelvey, 2004c). We use Ashby’s law of requisite variety – updated to the law of requisite complexity by McKelvey and Boisot (2008) – to establish that firms need complex internal dynamics to successfully cope with complex external dynamics, as follows: first, Ashby’s law pervades from outside to the lowest levels of a firm – it takes internal requisite complexity (degrees of freedom) to defeat external environmental complexity (degrees of freedom).

Second, entrepreneurs have to transform their firms into high-performing CAS. To accomplish this, they:
• have to fully address the adaptive challenges facing their firms in terms of the first principles of efficacious adaptation (McKelvey, 2004a); this is the adaptive part of CAS;
• they have to make sure appropriate complexity dynamics operate at all levels, as their firms grow, differentiate, and become multilevel, complex systems; this is the complexity part of CAS; and
• it takes scale-free dynamics to foster emergent complexity dynamics at multiple levels; this is the systems part of CAS.

Third, efficacious adaptation – via requisite complexity – comes only from having the right kinds of social capital elements in place at multiple levels. These elements are the short-term ties in moderate number that foster the emergence of the dynamic networks described in Newman et al. (2006).

We begin by reviewing CAS theory and then set out our propositions regarding the social capital requirements for enabling CAS dynamics in TNVs.

5.1 Applying the law of requisite complexity
Ashby’s law (updated) shows us that TNVs are CAS, for four reasons. First, TNVs exist in a complex world that is dynamical, nonequilibrium, and nonlinear. Second, entrepreneurship is about increasing requisite complexity; this is especially true for TNVs. This complexity usually materializes as entrepreneurs discover inadequacies and failures among their current products, services, business processes, and personnel. By definition, TNVs emerge to change the course of business or make things happen that had not happened before. When these kinds of changes occur among a network of competitors, suppliers, and customers, they increase the requisite variety confronting individual firms. Thus, TNVs add to external complexity and firms must respond by increasing their requisite internal complexity if they are to continue adaptive success (McKelvey and Boisot, 2008). TNVs increase legitimacy and enhance their success by building social network(s). These dynamical social networks (Newman et al., 2006) then become important vehicles for building requisite internal complexity to counterbalance external complexity.

Third, TNVs compete in fast-paced sectors where advanced technology invariably situates firms in chaotic circumstances. For example, the arrival of e-commerce and the “third wave” of telecommunications caused chaos until firms more effectively zeroed in on their contextual constraints. Clearly, the most successful TNVs are those that can come up with more innovative and more complex ideas than demanded by their environmental contexts. Since emergent ideas and structure have, at best, a probability of success, it takes excess internal variety (complexity) to match external variety (complexity) (Allen, 2001).

Finally, it is important to realize that as a TNV grows and develops a hierarchy, each level in the firm develops its own requisite complexity, given the demands placed on it by the level above. In this way, the effects of Ashby’s law cascade from the external environment down through the levels of the firm. Ironically, Mélèsè (1991) argues that the more appropriate the complexity at a lower level, the simpler the complexity needs to be at the next higher level. In other words, the levels below remove degrees of freedom from the system, making the job at the level above easier.
5.2 The key elements of internal complexity dynamics

We recognize three basic phases of complexity science. Phase 1 was developed by Prigogine (1997) and other scholars (Haken, 1977; Mainzer, 2004; Nicolis and Prigogine, 1989) who focus on adaptive tension and the first critical value of imposed energy in physical systems. Energy levels above the first critical value set off a process of creating order. Prigogine is famous for his dissipative structures that become pockets of order governed by the first law of thermodynamics. He also argued that conserving energy accelerated disorder, randomness, and entropy according to the second law (Swenson, 1989). This branch of complexity science is based in mathematics.

Phase 2 of complexity science arose in the Santa Fe Institute and emphasizes CAS behavior, especially how new order arises in (living) biological and social systems (Pines, 1988; Arthur et al., 1997). These scholars concentrate on heterogeneous agents interacting at what was previously called “the edge of chaos,” occurring at the second critical value of imposed energy. In between the edges of order and chaos is the region of emergent complexity — the “melting” zone (Kauffman, 1993). His spontaneous order creation begins when three elements are present:

1. heterogeneous agents;
2. connections among them; and
3. motives to connect — such as mating, improved fitness, performance, learning, and so forth.

Remove any one element and nothing happens. Bak (1996) argues that to survive, organisms must be able to stay within the melting zone, maintaining themselves in a state of self-organized criticality. The signature elements of the melting zone are self-organization, emergence, and nonlinearity. Self-organization results in emergence; that is, new order of some kind. According to Holland (2002), we recognize emergent phenomena as multiple level hierarchies, intra- and inter-level causal processes, and nonlinearities.

Phase 3 of complexity science includes econophysics (Mantegna and Stanley, 2000). This discipline is concerned with how order unfolds once the forces of emergent order creation are set in motion by self-organizing agents, such as biomolecules, organisms, people, or social systems. A key element of econophysics is scalability — the idea that the coast of Norway, for example, appears jagged no matter what kind of measure is used. Regardless of whether the measure is miles, kilometers, meters, or centimeters, the length of the coast looks jagged; the profile is inversely proportional to the length of the ruler; that is, the smaller the ruler, the longer the coast. This is “measure-based” scalability. Now consider a cauliflower. Cut off a floret, cut a smaller floret from the first, then a smaller one, then another, and so on. Other than increasingly small size, each floret performs the same function, and has roughly the same shape, as the floret above and below it in size. This feature defines it as fractal. This is an adaptive cause of scalability.

5.2.1 Fractals and power laws in networks. The econophysicist Barabási has connected scalability, fractal structure, and power law findings to social networks; his work is summarized in his book Linked (2002). Watts (2003) and Newman et al. (2006) have also contributed to the field. Barabási shows how networks in the physical and biological worlds, and social capital networks in the social world, are fractally structured such that there is a rank/frequency effect. This effect contains an underlying Pareto distribution of many social “loners” at one extreme and one very
well connected “star” at the other. The Pareto-distributed progression of increasing numbers of connections from, say, one link per loner to everyone linked to the star, is a negatively sloping straight line plotted on a double-log graph. This is the famous power law signature, dating back to Auerbach (1913) and Zipf (1949). For additional evidence see Newman (2005) and Andreiani and McKelvey (2007a).

5.2.2 Scale-free theory. These theories explain why fractals appear as they do. Though scalability may have been at the core of the Santa Fe vision (Brock, 2000), scale-free theories have only recently begun to be consolidated and featured collectively by the econophysicists (West and Deering, 1995; Mantegna and Stanley, 2000; Newman, 2005). The key feature that sets scale-free theories apart from most social science theories is that they use a single cause to explain fractal dynamics at multiple levels. The earliest dates back to 1638 – Galileo’s square-cube law.

Explanations of why some structures have adaptive success while others do not, range from biology to social science. If the same theory or principle applies to microbes and to organizations, it is assuredly scale-free. In what follows, we draw on seven of 15 scale-free theories presented by Andreiani and McKelvey (2007b). While others apply, the ones presented here are most relevant to creating TNV social capital networks.

5.3 Scale-free theories and TNVs
Gell-Mann (2002) defines effective complexity as regularities or schema that are found or judged to be useful. TNV entrepreneurs develop these schemas by separating the external complexity dynamics they can cope with, from random noise. Gell-Mann notes that regularities appear as equations (physics), genotypes (biology), laws and traditions (culture), and best practices (management). What is new is that he recognizes the chaos-derived regularity in CAS, which he defines by separating out the pink, brown, and black portion of Schroeder’s (1991) colored noise from white noise (Dooley and van de Ven, 1999). In doing so, he sets forth two regularities:

*Type 1.* The old simplicity of reductionism, equations, linearity, and predictions of old physics.

*Type 2.* The new simplicity of insignificant initiating events – butterfly-events – that initiate causal dynamics leading to nonlinearity, similar causal dynamics at multiple levels, power laws, and scale-free theory.

We describe Gell-Mann’s regularities in more detail below.

*Type 1* law-like regularities are the reductionist causal processes of normal science, which are predictable and easily represented by equations. Their data and information are much preferred in classical physics and neoclassical economics (Gell-Mann, 2002, p. 19). These regularities are the point attractors of chaos theory – defined by forces, equilibrium, and energy conservation. These regularities characterize existing empirical organization and management research. These may be confidently described via Gaussian statistics and allow predictions that become the basis of schemata and prescriptive solutions.

*Type 2* multilevel scale-free regularities are outcomes over time that result from an accumulation of random tiny initiating events that have lasting effects, are compounded by positive feedback effects over time, and become “frozen accidents” (Gell-Mann, 2002, p. 20). These are the strange attractors of chaos theory – never repeating, fostering indeterminacy, offering a different kind of regularity. These regularities focus on the
effects of tiny initiating butterfly-events (based on the title of a paper by Lorenz (1972) – "Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?"). They are the bifurcation points of chaos theory. The butterfly-events of chaotic histories are never repeated, are not predictable, and can produce significant nonlinear outcomes that may become extreme events. Consequently, describing these systems is at best problematic and easily outside the explanatory/scientific traditions of normal, reductionist science.

Gell-Mann concludes by noting that when butterfly-events spiral such that their effects are magnified at multiple levels, we see self-similarity, scalability, and power laws -- all elements studied by econophysicists. He calls them "middle level" theories.

6. Applying the first principles of efficacious adaptation to TNVs

Because they are living systems, CAS have to adapt to changing environments if they are to survive and grow, or else they must co-evolve with competitors in a stable niche (Kauffman, 1993; McKelvey, 1999). But what demands does adapting to changing environments impose on a CAS? What does it actually have to do? How would one know whether a TNV has adaptive structures and processes in place? In this section we briefly define seven "first principles of efficacious adaptation" defined in the literature some 40-70 years ago (McKelvey, 2004a). A first principle is defined as one logic step up from basic self-evident axioms, such as F = ma. In this axiom, force, mass, and acceleration are self-evident -- just stand in front of a bus or speeding sports car and you will feel the effect of its truth! Each has been discussed in the literature for decades and has survived without challenge. Collectively, they are multiplicative in that a system that is "zero" on any one of them will not survive, whereas the effects of two or more have a multiplicative adaptive effect.

Each of these first principles is a generative force driving efficacious adaptation in organisms and organizations. The seven principles are adaptive tension, variation rates, requisite variety, near decomposability, causal complexity, coevolution, and causal rhythms. We hold that these seven generative forces drive CAS development. The ability of any TNV entrepreneur to create viable emergent structures -- emergent requisite complexity -- capable of efficacious adaptation in changing environments comprising scarce resources and aggressive competitors is pursued within the confluence of these forces.

6.1 Ashby’s law of requisite variety

We have already drawn from Ashby’s (1956) foundational law of system complexity; namely, that in order to remain viable, a system needs to generate the same degree of internal variety as the external variety it faces in the environment. Essentially, external variety -- including “disturbances” or uncertainty -- can be managed or “destroyed” by matching it with a similar degree of internal variety: “Only variety can destroy variety”. (Ashby, 1956, p. 207). As already noted, McKelvey and Boisot (2008) update Ashby’s law to “requisite complexity”. But there is a cost to matching internal and external variety. The more external variety, the higher the internal costs of adapting, in terms of time and capital.

This principle easily applies to TNV adaptation. Effective strategic management requires that a firm’s structure, strategy, and mindset be aligned, both internally and externally (Eisenhardt and Schoonhoven, 1990). Entrepreneurial and managerial
cognition is bounded (March and Simon, 1993); thus, when firms encounter new phenomena, they have to:

- expand requisite variety as required (Wiklund, 1999);
- adapt to environmental changes (Zajac and Kraatz, 1993);
- limit their perception of reality to mitigate external variety – firms cannot respond to every degree of freedom in their environment (Boisot and McKelvey, 2006a, b); and/or
- deny the conflicting information.

When it comes to network ties, it is sensible for TNVs to increase the number of ties to garner increasing rates of return. But only to a point; a decreasing rate of return will set in when too much external variety disrupts the balanced degree of variety. Since firms cannot respond to every degree of freedom in their environment, and given that we know that moderate numbers of ties are best (see Kauffman, 1993 and Maguire et al., 2006, for all the applications of Kauffman’s discovery to organizations), we propose:

P1. TNVs enabling moderate numbers of ties among agents (employees) will achieve improved performance.

6.2 Maruyama’s principle of coevolution via positive feedback

Mutual causality via deviation amplification was initiated by Maruyama (1963). He suggested that a relationship that is mutually causal and that amplifies an insignificant or accidental start is likely to spiral into a different type of relationship depending on different (insignificant) initial conditions. Maruyama anticipates the coining of the term coevolution by biologists Ehrlich and Raven (1964). Kauffman (1993) states that organisms not only evolve, but also they coevolve. The more connections among modules, the higher the possibility of mutual causal dynamics (Okes, 2003), which magnify the emergence of order creation in biology (Goerner, 1994) and economics (Arthur, 1990; Ormerod, 1998).

In organizations, the defining issue is mutual learning by both the firm and the individuals within it (March, 1991). A variety of organization scientists have studied coevolutionary dynamics relevant to entrepreneurial settings (Meyer and Gaba, 2002; Siggeikow, 2002; Murmann, 2004). In the context of TNVs, learning via coevolutionary processes comes at a price. It is important for TNVs to coevolve with customer needs and competitor positioning. For example, Microsoft tended to customer needs by developing user-friendly platforms; it also connected with users by developing a system that locks users in when they coevolve with Microsoft’s products. In the context of technological competitiveness, users or products that do not coevolve will very likely lag behind and fail. Given limited time and capital resources, and the fast rate at which market, customers, and competitors change, the optimal rate for TNV coevolution is necessarily faster.

6.3 Prigogine’s phase-transition theory

One of the origins of order creation is a disequilibrium between two adjacent systems or “fields”, where one field enjoys a high concentration of resources (e.g. information, knowledge, capital, and market potential) compared to an adjacent other field (Prigogine, 1997). The disequilibrium sets up an adaptive tension, defined as
a contextually imposed energy differential (McKelvey, 2001, 2008). The energy
disparity causes a phase transition; that is, new order creation. Since tension seeks
resolution, this energy differential induces a creative response that generates new order
within the system as a whole (Barney and Arikan, 2001).

The concept of adaptive tension is particularly relevant in technological
entrepreneurship. The emergence of new industries, new ventures, or TNVs is, in a
sense, a technical or process innovation (Davenport, 1997). This type of innovation
largely results from an entrepreneur’s perception of disequilibrium relative to a firm’s
competitive environment (Eisenhardt and Schoonhoven, 1990). Such disequilibria drive
the process of opportunity identification and then innovation (Stevenson, 1999). This
process allows entrepreneurs to identify new markets, industries, products, and services
that can be capitalized on via the value-creating activities within a new venture. Long
ago Schumpeter (1942) turned our attention to the critical effect that phase transitions
and disequilibria have on the creation of new economic order. He called it “creative
destruction” as a result of environmental shocks.

6.4 Fisher’s change rate theorem
Fisher (1930) made the connection between variation and adaptation, a link that is now
all but axiomatic in the biological and social sciences. His basic theorem states: “The
rate of evolution of a character at any time is proportional to its additive genetic
variance at that time” (Depew and Weber, 1995, p. 251). In other words, adaptation to a
changing environment speeds up the rate that usable genetic variation becomes
available.

Fisher’s theorem is especially relevant to research on innovation in high-velocity
environments where knowledge creation provides the key to ongoing variations within
and hypercompetition increases (D’Aveni, 1994), rapidly creating knowledge becomes a
key competitive advantage (Leonard-Barton, 1995). As Prusak (1996, p. 6) says:

The only thing that gives an organization a competitive edge – the only thing that is
sustainable – is what it knows, how it uses what it knows, and how fast it can know
something new!

The speed of knowing something new is critical to TNVs, but the speed of shaping a
new thing is even more advantageous (Tushman and O’Reilly, 1997). The more
disequilibrium, the more phrase transition and the more new order creation. In the
context of the TNV, this means more changes and transitions and more opportunities
to create more new TNV structures and processes. Moreover, the shorter the product
life cycles, the more TNVs need to focus on their rate of change. Maintaining
short-term network ties assures the continuation of disequilibrium, phrase transition,
and order creation. Maintaining short-term ties supports faster re-shaping of TNV
structures and processes. Hence:

P2. TNVs enabling short-term ties can achieve improved performance.

6.5 Lindblom’s principle of causal complexity
Lindblom (1959) introduces the processes of parallel interaction, mutual adjustment,
and coordination that characterize social units facing complex and uncertain choice
and action situations. Lindblom’s principle is the foundation of Buchler’s (1966)
"interactional complexity" that arises once near decomposability is achieved. Groups of various kinds may be interconnected; each group has an agenda; each agenda pushes policies and organizational action forward. In Lindblom's work we have early, if not the first, recognition of multiple causal influences in CAS[3].

Cohen et al. (1972) observe that emergent, differentiated, semi-autonomous subunits generate the need to integrate "organized anarchy". The latter leads to added hierarchal levels and emergent integration processes among them (Galbraith, 1973). The task here is to solve key problems that can limit order creation and emergence. The principle issue of organized anarchy is one of top-down directing versus bottom-up emergent organizing – a causal duality. If this problem is not solved, the unit loses its adaptive capability.

6.6 Dumont/Dupuy's causal rhythms

The rhythm principle stems from Dumont's (1966) initiating study of Hindu society. He found that dominance oscillates between Brahmam and Rajah (religion vs secular forces) as the need for warfare comes and goes. In organizations, we see dualities such as centralization-decentralization and exploitation-exploitation (March, 1991). Most academics propose balancing these; March (1999) says balance is impossible. Dupuy (1992) adds the idea of fast or slow oscillation.

The dynamic rhythm idea, termed "circular organizing", also appears in studies by Ackoff (1981), Enenburg (1988) and Romme (1999). Interestingly, the biologist, Kelso (1995, 2004) also writes about coordination rhythms across various biological levels of analysis, from cells to fingers to brains. Further, he notes that these rhythms operate at different time scales (Kelso, 1995, p. 247). Thomas et al. (2005) find that oscillation dynamics also operate at different rhythms in firms, with profitability at stake. When a TNV is managing the duality of moderate number and short-term ties, it is managing the processes of parallel interaction and mutual adjustment, and coordinating a collection of diverse attributes of ties carrying different rhythms. These diverse ties may help TNVs face complex and uncertain choice and action situations. Thus:

P3. TNVs enabling both moderate number of ties and short-term ties are better able to coevolve with a changing environment.

6.7 Simon's principle of near decomposability

Simon's (1962) classic essay on the architecture of complexity articulates his design principle for modular systems. Complex systems consisting of nearly decomposable subunits (i.e. mostly independent from top-down control or interdependencies with other subunits) tend to evolve faster and toward stable, self-generating configurations. Simon's idea re-emerged as Weick's (1976) loose coupling concept and more recently as modular production and product design (Sanchez and Mahoney, 1996). Schilling (2000) suggests that modularity is a continuum describing the degree to which a system's components can be separated and recombined.

New venture creation is studied in terms of elemental behaviors or tasks that systemically integrate to drive organizational emergence (Carter et al., 1996). The early development of companies has long been framed in terms of increasing degrees and levels of structure and control (Chandler and Hanks, 1994). The need to continuously increase internal levels of differentiation and specialization has been a driving force in
the evolution of new organizational forms (Lawrence and Lorsch, 1967; Miles et al., 1999).

Given that TNV resources are limited and challenges are great, the main lesson from Simon's principle is that TNV structure has to consist of modules linked by very few strong ties, with most ties being short term. The few strong ties anchor stability and allow the firm to focus on cost control and efficiency; the short-term ties allow coevolutionary change to achieve the benefits of creativity, information, and knowledge (Perry-Smith and Shalley, 2003). Thus, we propose (Figure 1):

\textit{P4.} Performance of TNVs requires nearly decomposable modules connected with a minimal number of strong ties and mostly short-term ties.

7. How scale-free dynamics help TNVs satisfy the first principles

The seven principles apply even to the smallest system (even a few people working in a garage), but they become increasingly important, complex in their interaction, and difficult to enable as a TNV becomes larger with more people, modules, and levels. Gell-Mann's second regularity takes on an ever more crucial role as the number of levels in the firm increases and it attempts to make more and more small-to-large changes. Only in recently do we begin to see the relation between system change, scalability, and power laws. In short, the adaptive dynamics defined by each principle have to be effectively enabled at each level of a multilevel TNV if it is to survive and grow in a changing competitive environment. Entrepreneurs who only focus on one level, or do not succeed in enabling scale-free dynamics at multiple levels, will own TNVs with dubious survival capabilities.

How to assure each principle operates at each level of a TNV? In Table I, we define seven scale-free theories from the longer list put together by Andriani and McKelvey (2007b), and show how they relate to specific first principles. Our argument is very clear. A TNV, as a CAS, needs to meet specific adaptive demands – which we define in terms of the first principles. TNVs also need to assure that they have adaptive CAS dynamics operating at each level of their organizations. Otherwise there is an adaptive gap, which acts as a barrier to efficacious adaptation from top to bottom.

It follows that a TNV entrepreneur must assure that each of the following scale-free dynamics is operating in his/her firm at multiple levels – with no level where the scalability dynamic is inactive – so as to assure the activation of each first principle.

![Figure 1. Tie attributes and TNV performance](image-url)
First principles\textsuperscript{a} Scale-free theories from the natural and social sciences\textsuperscript{b}

<table>
<thead>
<tr>
<th>Requisite variety (Ashby)</th>
<th>Least effort. Word frequency is a function of ease of usage by both speaker/writer and listener/reader (Zipf’s (power) Law). Now found to apply to firms and economies in transition (Dahui \textit{et al}., 2005; Ishikawa, 2006; Podobnik \textit{et al}., 2006)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coevolution (Maruyama)</td>
<td>\textit{Preferential attachment}. As new agents arrive into a system, larger nodes with an enhanced propensity to attract agents will become disproportionately larger (Barabási, 2002)</td>
</tr>
</tbody>
</table>
| Adaptive tension (Prigogine) | \textit{(a) Turbulent flows}. Exogenous energy impositions cause autocatalytic, interaction effects such that new interaction groupings form (Prigogine, 1997)  
\textit{(b) Spontaneous order creation}. Heterogeneous agents seek out other agents to copy/learn from to improve fitness and generate networks (Kauffman, 1993) |
| Change rate (Fisher)      | \textit{Epidemics; idea contagion}. Often, viruses are spread exponentially – each person coughs upon two others and the network expands geometrically. But, changing rates of contagious flow of viruses, stories, and metaphors, because of changing settings such as almost empty or very crowded rooms and airplanes, result in bursts of contagion or spreading via increased interactions (Watts, 2003) |
| Near-decomposability (Simon) | \textit{(a) Square-cube law}. Surfaces absorbing energy grow by the square but organisms grow by the cube, resulting in an imbalance. Fractals emerge to balance surface/volume ratios (Carrero, 1987)  
\textit{(b) Connection costs}. As cell fission occurs by the square, connectivity increases by n(n−1)/2, producing an imbalance between the gains from fission versus the cost of maintaining connectivity. Consequently, organisms form modules or cells to reduce the cost of connections (Bykosi, 2003) |

\textbf{Sources:} \textsuperscript{a}McKelvey (2004a); \textsuperscript{b}Andriani and McKelvey (2007b)

\textbf{Technology-based new ventures}

\begin{tabular}{p{10cm}p{2cm}}
\hline
\textbf{7.1 Least effort} & 49  
\textbf{Zipf’s (1949) originally suggested that “least effort” best explained Zipf’s law. This is the power law of word usage known to apply to English, French, and Spanish. Least effort theory is now confirmed (Ferrer i Cancho and Solé, 2003); but it appears evident in changing languages (Dahui \textit{et al}., 2005). Applied to new venture creation, Zipf’s law holds that efficient and effective interactive transactions are similar to conversation or purchasing activities. Zipf’s least effort theory now seems best applied to changing situations. Thus, we now know that least effort theory applies to organizations (Andriani and McKelvey, 2007b) and economies that are in transition (Podobnik \textit{et al}., 2006). In management contexts, Zipf’s law holds true in firms that are changing and have high-growth rates (Ishikawa, 2006), but does not hold true for large firms with slow growth rates (Dahui \textit{et al}., 2006).} \\
\end{tabular}

\textbf{7.2 External tension} & 
\textbf{Already defined as essential for adaptation. Since tension can apply to any and all levels, it is scale-free. A good example of this kind of tension in the organizational}
world is Welch’s famous phrase to his division presidents, “Be #1 or #2 in your industry ... or you will be fixed, sold, or closed” (Tichy and Sherman, 1994, p. 108, paraphrased). See also Collins’s (2001) “face the brutal facts” element in his explanation of “good to great” firms.

7.3 Spontaneous order creation

In Kauffman’s (1993) biological theory, all that is needed to stimulate emergent structure in the form of connections are heterogeneous agents (DNA, cells, organisms, etc.) stimulated by the need to improve fitness of some kind – adaptive tension and positive feedback are implicit. Carley has applied this basic idea to organizations, learning and cognition, and emergent structure over many years (Carley, 1999; Carley and Svoboda, 1996; Carley and Hill, 2001). Kauffman’s approach is now widely applied to organizations; indeed, Maguire et al. (2006) list over twenty applications.

7.4 Contagion bursts

Incidents and theories about epidemics and pandemics have been with us for years. What Watts (2003) and Andriani and McKelvey (2007b) focus on is the reality that random interactions among people, such as spreading a virus via coughing, are quickly speeded up if the coughing occurs in a confined space or, such as on an airplane, they are sitting near each other for some length of time. Thus, the change-rate advantages stemming from Fisher’s law come when heterogeneous agents work in physical proximity or have easy networking capabilities. Whereas lengthy contacts may lead to groupthink (Janis, 1972), the idea here is that managers need to enable bursts of intense short-term tie development at moderate levels of connection here-and-there and now-and-then in their firms. This is what leads to bursts of communication, bursts of idea spreading, bursts of creativity, bursts of new product ideas, etc.

7.5 Square-cube law

This law, dating back to Galileo, defines the nature of the cauliflower. It holds that as the volume of an entity increases (dictated by survival advantages stemming from increased size), its surfaces (means of absorbing energy) do not increase, in order to maintain the ratio between energy use and energy absorption. Hence, fission takes place – as with the cauliflower – to keep the surface area large enough to supply energy to the increasing volume. This law has been applied to firms as far back as Haire (1959). Nowadays, it is used to describe the difference between surface employees (those who directly bring in resources), and volume employees (everyone else in a firm) (Stephan, 1983). Carneiro (1987) applies the law to explain the upper bounds of a village. The law limits a village’s size unless it develops what he terms “structural complexity”, where complexity grows at 2/3 power of the village population. Only by doing this does the village avoid splitting in two.

7.6 Connection costs

Simon’s near decomposability principle is brought to life at any level by balancing square-cube, fission-created modules with another scale-free theory – the cost of inter-module connections. Absent anarchy arises as modules increase their number of inter-module connections and connection costs increase at an exponential
rate (Bykoski, 2003). At some point it is more efficient to recombine modules to lower communication costs.

7.7 Preferential attachment
This scale-free theory rests on a positive feedback process in which existing resources accrue even more resources. This theory underlies the logic of increasing returns to scale (Arthur, 1990), in which firms making profits invest in other areas and thereby make even greater profits. It is obvious that high-tech firms and firms that focus on standardized products often benefit from preferential attachment. The key is to have the first significant means of requisite variety. Take the example of Apple: a creative software engineer designed the iPod; the firm aligned its strategy with the new competitive context (content fits with context – Stevenson, 1999); internal variety matched external variety; and explosive and increasing returns were the end result.

8. Discussion
Drawing on complexity science, we develop a conceptual framework that links the seven first principles and the concept of scale-free theory to inform and explain how TNVs manage social networks. We argue that short-term ties in moderate numbers are optimal for TNVs to achieve superior performance; that is, a mix of many weak and a few strong ties.

The primary contribution of this paper is to explicate the link among TNVs, social capital management, the seven first principles, and the concept of scale-free theory. This conceptual model should help TNVs achieve higher performance, effectiveness, and longevity in their rapidly changing world. We establish a baseline for further work using complexity science in entrepreneurial research.

Complexity science demonstrates that for a system to be innovative, creative, and changeable it needs to focus on disequilibrium. Indeed, it is disorderliness, irregularity, and difference that make the change process successful. TNVs that can use disequilibrium to drive far-from-equilibrium dynamics are more likely to prosper from innovation and change. But being disequilibrium requires a TNV to reside in the melting zone between order and chaos, a situation that is difficult to manage. However, it is CAS behavior in the melting zone that fosters self-organization, emergent new structures and processes, and the underlying scale-free causal dynamics extending across all organizational levels.

8.1 Implications for TNV research
Our paper is the first attempt to connect TNV research to recent findings about social network theories, long-standing principles of efficacious adaptation, and key elements of complexity science. We view our analysis as setting a baseline for future research in these important areas of research. As TNVs grow exponentially around the globe, they increasingly have to compete in a world of fast-changing technologies and internet networked communities of people from disparate cultures. Further research is required that examines optimal strategies for achieving superior TNV performance depends on connecting TNV performance theorizing to these new trends in the literature in ways that serve academic rigor and economic relevance.
More specifically we set up several research agendas:

• Test whether our four propositions about the relationship between moderate and short-term ties and TNV success are supported.

• Test whether TNVs following one or more first principles are more adaptive and economically superior.

• Test whether TNVs showing scale-free causes extending across multiple levels – Gell-Mann’s “middle level theory” – show improved economic performance.

• Test whether the combination of the three foregoing agendas in combination produce better TNV economic performance than any one by itself.

• Test whether the of rapid growth benefits from applying a complexity science perspective.

• Make all the foregoing tests in competitive contexts ranging from slow and simple to fast-paced and complex.

8.1.1 Is the CAS view well suited for disentangling issues in TNV transitions from startup stage to growth stage of the firm? With the foregoing research agendas we set up a true test of whether complexity science has much to offer TNV researchers. By doing this, we suggest steps away from the current literature’s focus on one stage of the life cycle and its failure to take on the complex issues of change and transition. Finally, our theoretical framework will benefit from empirical research and data collected from diverse cultural backgrounds. Testing whether it generalizes across different cultures is essential in this global age.

We have tried to set up a new theoretical framework for helping TNVs aiming to improve one pole of a duality by focusing on the opposite. This framework is very different from the extant literature on how firms get from Good to Great (Collins, 2001), and achieve stability through resources. Our unique framework suggests that TNVs achieve “stability through instability, gain strength through weakness, reach long-term goals with short-term plans, obtain predictability with disorder, and nurture directed creativity with chaos” – as we put it earlier – would be the basis for future TNV research to build upon. The test agendas mentioned above serve to guide empirical research in this area. We draw from the McKenzie and van Winkelen (2004) argument that increasing tension toward one end of a duality forces attention in the opposite direction.

Our paper clearly benefits from the social network literature. Even though social network analysis is increasingly popular in management research, its linear perspective limits needed areas of research; especially those relating to TNVs. Future research using social network perspectives will surely benefit from using the nonlinear (dynamical) view of order-creation dynamics offered by the Santa Fe Institute’s complexity theory and the more recent scale-free dynamics of econophysics that are captured in the theoretical framework discussed.

8.2 Implications for TNV management
TNV entrepreneurs need to aim for the first principles. If they do, they set up the conditions for scale-free theories to emerge, with potentially positive or negative extreme event outcomes, such as rapid growth in size and assets, or a disastrous move down a dead end. Entrepreneurs need to unleash multiple components of their ventures, but they also need to ensure that they delete or refocus any components that veer from the adaptive track.
8.2.1 Management by tension. We suggest that TNVs accumulate short-term ties instead of strong ties in their early life, to achieve the paradox of far-from-equilibrium. The chaotic tension of short-term ties and informal networks (Stacey, 1995) exists where actors are spontaneously and randomly organized among themselves. Short-term ties can be engines of innovation, creativity, and newness. They may create small perturbations, but they can have a huge impact on the system. These engines are the core for exploration (March, 1991) into the space of possibilities.

8.2.2 Working toward least effort design. Complexity theorists demonstrate that the future is unknowable and that it is impossible to select content area that “will be relevant for more than a rather short time period” (Stacey, 1995, p. 492). We suggest TNVs focus on the possibility of open-ended choices that emerge from chaotic dynamics and systemic feedback loops. This approach may also help TNVs to maximize already constrained resources without locking-up resources in maintaining strong network ties. Short-term ties also avoid the organizational and cognitive inertia that develops when long-term ties create homogeneity over time.

8.2.3 Creating positive feedback conditions. We suggest that TNVs need only a moderate number of ties. Too many ties waste valuable resources and attention; too few ties cannot provide enough feedback or variety to create synergy. Therefore, a moderate number of ties can help create positive feedback conditions to allow the emergent order creation.

Notes
1. Granovetter (1973) defines weak ties as more than one per year but less that two per week. Montgomery (1992) defines them as “non-frequent and transitory social relations.”
2. Here on out we will use “short-term ties” instead of “weak ties”. Montgomery’s definition stresses “non-frequent” and “transitory”. Granovetter’s classic definition implies transitory rather than “weak”. “Weak” could also mean persistent, but low-influence connections – a meaning that we wish to avoid.
3. This is one principle that does not originate in biology. In a personal note (August 8, 2004), Saltz (1986) notes that several authors made forays into causal intricacy prior to his book, but they were not picked up by mainstream biologists.

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