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Organizational Structure and the Creative Process

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ORGANIZATIONAL STRUCTURE AND THE CREATIVE PROCESS

by

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ABSTRACT

A creative edge can be a powerful source of competitive advantage in business, in war, in the arts, in science, and in life. In fact, creativity, innovation and the ability to adapt and change organizational structures in response to an increasingly fast-paced and competitive business environment are increasingly seen as essential for the success of many organizations.

A current trend in organizational theory associates increases in formalization and both horizontal and vertical integration with decreases in an organization's ability to innovate and adapt. Consequently, organizational change efforts often involve moving from traditional, hierarchical structures toward flatter, more flexible types of organizations (Damanpour, 1995; De Canio, Dibble, & Amir-Atefi, 2000; De Sanctis, Glass, & Ensing, 2002). However, as indicated by the failure of numerous downsizing and organizational change efforts, some structures may not be effectively reversible (Appelbaum, 1999; McKinley, 1993). Furthermore, reductions in structural complexity and size may not actually enhance organizational creativity (Damanpour, 1995).

This study uses a stochastic model to investigate possible causes for this apparent disconnect between theory and observation. The model is applied to simple, idealized organizations in order to investigate the relationships between individual creativity, organizational creativity, organizational structure and restructuring, and environmental uncertainty. A simplified formulation of the stochastic model is investigated analytically, and a more expanded formulation is analyzed using Monte Carlo simulation.

The model results suggest that reducing structure or increasing the autonomy of individual producers or subordinates will not necessarily yield increased creative performance. The most profitable organizations were those that converged to highly integrated structures. The simulation also indicated that, beyond a point, increases in both individual and leader creativity may not improve, and may actually detract from, organizational creativity.

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CHAPTER 1

Introduction

A creative edge can be a powerful source of competitive advantage in business, in war, in the arts, in science, and in life. In fact, creativity, innovation and ability to adapt and change organizational structure in response to a fast-paced and competitive business environment are increasingly seen as essential for many organizations.

The creative potential within an organization is generally regarded to reside in the creativity of its people. Accordingly, efforts for enhancing organizational creativity and its cousins (innovation, originality, insight and vision) often center around efforts to encourage individual creativity (Amabile, 1988; Sternberg & Lubart, 1995; Thompson, 2003; Williams & Yang, 1999). Damanpour (1995) points out that, in addition to actions to enhance individual creativity, organizations should adopt structures having levels of flexibility and control appropriate for the type of organization and its competitive environment.

Some types of organizational structures are considered to be more conducive than others in promoting individual creativity, allowing the organization to adapt to an uncertain and rapidly changing external environment (Damanpour, 1995; De Canio et al., 2000; De Sanctis et al., 2002). For example, entrepreneurial organizations with relatively flat and flexible structures are widely believed to be superior to bureaucratic organizations which have more traditional, hierarchical structures.

Both individual creativity and organizational structure are obviously important. But, the ultimate test of creativity, in an organizational context, is the production of a creative product that will be accepted in the external market. Organizational creativity may therefore be better understood using a systems approach which takes the organization instead of the individual as the basic level of analysis (Czikszentmihalyi & Sawyer, 1995). Such an approach would, at minimum, consider the creative individual, interaction between individuals, the organizational context and the external organizational environment. A number of conceptual models exist to demonstrate how these components relate, but empirical validation is largely lacking. This study includes these elements in a dynamic, analytic model and computer simulation to examine and gain insight into organizational creativity and guide further empirical research.

The study begins with a brief discussion of various definitions of creativity, and an overview of individual, group and organizational creativity concepts. A stochastic model of organizational creativity is then developed and evaluated. In the final chapter, conclusions are drawn that could be of practical use for leadership practitioners and applied researchers in the areas of organizational design, organizational change, and organizational creativity.

Definitions of Creativity

Much of the existing research on creativity has been generated within the academic disciplines of cognitive, behavioral, organizational and social psychology. Even within these related fields, the definitions and conceptions of creativity vary significantly. For example, creativity may be viewed as a subjective phenomenon unique to each human creator; it may be seen as an output of individuals or groups, or as phenomena that emerges from the contextual interaction of individuals and groups (Amabile, 1983; Czikszentmihalyi, 1996; Czikszentmihalyi & Sawyer, 1995; Taylor, 1988). Human creativity may be manifest at the individual level or at higher levels such as social systems, economic systems or business organizations. The creative process is not necessarily limited to human beings, however. The concept of creativity can be generalized to include emergence of novel or unique patterns and structures in a wide variety of non-human systems. For example, the emergence of organisms and ecosystems in nature may be regarded as a creative process. The Cambrian explosion, which was the rapid burst of speciation and diversity of complex, marine animal life that occurred on earth more than 500 million years ago, is a notable example. Additionally, many variations of creativity may be simulated, to some degree, by computational systems using the tools of artificial intelligence and expert systems (see Boden [1989, 1990, 1999] and Bentley and Corne [2000]) for numerous examples and descriptions of programs and applications).

Despite their differences, a significant number of researchers have adopted definitions that reflect the practical view that creativity is an idea or product that is novel, original or unique and also useful, valuable or appropriate (Brown, 1989; Meyer, 1999). Many also agree that a full description of creativity should include the creative process, the creative person and the creative situation or environment (Brown, 1989; Czikszentmihalyi & Sawyer, 1995; Meyer, 1999; Woodman, Sawyer, & Griffin, 1993).

The Creative Person

The psychological view of creativity as an individual characteristic is evident in a great many studies. Eminent creators such as Poincare, Mozart, Picasso and Einstein have been widely studied and reported on. As indicated by Gardner (1993), such creative individuals are highly differentiated in basic personality traits. Czikszentmihalyi (1996) agrees but finds that the most common trait is complexity. The distribution of creativity is highly skewed among the general population as well as in many domains such as scientific productivity where creativity is important (Dennis, 1954; Dennis, 1955; Kawamura, Thomas, Kawaguchi, & Sasahara, 1999; Lotka, 1926; Price, 1963). For example, Price's law tells us that the number of people who make half of all contributions is approximately equal to the square root of the number of people making at least one contribution. However, many believe that creativity is not limited to a chosen few, and some degree of creativity can be expected in most people (Weisberg ,1986).

An interesting question is, what are the abilities -- in particular those which can be measured or modeled -- that are required for creative production? Simonton makes a strong case for sheer productivity as the primary determinant of creative achievement. More products will result in more successful products, as well as more unsuccessful ones, with the probability of success for an individual staying fairly constant over time (Simonton, 1984, 1988, 1999). However, a considerable period of preparatory time (about six to ten years) is normally required before an individual becomes knowledgeable enough to make a valuable contribution in domains as diverse as art, science, literature and music, and this knowledge is seldom transferred across contexts. Additionally, creative products are generally not totally unique, but build on earlier knowledge or accomplishments (Weisberg, 1986, 1988, 1995a, 1995b, 1999), (Ward, 1995).

In his well known structure of the intellect model, Guilford (1950) associated creative achievement with complementary abilities of convergent and divergent thinking. Divergent thinking is used to create novel ideas, while convergent thinking is needed to analyze the ideas and bring them to fruition. For example, an artist may use divergent thinking to conceptualize and visualize a painting, but, convergent thinking and convergent production skills would be used to layout and actually produce the painting. Divergent thinking has been a central concept to the study of creativity in individuals and groups and is a focus of a wide range of creativity tests (Michael & Wright, 1988; Torrance, 1988). Although some have cast doubt on the ability of these tests to predict real world performance (Cattell, 1971; Gruber, 1988), others have found divergent thinking, independent of intelligence or expertise, to be a strong predictor of real-world performance in an organizational context (Mumford, Marks, Connelly, Zaccaro, & Johnson, 1998; Vincent, Decker, & Mumford, 2002).

The Creative Process

The creative process is generally described in terms of human cognition. For example, Wallas (1926) (as cited in Kirschenbaum, 1998) described four stages in the creative process: preparation, incubation, illumination and verification. Kirschenbaum (1998) elaborates on Wallas' stages to provide a taxonomy of creativity that consists of nine essential elements of creativity: contact, consciousness, interest, fantasy, incubation, creative contact, inspiration, production, and verification.

The Creative Product

Creative products can take on a wide variety of forms such as ideas, technical inventions, scientific theories, works of art, consumer goods or organizational forms. In order for a product to be considered creative it must be novel, original or unique and also useful, valuable or appropriate, as indicated in the definition given earlier in this study. (Jackson & Messick, 1967) add two additional criteria in the time domain. The first is condensation or coalescence or meaning, which means that some period of time may be required after the product is introduced until it is finally accepted. The second is obsolescence, which means the product must continue to compete over time in order to maintain its creative status.

The Creative Environment

Environmental and contextual factors have been shown to influence not only the creative process, and creative production, but also the selection of products considered to meet creative criteria at personal, organizational, societal, and cultural levels (Amabile, 1983, 1996; Czikszentmihalyi, 1999; De Canio et al., 2000; Gruber, 1988; Lubart, 1999). Czikszentmihalyi (1999) describes a field as those within the creator's environment who are responsible for selecting creative products for inclusion in a particular domain. He gives the domain of physics as an example where a relatively small number of leading university professors was adequate to validate Einstein's theories.

Creativity in Groups

The issue of individual versus group creativity is central to the study of the relationship of organizational creativity to organizational structure. If a novel, successful product in the market is the measure of creativity, then a key leadership question is, how should individuals be organized into groups in order to produce these products? If the criteria used earlier for individual creativity is applied to groups, then, hypothetically, the group should be capable of producing a novel idea through a divergent thinking process, and then bring the idea to fruition by a convergent thinking and production process.

In an organization where the creative outputs are the sum of the individual creative outputs, a flat organizational structure that maximizes individual creativity might seem most appropriate. But, this is seldom the case. Even in an art gallery, for example, the represented artists must compete for wall space, management attention, and promotional support. In other words, the organization supports the artist and mediates the artistic outputs. The creative output of individual artists is also mediated by the influence of colleagues as well as others who are not affiliated with the gallery. Scientific research, whether in universities, the private sector, or government is another example of a field where individual creativity is essential and directly linked to organizational outputs. Here, also, the organization and the influence of other scientists in the field strongly mediates outputs, but, in general, to a lesser degree than for artists (Pietruska-Madej, 2001). In most other types of organizations, however, ideas for creative products may be initiated by individuals, but the ideas are implemented and packaged as organizational outputs by groups.

The study of creativity in groups, organizations and other complex social settings is the center of an important body of creativity research. Much of this research is empirical and based on statistical analyses that use personal or organizational attributes such as individual abilities, motivation, leader attributes, and degree of centralized decision making as independent variables, and measures of creativity (or innovation, originality, etc;) as the dependent variable. (Amabile, 1983, 1988, 1996; Czikszentmihalyi & Sawyer, 1995; Dong, 2002; King, 1995; Scratchley & Hakstian, 2001; Tierney, Farmer, & Graen, 1999; Woodman et al., 1993). One might expect the research to indicate that the interactions of individuals would have a positive synergistic effect on divergent outputs of groups. For example, the popular technique of brainstorming assumes that the creative potential of groups exceeds that of the individual members. But, a large body of research in social and organizational psychology indicates the opposite is true (Andre, Shumer, & Whitaker, 1979; Diel & Stroebe, 1987; Thompson, 1993). As Thompson indicates, groups are better at convergent thinking but individuals are better at divergent thinking. "Nearly all laboratory studies have found that group brainstorming leads to the generation of fewer ideas than comparable numbers of solitary brainstormers in both laboratory and organizational settings" (p. 99). Although techniques are available to improve the creative ability of groups, in general, individuals working in groups tend to match their performance to that of the least productive member through a process of downward norm setting (Thompson, 2003, p. 101).

Creativity and Leadership

Just as individual creativity is often associated with individual achievement, organizational success is often associated with the creativity of the organizations' leadership. From Hannibal crossing the Alps, to General Douglas MacArthur crossing the beach at Inchon, to General Norman Schwarzkopf crossing the Iraqi desert, to Bill Gates spanning the globe with Microsoft Windows products, creative generals and Chief Executive Officers are often given credit for creative genius, even when the ideas may have originated elsewhere in the organization. Many other examples can be found where successful organizations have been founded based on the creative ideas of single individuals, or small groups of individuals who, in some cases, have assumed leadership of these organizations. Thomas Edison and Henry Ford are prominent examples from the industrial era, and, more recently, Michael Dell and Bill Gates in the information age. But, should, or can, these inspirational exemplars serve as effective examples for the day to day practice of organizational leadership? Possibly not, according to several leading creativity researchers.

King (1995) observed that highly innovative organizations are not necessarily the most supportive of individual creativity. Weisberg (1986) argues that much of what has been reported as creative genius is largely a myth. Simonton (1984, 1988), acknowledges the existence and importance of individual differences in creative ability, but maintains that risk taking is important for effective leadership, and, leaders must be willing to accept failure. Simonton's reasoning is that for both individuals and leaders, the probability of success for a given individual stays fairly constant over time, and the more trials will result in more successes as well as more failures. Thomas Edison, for example, despite numerous successful inventions, still had many failures. Most notably, he sold all of his stock in General Electric to finance his efforts to develop an economical method to separate iron from low grade ores. Unfortunately, he was unsuccessful and he lost his entire investment. Another conspicuous example was Henry Ford's failure with the Edsel automobile. A more recent example was the decision made by Bob Gannon, CEO of Montana Power Company to transfer most of the company's assets into a high technology telecommunications subsidiary called Touch America—unfortunately, just in time to join in the collapse of the dot.com market.

Sternberg and Lubart's (1996) investment theory of creativity seems particularly applicable for an organizational setting. They hold that the most successful creative products are not necessarily the optimal ones. Instead they are often the outliers that can be obtained at relatively low cost and then sold high through skillful promotion by leadership. Therefore, in order to capitalize on organizational creativity, leaders should be able to see problems in new ways, recognize good ideas, and persuade others to support the ideas. The world of business is replete with examples supporting this theory. Ray

Kroc's success in transforming the MacDonald brothers' creative idea for fast food into a vast business empire is one of the more familiar examples.

Organizational Structure and the Creative Process

There are probably as many ways to describe organizational structure as there are organizations to describe. Regardless of typology chosen, however, creativity and innovation are likely to be more important to some types of organization than to others, and the creative process can be expected to differ across organizational types and situation. The stress of environmental change or the threat of organizational decline can motivate even the most conservative organization to innovate (Bolton, 1993; McKinley, 1993). For other types of organizations, such as entrepreneurial organizations and research and development firms, creativity and innovation are essential for organizational survival. In general, the business environment and degree of innovation required for normal operations will influence organizational structure; and organizational strategy and structure will impact an organization's creative ability (De Canio et al., 2000; Fredrickson, 1986; Jones, 2000; McKinley, 1993; Miller & Friesen, 1984; Mintzberg, 1979).

The well known organizational typology developed by Mintzberg (1979) can be constructively applied to the study of the relationships between strategy, structure and the creative process. Mintzberg described an organization in terms of five components which are present in some degree in most organizations - although some are absent in some cases. The *strategic apex* consists of top management, boards of directors and others who have overall authority and responsibility. The *operating core* is the group responsible for actually producing the organizational output. The middle *line* is the group of middle managers between the strategic apex and operating core. The *technostructure* consists of planners, analysts, system designers and the like who support decision making by management. Finally, the *support staff*, which could range from cafeteria workers to legal staff, provides administrative and logistical support for the other components.

An organizational structure can be described in terms of the number of individuals in an organization, and the way individuals are grouped into higher level units. According to Mintzberg, the elements of structure yield five basic types of organizations. In the *simple structure*, the strategic apex and operating core are dominant; the operating core is fairly homogeneous; the support staff, technostructure, and the middle line are minimal or non-existent; supervision is direct; coordination is simple, decentralized and direct; and the environment is dynamic and competitive. Small entrepreneurial firms often fit this model. The second type, the *machine bureaucracy,* is more highly centralized and formal; coordination is characterized by formal rules, and the technostructure dominates. Large, mature firms often fit this model. A *professional bureaucracy* has an operating core of highly skilled professionals who are given considerable autonomy; coordination is by standardization of skills; and decision making is largely decentralized. The *divisionalized form* consists of a number of semi-autonomous units with the overall organizational structure often being reflected in each unit; control from above is by performance and control systems based on standardization of outputs. Many large corporations fit this model. An *adhocracy* is an *organic* organizational form which is highly adaptive, informal and decentralized; coordination is by mutual adjustment and requires a high degree of interpersonal interaction and communication. Matrix structures and project teams are often used by these types of organizations, and they are most appropriate in dynamic settings such as the fashion industry where short product cycles are driven by rapid and unpredictable changes in consumer preferences.

Miller and Friesen (1984) expanded on Mintzberg's theoretical typology in a comprehensive empirical study which concluded that the majority of organizations can be grouped into one of four successful or six unsuccessful archetypes defined by four categories of variables: environmental variables, information processing variables, structural variables, and decision making variables. Three reasons for the configurations are given. First, Darwinian-like selection acts on groups of organizations and eliminates less fit configurations. Second, individual organizations adjust their structures to achieve internal consistency in characteristics, maintain internal relationships, and to provide synergy in processes and fit with the situation. Lastly, organizational momentum keeps configurations constant to the point when change can no longer be avoided; then many variables change at same time in order to reduce the time out of equilibrium.

Miller and Friesen proposed and tested the relationship of innovation to structure under two different models. The *conservative* model may be associated with stable, bureaucratic type firms. (Although, the bureaucratic type which Miller and Friesen call a *planning* firm, makes conscious and continuous effort to produce innovative products.) A conservative organization engages in product innovation only to the degree required to respond to economic challenges. The *entrepreneurial* model may be associated with entrepreneurial firms and organic, adhocracies. Innovation is the preferred mode of operation for entrepreneurial firms and they will continue to innovate unless it becomes unprofitable to do so.

Unresolved Questions

"Traditional theory says that organizational growth results in increased administration, increased horizontal and vertical integration, increased formalization, and increased need for coordination due to a larger workforce"(McKinley, 1993). All of these attributes may detract from the organization's ability to innovate and adapt. One might reasonably expect that organizational innovation and adaptability could be improved by reversing the process through organizational restructuring away from traditional, hierarchical structures toward flatter, more flexible, organic types of organizations. This is often -- but not always -- the case. The failures of numerous downsizing and organizational change efforts indicate that some structures may not be effectively reversible. An organization that has evolved over a period may simply be too complexly interconnected and have too much organizational inertia to be significantly changed without disintegrating. Furthermore, reductions in structural complexity and size may not actually enhance organizational creativity. For example, Damanpour (1995), referring to his review of empirical research on organizational innovation states, " In fact, the cumulation of findings of past research shows only a modest positive association between participation in decision making and innovation, and no significant associations between both degree of formalization and extent of hierarchy and innovation" (p. 128)

Additionally, intuition and the abundance of well know exemplars may lead us to expect a strong relationship to exist between the creativity of individual organization members, creativity of leaders, organizational creativity and organizational success. Yet, as previously discussed, a significant body of literature suggests that these relationships may be weak or non-existent. Several pertinent questions arise from the foregoing:

(1) What are the relationships between organizational structure, organizational innovation and an organization's profitability? How, for example, would *typical* bureaucratic and entrepreneurial organizations compare in their ability to profitably produce creative outputs under various degrees of environmental change and uncertainty?

(2) How do the interactions between individuals and groups of individuals influence the evolution of organizational structure? For example, how would a strategy of cooperation between organization members and groups compare with a strategy of competition?

(3) What would be the effect of reducing the structure of a bureaucratic organization on its creative output and resulting financial performance?

(4) What would be the effect of increasing the structure of a simple, entrepreneurial organization on its creative output and resulting financial performance?

(5) What is the relationship between creativity in the workforce and the creative outputs of an organization? How creative should a workforce be? And for what purpose?

(6) Can simple strategies be identified that would allow organizations to effectively adapt their structures?

(7) And finally, how creative do leaders need to be and to what degree? Should they promote individual creativity in their organizations? A simple answer could be, more must be better. But is it? To help answer these questions we may benefit from a closer examination of the relationships between creativity of individuals, creativity of leaders and organizational creativity.

CHAPTER 2

The Model

As stated in the introduction, a full description of the creative process should include the creative product, the creative process, the creative person and the creative situation or environment. A study of organizational creativity obviously must also include the creativity of groups. This study represents these elements, and the relationships between them, in a simple idealized model which is intended to be only qualitatively accurate. The first part of this chapter provides a general, qualitative description of the model in terms of an idealized organization, an idealized product, an idealized, environment, an idealized process, and idealized profitability. The qualitative description is followed by a detailed mathematical description, which can be skipped by those not technically inclined or not interested in the mathematical structure underlying the model.

Qualitative Description of the Model

As shown in the functional description in Figure 1, individuals, characterized by their divergent and convergent creative production ability, are input into an organization where they are assigned to a group and given a function within the group as a supporter, producer or leader. Each group then generates products at a rate proportional to the number of members in the group. Products are submitted to an external selection environment (market) where they are either accepted or rejected with a resulting profit or loss accruing to the producers. Differences in profitability result in state changes within the organization as individuals and groups are absorbed by more profitable neighbors. A generalized semi-Markov process is used to model product generation, and a random field is used to model the organization and the interaction between individuals and groups. The generalized semi-Markov process and random field, which are the primary mathematical structures used in the model, are both stochastic process models which are described in further detail in the mathematical description section of this chapter. Before proceeding with the description of the idealized model, a brief rationale will be provided for using stochastic process models in the study.

A stochastic model of organizational creativity seems to be justified by the uncertainty, unpredictability and randomness inherent at every level in the creative process. Individuals have been shown to differ significantly in creative performance (Dennis, 1954; Dennis, 1955; Kawamura et al., 1999; Lotka, 1926; Price, 1963)), and Simonton, (1984, 1988, 1999) provided both empirical and theoretical evidence to suggest that the number of an individual's successful products is proportional to the number of products generated. More products will result in more successful products, as well as more unsuccessful ones. Simonton also demonstrated that although the probability of success for an individual producer stays fairly constant over time, determination of whether or not a specific product created by a specific individual will actually succeed in the market is a highly unpredictable endeavor. When individuals are combined into groups, prediction of creative performance becomes even more difficult. Moving to the creative environment, the uncertainly and randomness that permeates the economic environment in general is even more acute for novel, or creative products which are often subject to rapid shifts in consumer preferences that defy deterministic explanation.

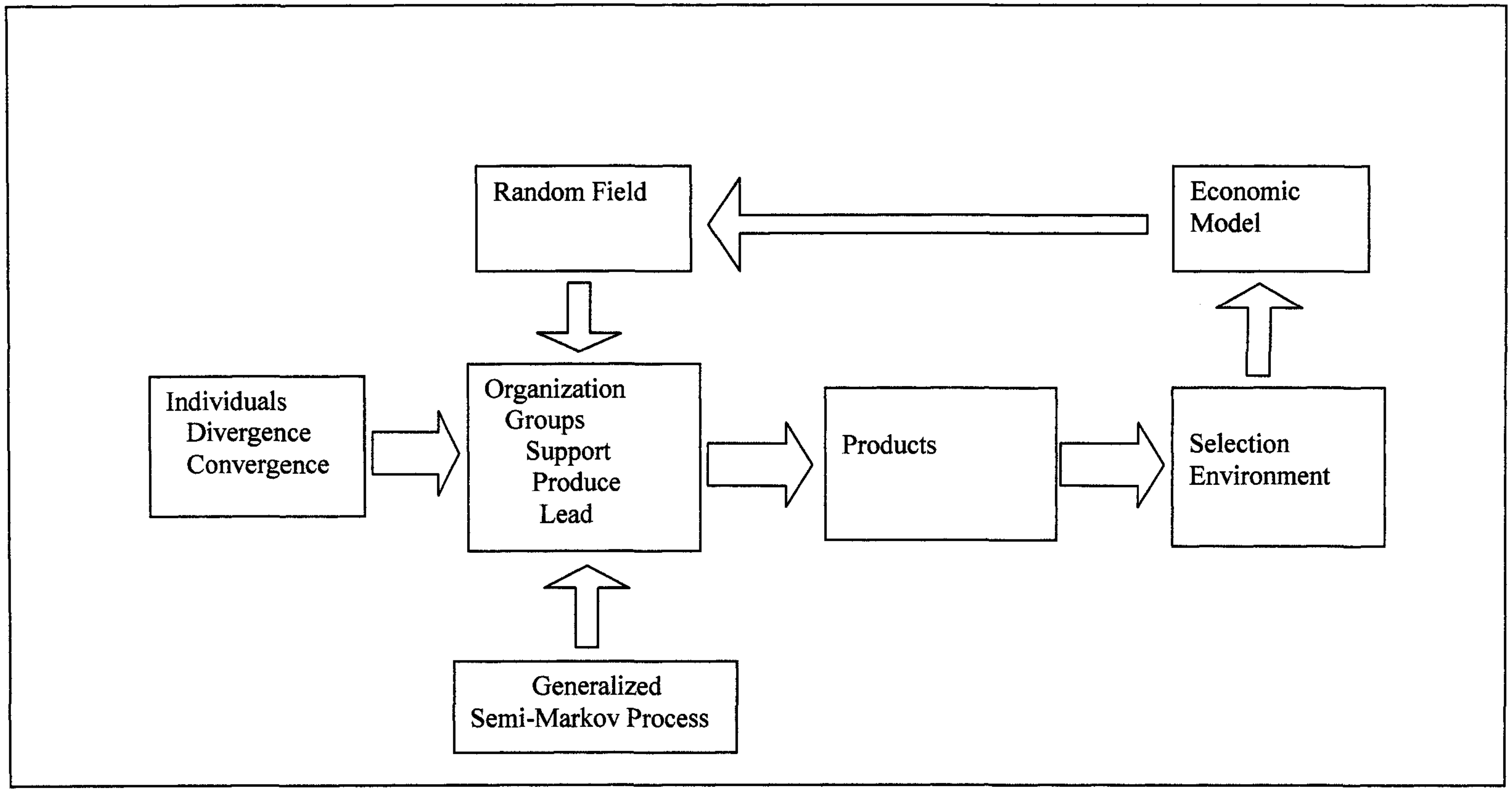


Figure 1. A functional description of the model. Individuals, characterized by their divergent and convergent creative production ability, are input into an organization where they are assigned to a group and given a function within the group as a supporter, producer or leader. Products are submitted to an external selection environment (market) where they are either accepted or rejected with a resulting profit or loss accruing to the producers. Differences in profitability result in state changes within the organization as individuals and groups are absorbed by more profitable neighbors.

An Idealized Organization

The extremes in organization types can be represented by two idealized organizations that roughly correspond to Miller and Friesen's (1984) conservative and entrepreneurial types. In my analysis, these two organization types will also serve as the extreme or limiting cases. To better understand them, first, consider a structurally stable, bureaucratic organization which chooses to enter a new and untested market by allocating slack resources, or by converting resources from other markets. The existing structure could be maintained, along with its limitations, or, the structure could be modified, and the expenditure of resources and associated risks could be accepted. If successful, the organization's creative effort could yield a marginal gain above steady-state profitability. Next, consider a new entrepreneurial start up which chooses to enter the same market. Assume this second organization has a simple, entrepreneurial form and is therefore only minimally constrained by existing structure. Also, assume that this organization might be able to increase profitability by modifying its structure.

In the first case, the conservative organization would be faced with the decision of whether to maintain its current structure or reduce its structure to be more similar to the entrepreneurial organization. In the second case, the entrepreneurial organization must decide whether to maintain its structure or to add structure, which would represent a move toward a more conservative type of organization. This study will examine the relative impact of such decisions on the creative performance of an idealized organization.

The idealized organization consists of three functional components: (1) leadership, (2) support, and (3) production. Each individual in the organization is assigned to one of these functional components. This description is similar to Mintzberg's taxonomy, except, the strategic apex and middle line have been combined into a leadership component; and the technostructure and support staffs have been combined into a support component.

Production ability is the ability to produce a creative product. It consists of divergent and convergent components which are represented by positive numerical values for each individual. The divergent component describes an individual's capacity to design a product which is novel or different from an established norm or from a previous product. The convergent component determines the ability to actually make the product and is defined here as a time rate of production.

Support is the ability to leverage the output of leaders by increasing their convergent capability. This is accomplished in the model by multiplying the convergent production scores of the supported leader by the number of individuals assigned to that leader's group. Consequently, the production rate for a given product is directly proportional to the number of individuals assigned to the group of the leader that created the product.

Leadership is the ability to leverage the output of one or more groups consisting of producers, supporters, and other leaders by allowing the group to produce the leader's product, or one of the products of a subordinate leader or producer which the leader designates. Leader creativity was modeled at two levels. At the low level, the group leaders' creative divergence is influenced and moderated proportional to the number of subordinate individuals in the group. This was accomplished in the model by multiplying the leader's divergent creativity parameter by the number of individuals in the leader's group. Since a higher divergence parameter equates to lower creativity, this effectively reduces the leader's creativity. At the high level, the leader's divergent creative parameter is not altered, and the leader's divergent creative parameter serves as the creative parameter for the entire group. The convergent ability of an individual assigned to leadership is increased proportional to the number of individuals in the leader's group. In other words, producers can think creatively and produce, but they cannot become leaders without supporters; supporters can increase the productivity of leaders, but cannot generate creative ideas; producers can both generate creative ideas and produce.

An Idealized Product

Products are described as points on the non negative real line (from zero to infinity). The zero point represents a normative or standard product; and a product's creativity is measured by its distance from this standard. The starting point for analysis has all individuals at the zero point which corresponds to production of the standard product. When individuals produce a new product, the change in profitability that results can be thought of as the marginal profitability of the innovation.

An Idealized Environment

The idealized environment is a *selection field* in the sense that the term is used by Czikszentmihalyi (1996). Selection of a product by the field for inclusion in the product domain is governed by a process which is unpredictable by the organization and may change over time. The sources of the unpredictability may vary. For example, they could result from deterministic chaotic processes, or, from chance processes which can be described by probability distributions. Unpredictability may also arise out of simple ignorance, or from inability to identify complex patterns. This study uses a probability distribution to model selection. In the idealized economy used here, it is assumed that the standard product, represented by the zero point on the product space, will be selected with certainty. The probability that a new product will be selected is assumed to be inversely proportional to its distance from the norm. The product's value, however, is assumed to increase as it increases its distance from the norm. So the more novel products are more valuable, but they are less likely to be selected.

An Idealized Process

The initial organizations began with each individual representing a group. In other words, an organization starting with one hundred individuals would begin with one hundred groups of one individual per group. Each simulated individual was given the initial organizational function of producer. The model is executed in two stages.

Stage one of the model is the group formation process where individuals start as independent producers and are consolidated into various organizational structures consisting of supporters, producers and leaders. The first step in stage one is for each individual to produce a candidate product by first generating an initial product and then incrementally producing more creative products until the first failure. At that point the producer goes back to the last successful product before the failed one, and that becomes the individual's candidate product. Each individual accumulates financial gains and losses from the candidate product until the termination of stage one or until the individual is absorbed into another group. Stage one terminates when the organization as a whole has produced a number of products equal to ten times the initial population size. In other words, an organization starting with one hundred individuals produces one thousand products during stage one. Individuals that fail to produce a successful product on the first attempt are set to a state of fail and have no further role in the simulation.

Hierarchies of groups form as less successful individuals change state to support more successful ones. Producers become leaders after they are assigned one or more supporters. Successful leaders and producers that are assigned to support other groups still maintain their states as leaders and producers. However, their impact on the supported group (in this version of the model) is the same as if they had been converted to producers. Dependent upon the parameters and the dynamics of the model, this process will produce a collection of simulated organizations which are adapted to their environment, and exhibit varying degrees of structure.

At one extreme, would be a conservative, hierarchical organization. The organization consists of a top leader, and a set of groups, each headed by subordinate leaders. At the other extreme, most of the successful individual producers and groups would remain independent and continue to produce at their respective locations on the creative domain. Such an organization would be representative of a flat, entrepreneurial organization. The entrepreneurial structures should produce a greater variety of products than the more hierarchical organizations.

Stage two is the process by which the group, with structure held constant, attempts to create new products after the environment has changed. A change of environment means that the product positions for each group and independent producer are set back to zero and they are required to produce new candidate products. During stage two the groups formed in stage one produce candidate products in a manner similar to individual production during stage one; except the unsuccessful, or less successful, groups are not absorbed by other groups. Groups accumulate gains and losses at the last successful product before their first failure in the same manner as individuals did in stage one.

Idealized Profitability

The model uses two primary profit measures to compare the effectiveness of the organizational structures it produces. The first measure, defined as short-term profitability, is the organizations *expected* rate of return, assuming that it maintains the organizational structure and product mix from stage one. The second measure, defined as long-term profitability, is the organizations *expected* rate of return for a new product mix selected after the market environment has changed. These measures are not measures of actual quantities but of expected rate of return per unit time for the entire organization. In this sense, the measures are actually projections of future profitability based on the organization's structure and product mix.

The profitability measures are derived by multiplying the rate at which each group can produce its product by that product's expected value. The expected value is the net financial gain from the product, if selected, multiplied by the probability of selection, minus the financial loss if the product is not selected times the probability of not being selected. The rate at which the product can be made is proportional to the number of individuals in the group producing that product. Thus larger groups tend to produce more products per time period than smaller groups do.

Simulation Methodology

This section provides a general description of the methodology used in the model. Each replication of the computer simulation produced a single organization. The primary outputs of the simulation include (1) number of independent groups within each simulated organization, which could be groups with leaders or independent producers, (2) functional composition of each organization, which includes the number of failures, supporters, producers and leaders, and (3) profitability. These output variables are functions of the set of initial conditions for the model and the model dynamics.

The initial conditions are represented by model parameters which specify the size of the organization (number of individuals initially assigned to the creative effort), the creative ability of each individual, the level of creativity exercised by leaders, the uncertainty in the simulated economic environment, and the level of responsiveness of individuals and groups to others within the organization.

Base Case Model Parameters

Since the objective of the model is limited to demonstrating qualitative relationships, no attempt was made to fit the model parameters to empirical data. The parameters related to individual creativity were normalized to be evenly spaced between zero and one and the environmental selection parameter was set at .5 as an aid in comparison. More specifically, individuals were randomly assigned divergent and convergent parameters of .25, .5, .75, and 1.0 according to a discrete uniform distribution. Individual responsiveness was measured by a parameter that will be referred to as *response.* Within stage one, within each organization, each individual was assigned the same response parameter. Simulation runs were made with the response parameters set at minus infinity, -1 0, 1, and infinity. A minus infinity value describes a situation analogous to pure competition. Individuals are completely independent and unresponsive to their neighbors. They become candidates for state change only if they fail as producers.

Negative response values indicate resistance to influence by neighbors and by extension relative unresponsiveness to environmental feedback. A response value of zero describes a situation of relative indifference where the individual is equally likely to maintain its present state or choose to join a more successful neighbor. Positive response values correspond to an altruistic environment where individuals are more likely to join a more successful neighbor than maintain their own states. At a response value of infinity, an individual will always join a more profitable neighbor. Leader creativity was simulated at both high and low levels for each selected value of the response parameter.

An exponential distribution with a parameter of .5 was used for the base case failure rate in the selection environment which corresponds to the simple economic environment used in the model.

Mathematical Description

This study models the creative process as a stochastic discrete event dynamical system driven by a *generalized semi-Markov process*. The events in the model are the products output by the individuals in the organization. These individual creative outputs are generated by independent *consumable* random variables. An *intensity parameter* associated with each random variable determines the rate at which the random variable is consumed, and, after consumption, another random variable is generated from the same distribution. In this study, realizations of the random variables represent creative products and the intensity parameters determine how fast the products will be produced. Since, for each individual creator, the probability of producing a product during an arbitrarily short period of time may be assumed to be very small, and the creative rates can be assumed to remain fairly constant, a Poisson probability distribution with exponential inter event times serves as a reasonable approximation.

The final element in the generalized semi-Markov model is a transition probability function which determines whether or not the event will be accepted. In this study, the transition function models selection of the product by the external field or market. The assumption that novel or creative products would, in general, be more costly and shorter in supply than other less novel products is consistent with current economic theory and argues for a non increasing (or downward sloping) demand curve. This seems to justify using an exponential probability distribution to approximate the transition function.

Creative events occur, in continuous time, as dimensionless point masses on the creative domain which is represented by the non negative real number line. The events (products) produce cumulative financial gains and losses for the individuals who generate them. The gains and losses, which are measured in arbitrary financial units, are assumed to be directly proportional to the product's distance from the zero point on the creative domain. This dynamic process is linked to and interacts with the organizational structure which is modeled as a *random field.*

A random field is a random variable defined over a set which takes its values in the *state space* of the elements of the set. The random field can be regarded as a collection of random variables (one for each element of the set) or, equivalently, as a vector. In this study the elements in the set are the individuals assigned to the organization. The individuals' state space consists of the assigned organizational function (lead, produce or support) and the point on the creative domain at which the individual is producing or supporting. The differences in cumulative gains generate financial potentials between the individuals which influence changes in the individuals' organizational state. Under the conditions of the model, the random field can be more explicitly described as a Markov random field. The Hammersly-Clifford theorem tells us that probability distributions for Markov random fields are equivalent to Gibbs distributions, assuming certain conditions are met (which they are in this model). Therefore, the financial potentials can be modeled as Gibbs potentials with transition probabilities given by a Gibbs distribution.

Definitions

This section provides a mathematical description of the organization. First, I will provide a mathematical description for the individuals in the organization:

$\{S\}$ is a set of individuals, $\{s_1 \ldots s_n\}$ assigned to an organization.

$\{R\}$ is the set $\{r_{s1} \ldots r_{sn}\}$ of parameters representing individual convergent creative ability for each individual in $\{S\}$.

$\{V\}$ is the set $\{v_{s1} \ldots v_{sn}\}$ of parameters representing the convergent creative ability which is equivalent to a time rate productivity for each individual in $\{S\}$.

Next I describe the organizational positions of the individuals in terms of the set of states they can assume within the organization:

$\{\Lambda\}$ is a denumerable set of states, $\{\lambda_1 \ldots \lambda_n\}$ for S.

The states represent the organizational function assigned to each individual in S (production, support and leadership, and the particular product associated with each individual).

I now define the relationships among the individuals in terms of a random field:

X is a random field defined over S which takes its values in Λ.

More specifically, X is a Gibbs field with transitions probabilities for the individuals being determined by a Gibbs distribution (see below for a description of the random field and Gibbs distribution).

Now that I have described the individuals and the manner in which they relate, I can describe the process by which they produce creative products:

Y is a generalized semi-Markov process, which is a stochastic system driven by a collection of random point processes, N.

Individual production is described as a Poisson process with exponential inter event distances. The individuals in S compete in time to produce successive creative outputs on C.

N assigns random inter event times for the outputs.

C is a one dimensional space of products on R^+ $[0, \infty]$.

H is a selection function that accepts or rejects each output on C at each event time.

H represents the uncertainty in the environment and also reflects the market preference for novelty. H is assumed to follow an exponential probability distribution.

Z is a collection of functions which calculate a set, $\{A\}$, of economic performance values such as cost and profit for creative production.

$\{A\}$ provides a description of the economic performance of the individuals and the organization as a whole.

The Stochastic System

Using the above definitions, we can give a concise description of the stochastic system used as a basis for the model:

$X(A): S \rightarrow \Lambda$

$Y(N, H): S \times \Lambda \rightarrow C$

$Z: S \times \Lambda \times C \rightarrow A$

$\Omega: S \times \Lambda \times C$ represents the space of possible configurations for the organization.

$F(S, \Lambda, C)$ is a probability distribution, in product form, defined over Ω.

Functional Forms

In order to move from a general description to a form suitable for simulation, a more detailed description of the model is provided below:

The probability density function for outputs on C is exponential,

$$re^{-rc} \qquad (1),$$

where r is specified for each individual.

The probability density for the number of outputs on C is Poisson,

$$(rc)^n e^{-rc} / n! \qquad (2)$$

The probability density for distance to failure on C is exponential,

$$he^{-hc} \qquad (3)$$

The probability density for number of failures on C is Poisson,

$$(hc)^n e^{-hc} / n! \qquad (4)$$

The probability of the joint event that one or more outputs are produced in the interval [0, c] and no failure has occurred in this interval is

$$e^{-hc}(1 - e^{-rc}) \qquad (5)$$

The profit and loss functions are represented by *ac* and *bc, respectively.*

The total profit for a set of products, represented by points on *C*, is given by,

$$A = \sum_i ac_i 1s - bc_i 1\bar{s}\ , \qquad (6)$$

where s and $\bar{s}$ indicate selection and not selection respectively.

Markov Random Field

Let S be a set $\{s_i; i = 1, N\}$.

Let Λ_{si} be the state space of s_i.

Let $\prod_S \Lambda_{si}$ be the configuration space for S (in product form) which can be written as Λ^s if all s have the same state space.

N_s is the neighborhood system for s.

$\{C\}$ is a collection of cliques in S such that all s in a clique are mutual neighbors. Two sites s and t are mutual neighbors if s is a neighbor of *t implies* that *t* is a neighbor of *s*.

V_C is a potential function defined over a clique.

$E(S) = \sum_i V_{ci}$ is an energy function defined over S which is the summation of the potentials in each clique. A singleton can also be a clique.

$X(S)$ is a vector-valued random variable over S that takes its values in the state space Λ^s for each s.

$\Pi_T(X) = Z_T^{-1} \exp^{-(T^{-1}E(X))}$ is a Gibbs distribution defined over $X(S)$.

$\Pi^s(X) = P(X(s) = x(s) \mid X(N_s) = x(N_s))$ is the local specification of the Gibbs distribution which gives the probability distribution of X at element s, conditional on the neighborhood system of s.

The Gibbs Distribution

In the base case study model, each individual has one neighbor -- the individual closest in absolute distance that has a greater accumulated economic profitability. The parameter T^{-1} in the Gibbs distribution is the response parameter in the model. If A_n is the profitability of the neighbor and A is the profitability of the individual being examined, then the conditional probability that the individual changes state to produce the neighbor's product is given by $1/(1+\exp-(\kappa*(A_n - A))$, where κ is the response parameter. The probability that the individual will maintain its current state is $\exp-(\kappa*(A_n - A))\ /(1+\exp-(\kappa*(A_n - A))$.

Chapter 3

Analysis

A Simple Case

The dynamics of the model are too complex to be fully described in closed form. In other words, we cannot determine exactly how the model will perform simply by manipulating the equations. Consequently, the model results are obtained mainly through simulation. Nevertheless, some important general results may be derived directly from the mathematical description and this will be done in this chapter before resorting to simulation, which will be covered in Chapter Four. The non-technically oriented reader may skip to the final section of this Chapter (Implications) and then proceed to Chapter Four with no significant loss of understanding. For the more technically inclined, the mathematical description provided in Chapter 2 should provide adequate background for understanding the following sections.

As a first step in analysis, the mathematical framework provided in Chapter 2 is applied to the simplest possible organization- a single producer that interacts with only one other individual. The expected value of the individual's divergent creative ability, (which will alternatively be referred to as divergence, divergent production, or creative range) is assigned a value of $1/r$, which is the expected value of the exponential distribution given by equation (1). We *can* also view r as the expected number of products per unit distance on C, since r is the rate parameter of a Poisson probability distribution (equation (2)). This means that, on average, the individual can expect to move a distance of $1/r$ from its last successful product location. Thus, as r increases, the distance between creative products decreases

Profitability and Product Position

Assume that the market selection function which gives the probability of product failure is a monotonically decreasing function of *C with* probability density *g(c) and* cumulative distribution function *G(c).*

The profit and loss functions are represented by *aC* and *bC, respectively.*

The total profit for a set of products, represented by points on *C*, is given by equation (6) as:

A = $\sum_i ac_i 1s - bc_i 1\bar{s}$, where s and $\bar{s}$ indicate selection and not selection respectively.

If b = 0, the expected profit, E(*A*), at point *c* is:

$E(A) = a\,c(1 - G(c))$,

Maximizing this function with respect to c gives,

$c = (1 - G(c)/g(c)$.

As an example, if *g* is exponential with failure rate parameter, *h*, as in equation (3) then profit is maximized at $c = 1/h$.

The profitable range for *c* if $b>0$ can be found as follows:

Set $E(A) = a\,c(1 - G(c)) - bcG(c) = 0$ and solve for *G(c),* which is the probability of failure before *c*. This gives,

$G(c) < a/(a+b)$, and $c < G^{-1}(a/(a+b)$ as the criteria for an economically successful product point.

If g is exponential, as above, then $0 < c < -(1/h)\ln(b/(a+b))$ is the profitable range and the maximum profitability is given by the solution to,

$$G(c) - c\partial\frac{G(c)}{\partial c} + a/(a+b) = 0\text{, or } e^{-hc}(1-hc) = b/(a+b) \text{ for the exponential}$$

form.

Profitability and Individual Creativity

The above shows that, as costs increase from zero to infinity, or as *a* approaches zero, the maximum profit point decreases from 1/h to zero. If we designate the maximum profit point as c^*, then an obvious question is how do we maximize the probability of successfully finding and producing at this point?

Assume a policy that has the individual produce at the last successful point before the first failure. In this case, we would want to succeed as closely as possible to c^*, and fail on the next step. We can show that an individual with an expected creative range (1/r) equal to c^* is most likely to achieve this goal.

The expected number of steps to reach c^* is rc^*, and the probability of successful selection, P (c^*), at c^* is less than or equal to the probability of selection P(c) at any point less than c^* since the selection function is monotonically decreasing on C. The probability, P(S), of successfully reaching c^* is therefore greater than or equal to $P(c^*)^n$, where n is equal to rc^*, the expected number of steps required to reach c^*. But P(S) for n =1 is greater than P(S) for any n >1. Therefore we conclude that, $r^* c^* = 1$, and $r^* = 1/c^*$ is the optimal r to reach c^*.

Given that the point is at c^*, the expected next point is $c^* + 1/r^*$, and since $1/r^* > 1/r$ for any other r considered above, and since the probability of failure increases monotonically on C, then the probability of failure at the next step is also greatest at r^*.

Individual and Group Dynamics

In the base case study model each individual has one neighbor-- the individual closest in distance that has a greater accumulated economic profitability from its candidate product. The parameter T^{-1} in the Gibbs distribution is the *response* parameter in the model. The probability that the individual will join a more productive one is given by the local specification of a Gibbs distribution.

The local specification for the single neighbor case gives the probability of changing state to support a neighbor as $1/(1+\exp-(\kappa*(A_n - A))$, where κ is the response parameter, A_n is the profitability of the neighbor and A is the profitability of the individual being considered for state change. The Gibbs potential is given by the factor $A_n - A$. Since no two independent distinct individuals or groups will produce the same product, the potentials must necessarily increase over time. As with two runners in a footrace, the faster will over time pull farther away from the slower. Direct examination of the above equation for the local specification shows that, for non negative values of the response parameter, the probability of an individual joining a neighbor approaches one as the Gibbs potential increases. We should expect, therefore, that, in this case, eventually the less productive individuals will be absorbed by more productive ones, resulting in a highly structured organization with only one group. Group structures arising under negative values of the response parameter, on the other hand, may or may not be highly structured, but overall they should be less structured than the organizations having non-negative response parameters. It is important to note, however, that, since profitability is a random variable, the outcome for any particular individual cannot be precisely determined.

Implications

Under the assumptions given in this section, an individual will produce until the first failure and then continue to produce at the last successful point until either its profitability becomes negative, it is absorbed into another group, or the termination criteria for the simulation is met. The weak law of large numbers tells us that the empirical proportion of successes at a production point will eventually approach the probability of success at that point; and, if an individual, or a collection of individuals, were allowed to repeatedly start over and find new creative points, an empirical estimate of the selection function could be obtained over time. As information on successful points accumulates, individuals, organizations and markets begin to learn the shape of the selection function and resources are shifted toward more successful products. As a product becomes more successful, the market will shift, at some point, and the product will loose its novel status. The product will then become a norm, and be a point of departure for other creative products. Thus, a successful creative agent needs to be able to quickly find an economically feasible point and produce at a rate fast enough to realize an acceptable gain before the market shifts.

The foregoing analysis indicates that an organization consisting of independent creative individuals should profit best by starting out with a large and diverse population of fast producers in order to quickly learn market preferences. Since most of these producers would fail at suboptimal or economically unfeasible points, the benefits of creative performance could eventually be outweighed by the benefits of copying the most successful products. On the other hand, production of a variety of suboptimal products could provide a hedge against an unanticipated shift in the economic environment.

Performance following an environmental shift (holding organizational structure constant) would give an indication of an organization's robustness. Organizational flexibility and adaptability are indicated by performance with modified organizational structures.

Traditional theory might predict that performance under high levels of uncertainty would be best with a mix of highly creative producers and leaders making a variety of products under an entrepreneurial structure. More specialized organizations, with fewer products being produced by a less creative mix of producers and leaders might be expected to do best under more stable environmental conditions. Unfortunately, analytic validation of general theoretical predictions and common sense assumptions becomes increasingly difficult as analytic models increase in complexity. Therefore, this seems to be a reasonable point of departure for further extension using Monte Carlo simulation.

Chapter 4

Simulation Results

This chapter discusses the results of the simulation as they pertain to the issues raised in the *Unresolved Questions* section of this dissertation. Following a brief summary, the relationship between individual creativity and organizational creativity will be discussed. Then, the effect of interactions between individuals and groups of individuals on the evolution of organizational structure, and the relationship between organizational structure and profitability will be presented. Next, the influence of leader creativity on organizational profitability will be examined. The chapter concludes with a discussion of the sensitivity of the model to its initial parameters and assumptions.

Summary of Results

The model did, in fact, produce a wide range of organizational structures which can be readily differentiated in terms of their relative profitability in both stage one and stage two. During stage one (organizational formation stage), organizations resembling the flat, entrepreneurial types were produced by negative response values. These organizations tended to have multiple independent groups, with each group producing a single product. Organizations resembling traditional, highly integrated, hierarchical types were produced by responsiveness levels which were zero or positive. These kinds of organizations tended toward a relatively small number of groups and products.

These results extend, and are consistent with, the analysis provided in Chapter Three. However, as the following sections will show, the performance of organizations in the simulation - as measured by their ability to create profitable new products - seems to contradict both the idea that increases in structure will necessarily result in a decreased ability to adapt and innovate, as well as the notion that reductions in structure are required in order for a highly structured organization to increase creative performance. The simulation also indicated that, beyond a point, increases in both individual and leader creativity may not improve, and may actually detract from, organizational creativity.

Individual Creativity

Individual creativity, as measured by divergent and convergent ability, was an important factor, but neither more nor faster turned out to be better. For example, as indicated by Table 1, individuals with divergent parameters of .25 (which means that expected distance between creative products is 4) experienced a sixty six percent failure rate. On the other hand, the least creative individuals (those having a divergent parameter of 1 and a distance between products of 1) experienced the lowest failure rates of only thirty four percent. Since the individuals assigned to the "fail" state are those that fail to produce a successful product on the first try, these results should not be surprising, and, in fact, for a sufficiently large number of trials, can be estimated by the theoretical probability that the first failure occurs before the first successful product.[1] For example, the theoretical probabilities of .66, .5, .4 and .33 that individuals with divergence parameters of .25, .5, .75, and 1, respectively, will fail on the first attempt, closely match the observed percentages of fails given in the second column of Table 1.

[1] The probability is h/(h+r), where h and r are the exponential failure rate and divergence parameters, respectively.

Table 1. Creativity and Organizational Function

	Organizational Function			
divergence parameter	fail	lead	produce	support
.25	66.0%	16.5%	9.1%	8.3%
.50	50.3%	20.6%	15.3%	13.9%
.75	40.3%	22.1%	20.3%	17.3%
1.00	34.2%	24.3%	21.5%	20.0%

The most successful individuals were not the fastest producers, either. For example, the individuals least likely to become leaders were those having the fastest production ability (convergence parameter equal to 1) and the greatest creative range (divergence parameter equal to .25). About ten percent of the individuals in this category emerged as leaders compared to the overall average of about 20 percent over all convergence and divergence values. The greater creative range made these individuals more likely to select a candidate product outside the profitable range, and then the higher convergent rate caused them to accumulate losses at a faster rate.

Analysis in chapter 3 predicted that the most successful individuals should be those having a creative range (the reciprocal of the divergence parameter) as close as possible to the value of the maximum profitability point, which for the baseline model was at .63. This result is obtained from the solution to $e^{-hc}(1-hc) = b/(a+b)$, as discussed in chapter 3, were h is equal to .5 and a and b are equal to 1. In the model, individuals with divergence of 1 were closest to .63 and, as shown in Table 1, were also the most successful in terms of percentage of leaders and producers. Table 2, demonstrates that these individuals were also more successful in terms of their profitability.

The average product locations for individuals can also be fairly accurately predicted by the location where the probability of successfully producing one or more products is maximized. This is the probability of the joint event that one or more products are produced in the interval [0, c] and no failure has occurred in this interval.[2] Table 2 compares results of the simulation with the theoretical predictions and also provides the expected unit profit at each product location. As can be seen, the theoretical predictions closely match the empirical observations of the average product locations for a simulation of only 300 organizations.

Table 2. Observed and Theoretically Predicted Product Locations

Creative Divergence Parameter	Observed Product Locations	Theoretically Predicted Product Locations	Expected Unit Profit
.25	1.6	1.6	-.16
.50	1.4	1.4	-.01
.75	1.3	1.2	.05
1.00	1.2	1.1	1.2

Taken together, Table 1 and Table 2 show that, on average, the individuals having creativity levels which most closely match the selection environment are the most successful. However, the tables should not be interpreted to mean that the least creative individuals should always be more successful. For example, if the maximum profitability point had been at 4 instead of .63, greater success for those individuals having a divergence parameter of .25 would be predicted. This suggests two important points. First, the creative mix of individuals strongly influences the absolute number of individuals that will survive to participate in the creative process, and the least creative

[2] The probability is maximized at $c = (-1/r)\ln(h/(h+r))$, where r and h are exponential rates for failure and production, respectively.

are, in fact, more likely to survive to participate further (given the unforgiving policy of the model). Second, what the appropriate creative mix should actually be, is strongly dependent upon the selection environment. Since the characteristics of the selection environment are considered to be unknown to the producers, these two points imply that diversity in the initial mix of individual creativity is desirable in order to maximize the chance of identifying a profitable mix of products. On the other hand, this same diversity will lead to a high number of initial failures.

Group Composition

The most important determinant of organizational structure was the nature of the interactions between individuals and groups of individuals which, in turn, was determined by the responsiveness parameter in the model. These relationships are summarized in Figure 2.

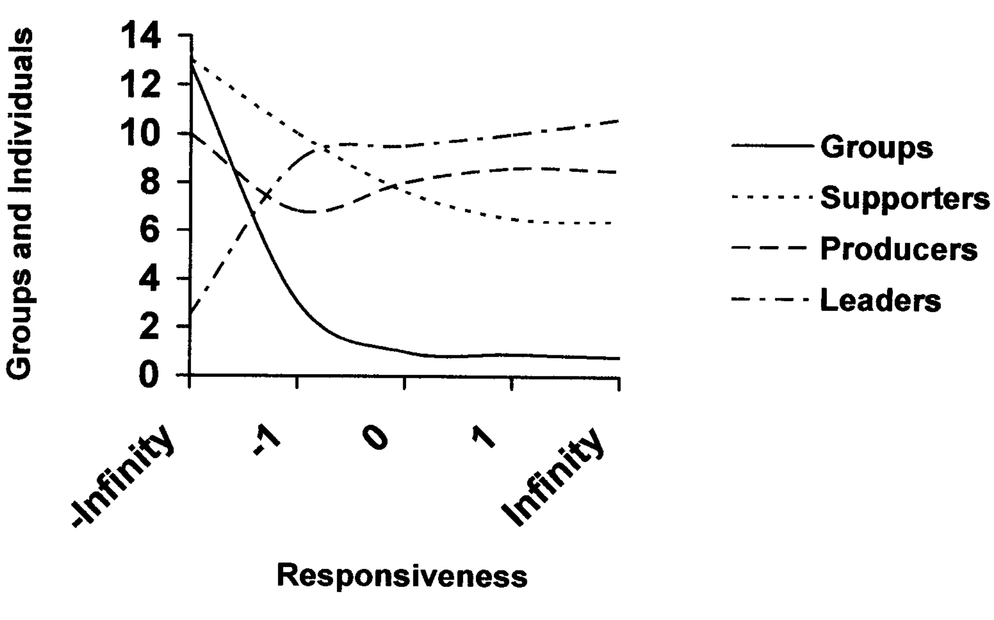


Figure 2. The relationship between organizational composition and responsiveness for an initial organization size of fifty individuals.

The simulation starts with all individuals being producers. At a response level of minus infinity, only failed individuals are assigned to support and only failed groups are absorbed by other groups. As the response level increases from or minus infinity to zero, both the average number of groups and the average number of supporters decrease relatively quickly, and then continue to decrease at a much slower rate over the positive responsiveness values. The number of leaders, on the other hand, increases rapidly over negative sensitivity values and then increases at a much slower rate at sensitivities from zero to infinity. This shift in organizational composition away from supporters and toward leaders and producers is caused by the increased probability for individuals to join neighbors as sensitivity increases. In other words, at high responsiveness levels, fewer individuals will be converted to support because they will tend to join more successful neighbors before they fail. When they do so, the more successful neighbors are converted to leaders.

While figure 2 provides the average number of groups at each responsiveness level, Figure 3 depicts the *distribution* of groups at the two extremes of responsiveness.

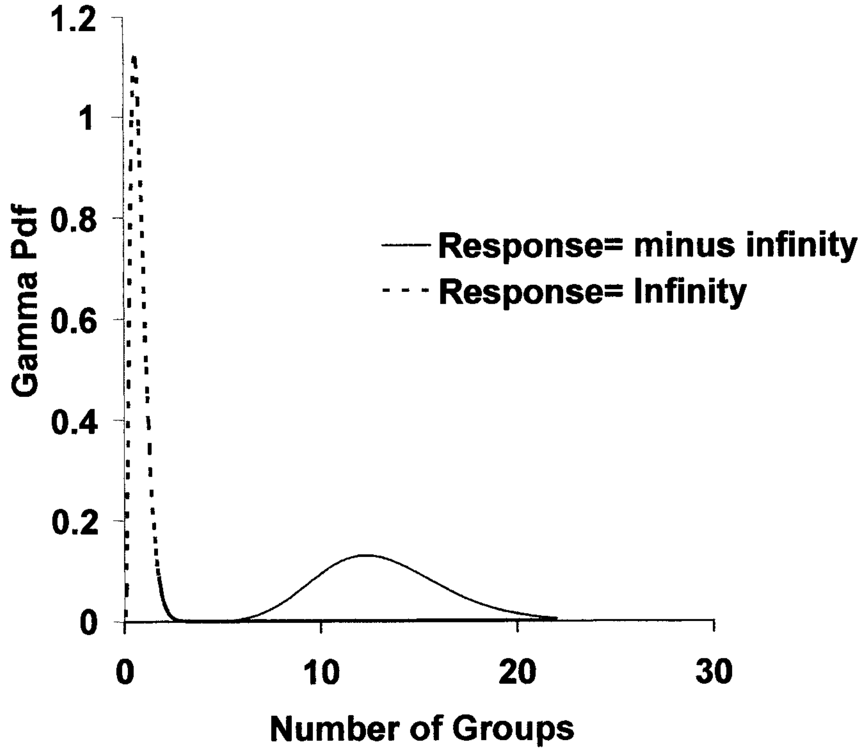


Figure 3. The distribution of groups for response levels of minus infinity and infinity, and initial group size of fifty individuals are approximated by Gamma (17,1.3) and Gamma (4, 5), respectively.

As predicted in the Chapter 3 analysis, the organizations tended to be highly integrated and tend toward a single group with response levels of zero or greater. The group distributions for simulated organization having ten, fifty, and one hundred individuals can be approximated by a family of Gamma probability distributions, with a unique distribution for each response level and each organization size. For example, the distributions for organizations of one hundred individuals were Gamma (30, 1.3) and Gamma (6, 7) for responsiveness levels of minus infinity and infinity, respectively. However, the graphs in figure 3 are for organizations of fifty individuals that are representative of the distributions of the two extremes of organizational structure: the highly diversified, entrepreneurial type and the highly structured, conservative type. The next section will show that responsiveness and the resultant organizational structure have an important impact on organizational profitability in both the short and long term.

Individual Responsiveness, Structure and Profitability

Recall that stage one of the model is the group formation process where individuals start as independent producers and are consolidated into various organizational structures consisting of supporters, producers and leaders. Stage two is the process by which the group, with structure held constant, attempts to create new products after the environment has changed. The individual response parameter is active only during stage one and, consequently, has a direct impact only on short term profitability.

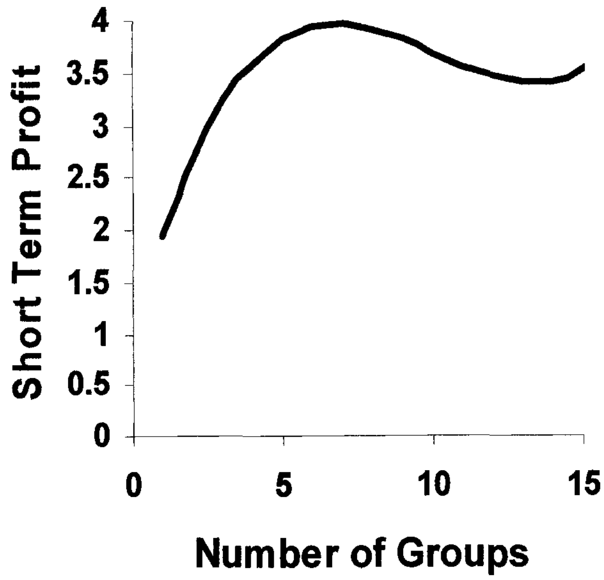
Table 3 shows the relationships between individual responsiveness, group structure, and short term profit. Running the model with the response parameter not activated is equivalent to a response of minus infinity. Decreases in profitability as well as an increase in the number of failed organizations occur if the response parameter is too high because individuals and groups begin to join others which may be only marginally effective or eventually non successful. Profitability is also significantly degraded if the response parameter is activated immediately in the simulation because the individuals will be more unlikely to have successful neighbors to join. This is equivalent to abandoning ones own product in favor of another before having a sufficient number of observations to make an effective decision. If the response parameter is activated too late, model performance is approximately the same as with a response parameter of minus infinity. The response parameter for the base case simulation discussed in this section was set to activate when the number of candidate products was equal to the number of individuals in the organization.

Table 3. Individual Responsiveness and Short-Term Profit

Individual Responsiveness	Number of Groups	FAIL	Number of Supporters	Number of Producers	Number of Leaders	Short Term Profit
Null	12.953	23.7833	13.1333	10.4500	2.6333	2.3545
-1.0	2.923	23.6400	10.0500	7.1633	9.1467	3.0948
.0	1.010	23.4900	7.4267	8.9767	10.1067	2.1267
1.0	.890	23.7533	6.3933	9.4500	10.4033	1.8506
Infinite	.887	23.7233	6.3967	8.9933	10.8867	1.8863

Note. The table entries indicate the averages over 300 simulated organizations for each individual responsiveness level for organizations of fifty individuals.

The main importance of individual responsiveness lies in its role in determining the distribution of the number of groups and the product mix the groups represent; which, in turn, determine the organization's profitability. Figure 4 shows that short-term profit rises sharply as the number of groups increases beyond one and then drops off. Long-term profit, on the other hand, drops off rapidly as number of groups increases beyond one and then levels off at negative profitability. So, the increased short-term profitability associated with increasing the number of groups carries a risk of greatly increased losses in the event of an environmental shift.



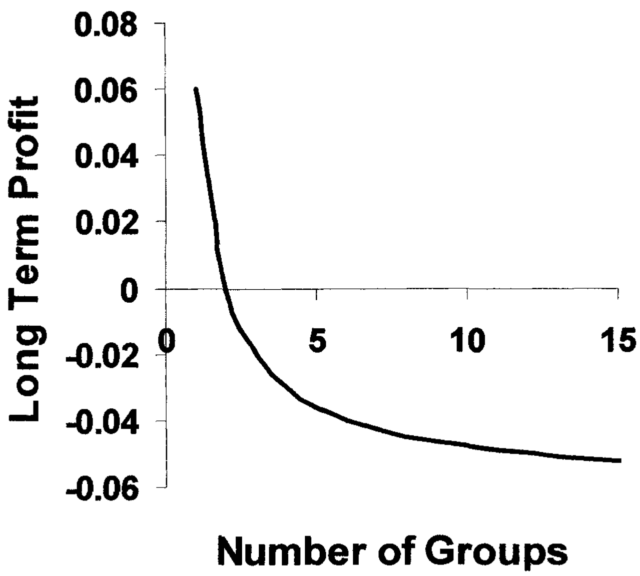


Figure 4. Expected short-term and long-term profit as a function of number of groups for an initial organization size of fifty individuals.

Approximating functions for short- term and long-term profit can be derived using polynomial regression. Short-term profit is approximated by $Y = .98 + 1.07X - .12X^2 + .004X^3$, where Y is short-term profit and X is number of groups greater or equal to 1 formed from initial organizational populations of 50 individuals. Long-term profit for the same organizations can be approximated by $Y = 1.09 - 1.2X + .075X^2$ for number of groups greater or equal to 1.

Profitability during stage two is only indirectly dependent on the response parameter since responsiveness only affects the interaction between individuals and groups during the process of group formation, and organizational structure is held constant during stage two. The primary determinants of long-term profitability during stage two are the level of leader creativity during this stage and the organizational structure developed during stage one. Short and long-term profitability given in Figure 4 correspond to the data in Table 3 and Table 4, respectively.

Leader Creativity and Long-Term profitability

Organizations produce creative outputs during stage two by producing until the first failure occurs in a manner similar to individual production during stage one. The major difference being that the organizational structure is constant in stage two and the level of leader creativity is varied. This inability of the organizations to further adapt and reorganize is one reason that profitability is consistently less for stage two than for stage one.

Low leader creativity produced more profitable results than high leader creativity when averaged over all organizational structures (see Table 4). Additionally, the more structured organizational types consisting of fewer independent groups outperformed less structured groups for all values of leader creativity and all sensitivity levels for both stage one and stage two (see Figure 3, Table 3, and Table 4).

Table 4. Leader Creativity and Expected Long-Term Profit

Leader Creativity	Responsiveness	Expected Long-Term Profit
High	Null	-2.2479
	-1.0	-2.0212
	.0	-.1062
	1.0	.0802
	Infinite	.0490
Low	Null	-1.4213
	-1.0	-1.6077
	.0	-.4592
	1.0	.6050
	Infinite	.6877

Note. Significance is $F(1,135) = 3.77$, $p = .05$.

The reason highly structured organizations continue to perform better during stage two is, surprisingly, because they are less creative than the more unstructured ones. The reduced creativity is due to the leaders' creativity being moderated proportional to the number of individuals in the group. So, leaders of large groups tended to be less creative in their product selection than leaders of small groups. Recall that under low leader creativity a leader's divergent parameter is multiplied by the number of individuals in the leaders group. Their creative products were therefore produced in smaller incremental steps which reduced the risk of failure. Organizations which were too creative failed more often in stage two for the same reasons that overly creative individuals failed more often in stage one. That is, they tended to produce beyond the profitable range. A major difference is that failure of any single individual during stage one has only a minor impact, while failure of even a single group during stage two has a major impact on the organization. Similarly, organizations with high leader creativity are more likely to fail than organizations having low leader creativity. These results suggest that, once a profitable mix has been found, when the fate of the entire mature organization is at stake, moderate or low levels of leader creativity in selecting new products is probably the best overall strategy.

Model Robustness

The selection parameter was tested at .1, 25, .75, and 1, in addition to the base case of .5. Several intermediate positive and negative values of the response parameter were also tested. The main influence of these variations was on the absolute value of the derived results and on the run times for the computer simulation. For, example, when the probability of selection was increased the organization became more profitable and a greater variety of products were produced. Consequently, a longer run time was required for the model to converge to an *adapted state*. The organizations were considered to be in an adapted state when the expected short-term profit values of all the independent groups had become positive in Stage one.

The model was also sensitive to the amount of time (or equivalently, to the number of products produced) spent in Stage one. The major impact of spending too little time in Stage one was that the organization would not have time to converge in structure and eliminate or subordinate lower performing groups. This result is equivalent to an environmental change before the organization has had enough time to adapt an effective structure under the existing environment.

The simulated organizations eventually converged to a single group, as predicted by the Chapter 3 analysis, if the response parameter was zero or larger, and the model was kept in Stage one for a sufficiently large number of repetitions. However, since the primary objective of the simulation was only to generate a variety of organizational structures for comparison and not necessarily to observe the steady state configurations, the model was terminated in stage one after the organizations had reached an *adapted state*. Using the baseline policy of producing a number of products equal to ten times the number of individuals resulted in 95 to 98 percent of the organizations converging to the theoretical steady state by the end of stage one. This indicates that all unprofitable groups had either failed or been absorbed by a more profitable neighbor. The organizations converged to the same basic configurations, and the qualitative relationships which are discussed in this chapter and the next remained valid over the range of parameters and numbers of repetitions described in this section.

The model was also tested with several different sizes of organizations. For organizations having initial populations of ten, twenty, fifty, and one hundred individuals, the qualitative relationships and relative distribution of organization types remained essentially the same. Additionally, as demonstrated in Table 5, outputs were directly comparable when they were transformed to a per capita measure by dividing by the number of individuals in the organization. Table 5 shows, for example, that organizations beginning with 10 individuals averaged .08 groups per individual and organizations beginning with 50 individuals averaged .09. The percentages are very close even though the organizations of size 10 were averaged over only 400 simulated organizations while the percentages for organizations of size fifty were taken from 2700 organizations.

Table 5. Comparison of Group Composition for Organizations of Sizes Ten and Fifty

Organization size	Groups	Fails	Support	Produce	Lead
10	.0818	.4567	.1924	.1798	.1711
50	.0914	.4738	.1799	.1819	.1644

Chapter 5

Conclusion

This chapter provides conclusions based on the results of the simulation and, as such, they may or may not be valid for actual organizations. Similarly, they may support, and be supported by, some existing studies and refuted by others. This study models idealized behavior of organizations as they attempt to create innovative products. However, enhancement of organizational creativity is certainly not the only reason for considering changes to organizational structure, and increased creativity is certainly no guarantee of increased profitability.

Nonetheless, the model results are consistent with many observations of real world organizations that show high failure rates for organizational downsizing and restructuring efforts. Additionally, although the model results may contradict some of the traditional views of organization theory, they are not inconsistent with much of the existing work in creativity. The model is actually highly supportive of the ideas and findings of several leading creativity researchers (King, 1995; Lubart & Sternberg, 1996; Simonton, 1984, 1988; and Weisberg, 1986, for example). However, I have been unable to find any study for comparison which, like this one, examines the relationship between organizational structure and the creative process in a large number of organizations over the organizational life cycle from initial formation to performance under environmental change. Therefore, instead of trying to reconcile the model with existing research, this section will simply state and briefly discuss conclusions from the simulation and end with possible strategic and leadership implications of the findings, and a recommended empirical research agenda which could expand upon them.

Main Conclusions

The simulation shows a strong relationship between the creative process and organizational structure. But, successful creative production is not a direct result of any particular structure. Instead, it is the result of the interaction between structure and process as the organization produces a collection of creative products and organizes itself to produce a profitable combination of them. Therefore, it seems reasonable to conclude that a proper understanding of organizational creativity requires an examination not only of organizational structure, but of the process by which the structure was created.

The model suggests that reducing structure or increasing the autonomy of individual producers or subordinates should not be expected to yield increased creative performance. The least successful organizations were not highly structured organizations that failed to reduce structure in response to environmental change. Instead, the poorest performance occurred amongst organizations that fail to build structure and reap the benefits of specialization on a core product. The most profitable organizations were those that converged to highly integrated structures, produced only a limited number of products, and which exercised low levels of leader creativity.

Independent producers and small groups often produced products having a higher unit value than the products produced by the larger, dominant groups; but with fewer members in the groups, the total profit rate was lower. In other words, ability to satisfice by quickly settling on a profitable product and then recruit neighboring individuals to support it was more important than ability to optimize by finding the most profitable product.

Under low leader creativity the products will be more alike. In the model, this means products are closer together and the incremental steps between products are smaller. Smaller incremental steps reduce the risk of failure for organizations and groups, just as they do for individuals. Thus, creative production in these more successful organizations could be described as conservative and incremental. These types of organizations were also the most robust with respect to their ability to produce successful new products after a change in their environment.

Effective creative production was strongly related to the degree of responsiveness of the individuals to their neighbors, and by extension to their environment. Since an idealized model was used, the model parameters do not tell us, in any meaningful way, what the optimal amount of sensitivity actually would be in a real world organization. Yet, the model shows that a clear maximum does exist. Somewhere between the pure competition, represented by minus infinity responsiveness in the model, and total acquiescence to any more profitable neighbor, represented by large positive values of the response parameter, performance rises sharply to a maximum and then drops sharply beyond it.

Strategic Implications for Leaders

In view of the foregoing, a simple, general strategy for developing an adaptive organization might be to first ensure diversity in the mix of creative individuals and provide adequate numbers of individuals to allow for failures during the organizational formation stage. The model further indicates that the organization should then effectively self organize, if the sensitivity parameters are set to the appropriate levels. This is, of course, much easier to accomplish in an idealized model than in an actual organization.

Real people, unlike the parameters in a simulation, are not easy to tune. Some are more likely to seek independence and others prefer cooperation, but the model tells us something between these extremes is best. Leaders can also be expected to differ in their openness to influence. In fact, knowing that individuals differ widely in their creative abilities, one might expect that some leaders would, over time, develop superior creative ability and insights that would be better left unmediated by group influence. In general, however, as evidenced by the cases of Thomas Edison and Henry Ford, even superior creative ability and a record of past success does not necessarily imply an ability to successfully forecast the market response and resultant profitability for a new idea or product. This ability cannot be guaranteed by past business success either, as illustrated by the case of Bob Gannon and Montana Power (CBS News.com, 2003).

In short, an adequate number of creative individuals with adequate diversity in their creative abilities is desirable in the organizational formation stage in order to ensure a diverse mix of candidate products. But, it is essential that the individuals quickly select and organize around a relatively small number of these products. Once that profitable mix has been found, when the fate of the entire mature organization is at stake, moderate or low levels of leader creativity in selecting new products is probably the best overall strategy.

Developing an organizational environment that provides the appropriate level of creativity and risk taking, and also maintains a proper balance between independence and cooperation is, in itself, a creative challenge which lies in the domain of leadership. Hopefully, the idealized model presented in this dissertation will contribute to an increased understanding of the creative process which could assist leaders in meeting this challenge. More importantly, perhaps, the tentative findings presented here may provide the basis for an empirical research agenda which, over time, could provide both increased understanding and practical guidance. A general approach is suggested in the following section.

Proposed Research Agenda

The general research agenda outlined below is based on the first conclusion in this section: Structure and process are intimately related and, therefore, should be studied together. The agenda items could represent discrete stand-alone studies. However, a much more comprehensive picture of organizational creativity would result if the studies were conducted as part of a coordinated sequence.

(1) Identify a collection of creative products which have been successful in the market place. Examine the social, economic and technical factors that contributed to their success.

(2) Examine the structures of the organizations that developed the products and determine how relationships between individuals, and groups of individuals influenced creative production. The model indicates that both pure competition and total cooperation or altruism are less effective within institutions than some intermediate level of cooperation.

(3) Determine how, and to what degree, organizational structures were realigned to accommodate or enhance creative production. The model indicates that noticeable structural change should occur during the formative stage. The model would also predict more failures should occur among the more diversified and loosely structured organizations than among the more hierarchical and integrated ones.

(4) Examine the impact of creative performance at various echelons in the organizational structure from the individual to groups to top leadership. The model results indicate that, in the more successful organizations, individual producers and leaders should have a major impact and a greater variety of new products should be introduced during the formative stage. In more mature organizations, group versus individual contributions should dominate. The model would also predict that the most highly creative leaders are more likely to lead their organizations to failure. Note that higher creativity, as used here, does not mean more skillful or more insightful. It means the leader adopts products that are more unusual or further from the norm.

(5) Examine the relationships between the evolution of organizational strategy, organizational structure, and creative production based upon findings of the above studies.

Extensions of the Model

The model developed in this study is very simple and the base case analyzed is limited in scope. However, the basic model structure, which uses a random field and a generalized semi-Markov process in conjunction with Markov chain Monte Carlo simulation techniques, is very general and has potential applicability for further study of both organizational creativity and organizational processes in general. For example, the simple one-neighbor interactions can easily be extended to more complex and more realistic kinds of interaction and influence between individuals and groups. Similarly, the one dimensional product space could be easily extended to model more complex creative products, and the selection environment could be changed to determine the influence of other types of uncertainty, such as deterministic chaos; or, the state spaces of the individuals could be enriched by assigning unique sensitivity levels for each individual. Many other extensions are also possible, but I will not attempt to provide an exhaustive list of them here.

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APPENDIX A

Sample Computer Program

The Main Program reads the subroutines and data files needed to execute the program and then simulates the number of organizations indicated by the value of mcounter. The input parameters for the fieldtest subroutine are the number of products to simulate and the sensitivity parameter. The sensitivity parameter can be set to any number or to 'NULL' or 'INF'. The saveresult and groupresult subroutines, which are not included in this appendix, save the results of the simulation to data files.

Main Program

```
  read "\\model\\data\\populate20.txt":
  read "\\model\\subroutines\\initialize.txt":
  read "\\model\\subroutines\\success.txt":
  read "\\model\\subroutines\\sendout.txt":
  read "\\model\\subroutines\\fieldtest.txt":
  read "\\model\\subroutines\\saveresult.txt":
  read"\\model\\subroutines\\groupinitialize.txt":
  read"\\model\\subroutines\\sendgrouplo.txt":
  read"\\model\\subroutines\\finalresult.txt":
  read"\\model\\subroutines\\groupresult.txt":

for mcounter from 1 to 1 do
  initialize();
  sendout():
  fieldtest(100,'INF'):
  saveresult():
  groupinitialize():
  sendgrp():
  groupresult():
end do:


for i from 1 to numgroup do
  numgroup,weight[i],grpstate[i][2],exp(-h*grpstate[i][2]);
end do;
```

Initialization Subroutine

```
    initialize:= proc()
    global individualPosit, marker,orgPosit,status,
    individualstate,A,pass,h,sense,
group1,counter,group2loc,a1,a2;
    local i;
    h:=.5:
    a1:= 1.0: a2:=1.0:
```

```
    for i from 1 to numIndividuals do
       individualPosit[i]:= 0:
       marker[i]:= 0.0:
       orgPosit[i]:= produce:
       status[i]:= green:
       individualstate[i][1]:= orgPosit[i]:
       individualstate[i][2]:= 0;
        A[i]:=0.0;
       counter[i]:=1;
       pass[i]:= 1;
       group1[i]:= individualstate[i];
    end do:
    group2loc:= 'group2loc';
    end proc:
```

Population generation Subroutine

This subroutine generates uniform random populations of size 'numIndividuals' with convergent and divergent abilities in "numcategories' which have values ranging from zero to one. v[i][1] is the divergent production for individual "i", and v[i][2] is the convergence rate for that individual. The parameter h is the exponential failure rate, and a1 and a2 are the profit and loss parameters, respectively. The population is saved in a text file, bgnxxx.txt which is read into the main program during execution.

```
populate:=proc()
global numIndividuals,
numcategories,h,a1,a2,v,individualstate;
numIndividuals:=100:
numcategories:=4:
for i from 1 to numIndividuals do
   v[i]:= vector(2);
end do:
rn:=rand(1..numcategories):
for i from 1 to numIndividuals do
   v[i][1]:= rn()/numcategories;
   v[i][2]:=rn()/numcategories:
   individualstate[i]:= list(numIndividuals);
end do:
end proc:
```

The sendout procedure produces a candidate product for each individual. The individuals that fail to produce a successful product on the first attempt are set to a state of "fail."

```
 sendout:=proc()

 local   decide, ik,m,i, deta,di;
 global marker,individualPosit, individualstate,
nextstatetime,nextstate,b,t,status,success,small,
a1,a2,h,profitind;
   # set first positions at random
   for i from 1 to numIndividuals do
      di:= stats[random, exponential[v[i][1]]]();
      nextstate[i]:= di;
      nextstatetime[i]:= di/v[i][2];
   end do:
   #iterate until all have stopped at last successful point
   b:={green};
   while member(green, b) do
      m:= + infinity:
      for i from 1 to numIndividuals do
         if status[i]= green then
            decide:=nextstatetime[i];
         if decide < m then
             small:=i; m:= decide;
         end if:
         end if;
   end do:
   for i from 1 to numIndividuals do
      marker[i]:= marker[i] + m*v[i][2]:
      nextstatetime[i]:= (nextstate[i]-marker[i])/v[i][2]:
   end do:

   ##test next event at marker, next state.
   success(marker[small]);
   if succeed = 'true' then
      individualPosit[small]:=
individualPosit[small],nextstate[small];
      individualstate[small][2]:= [individualPosit[small]]:
      deta:=stats[random, exponential[v[small][1]]]():
      nextstatetime[small]:= deta/v[small][2]:
      nextstate[small]:= marker[small] + deta:
   else
      status[small]:= yellow;
   if individualstate[small][2] < 0.00001 then
status[small]:= red;
```

```
   individualstate[small][1]:= support;    end if;
   end if;
   for i from 1 to numIndividuals do
      individualstate[i][2]:=
   individualPosit[i][nops([individualPosit[i]])];
   end do;
   for i from 1 to numIndividuals do t[i]:= status[i];end
do;
   b:= convert(t,set);
   end do:
   for i from 1 to numIndividuals do
   if individualstate[i][2]=0 then
individualstate[i][1]:='Fail'; end if:
   end do:
   profitind:=add((a1*individualstate[i][2]*exp(-
h*individualstate[i][2])
   -a2*individualstate[i][2]*(1-exp(-
h*individualstate[i][2]))),i=1..numI
   ndividuals);
   end proc:
```

The fieldtest subroutine simulates production of products at each candidate location, accrues profit and losses to individuals and groups, and models the interactions and state changes which result in formation of groups and changes of individuals' organizational function.

```
  fieldtest:= proc(iters,sensitivity)


global small, b55, A, pass, status, b, individualstate,
counter,  group1,group2,a1,a2,h,group3, kounter,group2loc,
weight,numgroup,profit1,failtotal,supporttotal,producetotal
,leadtotal,sense,div1;
 local i, marker,j, nexttime,m, decide,k2,deta,j1,neighbor,
 nextstate;

  sense:=sensitivity;
  for i from 1 to numIndividuals do
     marker[i]:= 0.0;

     A[i]:=individualstate[i][2];
   end do;
  for j from 1 to iters do
  kounter:=j;
  # find next event at stopped location.
```

```
for i from 1 to numIndividuals do
nexttime[i]:=stats[random,exponential[v[i][1]]]()/(v[i][2]*
nops([group1[i]]));
end do;
   m:= + infinity:
   for i from 1 to numIndividuals do
      if  status[i]<  red  then
        decide:=nexttime[i]:
                   if decide < m then
                      small:=i; m:= decide;
                   end if:
      end if;
   end do:
  for k2 from 1 to numIndividuals do
   if status[k2] <> red then
      marker[k2]:= marker[k2] + m*v[k2][2]:
      nexttime[k2]:=
  (nextstate[k2]-marker[k2])/(v[k2][2]*nops([group1[k2]])):
   end if;
  end do:
  if individualstate[small][1]<>support and status[small]<>
red then
     success(individualstate[small][2]):
     counter[small]:= counter[small]+1:
        if succeed = true then A[small]:= A[small] +
  a1*individualstate[small][2]:
            pass[small]:=pass[small]+1;

            deta:=stats[random,
  exponential[v[small][1]*nops([group1[small]])]]():
            nexttime[small]:= deta/v[small][2]:
            nextstate[small]:= marker[small] + deta:
         elif succeed <> true then A[small]:=A[small]-
  a2*individualstate[small][2]:
            if pass[small]/counter[small] < a2/(a1+a2) then
status[small]:= red; end if;
            if status[small]=red then
individualstate[small][1]:=  support;
end if;
        end if;
     end if;
            m:= + infinity:
            neighbor:= 'NULL';
            for j1 from 1 to numIndividuals do
                if status[j1]= green  or status[j1]= yellow
and A[j1] >0.0 and A[j1]>A[small]and j1<>small then
```

```
decide:=abs(individualstate[j1][2]-
individualstate[small][2]);
          if decide < m then
              neighbor:=j1; m:= decide;
          end if;
                end if;
        end do;
    if status[small]= red and status[neighbor] <> red then
  group1[neighbor]:= group1[neighbor],group1[small];
  #NOTE!! delete or comment out next line to keep supported
element as producer!!!!
  individualstate[neighbor][1]:= lead;
  end if:
  ###NOTE!! next line assigns suceessful producers to more
successful neighbors!!!
  if status[small]<> red and status[neighbor]<>red and
kounter >
  numIndividuals and  sensitivity <> 'NULL' and sensitivity
<> 'INF' and neighbor<>'NULL' and 1./(1. + exp(-
sensitivity*(A[neighbor] -  A[small]))) > rand()/10.^12
then group1[neighbor]:= group1[neighbor],group1[small];
individualstate[neighbor][1]:= lead;
status[small]:= red;
end if;
  if status[small]<> red and status[neighbor]<>red and
sensitivity =
  'INF' and  neighbor<>'NULL' and A[neighbor] > A[small]
then
  group1[neighbor]:= group1[neighbor],group1[small];
  individualstate[neighbor][1]:= lead;
  status[small]:= red;
  end if;
  end do;

 group2:= NULL;
for jk from 1 to numIndividuals do if status[jk] <> red
and individualstate[jk][1] <> support then group2:=
group2,[group1[jk]];
  end if; end do;
  if nops([group2]) > 1 then
     for j from 1 to nops([group2]) do
       group2loc[j]:=individualstate[op(group2[j][1])][2];
     end do;
  elif nops([group2]) = 0 then group2loc[1]:=0;
  elif nops([group2])= 1 then group2loc[1]:=
  individualstate[op(group2[1])][2];
  end if;
```

```
  numgroup:= nops([group2]);
  if numgroup > 0 then
    for i from 1 to numgroup do
   weight[i]:=(v[op(group2[i][1])][2]*nops(group2[i]));
     end do;
  end if:
  ind:=convert(group2loc,array):
  profit1:= add(weight[i]*ind[i]*a1*exp(-h*ind[i])
  -a2*weight[i]*ind[i]*(1-exp(-h*ind[i])),i=1..numgroup);
failtotal:=0;supporttotal:=0;producetotal:=0;leadtotal:=0:
  for i from 1 to numIndividuals do
     if individualstate[i][1] = Fail then failtotal:=
failtotal+1;
     elif individualstate[i][1] = support then
supporttotal:=
  supporttotal+1;
     elif individualstate[i][1] = produce then
producetotal:=
  producetotal+1;
     elif individualstate[i][1] = lead then leadtotal:=
leadtotal+1;
     end if:
  end do:
end proc:


groupinitialize:= proc()
   global grpPosit, grpmarker,orgPosit,grpstatus,
   grpstate,group2,numgroup;
   local i;
   if group2<  'NULL' then
   numgroup:=nops([group2]);
      for i from 1 to numgroup do
         grpPosit[i]:= 0;
         grpmarker[i]:= 0;
         grpstatus[i]:= green;
         grpstate[i][1]:= running;
         grpstate[i][2]:= 0;
      end do:
   else
     grpPosit[1][1]:=0;
     grpstatus[1]:='failed';
     grpstate[1][1]:=stopped;
     grpstate[1][2]:=0;
   end if;
   end proc:
```

```
groupinitialize();

      pass[i]:= 1;
      group1[i]:= individualstate[i];
  end do:
  group2loc:= 'group2loc';
  end proc:
```

The sendgrp subroutine has each group and individual produce a new candidate product after the environment has been reinitialized. When all groups and individual producers have produced a candidate, the expected values for long-term profit are calculated at the candidates' locations.

```
   sendgrp:=proc()
   local   decide, ik,i, deta,di;
   global grpmarker,grpPosit, grpstate,
nextgrpstatetime,group2, mgrp,
tgrp,numgroup,nextgrpstate,bgrp,t,grpstatus,success,grpsmal
l,a1,a2,h,weight,profit2,
div2,profit1,supporttotal,producetotal,leadtotal;
   numgroup:= nops([group2]);
   div2:= 'lo';
   if numgroup > 0
      then
         for i from 1 to numgroup do
             if numgroup=1 then

weight[i]:=(v[op(group2[1][1])][2]*nops(group2));
             elif numgroup >1 then

weight[i]:=(v[op(group2[i][1])][2]*nops(group2[i]));
             end if;
      end do;
   end if:
   ind:=convert(group2loc,array):
   profit1:= add(weight[i]*ind[i]*a1*exp(-h*ind[i])
   -a2*weight[i]*ind[i]*(1-exp(-h*ind[i])),i=1..numgroup);

failtotal:=0;supporttotal:=0;producetotal:=0;leadtotal:=0:
   for i from 1 to numIndividuals do
      if individualstate[i][1] = Fail then failtotal:=
failtotal+1;
      elif individualstate[i][1] = support then
supporttotal:=
   supporttotal+1;
```

```
      elif individualstate[i][1] = produce then
producetotal:=
   producetotal+1;
      elif individualstate[i][1] = lead then leadtotal:=
leadtotal+1;
      end if:
   end do:
   if numgroup > 0 then
   # set first positions at random
   for i from 1 to numgroup do
   if numgroup= 1 then
argmnt:=v[op(group2[i][1])][1]*nops(group2);
   else
   argmnt:=v[op(group2[i][1])][1]*nops(group2[i]);
   end if;
      di:= stats[random, exponential[argmnt]]();
      nextgrpstate[i]:= di;
      nextgrpstatetime[i]:= di/weight[i];
   end do:
   #iterate until all have stopped at last successful point
   bgrp:={green};
   while member(green, bgrp) do
      mgrp:= + infinity:
      for i from 1 to numgroup do
         if grpstatus[i]= green then
            decide:=nextgrpstatetime[i];
         end if;
         if decide < mgrp then
             grpsmall:=i; mgrp:= decide;
         end if:
    end do:
   for i from 1 to numgroup do
      grpmarker[i]:= grpmarker[i] + mgrp*weight[i]:
      nextgrpstatetime[i]:= (nextgrpstate[i]-
grpmarker[i])/weight[i]:
   end do:
   ##test next event at marker, next state.
   success(grpmarker[grpsmall]);
   if succeed = 'true' then
      grpPosit[grpsmall]:=
grpPosit[grpsmall],nextgrpstate[grpsmall];
      grpstate[grpsmall][2]:=
   grpPosit[grpsmall][nops([grpPosit[grpsmall]])];
       deta:=stats[random,
exponential[v[op(group2[grpsmall][1])][1]]]();
       nextgrpstatetime[grpsmall]:=
deta/(v[op(group2[grpsmall][1])][2]*nops(group2[grpsmall]))
```

```
      nextgrpstate[grpsmall]:= grpmarker[grpsmall] + deta:
   else
      grpstatus[grpsmall]:= yellow;
   if grpstate[grpsmall][2] < 0.00001 then
grpstatus[grpsmall]:= red;
   grpstate[grpsmall][1]:= stopped;    end if;
   end if;
   for i from 1 to numgroup do
   grpstate[i][2]:= grpPosit[i][nops([grpPosit[i]])];
   end do;
   for i from 1 to numgroup do tgrp[i]:= grpstatus[i];end
do;
   bgrp:= convert(tgrp,set);
   end do:
   end if;
   profit2:= add(weight[i]*grpstate[i][2]*a1*exp(-
h*grpstate[i][2])-   weight[i]*grpstate[i][2]*a2*(1-exp(-
h*grpstate[i][2])),i=1..numgroup);
   end proc:
  # SELECTION PROCEDURE
   success:= proc(x)
   global succeed,b1,h;
   b1:=stats[random, uniform[0,1]]();
      if exp(-h*x) > b1 then succeed:= 'true'; else
     succeed:= false;      end if;
   end proc:
```