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New Product Development as a Complex Adaptive System of Decisions

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Early research on new product development (NPD) has produced descriptive frameworks and models that view the process as a linear system with sequential and discrete stages. More recently, recursive and chaotic frameworks of NPD have been developed, both of which acknowledge that NPD progresses through a series of stages, but with overlaps, feedback loops, and resulting behaviors that resist reductionism and linear analysis. This article extends the linear, recursive, and chaotic frameworks by viewing NPD as a complex adaptive system (CAS) governed by three levels of decision making—in-stage, review, and strategic—and the accompanying decision rules. The research develops and presents propositions that predict how the configuration and organization of NPD decision-making agents will influence the potential for three mutually dependent CAS phenomena: nonlinearity, self-organization, and emergence. Together these phenomena underpin the potential for NPD process adaptability and congruence. To support and to verify the propositions, this study uses comparative case studies, which show that NPD process adaptability occurs and that it is dependent on the number and variety of agents, their corresponding connections and interactions, and the ordering or disordering effect of the decision levels and rules. Thus, the CAS framework developed within this article maintains a fit among descriptive stance, system behavior, and innovation type, as it considers individual NPD processes to be capable of switching or toggling between different behaviors—linear to chaotic—to produce corresponding innovation outputs that range from incremental to radical in accord with market expectations.

Introduction

It is widely recognized that effective new product development (NPD) processes are causally important in generating long-term firm success (Cooper, 1993; Ulrich and Eppinger, 1995; Wheelwright and Clark, 1995). They can lead to a core competence that either differentiates a firm from its competitors (Prahalad and Hamel, 1990) or provides a threshold competency that is necessary just to survive in fast-changing and innovative industry sectors. Given the importance and value of NPD to firm performance, researchers have developed descriptive frameworks based on linear, recursive, and chaotic system perspectives, which provide different insights and descriptive theories about NPD process structure and behavior. These are then often the basis for normative research, which seeks to predict and prescribe causality in NPD processes (Griffin, 1997b; Page, 1993).

Linear frameworks help explain how the organization and management of NPD processes relate to NPD performance, specifically to lead times and due dates. Yet this overriding focus on process structure, reliability, and control has tended to ignore the

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factors that govern the ability to innovate (Badaracco, 1991; Moenaert et al., 2000). This myopia occurs because linear frameworks represent the NPD process as an ordered, sequential, and relatively predictable system of activities (Bonner, Ruekert, and Walker, 2002). This leads to a mechanistic interpretation and focus on process efficiency, which is inclined to ignore how process factors such as flexibility, informality, feedback, and autonomy might influence innovation (Clark and Fujimoto, 1991; Dougherty, 1992; Griffin, 1997a). Consequently, researchers have responded by developing recursive and chaotic-based frameworks to understand better how these factors and resulting process behaviors are associated with different types of innovation.

To complement and to build on the linear, recursive, and chaotic frameworks, this article develops and presents a complex adaptive system (CAS) framework of NPD. It combines the system dimensions presented by Schoderbek, Schoderbek, and Kefalas (1985) with differences in NPD decision-making levels and rules to interpret how the CAS phenomena of nonlinearity, self-organization, and emergence occur in NPD processes. These constructs provide a basis for understanding the balance between the process order and control emphasized in the linear view and the process instability and creativity emphasized in the recursive and chaotic views. Thus, the CAS framework asserts that NPD process behaviors and configurations are not necessarily fixed. An individual process has the ability to adapt and to produce a range of process behaviors—linear to chaotic—with corresponding types of innovation output—incremental to radical.

The foundation of the CAS framework is the recognition that NPD processes are systems whose elements, known as agents, are partially connected and have the capacity for autonomous decision making and social action, known as agency. The decision rules, interactions, and outcomes of agents create three mutually dependent phenomena that define and characterize CASs: nonlinearity, self-organization, and emergence. Thus, studies of CASs are not concerned with the relative complicatedness or complexity of systems and their elements (Anderson, 1999; McCarthy, 2004; Morel and Ramanujam, 1999). They are interested in how certain systems are able to learn and to create new rules, structures, and behaviors at several interrelated levels. These characteristics are necessary and important for systems concerned with exploration and innovation, but they are also difficult to represent and to analyze using static, linear models.

The decision aspect of the framework acknowledges that the principal role of NPD agents is to make judgments and choices that bridge the gap between an idea and reality. This process agency is also a central component of CAS theory (Choi, Dooley, and Rungtusanatham, 2001; Eisenhardt and Bhatia, 2002; McCarthy, 2004) that helps to examine the black-box activities of NPD (Krishnan and Ulrich, 2001) regardless of functional perspective (Whetten, 1989). Thus, the present study assumes that NPD project teams deal with uncertainty through information processing (Galbraith, 1977) and that decision levels and accompanying decision rules affect the mode and viability of NPD operation, contingent upon a fit between the NPD process and its environment.

BIOGRAPHICAL SKETCHES

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Christen Rose-Anderssen worked as a naval architect and manager in the ship-building industry in Norway, Northern Europe and Asia for many years. He has worked with strategy, marketing, human resource management, and organizational change in offshore engineering. His main interests are in organizational change through collective work and the management of knowledge and learning for innovation through effective communication development across cultural boundaries in complex activity networks.

With this introduction, the contribution and the structure of this article are as follows. First, it provides a review of the linear, recursive, and chaotic NPD frameworks to understand their relative interpretations, benefits, and limitations. It then introduces and defines a CAS and proposes three NPD decision levels as constructs for the CAS framework. The aim of these two review sections is to position the contribution of this article within the context of NPD literature and to show how a CAS framework provides a complementary perspective that both combines and extends the linear, recursive, and chaotic descriptive interpretations. A CAS framework views individual NPD processes as adaptable or malleable systems capable of producing a range of behaviors to suit different innovation expectations, levels of market uncertainty, and rates of change. This interpretation forms the basis for four propositions that predict a fit among NPD process adaptability, the market expectations imposed on the process, and the effect decision levels have on the order and disorder in the NPD process. To support and provisionally test these propositions the second half of this article uses three case studies to describe and to characterize causes of CAS phenomena in relatively regulated and formally managed NPD processes. The case-study observations reveal how the configuration of NPD decision makers and corresponding decision levels and decision rules might affect process adaptability and the potential to produce innovative outputs congruent with the needs of its environment. Finally, the article concludes with a discussion of the implications that a CAS framework of NPD might have for managerial practice and suggests a future research agenda.

Literature Review

NPD Frameworks

To date, frameworks for interpreting and describing NPD reality are based primarily on three schools of thought that reflect three different systems views: linear, recursive, and chaotic.

Linear NPD frameworks stem from traditional and logical project management methods that seek to deliver appropriate outputs on time and within cost. They interpret the process of innovation as a series of events and activities, which are sequential and discrete in nature (Zaltman, Duncan, and Holbek, 1973). Also, process control and efficiency are dependent on the cooperation, coordination, and communication of those involved in the NPD process (Cooper and Kleinschmidt, 1986). By focusing on the structure of process and the interstage connections, linear frameworks attempt to explain how process behavior affects product quality, execution of key tasks, product development costs, product reliability, product variety, and managerial complexity (Muffatto and Roveda, 2000; Shepherd and Ahmed, 2000).

Probably the best-known framework based on the linear view is the stage-gate method (Cooper, 1990). This framework represents NPD as a sequential and ordered process of four to five stages of activities and decisions. These typically include concept development, product design, testing and validation, and product launch and ramp-up. The inputs into the system are new ideas and market needs, the system elements are resources such as engineers and marketers, and the outputs are new products (Clark and Wheelwright, 1993). Between the stages are gates or checkpoints, where the progress and outputs of the previous NPD process stages are evaluated. This logical and systematic representation of NPD helps to organize and to comprehend the complexity of the process (Clift and Vandenbosch, 1999) and to conceptualize the potential for parallel tasks and activities (Winner et al., 1988).

Although linear frameworks can reveal how inappropriate structure and poor control can result in planning and coordination problems, they tend to ignore the behaviors and system features that govern the innovative capacity of an NPD process (Bonner, Ruekert, and Walker, 2002; Clift and Vandenbosch, 1999; Johne and Snelson, 1988; Olin and Wickenberg, 2001; Quinn, 1985). This is in part because linear frameworks focus on and represent the structural logic of an NPD process, which then facilitates and promotes understanding of the factors that govern process lead time and consistency. The result is a descriptive compromise between NPD control and autonomy, each respectively influencing process reliability and process creativity.

During this period, researchers also challenged the assumption that NPD activities were exclusively an ordered and sequential system of discrete stages (Kline and Rosenberg, 1986; Leonard-Barton, 1988; Schroeder et al., 1989). A seminal article by Rothwell (1992) argued that the study of NPD as an automatic, dependable, and routine decision-making process did not explain how radical innovations emerge (Dewar and Dutton, 1986; Leifer et al., 2000; McDermott and

O'Connor, 2002; Utterback, 1996). As radical innovations or really new products can significantly alter and redefine markets (Cooper and Kleinschmidt, 1993; Schmidt and Calantone, 1998; Song and Montoya-Weiss, 1998), it is important to distinguish between NPD process characteristics that typically generate incremental product innovations and those capable of producing breakthrough products. To avoid contradictory or paradoxical representations, such differentiation requires the development and use of frameworks that are capable of interpreting the variations in process activities and structure, in accord with the mix of environmental and organizational factors that govern NPD behavior (Van de Ven et al., 1999; Crawford and Di Benedetto, 2000). Cooper, Edgett, and Kleinschmidt (1999, 2002), who were the main exponents of the stage-gate method, recognized that descriptive linear frameworks encourage linear management practices, which tend to produce only incremental innovations. To emphasize the significance of achieving a balanced product portfolio—that is, an assortment of both incremental and radical innovations—Cooper and colleagues also advocated the use of *strategic buckets* to define how management should allocate NPD resources in terms of innovation, market and product type. With these developments, a consensus had formed that innovation is a temporal process made of identifiable events but that the linear perspective fails to fully represent the connective, dynamic, turbulent, and fuzzy aspects of the radical NPD process. Thus, recursive and chaotic NPD frameworks were developed to advance interpretation and understanding of the types of activities that underlie the development of radical innovations.

Kline and Rosenberg (1986) offered one of the first alternatives to the linear framework. They presented a chain-linked model with feedback loops to describe the relationships and iterations among research, invention, innovation, and production. Leonard-Barton (1988) made similar observations in a study that described NPD as a series of small and large recursive cycles that represent project setbacks and restarts. These recursive frameworks of NPD seek to represent "events in which activity is multiple, concurrent, and divergent, in which the process includes feedback and feed-forward loops" (Adams, 2003, p. 232). Thus, recursive frameworks challenge the idea of orderly sequences and assert, particularly for radical innovations, that NPD stages overlap, creating fuzziness and disorder in the process (Adams, 2003; Constant, 2000; Schroeder et al., 1989; West, 1990).

From a descriptive stance, the recursive perspective assumes that the connections and boundaries between NPD events are less clear and rigid (Cheng and Van de Ven, 1996), because innovation is a process that is always dynamic, mostly nonlinear, and often untidy and muddled. For example, Repenning's (2001) study of *firefighting*—solving unplanned problems and challenges—in formal and controlled NPD projects concluded that firefighting is a self-reinforcing phenomenon more likely to occur in large complex projects. As the level of concurrent and cross-functional activity in NPD projects has grown, a corresponding increase has occurred in the dynamic complexity of NPD projects (Smith and Eppinger, 1997; Wetherbe, 1995). With these developments, Ford and Sterman (1998) argued that the frameworks for understanding NPD have simply not been keeping pace with this increased complexity. This results in inadequate descriptions and limited explanations (Paich and Sterman, 1993; Rechtin, 1991; Sterman, 1994).

The third NPD framework, the chaotic view, is an extension of the recursive framework (Cheng and Van de Ven, 1996; Koput, 1997). It assumes that chaotic behavior can occur in NPD processes and depicts highly innovative NPD processes as systems with random-like and nonlinear behavior that generate irregular or disordered actions. Such NPD processes are relatively unpredictable, as small changes in one part of the process can rapidly develop and take the system along new trajectories, referred to as sensitivity to initial conditions. To study innovation from this perspective Cheng and Van de Ven (1996) used a chaos-theory algorithm from physics to examine the effects of feedback loops in NPD. The result was a model suggesting that the process of innovation starts chaotically and finishes in stability and that the latter stages of product innovation are better suited to linear frameworks. The work by Koput (1997) also used a chaotic framework but was concerned with the dynamics of searching for innovation. The main conclusions were that the innovation activities of search, screening, and implementation are inextricably linked to each other and that understanding how process feedback loops influence the properties of these activities is an important and significant research challenge.

Together the three NPD frameworks provide a complementary hierarchy or ladder of abstraction for interpreting and describing different types of NPD reality (see Table 1). Linear frameworks provide a simple and logical overview of the process

Table 1. Linear, Recursive, and Chaotic Frameworks of New Product Development

NPD Framework	Descriptive Interpretation	Benefits	Limitations
Linear	A process with relatively fixed, discrete and sequential stages. The connections, flows, and outcomes of the process are comparatively deterministic.	Provides a simple and effective representation of the structural logic and flows. Suited to incremental innovation activity with relatively reliable market push or strong market pull forces.	Does not consider the dynamic behaviors and relationships associated with agency, freedom, and resulting innovations.
Recursive	A process with concurrent and multiple feedback loops between stages that generate iterative behavior and outcomes that are more difficult to predict.	Represents the dynamic and fluid nature of the process. Suited to more radical innovations with push–pull market force combinations.	Assumes similar behavior across the whole process and does not represent the structural and behavioral instabilities of the process.
Chaotic	A process where the linkages and flows are greater during the initial stages, resulting in different degrees of feedback across the process. The initial stages exhibit chaotic dynamics and outcomes that appear to be random and unpredictable, whereas the latter stages are relatively stable and certain.	Recognizes different system behaviors across the process and acknowledges the effects of highly cumulative causation. Suited to the search and exploration aspects of very radical innovations or really new products.	Focuses on differences between the stages and presupposes that the overall process configuration is fixed (i.e., does not consider process adaptability).

structure and flows. They are suitable for NPD projects that are significantly close to the customer and for innovations that are incremental or sustaining in nature. Recursive frameworks emphasize the feedback connections and nonlinearity in NPD, especially if greater levels of product newness or innovation are expected. Chaotic frameworks on the other hand assert that the initial stages of NPD tend to be chaotic and that the final stages are relatively ordered.

Individually, each framework provides valuable insights and understanding about the behavior and structure of NPD processes. However, collectively they are more than just rival frameworks. As a group, they provide rich and holistic interpretations of the NPD processes and facilitate a contingency theory approach (Galbraith, 1977; Lawrence and Lorsch, 1967; Scott, 1987). This is the basis of the theoretical view and contribution in this article. It proposes that a CAS framework is capable of facilitating interpretations of NPD reality that maintain a fit among descriptive stance, system behavior, and innovation type. Thus, the congruence of an individual NPD process is dependent on the connections and interactions between process agents. This system configuration will govern the process ability to switch or toggle between behaviors that range from linear to chaotic to produce corresponding innovations that range from incremental to radical.

Complex Adaptive Systems

The concept and study of CASs originates in the life and physical sciences (Gell-Mann, 1994; Kauffman, 1993, 1995; Prigogine and Stengers, 1984); has been developed and used by the engineering sciences (Frizelle and Suhov, 2001; Holland, 1995; Krothapalli and Deshmukh, 1999); and has been discussed significantly by the social sciences in areas such as strategic organizational design (Anderson, 1999; Brown and Eisenhardt, 1998; Dooley and Van de Ven, 1999; Eisenhardt and Bhatia, 2002; McKelvey, 1999), supply chain management (Choi, Dooley, and Rungtusanatham, 2001) and innovation management (Buijs, 2003; Chiva-Gomez, 2004; Cunha and Comes, 2003). To develop and to apply this perspective to the study of NPD, this section of the article introduces and defines a CAS and then shows how the key concepts of nonlinearity, self-organization, and emergence apply to NPD processes. This discussion provides the basis for the first two research

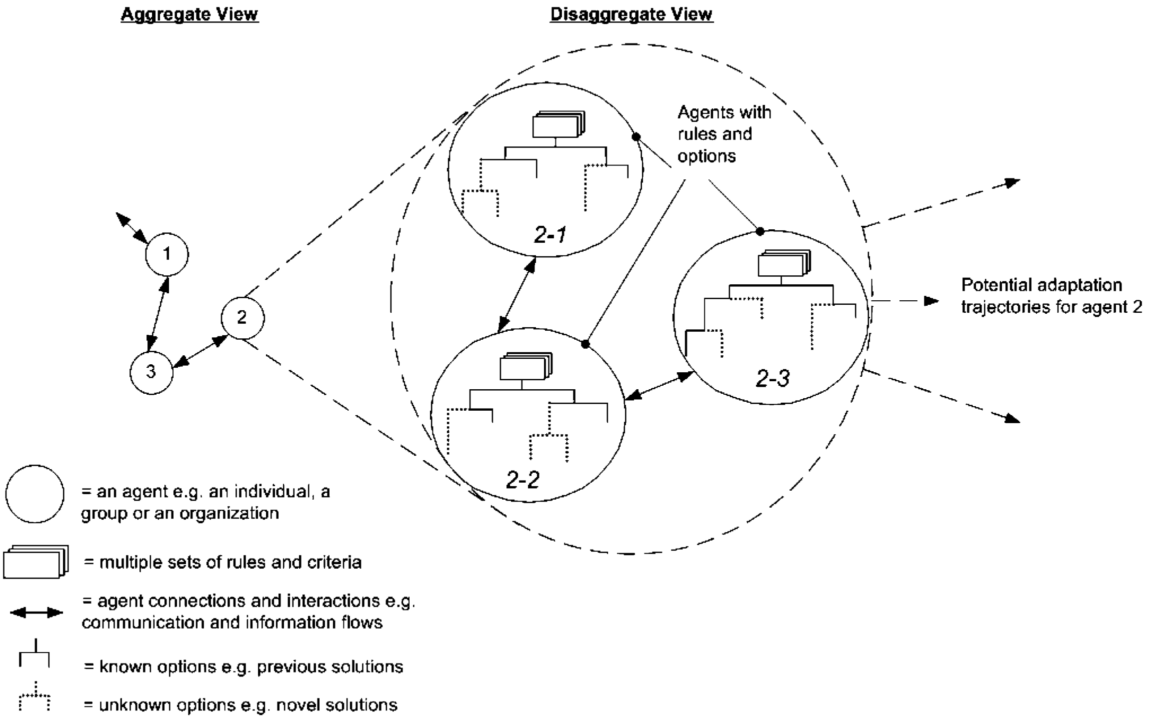

Figure 1. The Configuration of a Complex Adaptive System

propositions that reflect the exploratory and descriptive nature of this research. They are concerned with framing CAS concepts in NPD processes, as opposed to hypotheses that require measures (Eisenhardt and Bhatia, 2002; Whetten, 1989). As part of the introduction to CASs the limitations of the CAS perspective are considered, and it is argued that multiple methods are required to examine the multilevel and nested nature of CASs. This provides a rationale for using case studies to corroborate and to provisionally test the propositions.

Complex adaptive systems are complicated systems with the ability to develop new system configurations and corresponding levels of order or disorder (Dooley, 1997; Gell-Mann, 1994; Holland, 1995; Schoderbek, Schoderbek, and Kefalas, 1985). Appendix A provides an account of the differences between a complicated system and a CAS using four systems dimensions. These are (1) the number of elements that make up the system; (2) the attributes of the elements; (3) the number and type of interactions among the elements; and (4) the degree of organization inherent in the system (Schoderbek Schoderbek, and Kefalas, 1985). These dimensions illustrate how CASs differ from linear systems and chaotic systems, due to the structure and connectivity between the system elements, known as agents. Linear systems are highly structured and tightly coupled, leading to relatively high levels of predictability and efficiency but with low levels of adaptability (Eisenhardt and Bhatia, 2002). Chaotic systems, on the other hand, are relatively unstructured and loosely coupled, resulting in outcomes that appear so random and disorganized that it is not possible for the system to adapt. A CAS is somewhere between a linear and a chaotic system, with partially connected agents whose decision making and interactions produce behavior and outcomes that are neither fully controlled nor arbitrary. Brown and Eisenhardt (1997) called this level of connectivity *semistructures*. It produces system behavior that lies between order—no change or periodic change—and chaos—irregular change—and leads to the zone of system adaptability known as the edge of chaos (Kauffman, 1993).

Complex adaptive systems consist of a nested and scaleable system of agents; that is, the level of system abstraction could be an individual, a group, or an organization. To illustrate this, Figure 1 shows two levels of abstraction. With the first level, the aggregate view, there are three agents (1, 2, 3), each is assumed to be a recognizable group of people. The agents partially connect to and interact with other agents. Their actions and outputs— chosen options—are controlled by organizational rules and criteria (i.e., formal process procedures, checks). Their behavior, however, is also partly autonomous and affected by the self-directed decisions and actions of other agents throughout the CAS. The second level shown in Figure 1 provides a disaggregated view. It shows that agent 2 is composed of three agents (2-1, 2-2, and 2-3), each assumed to be the individual members of the group. The disaggregated view also shows more detail, with a basic illustration of agent rules and decision option space. The option space includes both relatively known options (i.e., previous solutions to similar problems) and relatively unknown options (i.e., novel solutions). As agents experiment with and select and reject both rules and option space, they produce a system agency and collective dynamic that results in nonlinearity, self-organization, and emergence. Together these CAS phenomena are the basis of adaptability in complex adaptive systems (Anderson, 1999; Choi, Dooley, and Rungtusanatham, 2001; Dooley and Van de Ven, 1999; McCarthy, 2004; Morel and Ramanujam, 1999; Stacey, 1995). The resulting behaviors and outcomes resist reductionism, the practice of analyzing and describing phenomena in terms of their simple or fundamental constituents. This is because the behavior of a CAS as a whole is different from the sum of the behaviors of the individual agents that comprise the CAS. A CAS is therefore capable of producing behaviors and system changes that are sometimes inconsistent with any rules imposed on the system as a whole.

If the notion of CASs is applied to NPD, then agents represent people and groups of people—depending on the level of analysis—within the process. They have the ability to receive and process information, such as marketing or engineering, and to respond in accordance with their current internal rules and their connections with other agents. They are able to follow rules and be self-directed—that is, they are able to sense changes in project expectations and circumstance and to respond in an independent, timely, and goal-directed fashion. Their current rules reflect their accumulated experience, but as they act and experiment within these rules the outcomes—good or bad—result in learning and potential modifications of their internal rules and evaluation criteria. These combined attributes and interactions of the individual agents govern the behavior and performance of the NPD process as a whole.

The limitations and criticisms of the CAS perspective revolve around how the accompanying theory, methods, and models have been developed and adopted. There is confusion and misuse of the terms *complex* and *complexity* (Eisenhardt and Bhatia, 2002), uncertainty about the use of research methods (Morel and Ramanujam, 1999), and misconceptions that system outcomes are purely random and therefore that nothing can be predicted (Baumol and Benhabib, 1989; Radzicki, 1990). These problems have become exacerbated as the interest in and expectations of CASs have grown. For example, there has been a general anticipation that CAS research would produce universal models and metatheories that apply to all types of systems. However, as argued by Levy (1994) this is very unlikely, as the causes of adaptability in physical, life, and social systems each have very different starting conditions. To acknowledge these different system contexts, Bradach (1997), Brown and Eisenhardt (1997), and Eisenhardt and Bhatia (2002) argued that the framing of CAS behavior in social systems will require qualitative research approaches to complement the computational methods developed by the physical sciences (e.g., agent-based models, cellular automata models). They suggest that case studies are well suited to capturing the rich and qualitative features of social CASs, and the highly iterative and descriptive nature of case studies permits theory building and initial theory testing.

A CAS framework of NPD extends the linear, recursive, and chaotic perspectives by recognizing that nonlinearity and feedback can occur at multiple levels between individual agents and between groups of agents. This in turn drives self-organization and emergence, which together enable the process to be malleable and to exhibit different modes of behavior—linear to chaotic. Existing NPD frameworks ignore these CAS characteristics or use a reductionist approach to model and to aggregate behavior. The aim of the next section is to elaborate on how nonlinearity, self-organization, and emergence appear in NPD and to conclude with propositions concerning the potential for complex adaptive behavior in NPD processes.

Nonlinearity. NPD processes are composed of feedback loops due to their connections. The feedback loops produce system sensitivity and disproportional outcomes known as nonlinearity. What happens locally in one part of the process often does not necessarily apply to other parts of the same process (Sterman, 2002). For example, if an NPD process is allocated extra resources, such as more designers, the result is unlikely to be a proportional increase in the number of ideas or products produced. The causes of nonlinearity in NPD include inadequate or late information—feedback problems—because the product design space can be infinite. In addition, development activities are typically a series of reiterations culminating in a market launch event (Hart and Baker, 1994; Jin, 2000). The potential outcome from this nonlinearity is a chaotic dynamic similar to that identified by Flake (1999) and Sterman (2002) in their system dynamic models. Although the phenomenon of nonlinearity in NPD is central to the recursive and chaotic frameworks, they do not provide interpretations that explain and predict how scaled behavior occurs across different process stages and decision levels.

Self-organization and emergence. The second and third phenomena of a CAS are both facets of adaptability and are the natural result of nonlinearity. Self-organization is the rate of increase of order or regularity in an NPD process (Von Foerster, 1960), and it arises due to the autonomous behaviors of the various agents that constitute the process not because of external or central control (Maturana and Varela, 1980). This is not because there is an absence of formal control rules; rather, it is because the process as a whole independently adapts and develops new configurations. As discussed earlier, this self-organized order arises when process agents are partially connected. If they were tightly coupled and highly structured then the process would be relatively rigid. On the other hand, an unstructured and loosely coupled set of agents would result in feedback and instabilities that inhibit the emergence of regularity. That is, the process would be so recursive that it would struggle to make progress toward new configurations and behaviors.

Anderson (1999) stated that for a system to self-organize it must maintain a level of internal energy that is proportional to the level of disorder imposed on the system by its environment. In terms of NPD, this means that the process should possess appropriate amounts of passion, enthusiasm, and curiosity to cope with the levels of stress, confusion, and uncertainty transmitted to the process. The ability to generate sufficient energy will depend on the number and variety of agents, along with the decision rules that govern process coupling, structure, priorities, timing, and permissions within which agents act (Eisenhardt and Sull, 2001; Chiva-Gomez, 2004). These factors are consistent with Schoderbek, Schoderbek, and Kefalas's (1985) first and second system dimensions and will govern system autopoiesis, the ability to preserve a coherent process form while evolving new ones (Maturana and Varela, 1980).

Emergence is thus the product of self-organization. It is the manifestation of new process characteristics due to the collective behavior of the agents, as opposed to the individual behavior of each agent (Anderson, 1999; Holland, 1995; Kauffman, 1995; Waldrop, 1992). In the NPD context, it is the materialization of different process configurations, which, like the innovations they seek to produce, are often not predetermined and sometimes are unwelcome and unwanted. Emergence occurs because the process allows experimentation, rule breaking, and exploratory actions, all of which can generate novel behaviors and corresponding levels of product innovation. This emergent capability is dependent on the NPD process having a variety or surplus that is congruent with the array of changes an environment may impose on the process. Thus, if a market requires high levels of innovation, the NPD process should have corresponding levels of internal variety to facilitate exploratory behavior. This condition is known as Ashby's law of requisite variety (Ashby, 1956) or as excess diversity (Allen, 2001) or as organization slack (Bourgeois, 1981; Nohria and Gulati, 1996).

In summary, the number and variety of agents in an NPD process, along with the resulting interactions, determine the potential for nonlinearity, self-organization, and emergence. These CAS phenomena are both causes and characteristics of adaptability, providing an individual NPD process with the ability to generate a range of process behaviors and corresponding innovation outputs in accordance with the degree of order or chaos imposed on the process. Formally stated these principles are the basis of Propositions 1 and 2:

> *Proposition 1: The rate of NPD process adaptability is determined by the rates of change and levels of stability or disorder imposed on the process, which leads to congruence between the innovative output of the firm's NPD processes—incremental versus radical—and the needs of its environment.*

> *Proposition 2: NPD process adaptability is determined by the number and variety of agents, their corresponding connections and interactions, and the ordering or disordering effect of the process rules and organization.*

New Product Development Decisions

The principal role of NPD agents is to make decisions that bridge the gap between an idea and reality.

To examine how different NPD decisions influence process adaptability and resulting innovation outputs, this study uses the widely recognized NPD stages of concept development, product design, testing and validation, and launch and ramp-up and three levels of NPD decisions: strategic, review, and in stage.

At the highest level, NPD decisions relate to the market and product strategy (Cooper and Kleinschmidt, 1986) and the funding and management of project portfolios (Cooper, Edgett, and Kleinschmidt, 1999, 2002). Typically, these decisions set the initial aims and objectives of an NPD project and then oversee the process from a strategic level. They are concerned with the target market for a new product, its desired competitive position or fit with the organization's current product offerings, and the technology platform to be employed (Bonner, Ruekert, and Walker, 2002). In the present article, these are called *strategic decisions*.

The second level of decisions occurs between stages. They are process milestone points that usually follow the completion of development stages such as concept development, product design, and testing (Clark and Fujimoto, 1991; Thomas, 1993). Such decisions include whether the project should proceed or be terminated or whether it should be reviewed and how it should proceed (Cooper and Kleinschmidt, 1991; Thomas, 1993). Decisions at this level are generally made by middle to senior managers, and the outcomes significantly affect NPD lead time (Murmann, 1994). In the present article, these are called *review decisions*.

Finally, the third level of decisions relates to those taken within and at the operational level of each process stage (Krishnan and Ulrich, 2001). Creative and exploratory behavior primarily occurs at this level, in accord with the degree of agency and freedom allowed or encouraged by the strategic and review decisions. At this level, the customer requirements are assessed using a range of direct and derived importance measures (Griffin and Hauser, 1993), and the characteristics of the product are decided. The outputs of these decisions vary for each stage of the development process. So for instance, at the concept development stage the outputs might address the assessment of customer requirements—that is, product specification decisions. At the design stage, such decisions could result in geometric models of assemblies and components, a bill of materials, and control documentation for production (Krishnan and Ulrich, 2001), whereas the testing and validation stage might deal with the cost of prototyping, the method of prototyping to be used, and how the experiments should be designed (Thomke, Von Hippel, and Franke, 1998). Finally, during the product launch stage, the output of these decisions might concern the need for test marketing and the sequence in which products are introduced to the market. In the present article, these are called *in-stage decisions*.

In addition to variations in NPD decision levels, different decision rules govern how the NPD process is supposed to operate. Decision rules refer to the way strategic, review, and in-stage NPD decisions are made and shape the process in terms of agent attributes and the degree of organization. These are consistent with Schoderbek, Schoderbek, and Kefalas's (1985) second and fourth system dimensions, as different decision rules will generate different types of NPD behavior (e.g., rules that promote order versus rules that promote disorder) with varying degrees of uncertainty. Together, decision levels and decision rules create NPD progress paths, or trajectories, with outputs that range from incremental to radical.

The CAS view reflects the NPD process in real time, as open, changing, and potentially adaptive. It implies that process agency can yield different NPD behaviors with trajectories and outcomes that may or may not be predetermined by the inputs. To some extent, the nature of the trajectories will be consistent with the linear, recursive, and chaotic NPD framework perspectives. For example, a trajectory where the effect of a decision on the project would be the one anticipated—such as the improvement of a certain product feature following customer feedback—is consistent with the linear framework. In contrast, a cyclical path is consistent with the recursive framework, as it will feed back and reuse similar and familiar decisions from previous and comparable projects. Finally, chaotic behavior in NPD is associated with the capacity to produce novelty or surprises, as any decision could create a potential change in trajectory direction. This is because decision outcomes can be amplified, producing paths that lead to good or bad process performance. The probability and degree of trajectory change will depend on which stage of the NPD process the decision takes place at and the hierarchal level of the decision making. It is important to note that chaotic trajectories are different from stochastic ones, which have such a rate of new and unwanted process inputs that the next process state or configuration cannot be deduced from the present one (Stewart, 1989). In contrast, a chaotic trajectory is so

Table 2. Complex Adaptive System Framework of New Product Development

NPD Framework	Descriptive Interpretation	Benefits	Limitations
CAS	A process with partially connected agents whose interactions cross stages and decision levels. Collectively they are able to produce a process dynamic between order and chaos, which results in process adaptability and the potential to generate different behaviors and innovation outcomes.	Assumes that overall process configurations and behaviors are malleable. They can be internally changed to match push or pull market forces and innovation expectations that range from incremental to very radical.	Semantic confusion concerning the terms *complex* and *complexity*. Challenges in framing and measuring the process constructs coupled with the misconception that process outcomes are random and therefore unpredictable.

sensitive to system changes that it appears stochastic but, in fact, exhibits patterns over time.

With this review of NPD decisions and building on P1 and P2, it is possible to deduce that different decision levels and decision rules will promote or constrain agent coupling and interactions, which in turn will determine the potential for adaptive behavior in an NPD process. These factors combine with the CAS phenomena of nonlinearity, self-organization, and emergence and the system dimensions concerned with the number and variety of agents, their coupling, and degree of organization. Together they provide the theoretical constructs for a CAS framework of NPD summarized in Table 2 and followed by Propositions 3 and 4.

> *Proposition 3: Strategic and review decisions and their accompanying decision rules generate order and disorder at the in-stage decision level of NPD, which results in corresponding potentials for process adaptability and matching innovations.*

> *Proposition 4: In-stage decisions and their accompanying decision rules are able to produce enough internal energy to explore and to produce self-determined process adaptability.*

The Study

The process this research followed was highly iterative. The review of existing NPD frameworks and accompanying theories were primarily deductive in nature and generated constructs and propositions concerning NPD as a CAS. The case studies presented in this section provide observations and descriptions of CAS phenomena in NPD processes that permit assessment and validation of the framework and its accompanying propositions. This combined top-down and bottom-up approach is an important and customary aspect of the research process. It facilitates theory building and the identification of possible correlations, which become the basis for quantitative descriptive models and normative theory building (Brown and Eisenhardt, 1997; Eisenhardt, 1989; Feldman, 2004; Whetten, 1989).

The rationale for using case studies was to observe and to describe the NPD process elements, interactions, and behaviors within their real-life settings. As a research method, it is well suited to relatively new research topics, especially when the phenomena are poorly understood and characterized (Eisenhardt, 1989). This is certainly the case with CAS interpretations of NPD processes. The case-study approach also provides a number of research contributions, including description (Harris and Sutton, 1986), theory building (Gersick, 1988), and initial theory testing (Pinfield, 1986). The following sections report how the case studies were selected and conducted.

Company Selection

Three companies were selected that would help conceptualize and describe CAS behavior in NPD processes. This multiple case-study approach is appropriate for examining phenomena such as CAS behaviors in more than one natural organizational setting. The names of the case-study companies are not disclosed and will be referred to as Company A, Company B, and Company C.

The companies were selected using criteria similar to those adopted by Swink, Sandvig, and Mabert

(1996). This required companies to (1) have substantial experience in NPD; (2) be developing relatively discrete products; (3) be classified as producing relatively incremental and predictive innovations for existing customers and markets; and (4) collectively represent a diversity of internal process characteristics in terms of size, rules, structure, and organization. It was also important to exclude NPD processes characterized as unstructured, free thinking, and relatively constraint free, as the aim was to identify the existence and potential for CAS behavior in a nonobvious NPD environment. Therefore, the focus was on processes typified as linear, organized, and controlled and with a tendency to develop products in consultation with their customers. In addition, the three case-study processes were required to be different according to Schoderbek, Schoderbek, and Kefalas's (1985) four system dimensions: number of elements, attributes of specified elements, number of interactions among these elements, and degree of inherent organization. Thus, the selection constrained any potential case variation due to extraneous process context—that is, government laboratories and other blue-sky research facilities were not considered—while focusing the study on the constructs central to the propositions.

The first and third dimensions—number of elements and number of interactions among those elements, respectively—relate to the number of agents, the level of decision-making authority, and the types and number of interactions that take place between each agent. These dimensions are central to P1 and P2; therefore, the case-study companies needed to exhibit variations in the size of their organizational and NPD process settings. Consequently, Companies A and B were large manufacturing organizations, and their NPD teams consisted of more than 60 designers and engineers located in different parts of the world. Company C was a relatively small organization, and its NPD team consisted of 12 engineers and designers, all located in the same facility. In all three cases, the total number of people involved in the process varied according to NPD stage, with the initial stages utilizing fewer people than the middle and final stages.

The second and fourth system dimensions—attributes of the elements and the degree of organization, respectively—relate to P2 and P4 and concern the decision rules and management practices that govern NPD agents and the process. To examine the second dimension and to ensure that the case-study processes exhibited some control and organization over the agents, it was important to identify the existence of a formal and documented NPD process within the organizations. To address this issue, the selected case-study companies provided process maps or workbooks that showed the NPD process used, along with identifiable activities, stages, and resources. The companies were also required to have formal and distinct operating budgets for their NPD processes. A similar criterion was also employed by McDermott and O'Connor (2002). To study the fourth dimension, the selected companies needed to exhibit different NPD management rules, structures, procedures, and technologies. For example, Company A operated a fixed multinational process based on expertise—that is, the NPD team members were located and organized in terms of geography and functionality regardless of the project—whereas Company B, also a multinational business, organized its NPD members according to a multidisciplinary matrix structure which changed according to the needs of the project. The process organization and structure for Company C were fixed and informal, with the same team working on all projects.

Data Collection and Analysis

Data were collected using questionnaires, structured interviews, and observation. The questionnaires were used to gather detailed information on the companies' NPD process. They included both closed and open-ended questions on the configuration of the process in terms of stages; the number and professional types of the people involved in the process; and information about the decision levels, decision rules, and any accompanying decision tools and techniques employed. The senior managers—chief executives, vice presidents, and directors—responsible for NPD in the case-study companies completed the questionnaires. The questionnaire data were then used to design semi-structured interviews for each of the case-study organizations. The interviews had two aims. The first was to overcome the limitations of questionnaire surveys such as item nonresponse bias—when some questions have not been answered—and nonconsistency in understanding of questions (Hussey and Hussey, 1997). The second aim was to achieve a deeper understanding about the type of process organization and decision rules employed by the NPD teams. To achieve this, 14 people in all were interviewed who collectively were involved at each stage and decision level of the NPD process. As reported by McDermott and O'Connor (2002) and Eisenhardt (1989) this use of multiple interviewees reduces the risk of undue influence that an individual interviewee may have on the study and brings a rounded and balanced insight into each case.

The final phase of data collection involved four sets of three-day visits at each company to observe current NPD activities and to attend NPD meetings. The aim of this phase was to observe, in real time, the actions and behaviors of people and to triangulate and to validate the data collected from the previous two stages. During these visits, secondary data such as Gantt charts, progress reports, and project notes were collected. Annual reports, company brochures, and corporate websites were also analyzed to gather background information about the case-study companies.

Framing New Product Development as a Complex Adaptive System

In this section, the cases are described to generate insights and to conceptualize NPD as a CAS. This involves a summary of the cross-case analysis, where the documentation for each case was reviewed to identify and to categorize any common factors that constrain or promote CAS behavior in terms of nonlinearity, self-organization, and emergence. The relationship among these phenomena, the decision levels—in stage, review, and strategic—and decision rules were evaluated to further refine and to build insights that would assess and provisionally test the propositions.

Nonlinearity in New Product Development

Despite the market-focused, project-controlled and relatively sequential nature of each NPD process studied, it was possible to identify nonlinear behavior in all three companies, especially at the in-stage decision level. For example, when Company A and Company B added new team members in an effort to advance and to improve progress, the outcome was not a corresponding improvement but was a temporary decrease in progress as the system learned to accommodate, to train, and to integrate these new agents during the first four weeks. This observation is consistent with existing research on the effects of adding NPD resources and changing team characteristics to increase NPD performance (Cooper and Kleinschmidt, 1991; Gomes et al., 2001). Another example of nonlinearity in Company A and Company B was what this present study calls *exponential expectation change*. This is when information such as project due dates increase or decrease exponentially when passed from agent to agent. This occurred because agents at different stages and levels would seek to cushion or to expedite process progress and outcomes by altering this type of information. It is important to note that these observations are not necessarily novel. Their purpose and value is to confirm that such behaviors exist and then, using a CAS lens, to better understand how simple rules of interaction, coupled with variations in agent-decision level, can generate different aggregated outcomes that affect process adaptability and innovation output. For example, with Company A, the senior managers based at their parent company took the strategic NPD decisions. These decisions focused on selecting the portfolio of products that would satisfy the market requirements in terms of functionality, performance, and cost. The senior managers would also decide the level of funding for and the timing and allocation of NPD projects for the company. Once these strategic decisions were made, the review and in-stage decision-making agents had relative autonomy to organize themselves and to develop new products within a recognized framework and set of governing procedures. Thus, Company A's strategic decisions had limited influence on any prospective nonlinear behavior in the NPD process.

The opposite situation existed in Company C, the smallest of the three case-study companies. The strategic decisions in this NPD process were the responsibility of the chief executive, who would constantly develop and change agreements with distributors and key customers, which in turn governed strategic decisions concerning the type of product architecture, the number of product variants, the supply chain, and the level of funding. The result was a process whereby the strategic decisions and in-stage decisions were closely coupled, and any changes in the strategic decisions significantly influenced in-stage behavior, generating NPD outputs that could be nonlinear—amplifying or reducing—depending on the stability of the market and the judgment of the chief executive.

The review-decision level provides checks and controls for any major NPD milestones. The case studies provided examples of how the frequency and duration of decisions at this level can affect the propensity for nonlinear behavior. For example, with Company A, the NPD director and a project-planning team conducted review decisions on a bimonthly basis according to project progress, funding availability, and a reevaluation of market and product priority objectives. The relative regularity and complexity of these decisions exerted a dampening control that sought to ensure a correlation between causes and effects. The situation was similar for Company B, but representatives from the NPD teams and the customer companies undertook the review decisions jointly. With Company C, the review decisions created positive and negative feedbacks that affected the type and level of nonlinearity. This occurred when the chief executive, who regularly participated at this decision level, made weekly decisions that reflected his approval or disapproval of the project progress. The scale and regularity of this decision feedback rapidly escalated and determined the direction of the project. These negative and positive feedback loops do not respectively correspond to criticism or praise. Rather, a negative feedback loop keeps the system at a desired state; it negates changes in the system; in contrast, a positive feedback loop has an amplifying or self-reinforcing effect on the system that eventually makes the system unstable and open to change. Thus, disapproval, or positive feedback, from the chief executive would quickly destabilize the project, counteract any progress made, and lead to a reorganization of activities, whereas approval, or negative feedback, would strengthen and maintain the current NPD configuration and trajectory. The frequency and intensity of the feedback loops in Company C regularly created behaviors such as system overconfidence, oscillation, growth, and overshoot as described by Sterman (1994) in his account of the fundamental modes of dynamic behavior.

At the in-stage decision level, agents deal with multiple decisions such as how the product components should be joined, if a certain material type would work, what color it should be, and what shape the product should have. Collectively these decisions involve producing and processing a rich diversity of rules and criteria that are the basis of creative activities and ideas in the NPD process. Thus, at the in-stage decision level the number of interactions and the type of organization—formal control versus autonomous—imposed on the decision makers influenced NPD nonlinearity. For example, Companies A and B used formal procedures, rules, and technologies to permit communication among engineers located in several countries. The technologies included groupware meetings, virtual e-rooms, intranet, collaborative product development platforms, and computer-aided design. The procedures and rules involved a formal design change and documentation process; a make versus buy assessment for each designed component; and an approval and sign-off procedure for an extensive range of in-stage product decisions for issues such as product color, material types, product shape, prototyping plans, vendor selection, and testing schedules. Feedback, changes, and adjustments in the process were also relatively formal to ensure traceability, accountability, and archiving of information for future NPD projects. By comparison, the in-stage decision makers in Company C were all located in the same office room, and the process of communication throughout all stages of the NPD process was relatively informal, open, and unmonitored.

In summary, the case studies revealed links between agency and nonlinearity across all three decision levels, with the degree and type of nonlinearity either constrained or propelled by the type and number of connections, interactions, and feedback loops with agents at the various decision levels. The associated dynamics and outputs from these relationships underpin the tendency for process adaptability in terms of self-organization and emergence, which are discussed in the next section.

Self-Organization and Emergence in New Product Development

As described earlier in this article, self-organization and emergence are simply two aspects of the same process capability: adaptability. New product development processes are able to adjust and to adopt new ways of working when their agents are free to connect, to communicate, and to cooperate in a way that produces sufficient levels of self-organization. Adaptability is a process behavior that cannot be attributed to any one agent, because, as observed in the case studies, it is the result of communal and mutual decision-making that occurs primarily at the in-stage level. Thus, even though NPD agents may follow simple rules or targets, it is possible for the process to generate behavior, which has the potential to be distinctly different and possibly more effective than that originally designed and planned by the organization.

As with nonlinearity, all three case-study companies exhibited self-organizing and emergent behavior. Companies A and B used collaborative product development software with process procedures and rules to facilitate and to record interactions among all decision levels and across all NPD stages. Yet despite this relatively high level of control and monitoring, when decisions occurred outside the boundaries set by formal practices and rules, instances of self-organizing behavior were observed. For example, with Company A the concept for an entirely new product technology developed during and after a game of golf that took place during a personnel development course that several members of the NPD team happened to be attending. The outcome was an unplanned and temporary social unit, with some of the NPD members meeting in person for the first time. The result was a new process configuration with novel system interactions and organization. As explained by one of the manufacturing engineers interviewed, "This innovation was the result of meeting and communicating in a non-work place environment. We were able to cooperate and problem solve without the normal bureaucratic constraints that make up the day-to-day grind of our jobs." Again, the identification of this type of brainstorming event is not unique and should not be credited to the use of a CAS framework. However, a CAS framework promotes and facilitates novel insights based on questions about how this event emerged with no one individual planning, organizing, and controlling it; about what sort of parallel interactions took place between the agents; and about what environmental conditions are required to facilitate the emergence of new working practices and outcomes. These issues are relevant to management practice because in an attempt to replicate the success of the ad hoc and informal brainstorming event, Company A went on to organize a biannual three-day retreat known as Exploration Days. These events were designed to allow NPD members to work, to socialize, and to learn in a rule-free environment. Yet participants from the original event who had also attended the Exploration Days stated that the two events were very different. With Exploration Days, the environment may have fewer regulations and restrictions compared to the normal workplace, but there are still expectations and rules not present during the golf event. For example, attendance at Exploration Days is compulsory for all NPD members, and the purpose is clear: to produce ideas.

Another instance where self-organizing behavior resulted in new emergent NPD practices was when NPD team members in Company B decided to disregard the process rules and procedures. Company B sought to formalize and to record all in-stage decisions because of significant customer involvement and regulation requirements for its aerospace products. Yet an occasion arose when process control procedures were ignored, creating an unplanned innovation. It occurred when a prototype component failed an important functionality test. Instead of documenting and reporting the failure, it was concealed from senior management to avoid an assessment of the project progress and viability. Motivated by the fear of project failure and termination, the NPD team members secretly revaluated the test results and explored substitute applications. The outcome was an unplanned and radical innovation with a level of commercial success much greater than the original NPD project application. This was a classic example of self-organization by rule breaking, whereby the decision-making agents exhibit unpredictable, or loose-cannon, behavior. Thus, even though the most controlled of NPD processes may appear to operate according to imposed organizational rules or accepted practices, they have the potential for self-organizing and emergent behavior. Olin and Wickenberg (2001) argued that rule breaking is a positive attribute, as their research shows that NPD processes that regularly break rules tend to be more creative. A possible reason for this is that rule breakers tend to be more entrepreneurial and exploratory in nature, whereas members of rule controlled NPD processes often feel constrained in their ability to discover new ideas, to take risks, or to develop solutions to problems.

With Company C, its in-stage decision-making environment was relatively unceremonious, dynamic, and disordered, which reflected the fluid and changing nature of its strategic and review decisions. The result was a NPD process that was highly adaptable with informal and new behaviors created regularly in response to the confusing and changing rules and unknown constraints and product specifications. This process of self-organization was a forceful and disorganized combination of top-down and bottom-up interactions. The top-down interactions were governed by the hierarchal structure and authority of the system in terms of decision levels such as strategic decisions, whereas the bottom-up interactions were due to the agency at the lower level of the hierarchical structure such as the in-stage decisions. Also, for Company C's relatively small size, the NPD process exhibited the greatest number and variety of system connections and interactions. This helped produce an emergent dynamic that was consistent with the notion of being far from equilibrium (Prigogine and Stengers, 1984) or at the edge of chaos (Kauffman, 1993), whereby the NPD process rarely maintained an ordered pattern of behavior. This state occurs when there are enough connections to be dynamic, nonlinear, and adaptable, but not so many as to make the system unstable or to cause it to disintegrate. To maintain a position at the edge of chaos required a continual and appropriate flow of energy importation—strategic decisions—balanced with an appropriate level of operational agency—in-stage decisions.

A final observation from all three case studies was the tendency for nonlinearity, self-organization, and emergence to vary according to the NPD stage. This was particularly the case with Companies A and B where the size of the teams and the duration of the projects provided an appropriate disconnect between concept development and product launch. Relative to the decision makers in the later stages, those at the concept development stage had more autonomy to develop their own ideas. As explained by the NPD director of Company A, "... with concept development we need to have some control, but if we try to control this stage finitely and take all the decisions for them, then that limits their influence and creativity."

Discussion

The notion of viewing NPD processes as a CAS is theoretically attractive. However, how does this systems perspective differ from existing NPD frameworks, and how do CAS concepts help to improve understanding of NPD? These questions were the motivation behind this study, which sought to develop and to describe the basis of a CAS framework using a systematic review of the literature and by applying the framework to case-study companies. In this section of the article, the resulting case observations and analysis are discussed to assess the propositions and to determine the potential for and consequences of CAS behavior in NPD.

The first proposition predicted that NPD processes conform to contingency theory and that their ability to adapt is governed by the rates of change and the levels of stability or disorder imposed on the process. The result is potential congruence between the innovative output of the NPD process—incremental versus radical—and the needs of its environment. With the context variations among Companies A, B, and C, it was clear that the relatively ordered and controlled environment of Companies A and B resulted in greater levels of process stability. Their environment had historically favored incremental innovations; accordingly, the processes were relatively formal and linear. With Company C, the process was exposed to an environment that rapidly and frequently switched between a relatively certain and stable environment to one that was highly turbulent and unpredictable. Consequently, it was observed that the process was also able to quickly adapt from a controlled and relatively static process to a relatively fluid and responsive process. Although the aim of this study was not to measure and to relate the performance of the NPD process to the type of configuration, other studies of theory and practice do show a correlation. With all three case-study companies, the observations did not refute or support the notion that variations in process stability or disorder would translate directly and respectively into incremental or radical innovations. This is simply because of the time lag between conducting the case studies and the eventual launch and market adoption, or rejection, of the associated innovation outputs. Thus, it was not possible to categorize adequately any resulting innovations as either successful or unsuccessful or as incremental or radical. However, a relationship is known to exist between system behavior and innovation output, and this study did find that NPD process adaptability occurred to maintain congruence between process behavior and the demands of the environment. Thus, it is proposed that this element of P1 is still valid and worthy of future verification.

The case studies were limited in number and focused on NPD processes characterized by a customer pull for engineered products combined with relatively low levels of market uncertainty and complexity. A consequence of P1 is that NPD process diversity and the potential for fit and misfit will be much greater than the cases presented in this article. Yet even with this limited range of environmental variety, the case studies yielded different process behaviors with corresponding potentials for process adaptability. Predicting the factors that govern this process adaptability is the basis of P2, which asserts that the number and variety of agents, their corresponding connections and interactions, and the effect of the process rules and organization will determine the potential for process adaptability. With each of the case studies, there were significant variations in how the agent tasks and roles differed (e.g., marketing, design, test) along with variations in the cognitive norms that accompanied each task and role. This diversity increases when considering the different process decision levels—strategic, review, and in stage—that agents occupy and the types of connections between the agents. The absolute number and variety of agents and resulting connections were greater in Companies A and B than in Company C. However, relative to the number of agents, Company C had a greater degree of agent variety, connectivity, and interactivity. The case-study findings also showed how the connections between agents were based on interactions that could be physical, social, or electronic in nature, with different capacities for promoting or restricting CAS behavior.

P3 and P4 predict how decision levels and rules promote or constrain process adaptability. The decision levels proposed and studied by this research provide architectural constructs for understanding the capacity for autonomous decision making and social action in the process. The case-study findings showed that the degree of coupling between decision levels and the frequency and type of feedback between agents at each level have the potential to produce or to limit CAS characteristics in NPD. This is because the relationships between agents across decision levels are influenced by their co-evolving behavior, their respective contiguity, and their appreciation of CAS behaviors across the process. The strategic and review decision rules exist to direct and to control the NPD process and, as a result, play a significant role in determining the intensities and kinds of interactions at the in-stage decision level. The agents at strategic and review levels are able to grant the necessary freedom or control and to respectively engender or to stifle nonlinearity and the resulting self-organization and emergence at the in-stage level. In effect, the strategic and review decisions create a top-down management energy that equates to order or disorder at the in-stage decision level, though behaviors associated with fear, curiosity, obsession, naughtiness, enthusiasm, and anxiety can at the in-stage level create a level of internal energy that results in a bottom-up generated process adaptability.

Finally, this study's process of building theory and provisionally testing propositions using case-study research was consistent with Eisenhardt's (1989, p. 546) account that case-study research bounces between deduction and induction, as "... an investigator may move from cross-case comparison, back to redefinition of the research question, and out to the field to gather evidence ..." This type of approach is appropriate for descriptive research, as it involves resolving case-study data to develop new interpretations, which can go beyond existing preconceptions of how NPD processes operate. In addition, the process of applying the framework to the case-study companies does help to validate or to refute the propositions, which in turn can help translate constructs into measures and propositions into hypotheses. Weaknesses of the case-study method include the potential for resulting theories that are overly complex as they too closely reflect the reality they have just studied. There is also the possibility that any resulting theoretical contribution could be too narrow due to the specifics of the data and the nature of the case studies. As this study was exploratory in nature and was motivated and guided by two established but separate research areas—descriptive interpretations of NPD and the study of CASs—it is unlikely that these issues will adversely affect the findings and contribution.

Conclusions

The theories and methods for defining and modeling CASs are broad, complicated, and often misunderstood as being an area of research concerned with solving the problem of complexity. Instead, they provide a perspective for theorizing and modeling systems based on the supposition that it is not possible to understand properly overall system behaviors by simply breaking the system down into constituent parts and then aggregating any observations to develop convenient and linear rules. This is because CASs are composed of agents, whose decision-making abilities result in self-determination and exploration at multiple levels within the system.

Overall, this research proposes and supports the notion that a CAS framework of NPD has descriptive value in terms of studying, classifying, and defining the attributes and relationships that govern adaptive behavior and outcomes in NPD processes. A CAS framework provides insights that complement the linear, recursive, and chaotic frameworks by inherently maintaining a fit among descriptive stance, system behavior, and innovation type. This is because a CAS framework views NPD processes as systems of partially connected agents, operating within strategic and review-decision rules that promote or constrain the potential for self-organization and emergence at the in-stage level. The result is adaptability, whereby individual NPD processes are able to switch between different process behaviors and the assumptions of the corresponding NPD framework.

Although this contribution is descriptive and academic in orientation, related implications can be found concerning how managers might develop and apply normative models to create and to operate NPD processes. Managers will need to consider how their traditional methods and tools will affect future process congruence and performance, bearing in mind that in terms of their size, structure, and behaviors, individual NPD processes are not eternally fixed. As with the environments they serve, they are able to adapt, which means that an individual NPD process has the potential for more than one system behavior. Thus, market expectations, innovation levels, process behaviors, and management approaches will all be dependent on each other in terms of system control and reliability versus system freedom and autonomy.

To design and to manage processes accordingly will require comprehension of how decision rules, agent variety, and agent connectivity influence the pace of process self-organization and emergence. This is because the agents within a NPD process are multiattribute switches whose links and outputs define the architecture, flows, and performance of the process. Such management insights would help avoid system lock-in or competency traps, where process configurations become contradictory or inconsistent with the mix of environmental and organizational factors that govern NPD goals and success. For example, if the rules and procedures from past NPD projects are simply applied to future projects that have new innovation and market expectations, then this contingency ignorance is likely to lead to NPD system behavior and innovation outcomes that are inappropriate in terms of cost, time, and level of novelty. The probability that this incongruence will occur is exacerbated if the organization that operates the NPD process also has company-wide practices and performance models that motivate and reward behavior inconsistent with the desired NPD market, expectations, innovation levels, and process behaviors. Awareness of these simple but high-level design rules will help managers shape and direct an individual NPD process to produce different innovations—incremental to radical—for different environments. This approach to NPD design would also encourage a strategic bucket approach to resource allocation within and across NPD projects.

Finally, to extend and to test the research presented in this article will require empirical models that go beyond the case-study insights and measure the relationships between the framework constructs and the resulting range of system states. Such research could help quantitatively address questions concerning how many agents are necessary for self-organization, what is a corresponding and appropriate concentration of connections, and what type and frequency of feedback is required to stabilize or to disorder the system according to its environmental characteristics and development stage. This would involve simulation and regression models that predict the process variable values needed to switch between behaviors and the impact of top-down directed process adaptation versus bottom-up self-regulated adaptation. As this involves modeling the structural and temporal dimensions of NPD processes, the use of graph theory techniques such as NK models (Kauffman, 1993) or Q-analysis (Atkin, 1978; Rakotobe-Joel, McCarthy, and Tranfield, 2002) would be appropriate. These methods provide graphical and mathematical methods for eliciting the relationships between two or more agents or sets of agents; therefore, it would be possible to represent process connections, interactions, and the presiding decision rules.

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Appendix A

Using Schoderbek, Schoderbek, and Kefalas's (1985) system properties framework it is possible to distinguish between complicated systems and CASs. The framework defines a system in general, as a set of elements with attributes that are connected by relationships to each other and to their environment to form a whole. It also proposes four dimensions that govern the control and behavior of a system and consequently distinguish CASs from complicated systems. These are (1) the number of elements that make up the system; (2) the attributes of the elements; (3) the number and type of interactions among the elements; and (4) the degree of organization inherent in the system.

From the given definition, the notion of a set refers to a collection of elements that are obviously meant to be within that set—for example designers within design departments, or a group of engineering and marketing personnel within NPD teams. The system elements not only constitute the system, but they are also the system's function. Each element will have attributes that reflect their properties and characteristics and thus determine the variety of elements in the system. For NPD processes, this refers to decision-related attributes as determined by job roles, skills, experience, and authority. System relationships are the interactions that connect the elements. They can be symbiotic, synergistic, or redundant, and for every relationship in a system there will be some form of interaction and organization. The system's environment will include any other system or element whose changes in attributes have an effect on the system. For NPD processes, the environment would include customers, competitors, and competing resources in the same organization. The final feature of the system definition, wholeness, indicates that a system is a meaningful family of elements, relationships, and attributes. There is natural purpose and a degree of organization governing the system's existence.

With this framework, a complicated system such as mechanical clock will have a somewhat high number of elements with relationships, attributes, and interactions that are relatively fixed and unchanging. This results in a comparatively low level of system organization with corresponding order, stability, and predictability. Such system features make it possible to understand, to model, and to reproduce complicated systems by dismantling the system to its constituent elements, known as reductionism. With a CAS, the system is still relatively complicated, but the system elements have the ability to change their individual attributes and interactions to produce new system configurations and behaviors. It is this ability to adapt that distinguishes a CAS from a complicated system.