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THE THREE FACES OF CORPORATE RENEWAL: INSTITUTION, REVOLUTION, AND EVOLUTION

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We examine corporate renewal by taking a structural approach and focusing on the routines and rules that are part of large, established, bureaucratic organizations. We characterize approaches to the management of innovation in terms of three different themes—institutional, revolutionary, and evolutionary strategies. The first two approaches involve intentional efforts to encourage innovation, either within the current organizational paradigm (institutionalizing innovation) or moving away from it (revolutionary innovation), while the evolutionary approach involves less conscious efforts to manage what is viewed as a random, probabilistic process. This paper uses simulation methodology to explore the effectiveness of these strategies on organizational innovation, performance, and resources. The behavior of the simulated organizational units is guided by assumptions of a learning model. Results indicate that innovation strategies sometimes have unintended effects that are both positive and negative in nature. Several lessons on managing innovation are offered.

INTRODUCTION

In this paper we explore corporate change and renewal in large, established organizations by examining how different types of innovation strategies affect organizational outcomes. We start from one of the hallmarks of the management literature: a concern with the trade-off between the flexibility and efficiency of large bureaucratic organizations (March and Simon, 1958; March, 1991). In a classic discussion of this trade-off, Thompson (1967: 148–150) termed its management the paradox of administration. In almost all discussions of this paradox, there is virtual agreement that at least some innovation, change, and corporate renewal is vital; Kanter (1983: 23) argues that organizations cannot survive without innovating. Despite this often espoused critical need for innovation, analysts

from March and Simon (1958) to the present (e.g., Tushman and Nelson, 1990; March, 1991) have observed that executing rapid, radical change in large organizations is more difficult and less frequent than executing routine, incremental change. Traditionally, organizational size, formalization, and complexity have been viewed as obstacles to innovation (Burns and Stalker, 1961; Thompson, 1965; Aiken and Hage, 1971; Pierce and Delbecq, 1977; Kanter, 1983; Rogers, 1983; Nadler and Tushman, 1989; Brown, 1991); Kanter (1985: 54) epitomizes this argument in her claim that when it comes to innovation, small is beautiful.

Two types of organizational change, incremental convergence and radical reorientation (Tushman and Romanelli, 1985), have been differentiated in the literature. Various terms have been used to describe this distinction, including persistence and change (March, 1981), frame-bending vs. frame-breaking change (Tushman, Newman, and Romanelli, 1986), and incremental vs. radical innovation (Dewar and

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Dutton, 1986; Ettlie, Bridges, and O'Keefe, 1984; Nord and Tucker, 1987). Thus, there seems to be an emerging consensus that large bureaucratic organizations experience short bursts of intense, discontinuous change followed by longer periods of convergence and incremental change.¹ Much of the literature on change and renewal has focused on the question of how to make organizations innovate more effectively; given the relative infrequency of radical change, this has often meant a focus on how to make organizations innovate more. Thus, our focus in discussing corporate renewal is on strategies that enhance the ability of large, bureaucratic organizations to make radical change to existing practices, routines, and structures. We will associate corporate renewal with the process of innovation, defined as nonroutine, significant, and discontinuous organizational change. We sharply differentiate the process of innovation from that of incrementalism or refinement to existing systems, structures, and technology (Kanter, 1983). Innovation embodies a new idea that is not consistent with the current concept of the organization's business (Galbraith, 1982: 6); as March and Simon (1958: 175) argued, it cannot be accomplished "... by a simple application of programmed switching rules." Damanpour (1991: 561) points out that radical innovations "...produce fundamental changes in the activities of an organization and represent clear departures from existing practices;" in contrast, incremental changes "...result in little departure from existing practices."

In our analysis, we focus on innovation broadly as a managerial process rather than narrowly as a purely technological process for two reasons. First, for any type of innovation to be implemented, management must be able to recognize and support opportunities for change; most innovations involve both technical and

administrative components (Leavitt, 1965; Van de Ven, 1986). Second, as Arrow (1971), Chandler (1977), Cole (1968), and Williamson (1983) argued, we have largely overlooked the contributions of administrative innovations because they are not as easily identified, protected, or patented as their technological or mechanical counterparts. Based on the assumption that innovation is an administrative process, we examine how different types of routine practices and strategies affect the amount and type of innovation that an organization experiences. As radical an outcome as innovation might be, we believe that it can be understood only in the context of routine organizational functioning. As March (1981: 564) observed: 'Most change in organizations results neither from extraordinary organizational processes nor forces, nor from uncommon imagination, persistence or skill, but from relatively stable, routine processes that relate organizations to their environments.' Examining routine practices as a source of innovation is particularly important for large organizations because of the ways in which fundamental organizational practices, especially the rationality and rules associated with bureaucracy, affect innovation (Howell and Higgins, 1990). We are not optimistic about the plasticity of the structure of large organizations, an assumption inherent in work that suggests making bureaucratic organizations more entrepreneurial (Kanter, 1983; Pinchot, 1985). Instead, our approach is to examine the structure itself and its effect on innovation; consequently, we focus on the organizational rather than the individual level of analysis. While we acknowledge that individuals can significantly affect bureaucratic innovation (e.g., Amabile, 1988; Downs, 1976), we have chosen to focus instead on organizational level variables because they have been the most widely studied and are recognized as primary determinants of innovation (Damanpour, 1991).

In examining innovation in established organizations, we adopt a view of organizations as experiential learning systems (March and Olsen, 1976; Levinthal and March, 1981; Levitt and March, 1988; Lant and Mezias, 1990; 1992). The themes of organizational learning and innovation have been intertwined previously, both in conceptual work (e.g., Angle and Van de Ven, 1989; Brewer, 1980; Stata, 1989; Tushman and Nadler, 1986; Tushman and Nelson, 1990; Brown, 1991)

¹ Population ecologists have argued that the structural inertia of organizations brought about by selection pressures is so great that most significant change and renewal comes about at the population level through the birth and death of new organizations (Hannan and Freeman, 1977; 1984). We agree with these analysts that a certain degree of structural inertia may be favored by selection pressures; however, we explicitly reject the proposition that this inertia is so high as to render fundamental change by existing organizations impossible, insignificant, or uninteresting. This will be especially true for organizations whose large size buffers them from selection pressures (Levinthal, 1990).

and in empirical research (e.g., Henderson and Clark, 1990; Cohen and Levinthal, 1990; Sahal, 1981). The principal contribution of a learning framework lies in the formalization of the insight that organizational change and innovation can be modeled as an experiential learning process. A learning model seems particularly appropriate because it takes into account the effects of history, and in particular, how the organization's past may affect its future capabilities for renewal and change (Lant and Mezias, 1990; 1992). We attempt to make two primary contributions in this study. First, by integrating the literatures on organizational learning and innovation, we offer a more complete theoretical framework for thinking about the problem of corporate renewal. The framework organizes the literature on change and innovation with three strategies that we label as institutional, revolutionary and evolutional. While none of these individual strategies is unique to our paper, integrating them into a single framework is. Second, by using a simulation methodology, we can perform the explicitly dynamic assessments suggested by this theoretical framework. Our contribution is to offer a model that produces results consistent with real world observations. Earlier work on the management of innovation has tended to rely primarily on rich, descriptive case studies (e.g., Howell and Higgins, 1990; Jelinek and Schoonhoven, 1990) or on broad, empirical studies across a number of different types of organizations (e.g., Tushman and Anderson, 1986); little work has been directed towards the routine processes that support the management of renewal, in spite of the recognized need for such work (e.g., Van de Ven, 1986). With our simulation analysis, we can assess the effectiveness of alternate renewal strategies for an organization adapting to an ambiguous environment.

THEORETICAL FRAMEWORK

The three faces of innovation

Following Kanter (1983), we define innovation to be the process of bringing any new, problem-solving idea into use in an organization. Like Kimberly (1981), Marcus (1988), and Rogers and Shoemaker (1971), our central criterion for defining innovation is that it must be perceived as new to the adopting organization. Innovation

thus represents discontinuous or 'frame-breaking' change that involves change in the underlying technology so that existing organizational skills and competence are rendered obsolete. In contrast, incremental change or refinement improves the performance of current technology by building on existing organizational know-how and competence (Tushman and Anderson, 1986). We recognize that the distinction between radical innovation and incremental refinement may not be quite so clear as these definitions seem to suggest; indeed, refinements sometimes lead to major innovations. For example, to develop new products, GE uses a 'multigenerational plan' by first introducing a version that embodies 'tried-and-true technologies;' only later does GE introduce versions based on newer, untried technologies (Stewart, 1991). However, because the distinction between refinement and innovation is one of the central notions in the literature on organizational innovation (Damanpour, 1991; Henderson and Clark, 1990) and for purposes of illustration, we make a sharp distinction between incremental refinement and radical innovation.

The emerging consensus concerning the need to manage innovation and corporate renewal has not been accompanied by agreement on the most appropriate strategy for managing innovation and renewal. Angle and Van de Ven (1989; 676) made this point: '[J]ust as we learned many years ago that there is no best way to manage, we expect that we will never find one best way to innovate.' However, while there may not be a single best way, it is important to delineate the costs and benefits, as well as the intended and unintended effects of different types of innovation strategies. Our review of the literature on the management of innovation identified three broad themes that represent fundamentally different strategies for managing organizational innovation: the institutional, revolutionary, and evolutional approaches. Organizations following the first two approaches employ intentional strategies to facilitate innovation, either within the current organizational paradigm (institutionalizing procedures to encourage innovation) or outside the paradigm (revolting against or ignoring institutional procedures). The third path, the evolutional approach, models innovation as a chaotic or probabilistic process not easily amenable to conscious attempts to increase its occurrence. Previous work on innovation implemen-

tation uses categorization schemes that can be subsumed within our framework. For example, Kimberly (1981) recognizes two approaches, revolutionary and evolutionary approaches to implementing managerial innovation, while Marcus (1988) details differences between a rule-bound, centrally authorized approach and an autonomous, evolutionary approach. The classifications used by Howell and Higgins (1990) in describing how 'champions' bring about technological innovation included categories analogous to the institutional and revolutionary approaches, but did not include a category corresponding to the evolutionary approach. We believe that the three part typology we propose is especially useful in facilitating a comparison of the trade-offs inherent in each approach; illustrating how these trade-offs might unfold over time is the focus of our simulation model.

Institutionalizing innovation

Much of the literature on innovation emphasizes the theme of rational, functional, planned innovation (Howell and Higgins, 1990). Successful innovation is seen as the outcome of an organized, purposeful, and systematic process (Drucker, 1985); innovation occurs by design and as a result of an organization's rules and procedures. In their study of high technology organizations, Jelinek and Schoonhoven (1990) found that innovation was an integral part of on-going operations. The institutional approach is illustrated by the case of David E., reported by Howell and Higgins (1990: 45–46). As vice-president of national accounts for a large financial institution, David became convinced of the need for an integrated office system. He followed the standard corporate approval process, carefully detailing the costs and benefits of the system and presenting an in-depth business case to the executive committee. David succeeded in selling the innovation to an entrenched bureaucracy by preparing a carefully documented business plan that promoted the benefits of the new technology on a financial basis. As David's story suggests, institutionalizing innovation involves manipulating bureaucratic rules so that learning new ways of doing things at the organization is facilitated (March and Simon, 1958; 184–188). The basic ideas of the institutional approach have been to devote more resources to innovation and highlight

its importance. While there has been some refinement of these standard notions (e.g., Tushman, 1977; Burgelman, 1984), they remain an essential, albeit occasionally overlooked (Howell and Higgins, 1990), part of conventional wisdom about innovation at organizations.

Much of the literature argues, however, that an institutional approach to innovation results not in the discovery of radical, frame-breaking innovation but in refinements to existing systems and technologies (March and Simon, 1958). Both Galbraith (1982) and Quinn (1985) argued that a linear process of devoting additional resources to innovation tends to result in minor, incremental changes rather than major, radical innovation. This idea has been one of the hallmarks of organization theory, harkening back to March and Simon (1958: 173) who wrote: "Individuals and organizations give preferred treatment to alternatives that represent continuation of present programs over those that represent change." Managerial concerns about the assimilation of a new technology often contribute to this tendency to maintain the status quo. Kotter and Schlesinger (1979: 107) describe this reluctance: 'More than a few organizations have not even tried to initiate needed changes because the managers involved were afraid that they were simply incapable of successfully implementing them.' As Brown (1991: 103) points out, concerns about implementation tend to shift the research focus '...away from radical breakthroughs toward incremental innovation.' To overcome this limit, two other perspectives on managing innovation have been advanced. The revolutionary approach assumes that problems in innovating are due to the organization's rules and procedures; consequently, change is introduced by disregarding or breaking the institutionalized rules. By contrast, the evolutionary approach suggests that changing the rules or processes of the system may not be feasible or fruitful. Rather, encouraging innovation requires changing the inputs to the system, typically by allowing the simultaneous development of multiple and varied projects, often at different levels of risk.

Revolution and innovation

The revolutionary approach to innovation involves conscious efforts to move away from the current organizational paradigm. Such intentional strat-

egies to move beyond the *status quo* are designed to overcome two problems with the institutionalization of innovation. First, revolutionary strategies recognize explicitly that important changes sometimes cannot be discovered by operating within the *status quo* (March, 1976); a change of paradigm (Brown, 1978; Pfeffer, 1981) or organizational theory-in-use (Argyris and Schon, 1978) may be necessary. Second, revolutionary strategies assume that resistance to change will block successful implementation of innovations produced by an institutionalized process (e.g., Kimberly, 1981; Rogers, 1983; Van de Ven, 1986). As Brewer (1980: 339) cogently puts it: 'One person's innovation is ordinarily another's destruction.' In the extreme, a revolutionary approach argues, as does Galbraith (1982: 14), that '...innovating and operating are fundamentally opposing logics.' As a result, organizations need to distinguish between structures designed for efficiency or production and those designed for innovation (Thompson, 1965; Delbecq and Mills, 1985; Galbraith, 1982; Kanter, 1983). Typically, operating organizations have structures that are mechanistic (Burns and Stalker, 1961) or segmentalist (Kanter, 1983), while innovating organizations are organic (Burns and Stalker, 1961) or integrative (Kanter, 1983). Revolutionary strategies advocate spin-offs, skunkworks, special ad hoc teams or autonomous work groups that operate outside the existing organizational structure (Kidder, 1981; Burgelman, 1984; Kanter, 1985). The rationale is that the dominant culture in established organizations is centered around rules that stifle innovation (Kanter, 1983). Organizational learning takes place only by breaking habitual and routine ways of thinking and acting (Senge, 1990a, b). Much of this work has pointed to the importance of individuals who fight for particular change, the innovation champions who operate as revolutionaries or renegades, deliberately violating bureaucratic rules and management directives. A good example is given in Howell and Higgin's (1990: 50) discussion of Jeffrey, a director of systems engineering for a major telecommunications company. He had become frustrated with bureaucratic resistance to a new technology and described how he overcame this opposition: 'What we were doing wasn't part of standard operating procedure . . . so I simply went out and bought the technology. I didn't bother fighting the traditionalism and the b.s.'

Examples of revolutionary strategies include temporarily relaxing rules and rational analysis (March, 1976), learning from hypothetical histories (Levitt and March, 1988; March, Sproull, and Tamuz, 1991), and questioning the norms and assumptions inherent in everyday organizational activities (Argyris and Schon, 1978). A revolutionary approach is embodied in what Brown (1991: 103) called pioneering research, which seeks to redefine corporate problems so as to discover new, radical solutions. The common thread in these revolutionary approaches is that they encourage playfulness (Glynn and Webster, 1992) so as to allow unusual and innovative behavior to emerge. In describing the technology of foolishness, March (1976: 81) argued that these strategies encourage innovation by offering '...temporary relief from control, coordination, and communication.'

In overcoming institutional barriers to innovation, however, the revolutionary approach is vulnerable in its dependence upon individual innovation champions. By assuming that individuals will shoulder most of the risks associated with innovation, the approach hinges primarily on what Sahal (1981: 32) terms the 'heroic entrepreneur' theory of innovation. What innovations are eventually adopted may depend less upon the quality of the idea or technology and more on the individual innovator's ability to persist and amass necessary resources and support. Furthermore, as Tushman and Nadler (1986: 82) note: 'Because organizational learning and innovation is a group and intergroup phenomena, individual contributors rarely produce the creative ideas or solutions required for complex or discontinuous innovation.' Finally, with the chaos that can ensue under the onslaught of questioning goals, violating rules, and breaking traditions, organizational efficiency may suffer. When innovations originate in separate centers or skunkwork teams, they are often difficult to implement; integrating across the organization's innovating and operating units is potentially problematic. This problem may be exacerbated when innovating units explicitly adopt structures that are viewed as being in opposition to the structures of the parent organization.

The evolution of innovation

Evolutional strategies to enhance innovation are less intentional than either the institutional or

revolutionary approaches. Strategies that encourage the evolution of innovation are designed to allow the organization to move beyond its current capabilities by making boundaries unclear. They embody the important idea that innovation is a chaotic, probabilistic process. After studying several of the world's most innovative large companies, Quinn (1985: 83) concluded: '[I]nnovation tends to be individually motivated, opportunistic, customer responsive, tumultuous, nonlinear, and interactive in its development.' There is an increasing awareness that theoretical development of this perspective is essential if we are to give appropriate attention to the role of chance in most organizational innovation (Angle and Van de Ven, 1989: 652). At the same time, the relative newness and underdeveloped state of the literature on the evolution of innovation may render such strategies difficult to recognize. For example, Quinn (1985: 78–79) noted that companies often permit redundancies or encourage several programs to proceed in parallel. Nadler and Tushman (1989) observed that managers often pursue alternative options or small-scale side bets. The evolutional perspective suggests that despite their espoused intentions or true genesis, the effect of evolutional strategies is to encourage innovation by a process of imperfect routine maintenance (Levitt and March, 1988).

These strategies are termed evolutional because they often seem emergent or unintentional for an individual organization; nonetheless, they need not be wholly accidental. Systematic attempts to encourage the evolution of innovation include using and experimenting with slack resources as a buffer against organizational controls (Cyert and March, 1963; Bourgeois, 1981), the promotion of those who take risks (March, 1981; 1988), glorification of organizational change as a managerial imperative (March, 1981), and loose coupling (Weick, 1979). In general, an evolutional approach involves making routines, performance measurement, and control less precise. As Angle and Van de Ven (1989: 679) suggested: 'It may be necessary, in order that the innovation have a chance to succeed, to relax traditional notions of managerial control.' Kanter (1985: 46) describes this as a portfolio approach, which involves '...seeding many diverse projects and many diverse experiments ... with an expectation that some will fail, but some will pay-off.'

Evolutional approaches to innovation are often characteristic of research linking individual creativity and organizational innovation. For example, one research and development scientist interviewed by Amabile (1988: 125) offered this observation: 'Quite often I will be tinkering in something that management will have no interest in, yet when I start to develop it into something, there will be a lot of interest. If they had close reins on me, they would have killed a lot of projects at an early stage and nothing would have resulted.'

The organizational learning perspective

Levitt and March (1988: 319) describe organizations as experiential learning systems that are '...routine-based, history-dependent, and target-oriented.' Unpacking this description is an excellent way to summarize the key points of the organizational learning perspective as we use it in this study. First, it is important to emphasize the view of organizations as routine-based systems that respond to experience. This model of organizations as experiential learning systems typically have three categories of routines: search, performance, and change.

1. **SEARCH:** Modeling of search routines focuses on the process by which organizations attempt to discover adaptive opportunities in an ambiguous world via a costly and routinized process of search (Simon, 1957; March and Simon, 1958; March and Olsen, 1976; March, 1981; Sahal, 1981; Nelson and Winter, 1982). Cyert and March (1963) make the distinction between search that is focused on improving and refining current practices, i.e., problemistic search, and search that is focused on changing the practices used by the organization, i.e., innovative search. They argue that it is innovative search that leads to fundamental organizational change. Levinthal and March (1981) translate this into the distinction between refinement search and innovative search.
2. **PERFORMANCE:** Performance routines typically underscore the argument that organizations compare actual outcomes against a moving target: an aspired level of performance that changes over time in response to experi-

ence. Several functional forms guiding the adaption of aspiration levels have been proposed (e.g., Levinthal and March, 1981; Herriott, Levinthal, and March, 1985); we rely on a general form of aspiration level adaptation that has been supported in empirical work (Glynn, Lant, and Mezias, 1991; Lant, 1992).

3. **CHANGE:** Change routines underscore the notion that organizational change, whether an attempt to refine current capabilities or to implement new and different capabilities, is a stochastic response to experience. Organizations are more likely to persist in activities associated with success and desist activities associated with failure (March and Simon, 1958; Cyert and March, 1963).

Second, it is important to emphasize that the learning process is history dependent; there are no unique equilibria or closed form solutions in this process. Two aspects of history dependence are particularly important in this study. First, following Amburgey, Kelly, and Barnett (1990), we assume that organizations have change clocks that are reset each time there is an innovation. For some time following a significant innovation, the effort and resources that normally would be devoted to search and change are devoted instead to getting the organization to function using the innovation that has just been adopted. Thus, there is a small window of time when there is no search or change following each innovation. If the organization is within this window of inertia, it will not search or change in the current period. The second consideration highlighted by a history dependent learning model is increasing competence: the well-known learning curve. It is well-established that over time organizations improve their performance with new technology, but at a decreasing rate (Yelle, 1979; Argote, Beckman, and Epple, 1990; Argote and Epple, 1990; Epple, Argote, and Devadas, 1991). Thus, we see an immediate reason why organizations may be reluctant to innovate: They will lose the competencies they have built using the status quo. Indeed, this notion is at the heart of Tushman and Anderson's (1986) distinction between competence-enhancing and competence-destroying technological change. Thus, when organizations innovate, they do not perform as

close to the true underlying potential of the new practices as they did with the old practices. The results are organizational myopia (Radner, 1975) and competency traps (Lave and March, 1975; Levinthal and March, 1981; Levitt and March, 1988). Inferior alternatives with which the organization has competence are preferred to superior alternatives with which the organization lacks competence.

Finally, the argument that organizational learning is target oriented highlights the importance of aspiration levels (March and Simon, 1958; Cyert and March, 1963; Mezias, 1988; Glynn *et al.*, 1991; Lant, 1992) in mediating the execution of change routines. The assumption that change is more likely when performance is below aspiration level has been a central tenet in the organizational learning literature. When performance meets or exceeds the aspiration level, change is less likely (March and Simon, 1958; Cyert and March, 1963); if change does occur under conditions of success, it is a largely serendipitous grab at an opportunity that is perceived as extraordinary (Levinthal and March, 1981; Harrison and March, 1984; Marcus, 1988). In addition, once it has been admitted that aspirations adapt to performance (March, 1981; Levitt and March, 1988; Glynn *et al.*, 1991; Lant, 1992), the picture is complicated considerably. The questions of how quickly aspirations adapt to performance, the pattern of subjective success and failure this generates, as well as the association of particular routines with this pattern of success and failure become crucial to understanding organizational outcomes (Levinthal and March, 1981).

Learning and innovation

The three innovation strategies we have outlined can be understood more completely when placed in the context of a learning model. The learning model directs attention to how an organization's routine-based strategies for encouraging innovation may have intended and unintended results under conditions of environmental ambiguity. Our contribution in this paper is to demonstrate how the three different innovation strategies suggest paradoxes and sometimes lead to unanticipated outcomes concerning both the type and the amount of innovation activity. We discuss three implications of the learning model for organizational innovation.

First, we have interpreted an institutional approach to managing organizational innovation as consistent with the strategy of devoting more resources to search within current organizational routines and structures. Two plausible assumptions about the context in which organizational search takes place suggest that institutional strategies will result in a skew towards refinement. First, if the adoption of a new innovation replenishes the pool of refinement opportunities (Levinthal and March, 1981), then immediately after adopting an innovation, refinement search will be especially productive. Second, if innovation opportunities improve as a function of time since the last innovation was adopted (Tushman and Anderson, 1986), then immediately after adopting an innovation, innovative search will be relatively unlikely to lead to discovery of good opportunities. This description is consistent with a cyclical pattern of technological innovation argued by Sahal (1981) and empirically demonstrated by Anderson and Tushman (1990); periods of technological ferment and high innovation are followed by periods of incremental modifications to the dominant design. Taken together, these two assumptions imply that, in the periods following adoption of an innovation, the organization will tend to associate refinement search with better performance and innovative search with poorer performance. *Ceteris paribus*, this leads to more resources being devoted to refinement search and fewer to innovative search. This will tend to delay the discovery of new innovations. An additional problem exacerbates this anti-innovation tendency further: Routine comparisons of an innovation and existing practices do not adjust sufficiently for the fact that competence has been built with existing practices. This evaluation bias tends to result in a 'competency trap' (Levitt and March, 1988) or reliance on the 'old winning formula' (Tushman and Nadler, 1986: 75) that precludes innovation. For all of these reasons, increases in total resources devoted to search will not increase the amount of innovation. We call this the paradox of institution:

THE PARADOX OF INSTITUTION: Devoting more resources to search in the context of routine organizational functioning will not increase innovation.

Second, using the learning model, we have interpreted revolutionary approaches to managing innovation as being consistent with the strategy of devoting more resources to search for those technologies that depart radically from current organizational competencies. In terms of the distinction between refinement and innovative search (Cyert and March, 1963; Levinthal and March, 1981), we assume that revolutionary approaches involve devoting more resources to innovative search. We have assumed that the distribution of innovation opportunities improves with the time since the last innovation adopted by the organization (Levinthal and March, 1981; Sahal, 1981; Tushman and Anderson, 1986). This implies that, in the periods immediately following the adoption of an innovation, devoting more resources to innovative search can only result in extensive search through a relatively sparse pool of innovations. A few organizations will find improvements, but the majority are not likely to find an innovation worth adopting. At the same time, the additional expenditures on innovative search are lowering the performance of the organization. Consequently, the majority of organizations will come to associate innovative search with poorer performance; this will tend to result in a reduction in the amount of resources devoted to innovative search. Taken together, these assumptions suggest a pattern of results that we call the paradox of revolution: Increasing the resources devoted to innovative search will not increase the amount of innovation. Initially, there may be an increase in the amount of innovation as a few organizations find innovations as a result of the additional resources devoted to innovative search. However, the majority of organizations will not find a useful innovation. The additional expenditures on search will lower their performance, and they will enter a cycle of reductions of expenditures on innovative search. As a result, the revolutionary approach will not increase innovation above the level that would have been observed in the absence of additional expenditures on innovative search.

THE PARADOX OF REVOLUTION: Devoting more resources to innovative search in the context of routine organizational functioning will not increase innovation.

Third, with respect to evolutional approaches

to managing innovation, the learning perspective offers the following observations. Levinthal and March (1981) modeled both innovative and refinement search as draws from a distribution of alternatives to current practices. They argued that the amount of improvement to be gained from these alternatives is symmetric around zero and that the variance of innovative search is greater than that of refinement search. They assumed that there is some error in the evaluation of alternatives, but, on average, organizations tend to reject alternatives that do not offer an improvement to current practices and accept those that do. In such a model of search, variance is an unmitigated good: An increase in the variance of the pool of search opportunities will increase the expected improvement to current practices to be realized by search (Kohn and Shavell, 1974; Levinthal and March, 1981). Learning models have also characterized organizational control systems as improving mean performance at a decreasing rate, but at the cost of reducing variance (March, 1981; 1988). If reduced variance translates into a narrowing of the pool of opportunities examined in search, this decreases the expected value of organizational performance in the long run (Levinthal and March, 1981). This is why the evolutional approach to managing innovation often endorses the loosening of organizational control. These observations translate into the value of variance, which is at the heart of the recommendations of evolutional approaches to managing innovation.

THE VALUE OF VARIANCE: Increasing the variance of innovative search, *ceteris paribus*, will lead to more innovation.

SIMULATION ANALYSIS

We have argued that organizations learn via a longitudinal process of considerable complexity; deriving the implications of this theoretical framework is quite complicated. It is difficult to predict how the processes will develop over time in different contexts to yield various organizational outcomes. The unfolding of these processes can be observed, however, in a computer simulation. A computer simulation can take a complex set of assumptions, simulate a

set of organizational processes, and represent the implications of these processes for organizational outcomes (Cyert and March, 1963; Levinthal and March, 1981; Morecroft, 1984; Herriott *et al.*, 1985; March, 1988; 1991; Lant and Mezias, 1990; 1992; Levinthal, 1990). In this paper, we use simulation methodology to study the strategic management issues of corporate renewal, change, and innovation. The basic rules that govern the behavior of the simulated organizations are described in the following sections; technical details of how these rules were operationalized are described in a separate Appendix. In keeping with our administrative perspective on innovation, our use of technology follows the broad definition proposed by Levinthal and March (1981: 187): 'By technology we mean any semi-stable specification of the way in which an organization deals with its environment, functions, and prospers.'

Our simulation model will be used to demonstrate how certain assumptions about organizational functioning lead to different predictions regarding organizational performance, resources, and innovation activity. Morecroft (1985) argued that simulations that address issues of organizational strategy should be careful to describe their premises and present partial tests of the simulation models. Following this advice, we carefully outline the assumptions of our model. To the extent that these assumptions are based on empirical evidence or are intuitively appealing, concerns about generalizability are mitigated. With respect to partial tests, the skeleton of our simulation program uses the decision rules described by Levinthal and March (1981). While our study goes beyond this skeleton to address a different set of issues, many of the decision rules are identical. Not only does this help to accumulate knowledge by explicit comparison with past work, it also allows us to rely on the partial model tests that they conducted. The purpose of our simulation is to clarify ideas about innovation and how they may lead to intended and unintended outcomes. The ability of a model to demonstrate the linkage between assumptions and outcomes is gained at the cost of imposing precision that can threaten the external validity of the analysis. Along these lines, the construction of the simulation model required a key assumption: The innovations we model are of a single type adopted by one cohesive unit in an organization. While most

organizations are innovating on multiple fronts simultaneously and innovations of different organizational units may impact each other over time, we restrict the simulation to an examination of the behaviors of one independent business unit over time. For the sake of clarity, we use the word 'unit' to capture this idea in our analyses.

Search routines

Search is modeled as the execution of a series of steps in the simulation program as depicted in Figure 1. The steps are as follows:

1. The possibility of search is checked against the unit's change clock (Amburgey *et al.*, 1990). If change occurred recently, the resources normally devoted to search are instead devoted to getting new routines running; thus, there is no search in the current period.
2. The cost of search for the unit is determined as a function of the amount of search done by the unit in the recent past. If there has been some search, the cost of search decreases with each search but at a decreasing rate; this is equivalent to assuming that there is a learning curve for search (Yelle, 1979; Levinthal and March, 1981). When there has been no search, the ability of the unit to conduct search decays; we assume that the cost of search increases at a decreasing rate with each period that the unit does not search.
3. The unit assesses whether search has been associated with success or failure in the recent past; based on this decision, resources devoted to search are increased or decreased. The rules by which this decision are made are presented in Table 1; the basic rationale is that when search is associated with success it is increased, and when it is associated with failure it is decreased. We follow Levinthal and March (1981) in having the unit make three separate decisions based on these rules in each period: The first concerns overall resources devoted to search, the second concerns resources devoted to innovative search, and the third concerns resources devoted to refinement search.
4. The unit determines if performance was above or below aspiration level in the last period. Following Cyert and March (1963) and Levinthal and March (1981), we impose the following rules: If performance meets or exceeds

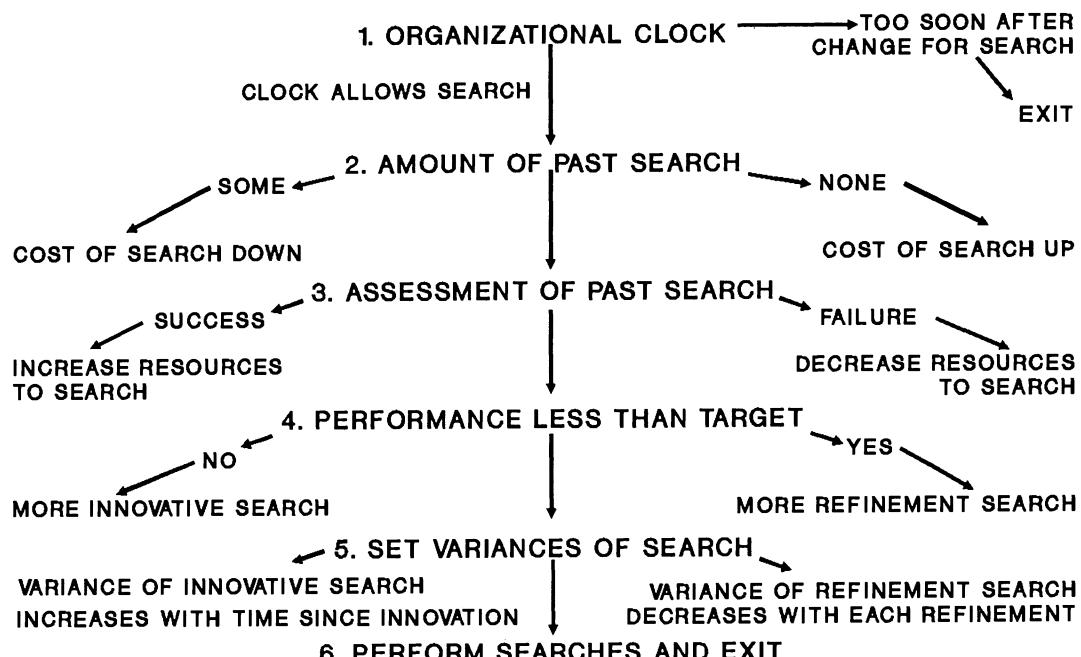


Figure 1. Flow chart for search decisions

Table 1. How resources devoted to search are changed in response to experience

		PERFORMANCE RELATIVE TO TARGET	
		MEETS OR EXCEEDS 'SUCCESS'	FALLS BELOW 'FAILURE'
SEARCH RESOURCES INCREASED IN THE LAST PERIOD	INCREASE	DECREASE	
	DECREASE	INCREASE	

Based on the rules in this Table, each unit makes three separate decisions in each period. The first involves total search resources, the second innovative search resources, and the third refinement search resources.

the aspiration level, then the unit devotes more resources to innovative search. Conversely, if performance is below aspiration level, then the unit devotes more resources to refinement search.

5. The variance of search processes is updated. We assume that the variance of innovative search increases with the time since the last innovation. This implies that the probability that an organization will discover worthwhile innovations increases as a function of time since the last innovation. We also assume that the variance of refinement search decreases with the total number of refinements already made to current practices; this is equivalent to assuming that there are decreasing returns to refinement (Levinthal and March, 1981). The time path of this decrement resembles the 'S-curve' function of technological progress described by Foster (1986: 32). 'Ships don't sail much faster, cash registers don't work much better, and clothes don't get much cleaner.' As more resources are put into the refinement of dominant designs, it becomes increasingly difficult to make progress because of the limitations inherent in the technology.²

6. The program exits the search routines.

² As we detail in the Appendix, the pool of refinement possibilities is replenished each time there is an innovation. Then the whole process of decreasing returns to refinements of current technology begins anew.

The Determination of performance

The determination of the unit's performance in the simulation is depicted in Figure 2. The steps in the program are described as follows:

1. The main source of ambiguity, the exogenous drift in the value of the underlying technology, is determined. Basically, this involves the determination of two random quantities: the magnitude of drift, depicted on the left, and the direction of drift, depicted on the right. Absent any action by the unit, a random walk on the potential value of the underlying technology is created. This complicates the unit's experiential learning by introducing variation in performance that is unrelated to the actions of the unit. This operationalization of environmental ambiguity follows Levinthal and March (1981), and the values of these quantities are set to correspond to the mean value of drift in their model.
2. The actual value the unit derives from its current practices is a function of where it is on the learning curve. If this is a period in which it has adopted an innovation, it moves to the bottom of the learning curve.³ In

³ Standard practice in learning curve discussions is to talk about the reduction in unit costs associated with experience; thus, organizations move down the learning curve. For analytical convenience in this study, units move toward a maximum potential level of performance with a technology as they gain experience with it; hence, we describe units as moving up the learning curve.

- periods subsequent to the first period after adoption, it moves up the learning curve; in keeping with empirical data, we assume that as the unit gains experience, its performance increases at a decreasing rate.
3. The performance of the unit is determined by taking the value of how well it did with current routines and subtracting the resources spent on search in the current period.
 4. The adaptive aspiration level is computed; as we model it, the aspiration level changes over time in a process that is both incremental, i.e., anchored on the aspiration level in the previous period, and adaptive, i.e. responsive to experience (Glynn *et al.*, 1991; Lant, 1992).
 5. The program exits the routines for determining performance.

Change routines

The determination of change in the program is depicted in Figure 3 and outlined below.

1. The possibility of change is checked against the unit's change clock. As with search, if the unit has only recently changed, then a subsequent change is not permitted.

2. Performance is compared with the aspiration level. If performance meets or exceeds aspiration level, then the probability of change is a function of the value of options the unit has found in executing its search routines. If performance is below aspiration level, then the probability of change is an increasing function of the amount by which the unit has fallen below aspiration level. The difference between performance and aspiration level is called the attainment discrepancy (Glynn *et al.*, 1991; Lant, 1992); hence, the notation in the figure is meant to convey that the probability of change is a function of the attainment discrepancy.
3. In keeping with our probabilistic model of organizational processes, we model the change decision as a random variable. Whether the unit will actually change in this period is a binomial random variable with the probability of success equal to the probability of change. If the draw from the binomial is a 'failure,' then the unit does not change in the current period, and the program exits the execution of change routines. If the draw from the binomial is a 'success,' then the unit proceeds through change routines.
4. Given that the binomial process allows the

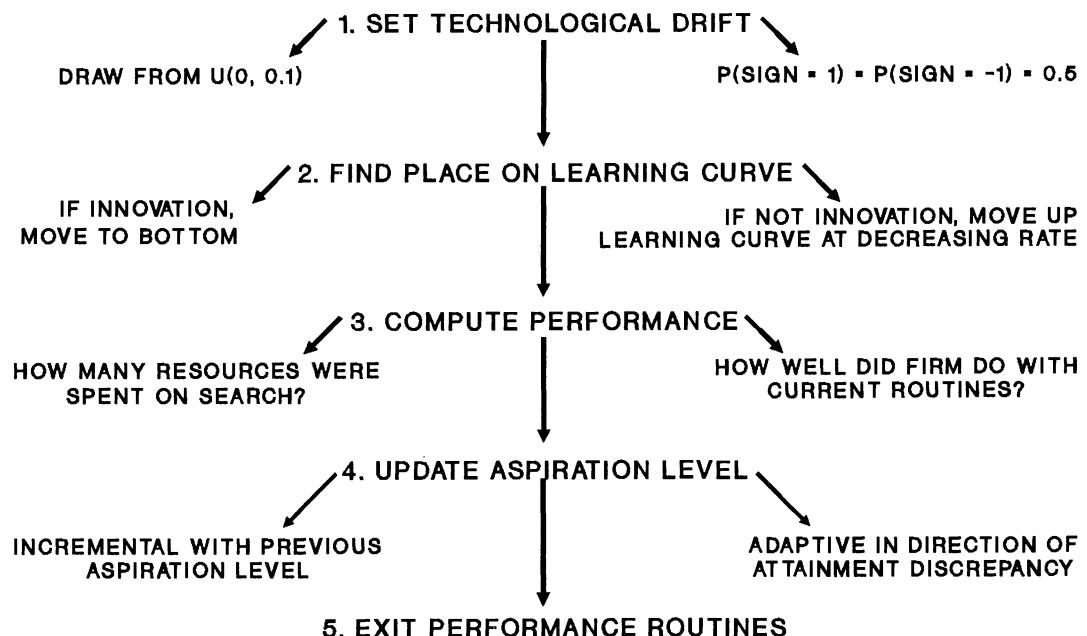


Figure 2. Flow chart for determining performance

possibility of change, the unit still must determine if it has discovered an opportunity, either a refinement or an innovation, which it believes is a preferred alternative to current practice. As in Levinthal and March (1981), we assume that the value of alternatives to current practices is known with some error. Based on this comparison, the unit may decide that there is some preferred alternative and adopt it. If the preferred alternative is an innovation, then the unit has undergone a major change; if it is a refinement, then the unit has undergone an incremental change. Conversely, the unit could decide that none of the opportunities discovered through search are preferable to current practices and exits the change routines.

5. The program now exits the change routines.

Simulating the behavior of organizational units

The three categories of routines are executed for 50 business units over 50 time periods. Each unit is initialized as if it had innovated, i.e., adopted a new technology, in period 0; all parameters are set to the same values as in Levinthal and March (1981). Three outcome measures are reported by the program:

- First, we observe the *mean total innovative*

changes (subsequent to the period 0 change) made by units in the population. This measure gives an idea of how many units have adopted a new technology as the program progresses through 50 periods.

- Second, we observe the *mean total refinements to current technology* made by units in the population. Each time an innovation is adopted by a unit, the mean of refinements to current technology is reset to zero. This measure gives an idea of the propensity of an average unit in the population to refine current technology.
- Third, we observe *mean total resources* of a unit in the population. In each period, the performance of the unit with its technology is added to total resources, and the total cost of searches conducted by the unit is deducted from total resources. This measure allows assessment of search in light of its effect on unit growth.

Operationalizing the innovation strategies

To operationalize the innovation strategies, we ran the program under four conditions. These represented a baseline model and three variants created to examine the paradoxes of institution and revolution as well as the value of variance. We contrast the four different conditions to determine the effects on the performance,

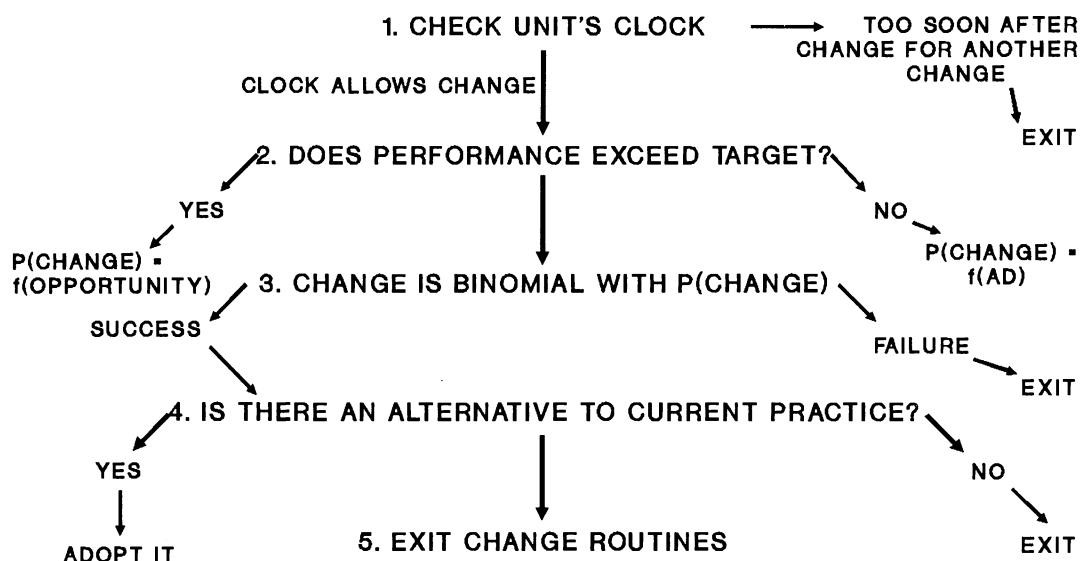


Figure 3. Flow chart for determination of change

resources, and innovation record of units when we vary the model as described below.

- The Baseline Condition: The program operates exactly as described in the flow charts.
- Variant One, The Institutional Approach: To test the paradox of institution, we made one alteration to the baseline program: As each unit executed its standard operating procedure for determining total resources to be devoted to search, the amount was increased by 25%.
- Variant Two, The Revolutionary Approach: To test the paradox of revolution, we made a different alteration to the baseline program: As each unit executed its standard operating procedure for determining the amount of resources to be devoted to innovative search, the amount was increased by 25%.
- Variant Three, The Evolutional Approach: To test the value of variance, we made a different alteration to the baseline program: As each unit executed innovative searches, the variance of the distribution of the outcomes of these searches was increased by 25%.

While these operationalizations are precise and parsimonious so as to make clear the link between existing theory and our results, there are some inherent limitations. Obviously, the model does not capture fully the richness or complexities of each of the innovation strategies. Moreover, it assumes that each unit follows only one strategy and does not change that strategy during the period of the simulation. Finally, the model does not take into account intra- or interorganizational factors that may influence the innovation process; our models are intended to depict the behaviors of an independent business unit operating within a large, bureaucratic organization.

Sensitivity Analysis

To assess the sensitivity of our results to the choice of parameters and structural equations that govern decision making by units, we ran six variations on the main model.⁴

1. Low ambiguity variation: Levinthal and March

⁴ The operationalizations of these conditions is described in greater detail in the Appendix.

(1981) termed the level of exogenous drift in technology a measure of ambiguity. We adopted the level of drift from their model for our main model; to test the sensitivity of our results to this choice, we also ran a variation with lower ambiguity.

2. High ambiguity variation: To further test the sensitivity of the model to this choice, we also ran a variation with higher ambiguity.
3. High inertia variation: Drawing on recent empirical work (Amburgey *et al.*, 1990), we posited that units would not search or change for some period of time following adoption of an innovation. In operationalizing the main model, we chose a value of two periods for this waiting time. To test the sensitivity of the results to this parameter, we chose a value that we believed represented a high level of inertia, 10 periods.
4. Slow increase variation: In consonance with much theoretical and empirical work, we posited that the value of innovation increased with the time since the adoption of the last innovation. To test the sensitivity of our results to the particular functional form of the relation between time since adoption and the value of innovation, we ran a variation that had a slower increase than our main model.
5. Fast increase variation: To further test sensitivity to this parameter, we also ran a variation where the value of innovation increased more quickly than our main model.
6. Additive variation: Following Levinthal and March (1981), we specified a multiplicative relationship among the quantities used by the unit to determine search expenditures. To test the sensitivity of the result to this specification, we ran a final variation that specified an additive relationship among these quantities.

RESULTS

The baseline model and its three variants are examined in a series of figures comparing effects for the four conditions: baseline, institutional, revolutionary, and evolutional. The figures compare the means of units in the four innovation conditions on three outcomes: innovative change, refinements to current technology, and resources. Given uncertainty about the distributions of these variables, we used nonparametric comparisons

to assess whether the conditions differed significantly. Thus, the comparisons we report are robust to violations of the distributional assumptions of a comparison like the *t*-test. In addition, these tests offer more conservative assessments of the significance of results than parametric tests.⁵

Results supporting the paradox of institution can be seen in several figures. First, Figure 4 depicts mean innovative changes by condition over time. During the first 18 periods following initialization of the simulation, there are no innovative changes in any of the conditions.⁶ The institution condition produces its first innovations in period 22, while the baseline condition does not produce its first innovation until period 25. However, from that point onward, the mean levels of innovation produced by the two strategies are not significantly different. This demonstrates support for the paradox of institution: Devoting more resources to search in the context of routine organizational functioning does not increase the level of innovation by the unit compared to the baseline strategy. Second, Figure 5 depicts the total number of refinements. The institution condition produces a higher level of refinement than the baseline condition throughout the entire run of the simulation; in fact, the level of refinement produced by the institution condition is significantly higher than that produced in the baseline condition ($p < 0.05$).

Support for the paradox of revolution is also indicated in Figures 4 and 5, by comparing the revolution and baseline conditions. The baseline condition produces innovations first, with the revolution condition producing its first innovations four periods after the baseline condition first yields innovations. However, from that point onward, the mean levels of innovation produced by the two strategies are not significantly different. Thus, as suggested by the paradox of revolution, the additional resources devoted to the search for innovations in the revolution condition do not produce a significant increment

to the level of innovation by the unit. Figure 5 demonstrates that the mean refinements produced by the revolution condition are at all times greater than the number of refinements produced by the baseline condition; this difference is statistically significant ($p < 0.05$). Thus, we found two types of support for the paradox of revolution: First, the additional resources spent on innovative search in the revolution condition do not yield significant increases in innovation relative to the baseline condition. Second, the additional resources spent on innovative search in the revolution condition actually result in significant increases in refinements relative to the baseline condition.

Finally, support for the proposition concerning the value of variance can be deduced from Figures 4 and 5. Figure 4 demonstrates the most substantive result: In terms of innovation, the evolution condition clearly dominates the baseline condition, producing a significantly higher ($p < 0.05$) level of mean total innovations. The evolution condition begins producing innovations in period 18 while the baseline condition does not produce an innovation until period 22. From that point forward, the evolution condition produces a higher level of innovation than the baseline condition in every period. Figure 5 demonstrates that the mean number of refinements to current technology produced by the evolution condition is somewhat less than that in the baseline condition. In the early part of the simulation, through about period 20, the mean number of refinements to current technology produced by the evolution and baseline conditions is fairly identical. Beginning in period 20, however, and continuing through about period 40, the mean number of refinements in the evolution condition is lower than that in the baseline condition. In the final periods of the simulation, the two conditions once again produce similar levels of refinement. Overall, the mean numbers of refinements produced by the two conditions are not statistically different; importantly, both the evolution and baseline conditions produce significantly fewer refinements than either the institution or revolution conditions.

The trade-off between the costs and benefits associated with different innovation strategies is illustrated in Figure 6, which depicts mean resources by condition over time. The pattern of

⁵ All of the comparisons we report below as not significant using the nonparametric tests are also not significant using *t*-tests.

⁶ Recall that the simulation was initialized as if all units had made an innovation in period 0 and we assumed that the value of innovation increases with the time since last innovation. This combination yields a period of no innovation following initialization of the simulation.

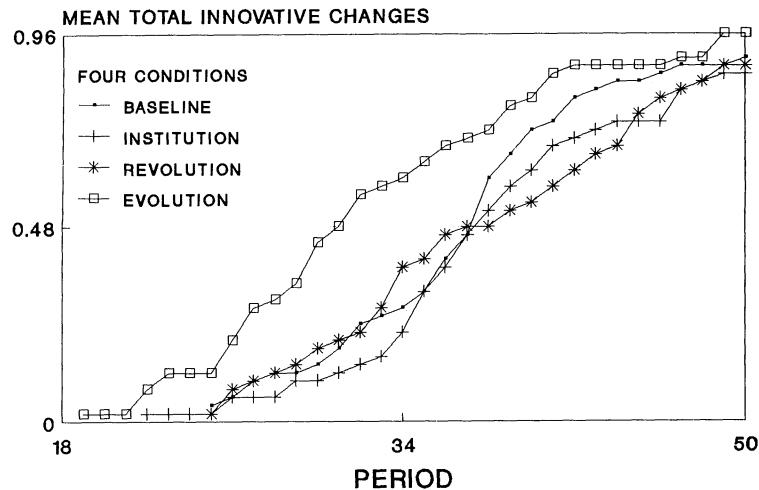


Figure 4. Mean total innovative changes in the four conditions

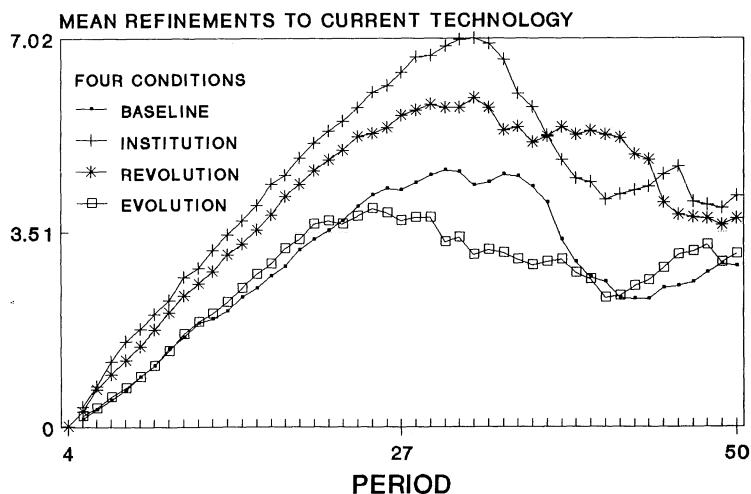


Figure 5. Mean refinements to current technology in the four conditions

findings is evident and consistent from about period 20 through period 50. The order of highest to lowest level of mean resources is evolution, baseline, revolution, and institution conditions. This demonstrates that the costs associated with more resource intensive strategies for managing innovation, i.e., the institutional and revolutionary approaches, are not sufficiently offset by the returns from the additional search that these resources buy. The average level of total resources in both of these conditions is significantly less than the level of resources observed in the baseline condition. While the size and timing of the gap in Figure 6 depends on parameter settings, several conclusions that arise from this

line of reasoning do not.⁷ First, the tenability of innovation strategies will be a function of how their costs are distributed over time. Resource intensive strategies to manage innovation will be sustainable only so long as the increment to performance justifies the expense. Second, the tenability of resource intensive strategies will probably be a function of competitive conditions. For the sake of simplicity, we have excluded competitive effects from our model, but we

⁷ It is notable, however, that the gap in resources depicted in Figure 6 was not altered greatly in the sensitivity analysis where we ran six variations on the baseline model that varied the parameters and structural equations.

believe they are of central importance for future work. For example, we do not believe that is a coincidence that Brown's (1991) pioneering strategy, which we categorize as a revolutionary approach to innovation, was developed in the context of an industry in which the basic production technology is changing rapidly. In such contexts, the value of innovation will recover more quickly following the adoption of one innovation as the underlying technology undergoes rapid transformation. Third, the long-run untenability of resource intensive strategies might actually assist managers in deciding when to devote more resources to the search for new technologies. For purposes of illustration, we have adopted a model of these strategies as binary, either off (baseline) or on (either the institution or revolution conditions). More sophisticated switching rules based on performance and resources might do better than the simplistic strategies we have outlined here. As managers interpret ambiguous experience to adjust search routines, feedback about the apparent costs and benefits of search could be an important piece of information (Nelson and Winter, 1982).

CONCLUSIONS AND IMPLICATIONS

We used a simulation methodology to explore the theoretical implications of following different innovation strategies in business units of large, bureaucratic organizations over time. Drawing

from the organizational literature, we developed a framework of three key strategies used to encourage innovation in established firms: institutional, revolutionary, and evolutional approaches. An organizational learning perspective was adopted to conceptualize the dynamics of the innovation process. This perspective suggested a focus on three key variables: search, performance, and change. We assessed the effects of the strategies on a business units' innovation record (i.e., refinement vs. innovation) and resources. Overall, the findings support Damanpour's (1991) contention that different organizational types, particularly as they may be defined by their strategic orientation, can influence the degree of organizational innovativeness. Furthermore, the results are noteworthy in several respects.

First, we found that intentional strategies may have unintended consequences. We found support for the paradox of institution: Units engaging in an institutional strategy did not tend to experience more innovation, in spite of increased resources devoted to search. Our result has a parallel in the real world of organizations: In a recent study, 32 of 34 companies were found to decrease investment in promising new technologies. Instead, the resources that would have been devoted to developing new technologies were devoted to the refinement of existing technologies in a futile attempt to ward off potential competitors with the new technology (Blanchard, 1989).

Second, we also found support for the paradox

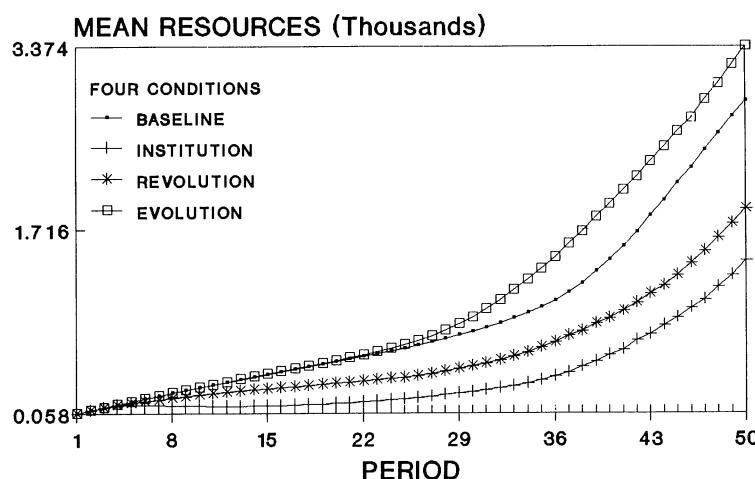


Figure 6. Mean resources in the four conditions

of revolution: Units engaging in a revolutionary strategy, purportedly designed to increase radical innovative change, garnered only transitory increases in the amount of innovation. The finding that units following either the institutional or revolutionary strategies did not produce significantly more innovation is consistent with empirical work demonstrating that greater organizational complexity and decentralization leads to incremental innovations (Ettlie *et al.*, 1984). This finding on the outcomes of these two strategies may not be trivial, for the different types of innovations make differential contributions to organizational effectiveness (Damanpour, 1991). For example, Hull, Hage and Azumi (1985) proposed that the success of Japanese manufacturing companies in the 1960s and 1970s might be attributed to their ability to make incremental innovations, while the success of American companies in this sector and during the same time might be related to their introduction of radical innovations.

Third, we found that a loosening of controls is beneficial when tighter controls lower the variance of stochastic search. There was a noticeable value of variance, in both discovering significantly more innovations and making significantly fewer refinements to current technology. Damanpour's (1991) meta-analysis of the innovation literature may offer a partial explanation for this result. His analysis of the existing research indicated that an organization's technical knowledge resources were more strongly related to radical innovation than incremental innovation. Perhaps organizations with more expansive knowledge bases are better able to take advantage of opportunistic search and the serendipitous discoveries it may yield (Cohen and Levinthal, 1990).

The findings of our simulation point to interesting questions about the role of management in the process of corporate renewal and innovation. Tushman *et al.* (1986) emphasize the importance of executive leadership, even attributing successful organizational performance and adaptation to visionary leadership. In the simulation presented here, management was assumed to operate in the context of a rigid organizational structure, not unlike that found in large, bureaucratic firms. Once a strategic direction for innovation was set, choices about search rules, performance, and change followed

a set of routines. Thus, our results adhere to the perspective articulated by Lant and Mezias (1992: 65): '...system dynamics limit the frontiers of individual efficacy and the possibilities for managerial leadership.' By demonstrating how these rules, followed consistently and unswervingly over time, affected outcomes, we have suggested some of the ways in which routines provide important bounds on managerial discretion and control. Moreover, support found for the paradoxes of institution and revolution suggests that under such limitations, managerial interventions may have unintended results. What such paradoxes suggest is the need for managerial attention to structural routines in the process of strategic decision making. In addition, the demonstrated value of loosening organizational controls and introducing variance into routine processes invites nontraditional definitions of the role of the executive and the management of organizational slack. Our results also speak to the centrality of attending to the costs and benefits of managing innovation while illustrating some of the complexities of attempting to do so. Strategies that attempted to induce a higher frequency of innovation by devoting more resources to search, i.e., both the institutional and revolutionary approaches, resulted in markedly lower resources over time than the evolutional and baseline conditions.

Of course, the generalizability and external validity of the results are important concerns. The use of a simulation model was chosen to underscore our belief that the roles of chance and routine have been relatively underemphasized in the literature of innovation and corporate renewal. We attempted to make our simulation as descriptive as possible and included empirical measures of parameters whenever possible. In addition, in order to build on past literature using simulation methodology to study strategic management, many parts of our program were replications of code from Levinthal and March (1981). This strategy of replication facilitated the tasks of premise description and partial model tests (Morecroft, 1985), thus addressing the question of generalizability directly. We believe that a strategy of replication and extension in applying simulation methodology to questions of strategic management, as we have done here, has merit. Moreover, the simulation results do not simply reflect the suppositions built into the

model, but yield knowledge that adds value beyond its explicit assumptions. The evidence for this is twofold: First, we base our simulation on assumptions drawn from empirical and theoretical work elaborating a view of organizations as experiential learning systems; this represents a statement of premise description, which, by articulating how assumptions of a learning model of organizations lead to simulated behaviors of organizational units, should make the link between equations and results clearer (Morecroft, 1985). This descriptive architecture of complexity does not present ready opportunities to 'rig' the results. Second, the sensitivity analysis indicates that the findings are fairly robust, even when parameter values and structural equations are varied. In order to encourage further research in this area, we close our conclusions with a discussion of some straightforward extensions of the analysis presented here.

A first possibility for future research would be to place this model of innovation in an interorganizational context. Competitive conditions could be modeled explicitly by having organizations pay some penalty for spending resources innovating in the absence of a significant increase in returns. Industry dynamics in the pattern of innovation could be modeled and various ideas about them could be tested. For example, in industries characterized by rapid technological change, greater expenditures on innovation might be tolerated because all organizations would be forced to make them. Second, the whole question of imitability (Lippman and Rumelt, 1982) could be explored. Returns to innovation can be related directly to the ability of the organization making the innovation to reap its rewards. Various imitability conditions, spanning a continuum from more to less imitable, could be explored. In addition, stochastic errors in imitation could be modeled as a source of innovation in and of themselves (DiMaggio and Powell, 1983). Third, simulations of organizational innovation could be used to pursue a course proposed by Sterman (1989): using computer simulations as a tool to produce a controlled environment in which to run experiments. Simulations might be used to examine the effects of different specifications of mechanisms that relate individual units to their organization and the organizations to an interorganizational context. The implications of these

findings might then be used to structure a set of experiments regarding how people interact with the proposed organizational mechanisms. It is our belief that the strength of these research projects would be their emphasis on a clear set of organizational routines as the source of corporate renewal and innovation. Such a clear set of routines in a setting of stochastic outcomes offers a real possibility for advancing our understanding of corporate renewal, change, and innovation.

APPENDIX: SIMULATION PARTICULARS

Choice of parameter values

Two basic considerations were most fundamental in the choice of parameter values. First, for reasons of cumulative knowledge building, many of our assumptions about search processes and parameter values correspond to Levinthal and March (1981). This contributes to cumulative knowledge because our results can be seen as a direct extension of theirs. The cumulative relationship between Levinthal and March (1981) and this study is further reinforced because this is an entirely original program written in Turbo Pascal.⁸ Since Levinthal and March (1981) used Basic, similarities in the conclusions demonstrate that they do not depend on choice of computer language. Second, in trying to set realistic parameter values, we relied on Tushman *et al.* (1986: 34) characterization of incremental adjustment: 'A popular expression is that almost any organization can tolerate a 'ten percent change.' ...these changes are still compatible with the prevailing structures, systems, and processes.' Thus, parameters meant to capture routine adjustment were set at 10% based on an empirical tendency for such adjustments to be near that level.

We also decided to initialize the simulation as if each unit had been founded in the period prior to the first. Thus, time since adoption of the current technology is set to zero. Thus, the search and change clocks of the unit are reset to zero. The unit is moved to the bottom of its learning curve on the current technology. Also,

⁸ Copies can be obtained by writing to the first author.

the unit incurs maximum search costs; since it has no prior experience with either innovative or refinement search, it does not have the requisite experience to begin lowering the costs of performing them.

Operationalization of search routines

The discussion of the operationalization of search routines will follow the flow chart for search given in Figure 1: The window of no search or change imposed by the search clock of the unit is set to two periods. An amount equal to the total resources devoted to search in the period of innovation is deducted in each of these periods but there is no search or change. Both innovative and refinement search are draws from uniform distributions. Innovative searches are draws from a uniform distribution with range as follows:

$$R_{it}^i = \pm(Pt_{it} + \tau^2) \quad (1)$$

Pt_{it} is defined to be the underlying potential of the technology used by unit i at time t ; following Levinthal and March (1981), it is set to 50 in the first period. τ is defined to be the count of the number of periods since the adoption of the most recent innovation. Thus, the mean value of technologies discovered by innovative search is always zero, since the distribution is symmetric around zero, but the variance increases with the range.⁹ As a result, the probability that the best technology discovered by innovative search will be an improvement over current technology increases with time since adoption of the current technology.

Refinement searches are draws from a uniform distribution with a range as follows:

$$R_{it}^r = (1 \pm \delta_{it}) \times Pt_{it}. \quad (2)$$

Pt_{it} is as defined above. δ_{it} is defined as follows: In the period immediately following an innovation, δ_{it} is set to 1/8 and remains at that value until three refinements have been adopted. From that point forward δ_{it} is set to $1/(TR_{it}^2)$, where TR_{it} is the total number of refinements

⁹ The variance of a uniform distribution is equal to the square of the range of the distribution divided by twelve. Since the range increases with the square of time since the last innovation, so does the variance.

made to current technology since adoption by the unit. Thus, the probability that current technology can be improved by further refinement decreases with the number of refinements already made.

The cost of search is proportional to the value of the underlying potential of the current technology. To initialize the simulation, the costs of both innovative and refinement search are set at the levels used by Levinthal and March (1981). Thus, the initial value of the minimum cost of innovative search is set to 0.0135×50 , the initial value of the potential of technology, and the minimum cost of refinement search is 0.01×50 . Units start out with a cost of search equal to the minimum cost of search raised to the power of $3/2$.¹⁰ With each search they perform, the exponent on the minimum cost of search decreases one half the remaining distance between its value and one. This results in the cost of search decreasing with the number of searches but at a decreasing rate. The exact functional form that results is depicted for the initial values of innovative search in Figure 7. When a unit does not search in a particular period, the cost of search increases at the same rate it decreases when the unit does search. Thus, the functional form of decay along the search cost curve is the obverse of the functional form of the decrease in search cost.

The assessment of past search proceeds as described in Table 1. The decisions involve three variables: Total Search Potential, TSP_{it} , Innovative Search Potential, ISP_{it} , and Refinement Search Potential, RSP_{it} . Following both Levinthal and March (1981) and the 10% rule, we operationalize increases and decreases to search resources as follows: If the assessment of total search is that it has been associated with failure, then TSP_{it} is reduced by 10%; if it has been associated with success, then TSP_{it} is increased by 10%. The assessments of innovative search and refinement search are operationalized identically. Actual resources available for search are defined by two equations. The first defines innovative search resources, ISR_{it} :

¹⁰ Initial values of the minimum cost of search are less than one resource unit. For values of cost of search less than one resource unit, the cost of search is multiplied by 10, raised to the exponent appropriate to their experience, and then deflated. This avoids the problem that squaring quantities less than one would have the opposite effect of that intended.

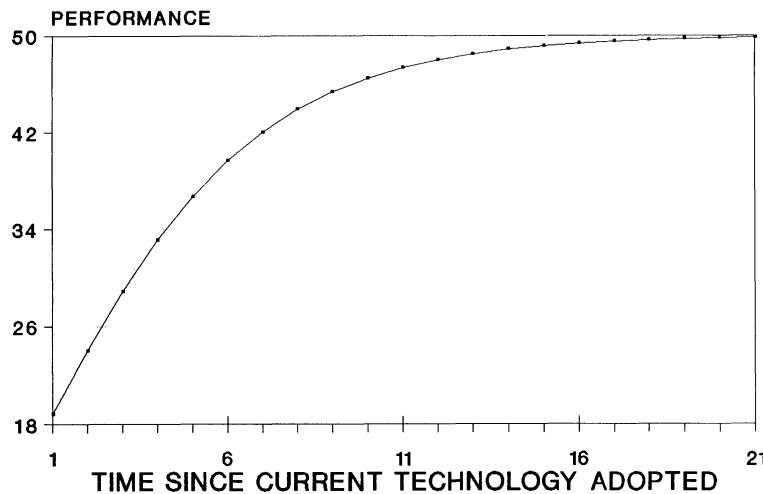


Figure 7. The learning curve assuming no innovation and a maximum of 50

$$ISR_{it} = TSP_{it} \times ISP_{it} \times TP_{it} \quad (3)$$

where TP_{it} is defined to be the actual performance the unit achieved with its technology in the most recent period. RSR_{it} is defined as in (3) with the substitution of RSP_{it} for ISP_{it} .

Actual resources devoted to search depend on the assessment of performance. If performance meets or exceeds aspiration level, then $RSR_{it} = RSR_{it}^{1,1}$ and ISR_{it} is left as is. Conversely, if performance is below aspiration level, then $ISR_{it} = ISR_{it}^{1,1}$ and RSR_{it} is left as is. The allowed number of searches is determined by taking the resources to be devoted to each type of search, dividing by the cost of that type of search, and rounding to the nearest integer. The unit takes a number of draws from the appropriate distribution equal to the number of searches. To operationalize myopia with respect to new technology, the value of innovative draws are deflated by raising them to the 0.75 power.

Operationalization of performance routines

The discussion of the operationalization of performance routines will follow the flow chart for performance given in Figure 2. As indicated in the figure, the value of technological potential drifts in each period, the draws from drift are uniform on the interval (-0.1, 0.1), thus the value of technological potential in the current period is in between 90% and 110% of the value

of the technological potential in the previous period. Movement on the learning curve is as follows: The technological performance of the unit, TP_{it} , is a function of the underlying value of the potential of the current technology. The form of this relation is as follows: $TP_{it} = Ptl_{it}^{\lambda_{\tau}}$. The subscript τ on λ is meant to signify that it is a function of time since adoption of the current technology. In the period of adoption of the new technology, λ_0 is set to 0.75. In all subsequent periods until adoption of the next technology, the value of λ_{τ} is set by the following incremental formula:

$$\lambda_{\tau} = \lambda_{\tau-1} + (1 - \lambda_{\tau-1})/2 \quad (4)$$

In keeping with empirical data, the rate at which performance increases as a function of experience decreases as a function of time; the shape of this function is analogous to that presented in Figure A1. Refinements change the value of the underlying potential of the current technology but do not affect the learning curve. Adoption of a new technology automatically resets the exponent to 3/4, and movement on the learning curve begins anew.

Performance, P_{it} , is defined as follows:

$$P_{it} = TP_{it} - ISR_{it} - RSR_{it} \quad (5)$$

Thus, performance is determined by how well the unit does with its current technology minus

the costs of all innovative and refinement search.

Aspiration levels, AL_{it} , are set using the attainment discrepancy model (Lant and Mezias, 1990; 1992; Glynn *et al.*, 1991; Lant, 1992):

$$AL_{it} = \beta_0 + \beta_1 AL_{i,t-1} + \beta_2 (AL_{i,t-1} - P_{i,t-1}) \quad (6)$$

The parameter β_1 determines the level of incrementalism in aspiration level updating while the parameter β_2 determines the responsiveness of the process to performance feedback. The actual values of the β_s used are uniform on the range of the highest and lowest values of each parameter estimated by Lant (1992).

Operationalization of change routines

The discussion of the operationalization of change routines will follow the flow chart for change given in Figure 3. The change clock of the unit is set to two periods; for two periods following the adoption of an innovation the unit cannot change. Performance is assessed relative to target by comparing P_{it} and AL_{it} . If performance equals or exceeds the aspiration level, the probability of change depends on whether the best alternative technology found through search is an innovation or a refinement. For innovations, the probability of change equals the difference between the performance with current technology and the best technology found through innovative search divided by τ (cf. equation (1)). If performance equals or exceeds the aspiration level and the best alternative technology found through search is a refinement, then the probability of change equals the best refinement draw divided by δ_{it} (cf. equation (2)). If performance is less than aspiration level, then the actual amount by which performance falls below aspiration level is divided by $MinAL_{it} - P_{it}$ to obtain the probability of change.

To determine whether a unit changes in a given period, a draw is taken from a binomial distribution with the probability of success equal to the probability of change determined in the previous step. If that draw is a failure, then the unit exits the change routines. However, if the draw is a success then the unit proceeds to evaluate the available alternative technologies, both refinements and innovations, found through search. If no alternative superior to current technology is available, then the unit exits.

Operationalizing the four variants

Four conditions were used to operationalize the theoretical framework: In the baseline condition, all parameters are set exactly as described above. In the institution condition, TSP_{it} is multiplied by 1.25 to operationalize the 25% increase in resources devoted to search. In the revolution condition, ISP_{it} is multiplied by 1.25 to operationalize the 25% increase in resources devoted to innovative search. In the evolution condition, the range of innovative search is multiplied by 1.25 to operationalize a 25% increase in the variance of innovative search.

Operationalizing the sensitivity analysis

To assess the stability of our results, a sensitivity analysis was conducted; we varied both parameters and structural equations to test the sensitivity of our results to several features of the simulation program. We will first discuss how we varied parameters and then how we varied structural equations; both will be discussed in the order they were presented above. The first parameter varied was the length of the change and search clock. The value of two periods was the one used in the simulation presented in the body of the paper; the values of 0 and 10 were used as minimum and maximum to test the sensitivity of the results to this parameter. The second parameter varied was the level of technological drift. A value of 10% was used in the body of the paper; we chose the values of 20% and 33% to test the sensitivity of the results to this parameter. The first structural equation that we varied was the exponent of τ in equation (1). We ran three variations on this equation to test the robustness of the results under conditions of slow ($\tau = 1.5$), moderate ($\tau = 2$), and rapid ($\tau = 2.5$) technological change. The second structural equation variation involved substituting an additive relation for the multiplicative relation of search potentials in determining search expenditures. To do this we changed equation (3) as follows and made the same changes for the calculation of RSR_{it} :

$$ISR_{it} = \frac{TSP_{it} \times TP_{it}}{4} + \frac{ISP_{it} \times TP_{it}}{4} \quad (7)$$

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