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Adaptation on Rugged Landscapes

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A simple model is developed to explore the interrelationship between processes of organizational level change and population selection forces. A critical property of the model is that the effect on organizational fitness of the various attributes that constitute an organization's form is interactive. As a result of these interaction effects, the fitness landscape is "rugged." An organization's form at founding has a persistent effect on its future form when there are multiple peaks in the fitness landscape, since the particular peak that an organization discovers is influenced by its starting position in the space of alternative organizational forms. Selection pressures influence the distribution of the organizational forms that emerge from the process of local adaptation. The ability of established organizations to respond to changing environments is importantly conditioned by the extent to which elements of organizational form interact in their effect on organizational fitness. Tightly coupled organizations are subject to high rates of failure in changing environments. Furthermore, successful "reorientations" are strongly associated with survival for tightly coupled organizations, but not for more loosely coupled organizations that are able to engage in effective local adaptation.

(*Organizational Adaptation; Organizational Forms; Environmental Selection*)

1. Introduction

A considerable body of work in the organizations literature addresses the diversity of organizational forms in a population. Ecological arguments (Hawley 1968) suggest that the diversity in forms reflects the diversity in the environments in which organizations operate. Within the context of ecological analysis, this isomorphism between organizational forms and the environment stems from a population level process of the birth and death of individual organizations (Hannan and Freeman 1977, 1989). Contingency theories share this concern of ecological analysis with a mapping from facets of the environment to features of organizations, but differs with regards to its assumptions of organizational-level adaptation to the environment. Over the last two decades there has been an ebb and flow in the degree to which researchers have focused attention on organizational level versus population level forces of change. In addition, a stream of empirical work has emerged that attempts to identify the relative impact of organizational adaptation and population selection processes (Singh et al. 1986, Haveman 1992).

While there are some exceptions (Lant and Mezias 1990, Bruderer and Singh 1996), researchers have tended not to address the interrelationship between processes of firm level adaptation[1] and population level selection pressures. Adaptation and selection are not wholly opposed or contrasting forces, but are fundamentally interrelated (Levinthal 1991). For selection processes to be meaningful, organizations must exhibit stable sources of heterogeneity. Organizational adaptation may contribute to these stable sources of organizational level differences that, in turn, form the basis of differential selection.[2] The interrelationship between ad-

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[1] Adaptation is interpreted here to mean a change in a significant attribute of the organization. For the purposes of this analysis, this is represented as a change in the organization's form. As defined in this manner, adaption need not have a positive relationship to the probability of survival.

[2] Indeed, in making their argument for the importance of organizational inertia, Hannan and Freeman (1984) draw upon Nelson and Winter's (1982) ideas regarding the development of organizational routines.

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aptation and selection processes is sufficiently complex as to merit the characterization of an analytical model. The desire here is to specify a simple model that captures some of the central factors of interest.

A useful starting point for an analysis of adaptation and selection processes is a specification of a mapping from a characterization of an organization's form to a statement of its relative fitness or likelihood of survival. An important concept in this regard is Sewell Wright's (1931, 1932) notion of a fitness landscape. A fitness landscape consists of a multidimensional space in which each attribute (gene) of an organism is represented by a dimension of the space and a final dimension indicates the fitness level of the organism.

Organizational level adaptation leads organizations to modify their existing form in an attempt to enhance their fitness. In the context of Wright's framework of a fitness landscape, March and Simon's (1958) concept of neighborhood search can be thought of as local "hill climbing" (Holland 1975), where the height of the hill reflects the fitness value of the associated organizational form.

Such a process of local adaptation has important implications for the diversity of organizational forms. It suggests that the diversity of forms is determined by historical effects that influence an organization's form at founding (Stinchcombe 1965) and the topology of the space of alternative forms over which organizations search. An organization's form at founding will have a persistent effect on its future form when there are multiple peaks in the fitness landscape, since the particular peak that an organization discovers is, in large measure, determined by its starting position in this space of alternative organizational forms. Imprinting effects persist as a result of the path dependence of the search process. Local search in a rugged landscape provides an important source of diversity of organizational forms apart from the external logic of ecological arguments or contingency theories.

In the context of population genetics, Kauffman (1993) demonstrates that the topology of the fitness landscape is determined by the degree of interdependence of the fitness contribution of the various attributes (genes) of an organism. Population genetisis refer to such interactions as epistatic effects (Smith 1989). Perhaps the most prominent example of such interdependence in the management literature is Chandler's work (1962) on the relationship of a firm's strategy and organizational structure. Miller and Friesen (1984) develop a broader notion of the overall configuration of a firm's strategic policies and organizational structure. The McKinsey consulting group's 7S framework is a well known application of this idea that it is important to consider the degree to which the various facets of an organization's policies are mutually reinforcing (Waterman, Peters, and Phillips, 1980). Within the context of human resource policies, Ichniowski, Shaw, and Prennushi (1994) and MacDuffie (1995) demonstrate the importance of systems of human resource practices and argue that these systems emerge as a result of complementarities among the various practices. Recent work in the economics literature by Milgrom and Roberts (1990) also points to the need to examine, what they term, complements among a firm's choices of product lines, production strategies, and technology.

The presence of interaction effects suggests that considerable diversity of organizational forms may be present, even if the population of organizations are operating within the same niche or environmental setting. The process of local search and adaptation leads to the emergence of a few dominant organizational forms. These forms correspond to local peaks in the space of alternative organization forms. Selection pressures then operate over time to influence the frequency distribution over these dominant forms that emerge from the process of organizational level adaptation. In this sense, organizational adaptation generates the systematic heterogeneity that then forms the basis for differential selection. Ultimately, if the organizations are operating within the same niche, one of these organizational forms will come to dominate the population of organizations.

Lastly, how these dual processes of organizational level adaptation and population level change operate in a changing environment is examined. The relative impact of adaptation and selection in a changing environment is determined by the degree of epistatic interactions within organizations. High levels of epistatic interactions impede the effectiveness of organizational level change. As a result, under a setting of high epistatic interaction, a substantial change in the environment results in a change in the population of organizations largely via the death of existing organizations and the birth or entry of new organizations. Furthermore, organizations that are tightly coupled are more dependent upon a successful reorientation as a basis for effective adaptation; whereas, less tightly coupled organizations can engage in effective local adaptation in response to a shift in the fitness landscape.

This last finding is of particular relevance to recent interest in the survival of incumbent firms in the face of Schumpeterian environments (Abernathy and Clark 1985, Tushman and Anderson 1986). The impact of epistatic interactions on the ability of established organizations to adapt to a changing environment puts a new slant on the notion of competence destroying changes (Abernathy and Clark 1985, Tushman and Anderson 1986). Incumbent firms may have difficulty navigating a changing environment not only because the changes in the environment negate the value of some of the organization's existing assets, but also because a tightly coupled organization (Weick 1979) may have difficulty adapting to such changes.

2. Model

The prior discussion suggests that the structure of the fitness landscape of organizational forms is an important determinant of organizational diversity. What, in turn, determines the structure of the fitness landscape? For instance, does the landscape consist of a single, global peak, or are there a variety of local peaks? Furthermore, how smooth is the landscape? That is, is the fitness value of neighboring points likely to be similar or do fitness values change in an abrupt manner with a change in location? What might determine the smoothness of the fitness space?

First, consider what smoothness means; it is the change in fitness value with a change in a particular organizational attribute. One reason why the space may not be smooth is that a particular attribute, say an organization's choice of strategy, has a considerable impact on the organization's performance. Thus, even if all other elements that comprise an organization's form are held constant, a shift in its strategy might greatly perturb the organization's fitness level. This argument, however, would merely suggest that the fitness space is discontinuous or "rugged" with respect to one dimension of organizational form but smooth with respect to other attributes of the organization.

An alternative factor that influences the relative smoothness or ruggedness of the fitness landscape is the degree to which the fitness contribution of a particular attribute of an organization's form depends on other attributes of the organization. If organizational fitness is highly interactive, that is, the value of a particular feature of the organization depends on a variety of other features of the organization, then the fitness landscape will tend to be quite rugged. In such a setting, even if only one element is changed, the fitness contribution of those attributes that did not change might still be effected.

The analysis here develops a simple analytical structure to model interaction effects and explore the implications for processes of adaptation and selection. In doing so, it builds on the work of Stuart Kauffman (1993). Kauffman has developed a simple, but powerful analytic structure to represent epistatic interactions, which he terms the *NK* model. An entity, an organization for our purposes here, is characterized as consisting of N attributes where each attribute can take on two possible values.[3] Thus, the fitness space consists of 2^N possible types of organizations. The degree to which the fitness of the organization depends on interaction effects among the attributes is specified by the variable K. In particular, the contribution of a given attribute of the organization to the organization's overall fitness is assumed to be influenced by K other attributes. Therefore, if K equals zero, then the contribution of each element of the organization (such as strategy, personal system, structure, etc.) is independent of all other attributes. At the other extreme, if K equals $N - 1$, then the fitness contribution of any one attribute depends on the value of all other attributes of the organization. This framework specifies the intensity of interaction effects via the parameter K, but provides no restrictions on the particular functional form of the interaction effect.

Consider how organizational fitness is calculated for an organization for which N equals 10 and K equals 3.

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[3] The model can be extended to an arbitrary finite number of possible values of an attribute, but the qualitative properties of the model are robust to such a generalization.

Suppose that an organization is specified by the string (1, 0, 0, 1, 1, 1, 0, 1, 0, 0). Consider the contribution of the first element of this string. This value depends on the K successive elements in the string.[4] Thus, the value of 1 in the first element of the string depends on the value of the second through fourth elements of the string. A random number, generated from an uniform distribution ranging from 0 to 1, is assigned to constitute the fitness contribution of a 1 in the first element of the string when there is a 0, 0, and 1 in the second, third, and fourth elements of the string, respectively. A distinct random number is assigned for the case where there is a 1 as the second element of the string rather than a 0, or any change in the third, or fourth elements. Thus, each attribute can take on 2^{K+1} different values, depending on the value of the attribute itself (either 1 or 0) and the value of the K other attributes with which it interacts (each of these K values also taking on a value of 1 or 0). This assignment is repeated for each of the N attributes of the organization. The overall fitness for a particular organization is simply the average for the N attributes that comprise it.

The specification of K, the degree of epistatic interaction, determines the smoothness of the fitness landscape. If K equals zero, then the fitness contribution of each attribute is independent of all others. As a result, such a landscape is smooth in that a change in a single attribute leaves unchanged the fitness contribution of the other $N - 1$ attributes. In such a setting, two adjacent organizations can differ in their fitness level by at most $1/N$, the maximal fitness contribution of a single attribute. In contrast, as K increases the landscape becomes more rugged; a change in a single attribute effects the value of K other attributes of the organization. In general, the maximal difference in fitness value between two such strings is $(K + 1)/N$. In the limit, when K equals $N - 1$, a change in a single attribute changes the fitness contribution of all the attributes of the organization. As a result, adjacent locations in the fitness space need not have similar fitness values. In this sense, the value K determines how rugged or correlated is the fitness space.

The variable K not only influences the degree to which neighboring points in the fitness space are likely to share similar fitness values, but also the number of peaks in the fitness space. If K equals zero, then there is a single peak in the fitness space. If the fitness contribution of each attribute is independent of all other attributes, then fitness can always be enhanced by shifting a single attribute unless all attributes are set at the value that yields maximum fitness. When K exceeds zero, there are multiple peaks in the fitness space. When the fitness contribution of organizational attributes is interdependent, a change in a single attribute may result in a decline in overall fitness even though a change in multiple attributes might enhance the organization's fitness. In general, the number of peaks in the fitness space tends to increase with K.

2.1. Adaptation

Two processes of organizational level change are modeled. One is a process of local search in which the set of organizational forms in the immediate neighborhood of the existing organization is examined (March and Simon 1958, Cyert and March 1963). A neighborhood is defined as those forms that vary from the current organization by only one attribute. Therefore, if there are N attributes that comprise an organization, then each organization has N different organizational forms in its immediate neighborhood.

Organizations are assumed to be able to identify alternative forms in their immediate neighborhood whose fitness value is superior to their current level of fitness. Furthermore, they are assumed to be able to modify the single attribute that differs between the two forms so as to achieve this higher level of fitness. In this manner, organizations "walk" over the rugged landscape of alternative forms where the height of the landscape is the fitness value of a particular organizational form (Kauffman and Levin 1987, Smith 1970). The organization is not assumed to choose the steepest gradient in its so-called walk over this space (i.e., the alternative form in

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[4] The string is treated as circular for the purposes of determining fitness values. For instance, using the above example, consider determining the fitness contribution of the ninth element in the string. The fitness value of that element depends on the value of the tenth, first, and second elements in the string. An alternative formulation of the model is to postulate that the interaction effects are with K randomly chosen other elements of the string. This alternative formulation results in similar behavior as the model analyzed here (Kauffman 1989, p. 561).

its neighborhood that has the highest value), but merely the first superior form that it discovers.

Research on organizational change has identified not only processes of local adaptation, but also the adoption of alternatives far removed from the organization's current mode of operation (March and Simon 1958, Nelson and Winter 1982, Tushman and Romanelli 1985). The literature offers two distinct bases for such radical changes. One line of argument relates to an organization's innovative activity and suggests that, with some modest probability, these efforts will yield a substantial improvement in an organization's technology or performance (Nelson and Winter 1982, March and Simon 1958). Another line of argument is associated with the idea of failure-induced search (March and Simon 1958, Tushman and Romanelli 1985).

In this analysis, such radical change is modeled by assuming that each of the N attributes of the organization are specified anew at random.[5] Kauffman (1993) uses the term "long-jump" to indicate such a change. Following the terminology of Tushman and Romanelli (1985), such a change can be thought of as a reorientation. Each period, an organization draws at random a new organizational form in the space of 2^N alternatives. The organization then compares the fitness value of this new organizational form with its current form and adopts the new form if it is superior to its current one.

Nominally, such a specification only captures the idea of innovative search. However, the likelihood that an organization will find an attractive "innovative search" depends on the fitness value of its current form. An organization with a relatively high fitness value is very unlikely to find that a given random innovation draw yields an attractive outcome. As a result, even though the frequency of innovative activity does not depend on an organization's performance, the likelihood of a radical organizational change is quite sensitive to the organization's current performance. Thus, the relationship between poor organizational performance and "long-jumps" emerges endogenously in the model.

An interesting relationship also emerges between the rate of local adaptation and long-jumps. Early on, when the current organizational form is likely to have a modest fitness level, long-jumps are relatively frequent. Subsequently, as organizations obtain higher fitness values, long-jumps become increasingly rare. In addition, a successful long-jump provides a renewed opportunity for local adaptation. Much in the spirit of Nelson and Winter's analysis (1982) of the relationship of refinements of existing technologies and the discovery of new technologies, a successful long-jump takes the organization to a new area of the state space of alternative organizational forms. Furthermore, if the fitness space is correlated, it is likely that there are organizational forms in the neighborhood of this new location with even higher fitness values, resulting in the opportunity for local adaptation.

This characterization of the search process is relatively favorable to the possibility of organizational change in two respects. First, only desirable changes are executed. The phenomenon suggested by March (1981, p. 567) that for some organizations "efforts to survive will have speeded up the process of failure" is not reflected in the model. Second, there is no direct cost attributed to organizational change. In a final section of the analysis, the robustness of the results to the introduction of noise into the search process and the possibility of the adoption of inferior organizational forms is considered.

2.2. Population Level Processes of Change

There are two basic elements of population level change: the birth and death of individual organizations. Following the biological literature, the rate of survival for a particular organization is determined by its fitness level relative to the most fit organization in the population (Wilson and Bossert 1971). Furthermore, as is the norm in the mathematical genetics literature (Smith 1989), the total number of organizations in the population is assumed to remain constant over time. As a result, the model does not address issues of population dynamics and niche-based competition. An important extension of this work would be to incorporate such features into the model structure. The current analysis

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[5] This is clearly the simplest, baseline representation of distant search. Possible modifications of this baseline process include making the probability of sampling a particular form a function of distance from the current form and of saliency (the number of organizations associated with a given form). A more complex extension would be to consider recombinations (Holland 1975) of forms discovered by search and the current form.

examines the patterns of diversity that emerge within a single niche.

In modeling the birth of new organizations, two different specifications are considered. One is the specification of a new organization whose attributes are chosen at random. The other consists of the replication of an existing organizational form. The likelihood of a new form being determined at random versus an existing form being replicated is assumed to depend on the overall fitness level in the population. In particular, if the overall fitness of the population is high, replicating existing forms should be relatively attractive to founders (Aldrich and Fiol 1994).[6] Alternatively, when the overall fitness level is low, it seems less likely that founders of new organizations will take as their model existing organizational forms. Reflecting this argument, the probability of a random birth or of birth via replication is assumed to equal the genetic load of the population.

The genetic load of a population is a standard summary statistic for the overall fitness of a population in the population genetics literature and is defined as one minus the ratio of the average fitness value in the population to the maximum fitness value (Wilson and Bossert 1971). Thus, the genetic load ranges from zero to one, where zero represents a population in which all organizations share the same fitness value and one indicates a population in which there is a maximal difference between the average fitness value and the value of the most fit organization in the population.

If a new organizational form is specified by the replication of an existing form, then the probability of a given form being replicated is determined by its relative fitness in the population, with more fit forms being proportionately more likely to be replicated. More formally, the total fitness value of surviving organizations in the population is summed. The probability of any one organization being replicated is simply its fitness value divided by this sum.

Even though the total number of organizations is kept constant, the number of organizations of a particular form may change substantially over time. In contrast to the case of local adaptation in which multiple organizations obtain the same form as a result of individual organizations finding the same local peak in the fitness landscape, the process of organizational births and deaths leads to multiple numbers of the same form as a result of the replication of existing forms.

2.3. Summary of Simulation

The first procedures of the simulation initialize both the fitness landscape and the initial population of organizations. The fitness landscape is initialized by specifying the fitness value of each of the 2^N possible organizational forms. For each possible organizational form, each element in the N-length string may take on 2^{K+1} values depending on the value of the K other elements with which it interacts. For each of these combinations, a random number is assigned, where the random number is drawn from an uniform distribution ranging from zero to one. The fitness landscape, once specified, is fixed. Organizations may change their attributes, and hence their fitness, but the fitness value of any given form remains stable.

The initial population of organizations is specified by choosing each of the N attributes (either a one or zero) at random, where there is an equal probability associated with the two possible values. Within the simulation, the value of N is set at 10. This procedure is carried out for each organization in the population. The fitness level of each of the organizations is then assigned by identifying the corresponding organizational form in the fitness landscape (i.e., a table of fitness values for each possible organizational form) previously specified.

After this initialization, the following sequence of steps is repeated for the number of time periods of the simulation. First, it is determined which of the organizations that existed in the prior period survive. Second, those organizations that survive engage in both local and distant (i.e., long-jump) search efforts. Organizations that discover a superior form adopt that new form. Finally, new organizations are specified to replace those that did not survive from the prior period. The total number of organizations is kept constant from one period to the next; for the purpose of the simulation runs described here, that number is set at 100. The probability that a given new organization replicates an existing

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[6] This attraction to existing, successful forms depends importantly on the assumption of a single niche and the absence of any "crowding" effects associated with the selection pressures for any given organizational form.

organizational form equals 1 minus the genetic load of the surviving set of organizations and the probability that a given new organization is specified at random equals the genetic load. If a new organization is specified by the replication of an existing form, then the probability that a particular organization is replicated is equal to its fitness value divided by the total fitness values of the set of surviving organizations. These three basic procedures are then repeated for the duration of the simulation.

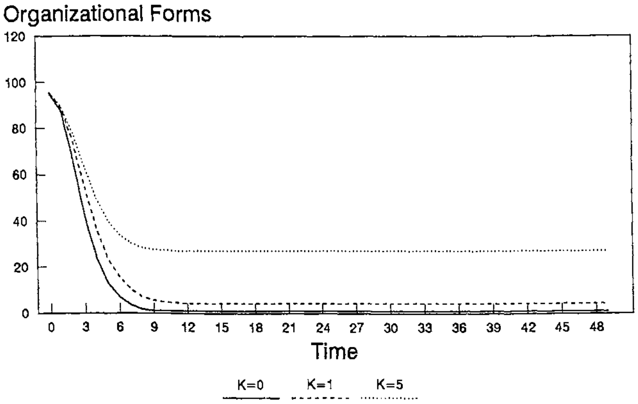
For each set of parameter values examined in the results, a hundred different landscapes and population histories are examined. Therefore, the results, unless otherwise indicated, reflect the average behavior of a hundred runs of the simulation where for each run there is a distinct fitness landscape and a distinct population of a hundred organizations.

3. Emergence of Order

3.1. Organizational Adaptation and Basins of Attraction

Before considering the interaction between adaptation and selection processes, it is useful to examine the implications of local adaptation alone. In particular, consider the "order" represented by the reduction in organizational forms that results from a process of local adaptation alone (i.e., no long-jumps and no selection pressures). Figure 1 indicates the results of such an analysis. An hundred different landscapes and population histories were generated for each parameter setting. For each landscape, a population of 100 organizations was specified at random. The results reported are an average over these hundred runs of the simulation.[7] The initial specification of organizational forms results in an average of 95.44, 95.57, and 95.61 distinct organizational forms, respectively, for the $K = 0$, $K = 1$, and $K = 5$ settings. Quite rapidly, the number of different forms diminishes. Organizations search in their immediate neighborhood for superior alternatives. This search process continues until organizations reach a local optimum. Thus, the radical reduction in the number of organizational forms reflects the fact that while the organizations were initially distributed randomly in the landscape, many organizations share the same local optimum.

Figure 1 **Emergence of Order (Local Adaptation)**



The number of local optima that are reached increases as the landscape becomes more "rugged." In particular, consider the landscape that results when $K = 0$. As noted earlier, when $K = 0$ there is a single maximum in the space of alternative organizational forms. If an organization is located at any point other than the optimum, there is a location in the immediate neighborhood, involving a change in a single attribute that enhances the organization's fitness. Since $K = 0$, changing this attribute improves the organization's fitness independent of the other $N - 1$ attributes. Therefore, as Figure 1 indicates, a process of local adaptation results in all organizations "walking" to this optimum.

For $K > 0$, the landscape has multiple local optima. More generally, as K increases and the landscape becomes less correlated, the number of local optima increases. As a result, the curve for $K = 5$ in Figure 1 asymptotes at a higher number of distinct organizational forms then the curve for $K = 1$ and, in turn, the curve for $K = 0$. This property of organizations being "trapped" at a suboptimal local peak is clearly an implication of the limited nature of local search. The "ruggedness" of the landscape has an impact on organizational form to the extent that there are peaks and valleys beyond the organization's "vision." Thus, greater vision attenuates the effect of a given level of K. However, as long as the organization's vision is such that it can

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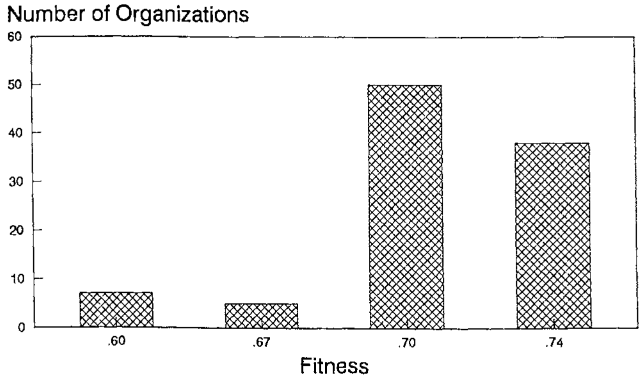
[7] This same procedure is used in the subsequent analyses as well unless otherwise noted.

not scan the entire landscape, the qualitative properties of search leading to, possibly inferior, local peaks remains. Furthermore, the number of such peaks increases with K for a given range of neighborhood search.

Kauffman (1993) terms the set of locations in the landscape for which local search results in a common local optimum as belonging to a common "basin of attraction." Basins of attraction have an interesting property in that the breadth of a basin is positively correlated to the height of the local optimum to which the basin leads. In particular, higher local optima tend to have broader basins of attraction. Figure 2, based on the results of a simulation of a single arbitrary landscape, provides some sense of this. Even with only local search, peaks with greater fitness values tend to attract more organizations. As result, not only does order emerge via the reduction of organizational forms in the population, but the frequency of forms in the population tends to correspond to their fitness values even in the absence of selection pressures.

This analysis of local search in complex landscapes has important implications for contingency theory arguments regarding variation in organizational forms in a population. Contingency theory is typically expressed as an argument for a correspondence between facets of organizations and features of the environment in which organizations function (Lawrence and Lorsch 1967). In the context of the model developed here, all organizations face the same environment. What differs is their initial composition. As a result of these different starting points, different organizations are lead to adopt distinct organizational forms. Local search in a multipeak landscape results in organizational adaptation being path- or history-dependent. As a result, the observed distribution of organizational forms in a population may reflect heterogeneity in the population of organizations at earlier points in time rather than variation in niches in the environment, as suggested by ecological analyses (Hannan and Freeman 1977), or a set of distinct external conditions, as generally suggested by contingency theories (Lawrence and Lorsch 1967).

Figure 2 **Distribution of Organizational Forms (Local Adaptation, $K = 1$)**



For instance, both United Parcel Service and Federal Express are very successful companies, operating in the same business of delivering mail and packages. Their organizational solutions to this common mission, however, are quite distinct (Cappelli and Crocker-Hefher 1996). These differences reflect the imprinting at founding (Stinchcombe 1965) of distinct systems of control. United Parcel Services was founded at a time when Taylorism and the principles of scientific management were dominant. Federal Express was developed in more recent years and the organization reflects the emphasis in recent years on information technology and employee empowerment. Again, while the organizational "solutions" are radically different, they are both quite effective.

This argument for a path dependent pattern of adaptation is given, at least indirect, empirical support by Eisenhardt's (1988) work on compensation systems in retail stores. Eisenhardt finds that a set of variables reflecting the contingencies of the "technology" of the employees' work activities help explain the variation in compensation systems, but that in addition the age of the retail establishment has a significant effect on the use of particular compensation systems. The set of practices reflect both the demands of the setting and the set of practices that were prevalent at the time of the organization's inception. In concluding, Eisenhardt suggests that the evidence point to equafinality and the existence of multiple viable systems of controls.

The implicit assumption of most empirical analyses is that organizations have an additive fitness structure in that the fitness contribution of each element of the organization is assumed to be independent of other attributes of the organization. In the formal structure of the model developed here, such an assumption implies that K equals zero. Indeed, it is the case that when K equals zero there is a unique mapping from organizational form to organizational fitness. In such a setting, since all organizations face the same environment, one unique form emerges from a process of local adaptation. Such a setting, however, is not likely to be reflective of organizations. Organizations are complex social systems and, as a result, are likely to be subject to a large number of epistatic interactions. This suggests that the mapping from organizational form to effectiveness measures, whether these measures are survival rates as in ecological analysis or financial performance as in the case of many applications of contingency theory, may be exceedingly complex. In particular, there is unlikely to be an unique mapping of organizational form to an effectiveness measure and, as a result, the observed distribution of forms is likely to reflect both the demands of the environment and the organization's unique history that has lead it to a particular peak in the landscape.

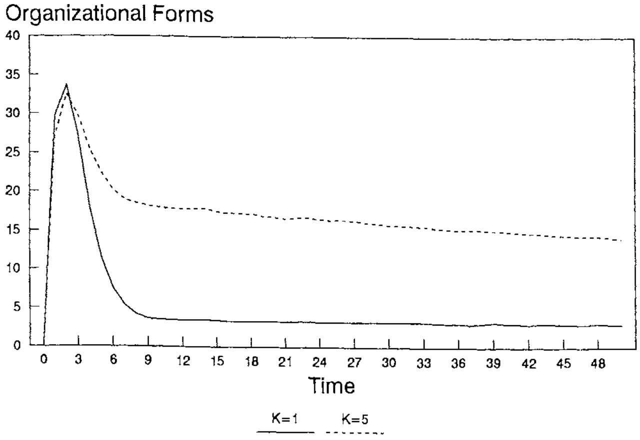
3.2. Radiation of Forms

An alternative way of examining the emergence of "order" within a population of organizations is to examine the radiation of organizational forms. Radiation of forms is a term used by biologists to refer to periods of dramatic growth in the diversity of a population. The initial condition for the prior simulation was a situation of maximal diversity. Organizations were scattered randomly over the landscape of possible organizational forms. Consider the alternative extreme setting of no diversity. All organizations in a given landscape are assigned to the same, arbitrarily chosen, organizational form. Furthermore, in addition to the process of local adaptation, assume that organizations are able to engage in the far less systematic search for attractive long-jumps.

Figure 3 indicates the change in the number of distinct organizational forms in the population over time. In the first few periods of the simulation, roughly half of the organizations are able to identify an attractive long-jump and adopt a distinct organizational form. After this initial explosive radiation of organizational forms, the process of local adaptation leads to a rapid decline in the number of distinct organizational forms in the population.

This radiation of forms and subsequent decline in the number of distinct forms bears a similarity to characterizations of industry evolution (Utterback and Abernathy 1975; Anderson and Tushman 1990). Early in an industry's development there tends to be experimentation with a variety of distinct forms. For instance, early on in the automobile industry there was experimentation with a variety of alternative engine designs (gas, electric, steam) (Arthur 1989), and, at a somewhat later period, experimentation with distinct production technologies (craft versus assembly production) (Bresnahan and Raff 1992). Over time, this variation reduced and a dominant design (Utterback and Abernathy 1975) for both the product technology and manufacturing process emerged.

Figure 3 Radiation of Forms Under Adaptation

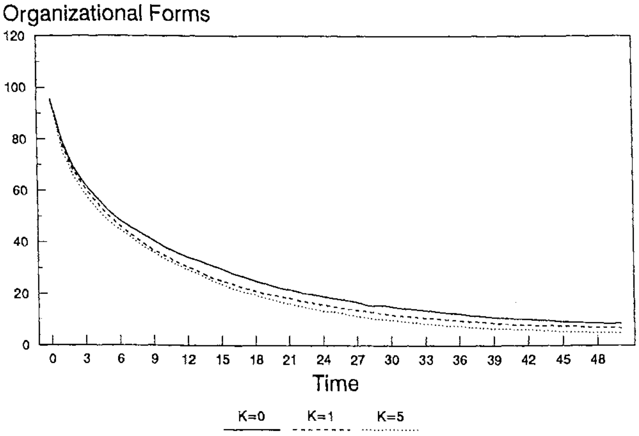


With a rugged fitness landscape, that is a landscape with multiple local optima, a single dominant form will not emerge from a process of adaptation. However, after a brief period of considerable experimentation with radically different forms, there is a steady convergence to a small set of forms that correspond to the local peaks in the landscape.

3.3. Selection Processes

Order may emerge from a pure selection process as well. Figure 4 indicates the diversity of organizational forms when the simulation is run without any organizational adaptation. Change occurs solely as the result of birth and death processes. As Figure 4 indicates, there are two important distinctions between the manner in which order emerges via selection versus a process of organizational-level adaptation. First, selection differ-

Figure 4 Emergence of Order Under Selection



entiates among organizational forms based on the global properties of the landscape whereas the forms that emerge as the result of adaptation are quite sensitive to the local topology of the landscape. As a result, a selection process drives the population towards a single, most fit, organizational form. This result highlights the fact that in this model there is only one niche and all organizations compete for survival with each other. As a result, a selection process leads to the emergence of a single organizational form. Consistent with the global nature of selection processes, the number of distinct organizational forms in the population is insensitive to the value of K. In contrast, the number of forms that emerge from a process of local adaptation is directly effected by the degree of epistatic interaction (i.e., K) and, in turn, the number of local optima in the landscape.

Another contrast with the process of organizational adaptation is that the rate at which variation in organizational forms is reduced is considerably slower under a selection process. These two properties of a selection process, its global rather than local basis for differentiating among organizational forms and its slower rate of differentiation, have important implications for the way in which the joint processes of adaptation and selection interact.

There is, however, a subtle caveat to the statement that selection pressures are invariant to the value of K. Recall that the probability of an organization surviving is determined by the relationship between its fitness value and the maximum fitness value in the population of organizations. As K increases, the landscape becomes more "rugged" and, as a result, the expected value of the maximum fitness level increases.[8] Therefore, the intensity of selection pressures increases somewhat with higher K values, resulting in a more rapid decline in the number of alternative organizational forms over time.

3.4. Interaction of Adaptation and Selection

Examining adaptation and selection processes in isolation is useful in order to gain an understanding of the implications of the two processes, but ultimately the critical challenge is to understand the joint effect of these two processes of population change. As noted above, the process of local adaptation operates much more quickly then selection forces to reduce the number of distinct organizational forms in the population. Adaptation thus generates the set of "dominant" organizational forms. Over time, selection pressures operate so as to change the frequency distribution of those organizational forms that emerge from the process of organizational adaptation.

This pattern is illustrated in Figure 5, based on a single simulation of an arbitrary landscape. While the population of organizational forms were distributed randomly in the initial setting, by period 10 this diversity of forms has sharply diminished. The distribution of organizational forms at time period 10 is largely determined by the process of local adaptation. Subsequently, selection forces operate to change the distribution of forms across the four types of organizations that emerged from the process of organizational adaptation.

The global nature of selection pressures drives the population over time towards the existence of an unique form. However, adaptation guides and limits the selection process by determining the set of organizational forms over which selection occurs. In particular, the form that comes to dominate the population need not be the most fit form in the population but

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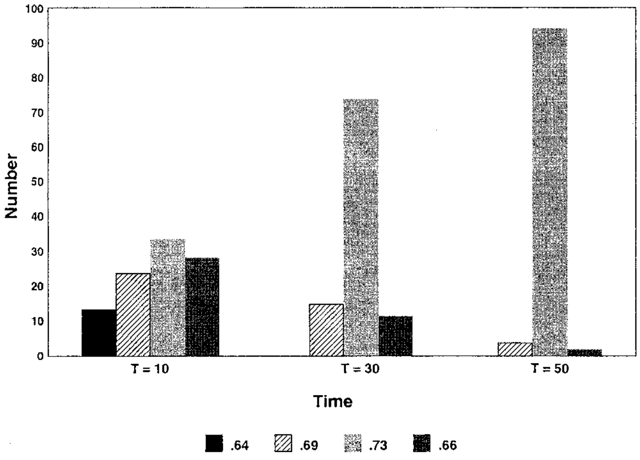
[8] There are two effects at work here. The *average* value of the local peaks declines slightly with K, but the number of local peaks increases dramatically with K. The net result is that the expected value of the *maximum* fitness value increases with K.

Figure 5 **Distribution of Forms (Joint Adaptation and Selection, $K = 1$)**



merely the most fit form "discovered" by the process of organizational adaptation.[9] Furthermore, the speed at which selection drives the population to an unique form is slowed by the fact that organizations have moved toward the various local peaks associated with their particular starting point and, therefore, reduced the variation in organizational fitness levels in the population.

4. Adaptation in Changing Landscapes

The prior section provides some insights regarding the interrelationship between organizational level adaptation and population level selection in stable selection environments. Questions of organizational level adaptation, however, are posed typically with respect to organizational changes in response to changing external environments (Tushman and Romanelli 1985). A particular variant of this question which has received considerable recent interest is the challenge posed for established firms by Schumpeterian environments (Abernathy and Clark 1985, Tushman and Anderson 1986). Therefore, to understand further the interrelationship between organizational level adaptation and population level selection, it is of interest to examine how these two processes interact in a changing external environment. Both modest, or incremental, and relatively dramatic changes in the fitness landscape are examined.

To explore these issues within the context of the model, the simulation analysis was re-run such that, half-way through the simulation (i.e., period 25), the fitness landscape was respecified. In the analysis underlying Figure 6, only the fitness contribution of the first element of the N-vector array that characterizes an organization is respecified. Since only one element has been changed, the greatest possible immediate impact on the overall fitness of the organization can only be $1/N$, or .1 in the case of the specification used in the simulation. Furthermore, the expected impact of the respecification on the fitness value of the current organizational forms is independent of the value of K, the measure of intensity of epistatic interactions within organizations.

Figure 6 indicates the proportion of organizations that exist at the 24th time period that continue to survive in a given period. Organizations that exist prior to the change in the environment represent established or incumbent enterprises.[10] Despite the fact that the immediate impact of the change in the environment on organizational fitness is independent of K, the likelihood of an organization surviving such a change is quite sensitive to the intensity of epistatic interactions within the organization. This contrast results from the fact that the ability of the organization to adapt effectively to the new landscape is influenced by the level of epistatic interactions within the organization.

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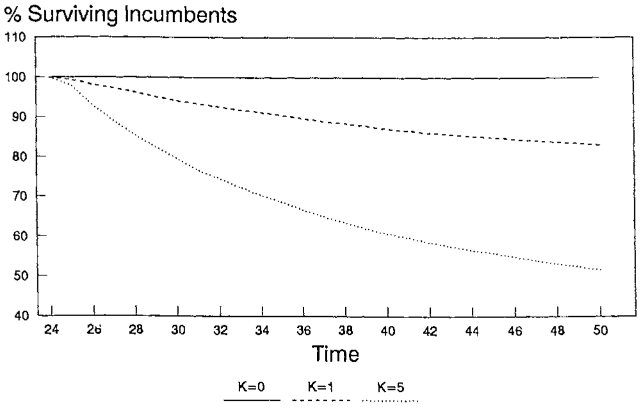
[9] From the set of initial organizational forms, there need not be a path (a sequence of organizational forms with increasing fitness values) that leads to the global peak in the landscape. Thus, local search need not lead to the maximum. It is true, however, that as the number of time periods increases to an arbitrarily large number, the process of long-jumps will ultimately lead to the discovery of the maximum. However, this is an asymptotic property and the discovery of the maximum need not occur for a given finite population history.

[10] In a stable environment, the model generates the usual pattern of negative age dependence for organizational mortality (Freeman et al. 1983). However, the effect of organizational age on the likelihood of survival is fully captured by the organization's position in the state space of alternative organizational forms. By period 24 in the analysis characterized here, all organizations are located on a local peak in the landscape. Therefore, it is reasonable to associate the advantages (and liabilities) of incumbency with the entire set of existing organizations.

Figure 6 **Survival in Changing Environments (Change in Fitness Contribution of One Dimension**



With a low K value, an organization can change a particular attribute without significantly impacting the fitness contribution of other organizational attributes. Put more abstractly, with a low K value, the organization faces a highly correlated fitness landscape and is therefore able to engage in effective local adaptation. This consideration of the impact of epistatic interactions on the ability of organizations to adapt to changes in their environment corresponds to Henderson and Clark's (1990) discussion of the challenges posed by architectural innovations. Architectural innovations, as characterized by Henderson and Clark, do not involve substantial changes in the underlying components of a firm's products or production process, but change the linkages among the components. They observed the drastic impact on the competitive viability of firms in the photolithographic alignment equipment industry of modest changes in the underlying technology. Architectural changes are changes in a tightly coupled system (i.e., have a high degree of epistatic interactions) and, as a result, organizations have great difficulty adapting despite the modest degree of technical change.

The effect of K on the ability of organizations to adapt to changing environments is also consistent with the distinct between the survival implications of changes in peripheral and core features of an organization (Hannan and Freeman 1989, Singh et al. 1986). Core features of an organization are those elements which have an high degree of interdependence with other elements of the organization; by contrast, peripheral features are relatively loosely coupled to other elements of the organization (Hannan and Freeman 1989). This contrast can be captured by postulating different values of K among organizational attributes.

4.1. Reorientations and Changing Environments

With higher levels of K, local adaptation is not an effective response to a change in the fitness landscape. A change in a single organizational attribute is likely to have repercussions for the fitness contribution of a variety of other organizational attributes. As a result, with a higher level of K, survival subsequent to a change in the fitness landscape is much more dependent on a successful long-jump or reorientation than local adaptation.

Figure 7 indicates the frequency of one or more long-jumps for those incumbents (i.e., organizations alive in period 24) that have survived until the specified time period relative to those that have not survived.[11] With a low K value, there is little distinction between the frequency with which surviving and nonsurviving incumbent organizations engage in a reorientation. This lack of a strong association is particularly striking given that a successful reorientation implies the movement to an higher fitness level and is therefore survival enhancing. In contrast, Figure 7 indicates that with a high K value there is considerable discrepancy in the rate at which survivors and non-survivors engage in reorientations. Thus, as suggested by the work of Tushman and Romanelli (1985), there may be a correlation between survival and reorientations, but the analysis implies that this correlation should be present only for organizations that have a relatively high intensity of epistatic interactions. When organizations are tightly coupled, and as a result the fitness space is only weakly correlated, local adaptation is not very effective. Under such conditions, survival in the face of a changing environment becomes more linked to a successful long-jump or reorientation.

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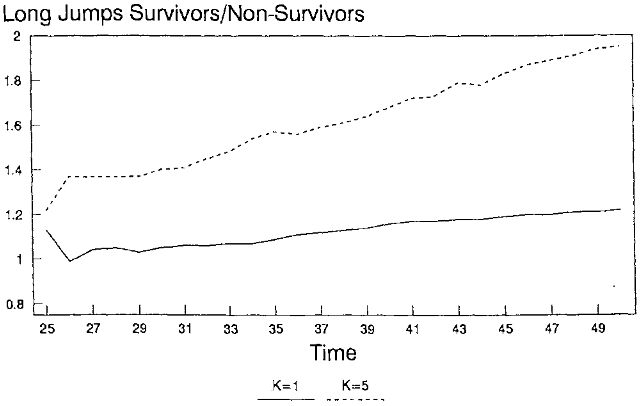
[11] For those organizations that have failed by the indicated time period, obviously a long-jump may not occur after the point of failure. However, as other organizations fail in subsequent time periods, the proportion of nonsurvivors that engaged in a long-jump during their life time may change.

Figure 7 **Reorientations in Changing Landscapes (Change in Fitness Contribution of Five Dimensions)**



5. Robustness

The robustness of the simulation results can be considered with respect to the existing model structure in terms of how representative the runs of the model that are presented are of other possible realizations of the model. Robustness may also be considered from the perspective of the model structure itself. How sensitive are the results to particular features of the model structure? This latter sort of inquiry into robustness is clearly much more open ended. Addressed below are the features of the model, the search process and the nature of the competitive dynamics, which seem most critical to consider.

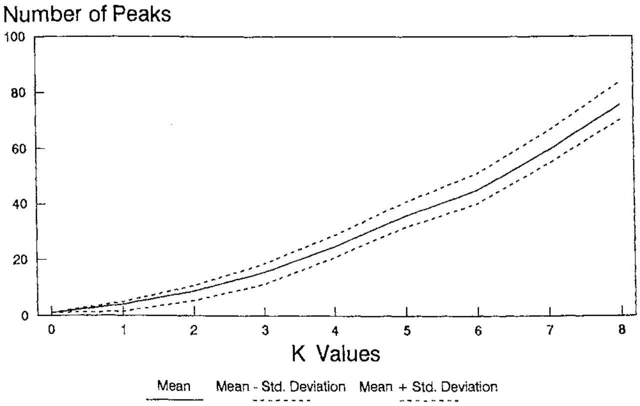
The representativeness of the results is, to a great extent, already addressed in that the simulation results are based on the average of an hundred different runs, where the landscape and population dynamics underlying each of the runs are generated by a common set of parameter values. Further, as shown in Figure 8, the individual fitness landscapes generated by a given parameter value tend to be highly correlated. Figure 8 indicates the mean number of peaks (i.e., local optima) for a given value of K and the mean value perturbed by plus and minus the standard deviation of the number of peaks in a run of an hundred landscapes. The band of plus and minus one-standard deviation follows quite tightly the mean value as K increases from 0 to 8.[12] Thus, any given landscape is likely to be fairly representative of the population of potential landscapes.

5.1. Noisy Search

The analysis of the search process made a sharp distinction between local and more distant search. Local search is assumed to be highly effective. The organization can search its immediate environment until it has found a superior alternative form or has exhausted the possible forms in its immediate vicinity. Furthermore, the organization can costlessly adopt a superior form that it has identified through this search. Nonlocal search is assumed to be far cruder. Only one form out of the set of 2^N possible forms is examined. A generalization of this dichotomous treatment of local and distant search would be to postulate that the evaluation of possible alternative forms is noisy and that the degree of noise increases with the distance between the current form and the proposed form. Noise is taken to mean that an assessment of the fitness value of a possible form equals its true fitness value plus an error term. It is this error term that is an increasing function of distance. Under this assumption, local search is still more precise than more distant search but all search is subject to some degree of noise. This structure has, as an implication, the property that search may be costly in that the organization may adopt a form that is in fact inferior to its current form and thereby increase its risk of failure.

The analysis is carried out as before with the exception that the evaluation of fitness within the search process is modified as outlined above. Perceived fitness

Figure 8 **Variation in Landscapes (Number of Local Peaks)**



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[12] The simulation was run using Turbo Pascal. For this installation of Turbo Pascal, the computer memory constraints are such that the maximum value of K that could be run with $N = 10$ is $K = 8$.

equals the actual fitness plus an error term. The error term is distributed uniformly from $-E$ to E, where $E = \Delta\epsilon$ and Δ is the number of attributes by which the proposed form differs from the current organizational form and ϵ is a parameter indicating the intrinsic level of noise in the search process. The prior model is then a special case of the new model with an ϵ value of 0.

It is appropriate to calibrate ϵ relative to the magnitude of the distribution of actual fitness values. A random organizational form, in expectation, has a fitness value of 0.5. Calculating the distribution of fitness values in a landscape reveals that the standard deviation of fitness values is 0.09.[13] Consider what variation in ϵ implies in terms of the noise of the search process relative to the variation in the actual fitness values in the landscape. On average, a random draw from the landscape differs from a given organizational form by 5 attributes ($N/2$). Therefore, if $\epsilon = 0.025$, then a possible long-jump has an expected noise level in its evaluation of over two-thirds the standard deviation of actual fitness values.[14] This represents a rather high level of noise relative to the underlying distribution of possible fitness values. Therefore, an ϵ value of 0.025 was used to represent a setting of relatively noisy (i.e., costly search) and a value of 0.01 was used to represent a setting of low noise.

The analysis of this structure is focused on three properties of the model: the emergence of "order" among the population of organizational forms via a process of local adaptation, the pattern of survival when the population is subject to a changing landscape, and the association between long-jumps and the survival of established organizations in a changing environment.[15] The effect of pure selection need not be examined since this change in the model structure only effects the search process.

The number of different organizational forms does increase with the noise level of the search process though the qualitative property persists of a sharp, rapid decline in the number of forms with time. Even the apparent increase in the number of forms with higher levels of noise is a bit misleading. A noisy search process results in continual high rates of organizational change. In particular, with a noise level of 0.025, rates of local adaptation average some eighty percent of the population at latter stages in the population history; whereas, under settings of no noise, there is almost no adaptation at later stages in the population history. In a correlated fitness landscape, noisy evaluation of points near a local peak will often look superior to the perceived fitness value associated with the actual peak. As a result, a noisy search process results in a "cloud" of organizations dispersed in the near neighborhood of local peaks. Therefore, while the number of non-identical forms increases with noise, those forms not associated with local peaks tend to differ by only one or two attributes.

While higher levels of K increase the number of local peaks in the landscape, higher levels of K also reduce the degree of dispersion of organizational forms around local peaks. With a higher level of K, the fitness landscape is less correlated; as a result, for a given level of noise in the evaluation of fitness levels, it is less likely that an organization will mistakenly move off of a given local peak.

Figure 9 illustrates the survival rates of "incumbent" organizations subsequent to a modest shift in the fitness landscape under a setting of noisy search for varying levels of K. The hundred percent survival rates with $K = 0$ observed in a setting of no noise are clearly not robust to the introduction of noise in the search process. In settings of significant noise, the survival rates with $K = 0$ and $K = 1$ are indistinguishable. However, as K increases in magnitude, we have the same result as before. Relatively uncoupled organizations tend to have high rates of survival in the face of modest changes in the fitness landscape; however, these same modest changes in the landscape tend to pose severe threats to the survival of more tightly coupled organizations.

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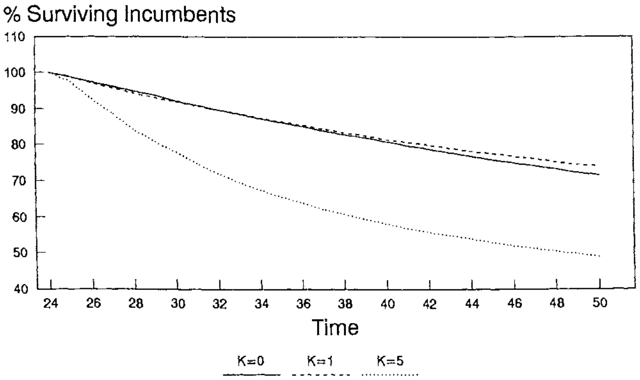
[13] This was calculated based on population distributions for a set of 100 arbitrary landscapes for a given K value. The standard deviation is relatively insensitive to the value of K.

[14] This was calculated as follows. The distribution of the noise term ranges uniformly from $-E$ to E. The expected deviation (in either a positive or negative direction) is then $E/2$. Thus, the expected noise for a long-jump with $\epsilon = 0.025$ is $(0.025/2)*5$, where the number 5 represents the expected number of attributes that differ from the proposed and current organizational forms. This yields a value of 0.0625, which is a bit over $\frac{2}{3}$ of the value of the standard deviation of 0.09.

[15] In order to economize on space, figures of simulation results are not included for all of these analyses.

Figure 9 Survival in Changing Environments (Change in Fitness Contribution of One Dimension (Noise = 0.025)



Consistent with the prior discussion of the effect of *K* on the degree to which organizations may mistakenly wander from local peaks under conditions of noise, there is an additional effect present. Under settings of very high noise, higher levels of *K* can enhance survival rates by mitigating this tendency for organizations to wander from peaks in the fitness landscape. An high level of *K* results in a lower correlation among neighboring points. As a result, for a given level of noise, an organization is less likely to mistakenly move from a local peak to an inferior form. More generally, a more rugged landscape tends to induce inertia, which, given a very noisy search process, tends to enhance survival prospects. This survival enhancing role of *K* is not associated with the adaptability of organizational populations in the face of shifting landscapes. Rather, it is a baseline property of organizational populations under settings of noisy, and as a result, possibly mistaken search.

Lastly, the relationship between the tendency for an organization to experience a "reorientation" and survival rates is examined. The same pattern is observed as in the setting without noise. Under levels of low coupling, there is little association between the tendency to experience a reorientation and survival rates; however, for more tightly coupled organizations, there is a strong positive association between reorientations and survival rates. This property still holds despite the fact that noise has the effect that organizations may engage in long-jumps that involve the adoption of a form that is in fact inferior to their current form. However, in a correlated landscape, even such seemingly dysfunctional long-jumps may have positive longer term survival implications. Even if the immediate form adopted is inferior, by moving the organization to a new region of the landscape, the long-jump may prompt a process of local search that identifies a superior organizational form.

6. Conclusion

The diversity of organizational forms is generally explained by appealing to the diversity of the environments in which organizations operate (Hannan and Freeman 1977, Lawrence and Lorsch 1967). Such arguments, however, hinge on the presence of a well-defined mapping between organizational fitness and features of the environment. For complex entities, such as organizations, there are likely to be a number of local optima with nearly equivalent performance. To the extent that variation in organizational form results from a process of local search and adaptation, then the observed variation in forms may have much more to do with an organization's structure at founding then current environmental contingencies.

The impact of initial imprinting persists even though organizations engage in considerable adaptation. This persistence is the result of two properties. First, the terrain over which organizations search has many local peaks when organization effectiveness is influenced by interaction effects among organizational attributes. However, as long as the fitness space of alternative organizational forms is somewhat correlated (i.e., similar organizational forms tend to have similar fitness values), local search will prove an important mode of organizational adaptation. This combination of local search in conjunction with a rugged landscape results in the persistent impact of imprinting effects, despite the absence of organizational inertia. Thus, Stinchcombe's (1965) arguments regarding imprinting effects do not depend on organizational inertia in the narrow sense of an absence of organizational change. Local search in a rugged landscape is sufficient to generate a persistent effect of founding on organizational form.

The other basic issue addressed here is the persistence of organizations in changing environments. This question is typically treated as a distinct issue in the literature from the question of organizational diversity. The analysis developed here suggests that the degree of epistatic interactions within organizations has important implications for both understanding the persistence of organizations across time, as well as the diversity in a population of organizations at a point in time.

With more complex interactions, it is less likely that established organizations are able to respond effectively to changes in their environment. Indeed, the systems literature (Ashby 1960, Glassman 1973, Weick 1979), suggests that adaptability is enhanced if there is a modest degree of interaction among the system's components. In, what Ashby (1960) terms, a fully joined system, a perturbation in one variable requires adjustment in all other variables in the system, making adaptation improbable (Glassman 1973: 84). Perrow's (1984) makes a similar argument when analyzing the possibility of "normal" accidents in complex, tightly coupled systems. Due to the complex and uncertain feedback among system elements, a failure in a particular component may engender a broader system failure.

As suggested by Burns and Stalker (1961) in their discussion of organic structures and Burgelman (1991) in his arguments concerning the importance of autonomous innovation efforts in fostering organizational renewal and vitality, the degree to which a firm is composed of loosely coupled subsystems provides important insights in understanding the variation in survival among firms facing a changing environment. Tightly coupled organizations can not engage in exploration without foregoing the benefits of exploitation. For a tightly coupled organization, efforts at search and experimentation tend to negate the advantages and wisdom associated with established policies and thereby place the organization at risk of failure. In contrast, more loosely coupled organizations can exploit the fruits of past wisdom while exploiting alternative bases of future viability.[16]

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