

Intermediate Selection on a Developmental Journey

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Abstract

We examine the joint processes of organizational development and population selection to highlight a dynamic interaction overlooked when considering the processes in isolation. Selection does not operate on quasi-stable traits directly, but rather on contemporaneous performance. Consequently, stable search strategies may be favored by selection on bases other than long-run performance, such as intertemporal performance stability and the rate of performance improvement. Using a computational model of firm innovative efforts guided by stable search strategies under alternative selection regimes, we find that the relative efficacy of alternative search strategies is reversed depending upon the inclusion or exclusion of selection.

1 Introduction

Theories of population level change posit two different modes through which overall efficacy is maintained and enhanced - the developmental and selectional modes of change.¹ The relationship between these alternative modes of change, however, has not been adequately addressed in the organizations literature. On the one hand, theories of search and learning, (based on early work by Simon, 1955; Cyert and March, 1963) have focused almost exclusively on the nature of organizational level development; while, on the other hand, ecological theory (Hannan and Freeman, 1977; Hannan and Freeman, 1984) has focused almost exclusively on processes of population level change in the form of entry and exit of individual organizations. Only rarely have the two bodies of work intersected (cf. Barnett and Sorenson, 2002). While both developmental and selectional theory have made significant contributions to our understanding of the sources and consequences of change, many scholars have begun to note the need to integrate theory across levels of analysis (Amburgey and Singh, 2002).

The intersection of selectional and developmental forces is most pronounced during the earliest periods in the lives of organizations. It is during these early periods of flux and tumult that organizations undergo the most rapid development, and at the same time, are most vulnerable to selection. We seek to understand the relationship between developmental and selectional modes of change by understanding the factors associated with developmental processes that affect the efficacy of selection. In particular, we highlight the time-path of organizational development – the speed of performance improvement and the level of intertemporal stability of performance – which is importantly influenced by firms' search strategies.

In order to make this discussion more concrete, consider these issues in the context of firm-level innovation efforts. The typical image is that of young firms in a new, innovation oriented, industry in which new products require months or years to take shape. In such a context, firms compete for resources

¹ We use the term development here, rather than adaptation, to highlight that organizations or routines may undergo changes that may or may not be performance or survival enhancing.

not in product markets where selection is myopic; rather, firms compete for resources to sustain innovative efforts in capital markets where selection is forward looking and survival is determined on the basis of expectations of future performance (Schumpeter, 1934).

The joint processes of development and selection pose two related questions regarding the efficacy of alternative search strategies. From the perspective of an individual organization, the presence of selection in conjunction with development suggests that search strategies that yield rapid increases in organizational performance would be attractive, even at the expense of reduced long-run performance. Alternatively, from the perspective of an actor selecting among a set of initiatives, consider for instance a venture capitalist allocating resources among a set of emerging companies, the question becomes how informative are current measures of performance for long-run performance outcomes. This latter issue leads us to highlight the role of differential ‘selectability’ associated with alternative search strategies – an organization level construct that measures the information content embodied in contemporaneous performance - as a critical determinant of the efficacy of selection. Indeed, this issue poses a broader question for analysis of selection processes: What in fact constitutes the bases of selection - organizational performance or some stable underlying trait of the organization?

In the following section, we consider more fully the need for and possibilities of the integration of developmental and selectional modes of change. In reviewing the literature, we identify the central assumptions underlying each theory. These assumptions become the basis for our computational model in which we highlight the role of intermediate selection as an important mechanism in the integration of developmental and selection-based theory. In particular, we model organizations undertaking an innovation journey in a task environment that consists of two nearly decomposable domains (technology and product-market). We model stable heterogeneity in R & D (search) strategy - organizations vary in their level of coupling (Thompson, 1967) between search activities across the technology and product-market domains. We also model the manifestation of those search strategies in terms of performance which changes markedly as the developmental process plays out. At the same time, we model

organizations subject to performance based selection while still at intermediate stages of their development efforts.

2 Development and Selection: The Two Faces of Evolution

Evolutionary perspectives on organizations have made significant headway in the social sciences over the past three decades since Campbell (1969) first argued for the evolutionary character of social systems. An evolutionary view requires three fundamental elements— variation, retention, and selection. It is from these three elements that one of the central debates in the organizations literature arises - that of the relative role of developmental versus selectional processes in accounting for the dynamics of population level fitness. The debate focuses on two central questions. The first question relates to the source of variation. Variation may arise from intraorganizational processes of change, or extra-organizational (i.e. population level) processes of entry and exit – with the debate revolving around which of these sources of variation dominate. The second question relates to the timing and strength of selection. At what rate are more or less fit organizations selected out and to what degree do more fit organizations experience higher growth rates than less fit organizations.

There have been a number of prominent calls for the integration of developmental and selectional perspectives over the past decade (Levinthal, 1991b; Scott, 1992; Bruderer and Singh, 1996; Levinthal, 1997); nevertheless, progress has been slow and scholars continue to debate both the issues and the degree to which progress has been made (Amburgey and Singh, 2002; Barnett and Sorenson, 2002). In the remainder of this section, we describe in more detail the developmental and selectional perspectives and suggest an integration of the two views that takes into account these two central questions.

2.1 Developmental view

The most prominent school of thought on the process by which development is realized – and thus variation introduced - is that of organizational learning. The early work of Simon (1955), Simon and March (1958), and Cyert and March (1963) provided the foundations for a behavioral perspective on organizational action. Fundamental to the behavioral view are two assumptions that are in stark contrast

to the rational actor views of neoclassical economics: (a) organizations are boundedly rational and thus are unable to evaluate fully the consequences of all available alternatives; and (b) there exists no fixed alternative set from which the organization chooses. The implications of these assumptions for the nature of organizational action are broad. First, organizations engage in a process of search in order to identify feasible alternatives. Second, given that search is costly - requiring the allocation of attention and scarce resources to acquire and process information - organizations satisfice based on attaining endogenous aspiration levels. Third, the search process is cumulative in nature in that the lessons from history are encoded in organizational routines (Nelson and Winter, 1982; Levitt and March, 1988) - the organizational mechanism through which a variation, once introduced, is retained across time. Fourth, search is typically local in nature because organizations expect to discover solutions to problems in the vicinity of current activities. Finally, taken together, local search and cumulative knowledge lead to path dependence in that the alternatives considered at any point in time are a function of historical actions and outcomes.

The developmental perspective holds that improvement in population level fitness comes from variation (enhancement) in fitness within individual organizations over time and the differential growth of those organizations that are more fit. While, in general, the developmental view suggests that organizations benefit from change and learning, the literature is not insensitive to the difficulty of change efforts (Leonard-Barton, 1992; Kraatz and Zajac, 2001) and their possibly maladaptive nature (Levinthal and March, 1993). However, in largely ignoring the role of selection, the developmental literature makes an additional implicit assumption regarding selection – an assumption that becomes particularly clear in the modeling oriented literature (Levinthal and March, 1981; March, 1991; Rivkin, 2000). Analysis of the efficacy of alternative search strategies generally consists of a characterization of the time paths of fitness values under different search strategies and compares their asymptotic values. In some cases, attention is paid to the rate at which this asymptote is reached (Siggelkow and Rivkin, 2004), but the implicit

assumption is that relevant ranking of relative performance consists of relative asymptotic performance, suggesting that selection only applies to these limiting states of the adaptive system.

2.2 Selection-based view

The selection-based perspective is most fully developed in the ecology literature (Hannan and Freeman, 1977; Hannan and Freeman, 1984) which focuses on differential rates of birth, death and growth under the assumption that organizations suffer from relative inertia. Two theoretical rationales have been put forward as to the source of inertia. The first claim relates to the pace of organizational change and suggests that while organizations change, they do so only slowly relative to the pace of environmental change - thus they suffer from relative inertia (Hannan and Freeman, 1977). The constraints on organizational change are both internal and external. Internal constraints include existing resources and capabilities (Kraatz and Zajac, 2001) capital equipment and trained personnel, the role of norms, history and tradition (Hannan and Freeman, 1977; Scott, 1992), as well as the need to maintain internal political equilibrium. External constraints include limited information flows and issues related to the legitimacy of change. The second claim is that inertia is the by-product of a selection process that favors reliability and accountability (Hannan and Freeman, 1984; Hannan and Freeman, 1989; Carroll and Hannan, 2000). Organizations exhibit reliable and accountable performance when their behavior is based on organizational routines (Nelson and Winter, 1982), even when the routines in question are themselves innovation routines (Zucker, 1987). A by-product of routinized behavior is inertia. Thus, inertia is a logical outcome of selection processes favoring reliability and accountability (Peli, Polos, and Hannan, 2000).

In the selection-based perspective, the source of variation is not within-organization changes in efficacy over time, but rather, population level processes of entry and exit. Selection processes drive enhanced performance at the population level by removing poorly performing organizations. In addition to this reduction in variation across organizations, variation within individuals diminishes over time as processes become increasingly routinized. The net effect is that selection processes occur relatively early and diminish in strength as time passes.

A fundamental issue for a selection argument is what constitutes the basis of selection (Freeman, 1978). In ecological analyses, the fundamental heterogeneity among organizations is the variation in organizational form. However, selection processes typically do not act directly on variability of organizational forms but rather on the current substantiation of the organization in product and capital markets. Thus, different organizational forms may generate more or less innovative products, but it is the set of more or less innovative products to which product market selection responds.² Consider, for instance, Barron, Burton, and Hannan's (1996) analysis of HRM systems among start-up enterprises. These HRM systems are shown to be relatively fixed organizational traits and arguably constitute a fundamental feature of organizational form. While the survival rates of these start-up enterprises may well be influenced by this property of their form, this influence is mediated by the firm's rate and success in bringing products to market and the response with which product markets responded to these offerings. In the biological context, this same contrast can be seen by the fact that differential rates of survival are a function of an organisms phenotype and that selection does not operate directly at the genetic level (Dawkins, 1976). Our joint examination of development and selection highlight this important issue that has largely gone unaddressed in the literature.

2.3 Syntheses Proposed in Literature

The above discussion highlights four key elements that are central to the understanding of the intersection of developmental and selection-based theory: (1) Organizations possess both elements that are relatively stable, and elements that are significantly more changeable. (2) Development processes that result in change are often guided by an overarching set of stable routines. (3) Selection is weighted toward early periods in the lives of industries and organizations. (4) Selection is not a random process, but instead follows a specific logic – the debate largely revolves around the specification of the selectable characteristic. Prior research aimed at synthesizing developmental and selection-based theory reflects

² Legitimacy, in contrast, is one potential basis of differential selection that may correspond more directly to the organizational form itself.

attempts at recognizing one or more of these key elements. This research has followed two distinct paths which we label as (a) the boundary approach; and (b) the interactionalist approach.

The boundary approach seeks to specify conditions under which one or the other rationales are more applicable and has focused on three arguments. The first such argument is that selectional perspectives are more relevant over long periods of time (Scott, 1987). In fact, it is the norm in the ecology literature to attempt to capture the entire history of a population in order to avoid severe left truncation of population histories that might distort empirical analysis (Carroll and Hannan, 2000). Scott (1987) suggests that the use of long periods offers an additional benefit – over long enough periods of time, processes of entry and exit may be a greater source of variance than developmental processes. The second argument holds that selection is more relevant in core organizational features than in peripheral features (Singh, House, and Tucker, 1986). Failure risk is greater in core functions because they are, by definition, more interdependent, and there are significant challenges associated with adapting across multiple dimensions/domains (Hannan and Freeman, 1984; Levinthal, 1991b; Sorenson, 2003). More generally, this synthesis distinguishes the content of change from the process of change (Barnett and Carroll, 1995) and suggests that the survival benefit of change in certain types of content must be called into question (Haveman, 1992; Amburgey, Kelly, and Barnett, 1993). The third argument holds that selection processes act more strongly on small organizations. The liability of small organizational size has been incorporated in numerous ecological studies (see Carroll and Hannan, 2000 for a review) which suggest that mortality may decline with increasing size since small organizations, lacking significant resource buffers (Thompson, 1967), typically exist very close to the extinction boundary (Levinthal, 1991a).

The interactionalist approach follows a process perspective (Barnett and Carroll, 1995) and argues that we must specify how the processes of development and selection act together to generate the observed patterns of population level performance enhancement (Levinthal, 1991b; Amburgey, Kelly, and Barnett, 1993; Levinthal, 1997). This research has followed one of three main routes. In the first case, researchers have argued that adaptation gives rise to an increased likelihood of failure. This effect may be

driven by the fact that organizations face two competing risks when they change - the typically well known risk associated with uncertain fitness in a given environment as well as the reorganization risk associated with change (Miner, Amburgey, and Stearns, 1990). The reorganization risk differs from the earlier discussion of boundary conditions in that it suggests that the *process* (Sorenson, 2003) rather than the *content* of change engenders an increased risk of failure. While content changes make boundary type integrations of development and selection possible, selection risk that results from the process of change itself leads to a need for a more integrated approach to a synthesis of development and selection.

The second interactionist argument invokes a co-evolutionary process of organizational change. Barnett and Hansen (1996) highlight the “red queen” effect and have argued that selection pressures may trigger adaptive responses which, in turn, may lead to more severe selection pressure. That is, the strength of selection pressure may be a function of the rate at which organizations are able to develop via learning. More generally, the level of selection pressure is at least partially endogenous to the behavior of firms in the ecology (Dobrev, Kim, and Carroll, 2003)

A third perspective of the interactionist agenda is that development and selection are fundamentally inter-related processes. Development processes of learning lead to stable heterogeneity that forms the fodder for selection (Levinthal, 1991b; Levinthal, 1997). Learning opportunities associated with the exploitation of existing activities and capabilities constrains further development (Ingram and Baum, 1997), as these capabilities become rigidities (Leonard-Barton, 1992). That is, experiential learning leads to inertia which makes population level selection increasingly the primary basis of population change.

2.4 Intermediate Selection and the Integration of Selection and Development

Our own effort to integrate the developmental and selection-based perspectives focuses on *intermediate selection* - selection that takes place prior to the emergence of stable heterogeneity. Intermediate selection poses a challenge for both the developmental and selection based views. For the former, intermediate selection raises the possibility that search strategies that lead to superior performance

may not in fact lead to superior survivability. For the latter, intermediate selection raises the issue of the efficacy of selection – as selection over a moving target degrades the ability of selection processes to lead to enhanced population level performance.

We focus on the early stages of organizations' life histories. This early period is central from a selection-based view point as a result of the liability of newness (Stinchcombe, 1965). New and small organizations have been found to be at greatest risk of failure (Carroll and Hannan, 2000). However, this early period is also very salient from a developmental view point. Starting from some initial condition, the opportunities for incremental learning processes should be at their greatest level. Thus, both processes are at their most powerful early on in an organization's life. As a result, the intersection of selection and development during this embryonic period is crucial for understanding selectional dynamics in later periods. Organizations face both long term and short term survival challenges (Levinthal and March, 1993). If they do not survive in the short term, they cannot exist to form part of the population of older more mature firms, regardless of the fitness they *would* have exhibited had they had the opportunity to grow old. We look simultaneously at development and selection during the early organizational period of intense flux and vulnerability.

Consideration of intermediate selection focuses attention on the developmental trajectories of new organizations. While these trajectories are influenced by the nature of the task environment, firm level choices with respect to search strategy have a significant affect on the time-path of organizational development – on both the speed of performance improvement and the nature of the developmental trajectory (e.g., whether it is monotonic with respect to time or the degree to which performance has a high or low serial correlation). In the ensuing agent simulation, we seek to extend theory by integrating the above noted central assumptions of developmental and selection based theories into a model that accounts for both: (a) stable strategies that guide the search, and (b) selection on the contemporaneous performance manifestation of the developmental process.

3 Innovation and Intermediate Selection

To provide a context for exploration of the relationship between selection-based and developmental processes, we consider one particular type of developmental journey – the innovation journey. Organizations innovate each time they invent, develop, and implement new products or processes. In the organizations literature, innovation has been modeled from a process perspective that characterizes the innovating organization as it progresses through a series of stages that follow a (reasonably) predictable sequence. The innovation process – and organizational choice behavior in the face of novelty more generally – is encumbered by two significant challenges: uncertainty due to imperfect knowledge of means-ends relations (Daft and Lengel, 1986); and ambiguity regarding differential evaluations of the relative merits of various goals (Garud and Van de Van, 1992). Given these challenges, firms engage in trial-and-error search in which they evaluate the potential outcomes associated with a particular action. Van de Van et al. (1999) argue that the stage like characterization oversimplifies the innovation process, and instead describe the process as an innovation journey - an uncertain and dynamic process that proceeds along a developmental path from initiation towards a conclusion in the form of either implementation or termination. In the following sub-section, we consider factors that affect the shape (speed and stability) of the developmental trajectory.

3.1 Innovation Journey and the Task Environment

The level of stability of developmental process is driven partially by the nature of the task environment³ and in particular, the relationship between the different domains of activity required in the innovation process (i.e. technology, product market, production, etc). Over the past decade, scholars building on Simon's (1962) insights into nearly decomposable systems have made significant progress in understanding the role of decomposability in product innovation, production, and organizational design (Baldwin and Clark, 2000). The general result is that near decomposability enables more rapid

³ Task environment generally refers to three elements of the environmental context: munificence, dynamism, and complexity. We focus primarily on the complexity dimension.

development than could be achieved in a task environment that had the same level of complexity but was fully interdependent.

Firms have a multiplicity of choices in the search (R & D) strategy and therefore, innovation journeys are heterogeneous in their developmental path. These firm level choices include the level of novelty in innovation (search near or far), the extent to which the search processes is on-line versus off-line (Gavetti and Levinthal, 2000), and the direction of search. A task environment that consists of multiple nearly decomposable domains of activity provides firms with additional degrees of freedom to make choices with regard to search strategy. Firms may choose to pursue a problem solving strategy that involves the decomposition of the problem into a set of sub-problems that can be solved independently (Simon, 1962; Marengo, et al., 2000). Recognizing this facet of search problems opens a new set of firm level choices - how to allocate scarce search resources across multiple nearly decomposable domains of search activity.

Consider a task environment that consists of two domains of activity: the technology domain and the product-market domain. Two simple search strategies that new innovating organizations may undertake are as follows. First, the firm may share all early resources equally between technology and product-market developmental activities using a developmental process that is highly iterative – cycling between technology and product-market concerns. Such a search strategy might include the involvement of marketing in the technology development process, tailoring the product to specific market segments, and engaging in significant prototype testing within potential customer organizations early in the development process.

This simultaneous allocation of search effort across both nearly decomposable domains in search of local (within domain) optimal performance has significant benefits in that it enables integrated trial and error learning across the entire system which tends to reveal problems more rapidly and in doing so stimulates learning. At the same time, this ‘tight coupling’ approach tends to degrade the pace at which performance improvements are achieved. Even a small change in one domain may lead to a cascading series of changes that cycle back and forth across all domains of activity. This problem arises as

adaptation in one domain, which improves performance locally, negatively affects performance in the other modules (and thus lead to remedial action in those domains). For example, Baldwin and Clark (2000: 31) argue that the distinction between design and production is important because “when design and production are carried out at the same time and in the same place, they will engender conflicting objectives. Searching for something better slows down production and uses resources.”⁴

An alternative search strategy, given a nearly decomposable task environment, is that of transforming the parallel adaptation problem into a sequential problem - where learning in one part of the organization is purposefully repressed in order to enhance learning in another (Baldwin and Clark, 2000) – that is, the firm may superimpose temporal decomposability. For example, a firm may focus on developing and refining its technology - optimizing locally on the technological performance dimension, while purposefully taking very little notice of the product-market elements associated with product market success. Later on, once a given technological performance threshold has been reached, the firm might begin to investigate attributes of the product market positioning and marketing. Thus, a firm may allocate all early resources to technology development and throw the nearly completed technology over the ‘wall’ to production and marketing (while perhaps continuing to make incremental technological adjustments).

In a nearly decomposable task environment, organizational choices vis-à-vis the allocation of search effort will lead to heterogeneity in developmental paths - with significant implications for the speed and stability of developmental trajectories. The tight coupling approach and the temporal decomposition approach represent two polar forms of innovation journeys (given the simple task environment described above). In general, these alternative search strategies entail a trade-off of expected asymptotic fitness (i.e. at the conclusion of the developmental process) for a faster pace of development and enhanced intertemporal stability. However, this trade-off is only relevant when considered within the context of the selection environment. Intermediate selection has a sharp effect on the performance of

⁴ Although there are clearly opportunity costs involved in the decoupling of production and design

alternative search strategies in that both survival expectations and performance conditional on survival will, in large part, rest not on expectations of unconditional asymptotic fitness, but rather on the details of developmental trajectories. In the following section, we describe a simulation model that seeks to understand how selection processes interact with these heterogeneous developmental processes.

4 Simulation Model

We model the neck-and-neck race between firms at the earliest stages of technological development – a context consistent with an ecological perspective on the formation of new populations. Consider an innovation centered industry in which competition between new innovation oriented organizations within an industry occurs on the basis of technological and product market performance. These organizations interact with each other only via the selection process such that superior performance of one organization decreases the probability of survival for all other organizations within the industry (all else being equal).⁵ Innovation efforts are modeled as search over a space of possible technologies, as well as a set of possible product-market positions. There is an important complementarity between technology and associated business functions. Product market search might entail activities such as market research, contacting potential customers, placement of prototypes on customer sites for testing, and perhaps even early sales.

To construct our model of the product development process, we employ as an analytical tool the NK model developed by Kauffman (1993) which has found growing acceptance in the management literature in studies of search (Levinthal, 1997), cognition (Gavetti and Levinthal, 2000), imitation (Rivkin, 2001) and organizational structure (Rivkin and Siggelkow, 2003). The basic model of Kauffman (1993) consists of a structure for defining a fitness landscape. As this framework has been applied in the management field, the nature of search and evaluation mechanisms have been elaborated and selection forces have been incorporated into the basic structure. Each of these elements is characterized below.

⁵ Thus, we are modeling a process of diffuse rather than direct competition among firms. That is, firm A does not affect the performance of firm B, other than via the indirect affect of relative performance on probability of surviving selection.

4.1 *Landscape Topography and Fitness Function*

We model organizations as pursuing R & D strategies that involve search on two distinct but interconnected landscapes, which we conceptualize as: (T) technology space, where search is conducted over the range of technological possibilities for feasible technical solutions, and (P) product-market space, where search is conducted over the range of product market attributes of the product such as what customers to target and what forms of distribution to use to target them. This dual landscape specification is broadly consistent with Kirzner's (1979: 179) notion of entrepreneurship as search for an "understanding of how means combine to achieve ends". More generally, the need to search across multiple landscapes simultaneously is consistent with the broad literature that suggests that organizations must find a set of policy choices that are internally consistent (Siggelkow, 2002). We assume that the boundaries of these two landscapes, along with the level of interdependencies between them, and the performance metrics in each, are defined exogenously and thus are not subject to managerial discretion.

In adapting the NK model to the case in which firms conduct search on two distinct but related landscapes, we build on recent efforts to apply this simulation framework to issues of organizational design (Rivkin and Siggelkow, 2003; Ethiraj and Levinthal, 2004) in which interactions across sub-problems (landscapes) play a central role. In the remainder of this section, we verbally describe the simulation and present a simple example. A detailed mathematical treatment of the simulation specification is included in the Technical Appendix.

As noted above, we implement two landscapes: T and P. A location on each landscape is characterized by a vector of policy choices in technology space, $N^T = (a_1^T, \dots, a_{n^T}^T)$, and product-market space $N^P = (a_1^P, \dots, a_{n^P}^P)$, of lengths n^T and n^P respectively. We let each policy choice correspond to a particular binary decision variable, where, for example, the choice of 1 might imply the choice of flash memory rather than a disk drive in the design of a new electronic product. Consider the example in Figure 1. An organization's locations on each landscapes is represented by vectors of length $n^T = n^P = 4$ such that $N^T = a_1^T a_2^T a_3^T a_4^T$ and $N^P = a_1^P a_2^P a_3^P a_4^P$. Thus, there are $2^{n^T} = 2^{n^P} = 2^4$ possible combinations

of policy choices in each space. The firm's complete position in the combined spaces of technology and product-market can be represented by the vector N^C (of length $n^C = n^T + n^P$), such that $N^C = \{N^T, N^P\} = (a_1^T, \dots, a_{n^T}^T, a_1^P, \dots, a_{n^P}^P)$.

----- Insert Figure 1 about here -----

Kauffman (1993) shows that the NK landscape has a topography that varies with the number of interactions between policies, where low levels of interactions result in a smooth landscape (at the extreme, a well behaved single peak) and high levels of interactions result in very rugged landscapes with many local peaks. Interactions can occur both: (a) within a landscape, and (b) across landscapes (Simon, 1962).

Within landscape interactions are characterized by the vector K_j^W (length k^W) of policy choices with which policy a_j^T (or a_j^P) interacts on its own landscape (where j indexes the policy choice). The example in Figure 1 demonstrates the interaction space in which $k^W = 2$ (technology space in upper left quadrant and product-market in lower right). In the example, the payoff to policy a_1^T (choice of 0 or 1) in technology space is a function of the choices made for the policies in the vector $K_1^W = (a_2^T, a_3^T)$ - this relationship between policies is characterized by an "x" in the appropriate cell. Referring back to the example in Figure 1, if we let $N^T = a_1^T a_2^T a_3^T a_4^T = 1110$, then $K_1^W = (1,1)$ and the fitness contribution of policy choice a_1^T is a function of selecting a 1 for bit a_1^T , as well as selecting $a_2^T = 1$ and $a_3^T = 1$. Changing to $a_3^T = 0$ would alter the fitness contribution made by the choice of $a_1^T = 1$, while the policy choice setting for $a_4^T = 1$ or 0 has no effect on the fitness contribution of a_1^T .

Across landscape interactions are characterized by the vector K_j^B (length k^B) of policy choices in the *other* landscape that affect the performance contribution of a policy choice in the *focal* landscape (the "o"s in the upper right and lower left quadrants in Figure 1). That is, complementarities between

technology and product market activities may give rise to interdependencies that complicate the innovation process as search activity in one domain both informs and affects progress in the other. In the example, with $k^B = 1$, the fitness contribution of a_1^T is also a function of the choices made for the policies in the vector $K_1^B = (a_2^P)$. In total, the payoff associated with an individual policy choice is conditional on all policy choices (within and across landscapes) with which it interacts. In our example, the pay-off associated with policy choice one in technology space, a_1^T , is $\pi_1^T(a_1^T | K_1^W, K_1^B) = \pi_1^T(a_1^T | a_2^T, a_3^T, a_2^P)$. The payoffs to each of the $2^{1+k^W+k^B}$ distinct vectors associated with a policy choice is generated by a draw from a uniform distribution $u[0,1]$.

The fitness associated with a position on the technology landscape N^T is simply the average of the fitness contributions of each of the individual policies choices such that

$$\Pi_j^T = \frac{1}{n^T} \sum_{j=1}^{n^T} \pi_j^T(a_j^T | K_j^W, K_j^B). \text{ There is a analogous expression for the fitness associated with } N^P. \text{ The}$$

total fitness of a position in the combined landscape (defined by the vector N^C) is the average fitness across both the technology and product-market landscapes such that $\Pi_j^C = \frac{1}{2}(\Pi_j^T + \Pi_j^P)$.

4.2 Search and Evaluation

Within organization variation is central to developmental models and this variation may be of two sorts. First, there may be variation across the developmental paths that firms follow due to stochastic processes (Levinthal, 1991b). We generate such variation by randomly assigning each organization an initial location in both technology and product-market spaces. This random initial location introduces *ex ante* resource heterogeneity. In the model, organizations engage in an adaptive learning process in which all search is local and follows a trial and error, local hill climbing approach and, as such, organizational outcomes are sensitive to initial conditions and thus subject to path dependence.

Search in technology space is local - performed by evaluating the consequences for technology space fitness of flipping a policy choice a_j^T chosen at random. The evaluation process of technology search is assumed to be off-line such that, if performance in the T landscape is improved by making the change, it is implemented (Gavetti and Levinthal, 2000). Otherwise, the potential policy change is discarded. Off-line evaluation is possible when the efficacy of a choice can be determined using such things as cognitive evaluation, computer models, structured experiments, animal models, prototypes, etc. For instance, a particular combination of chemicals may be evaluated *in vivo* in a laboratory, without the need to proceed to test it directly by selling the chemical in the product market.

In contrast, while search in product-market is also local, it is assumed to be conducted on-line. On-line evaluation reflects a context in which it is not possible to determine the value of a change in a single policy element in the absence of actually implementing the change. In addition, evaluation of product-market search outcomes reflects combined technology and product-market fitness. Consumers evaluate a technological artifact in conjunction with a particular market position and can not evaluate a market position in the abstract. As a result of the on-line nature of product market search, fitness at the end of the period may be either higher or lower than at the beginning of the period. If fitness is lower, then in the next period the organization returns to its earlier position and attempts to test another policy choice. Once all single policy choice changes have been examined and found to be inferior, the on-line search stopping rule comes into effect and the organization no longer engages in search in product-market space.

Second, variation may arise in the form of heterogeneity in search strategies. We generate this source of variation by modeling two types of organizations that vary in how they search the technology and product market spaces. The innovation literature views the nature of the relationship between search in the technological and product market landscapes as a critical element of R & D strategy (Iansiti, 1998) and thus, we view the decision on the timing of the commencement of search in the product market space (early or late) as one critical dimension of the organization's search strategy. When significant resources

are available and time pressure is low, tasks (both within R & D and across the R & D-marketing-production boundary) can be carried out sequentially. However, when resources are scarce, time pressure may become severe and many tasks must be carried out concurrently in order to reach the target (Mansfield, 1968; Freeman, 1982).⁶

Specifically, organizations are assumed to differ in the way in which they manage the interactions between the multiple search domains (technology and product-market): (1) Coupled organizations choose a tight coupling approach to managing interdependence between domains of activity. These organizations allocate their search effort each period equally across both the technology and product market spaces. (2) Decoupled organizations choose a temporal decoupling approach to managing interdependence between the two domains of search. To do so, these organizations initially allocate all their search effort to the technology space and, after a fixed time period, then allocate their search equally between the two domains. We set the total magnitude of search resources to be two per period and specify the breakpoint in the decoupled organizations' search strategy as period 15 (results are robust to changes in this breakpoint).

4.3 Selection

In an ecology of organizations, resources are, by definition, scarce and competition for these resources leads to both differential growth and exit in which selection across the population removes less effective organizations and reallocates resources to surviving organizations. In order to understand the relationship between developmental trajectories and selection processes, we model adaptation and selection (exit) in the absence of replacement. Selection regimes in our model may vary on three dimensions. First, selection may vary in its intensity – weak versus strong. Selection in combined technology and product-market space is implemented as the outcome of a stochastic process such that the

⁶ Note that we are in no way suggesting that the two search strategies highlighted above are the only potential R & D strategies, but rather that the differences between these two particular search strategies capture an important form of heterogeneity and are useful for highlighting the phenomenon we seek to explore.

probability of survival is $s_{i,t}^C = \left(\Pi_{i,t}^C / \text{Max}(\Pi_t^C) \right)^{Z_t^C}$ where $\Pi_{i,t}^C$ is the fitness of organization i at time t in the combined space C , $\text{Max}(\Pi_t^C)$ is the maximum fitness achieved by any firm in combined space at time t ; and Z_t^C is the strength of selection. At the time of selection, a random number R is drawn from a uniform distribution, and a firm survives if $s_{i,t}^C > R$. In this way, our implementation of selection imposes on organizations competitive consequences since the probability of failure for a given organization is negatively impacted by improvements in the fitness of the leading organization.

Second, selection may vary in the frequency of its occurrence. In particular, we contrast selection processes that are continuous with those that occur at discrete points in time. One example of a discrete selection environment is venture capital based financing which typically involves a process of staged financing in which the organization is allocated only a portion of the resources needed to fully complete development. Subsequent resource allocations are contingent on meeting interim milestones. Thus, organizations compete not only in the product market, but also in the market for financial resources (Block and MacMillan, 1985). This resource staging process is one of temporally discrete selection.

Third, selection may vary in its domain of application – that is, selection can occur in the combined technology-product space, or it may occur in the technology subspace alone. Thus, we allow for technology space selection such that $s_{i,t}^T = \left(\Pi_{i,t}^T / \text{Max}(\Pi_t^T) \right)^{Z_t^T}$. Technology subspace selection is broadly consistent with an empirical context in which early selection may take place on the basis of technological milestones alone. Continuing with the venture capital example, early selection often occurs on technology performance alone since it is difficult to judge directly the potential product-market performance of a venture that is not yet competing in the product-market.⁷

⁷ Note that the inability of financial markets to select on product-market domain performance at early stages of development does not preclude organization level search and learning in the product space. Informal early feedback from potential customers obtained via search in the product-market domain may be used by an organization's managers to provide useful guidance and provides a significant mechanism for translating market valuations into terms managers can use to improve the efficacy of search

5 Analysis

We use the fitness landscape described above as an analytical tool to engage in four sets of analyses. All simulations are for an $n^C = 20$ landscape consisting of two sub-landscapes (technology and product market) each $n^T = n^P = 10$. Thus, there are approximately one million (2^{20}) locations on the combined landscape. The interaction structure within each sub-landscape is specified as $k^W = 5$. The interaction structure between landscapes is specified such that the two sub-landscapes are connected by, on average, $k^B = 2$ interactions. A simulation run lasts for 100 periods. Each simulation run includes 200 organizations seeded randomly on the landscape, and divided equally between the two search strategies. All results are averaged over 100 runs, and thus we simulate in total 20,000 organizations.

While the results presented below are specific to the task environment described above, the main conclusions we draw are remarkably robust to alternative specifications of the task environment. We have confirmed robustness to all major alternative specifications including changes to: (a) symmetry in the between landscape interactions; (b) number of policy choices; (c) number of within and between interactions (with near decomposability maintained); and (d) product-market search as off-line instead of on-line. We have also examined robustness to changes in the decoupled search strategy in terms of the time at which such firms commence product-market search. Indeed, as the time of product-market search onset increases, our results become progressively more pronounced.⁸

In exploring the basic relationship between search strategies and selection, we conduct our analysis under a variety of selection regimes. In the first simulation, we run a baseline, no-selection model. In the second simulation, we investigate the effect of a simple continuous selection regime on the

in the technology space (Baldwin & Clark, 2000). However, the information obtained may be highly impacted and difficult to communicate to financial markets (or venture capital firms), thus making it unusable as a basis for selection. This creates a wedge between feedback, the organization's ability to learn in the product market, and selection, the ability for the organization's product market performance to be a basis for selection.

⁸ The results are also robust to some lowering of the time of product-market search onset, although, in the extreme, as product-market search onset approaches $t=0$, the modified decoupled strategy becomes identical to the coupled strategy.

outcome of a search process. The third simulation changes the nature of the selection regime to the case of a selection process that is discrete in time, a structure more consistent with distinct selection decisions as in the venture capital context. In the final simulation, we highlight the fact that selection may not always be possible in the product market, and thus we investigate discrete selection that occurs at an early time period within the technological sub-space alone. The analysis of discrete selection regimes also serves to facilitate a better understanding of the processes underlying the results observed in the continuous selection case as it allows us to distinguish between the effects of varying the timing of selection and the intensity of selection.

5.1 *Baseline (non-selection) Model*

In order to ground the discussion of the models, it is useful to examine the developmental trajectories that result from different choices regarding search strategy in the absence of selection. In this baseline model, the results reflect only the underlying dynamic of fitness development over time. As noted earlier, we model two types of organization search strategies: Coupled organizations pursue a search strategy that includes search in the technology and product landscapes simultaneously in each period, while the decoupled organizations initially pursue search only in the technology domain and postpone product-market search until initial technological progress has been made.

The results from the no-selection model are presented in Figure 2 which maps average firm fitness across time across the combined technology-product market domain. Given the nearly decomposable nature of the task environment, the two search strategies lead to very different developmental trajectories. In the absence of selection, the developmental trajectory of decoupled strategy organizations (relative to that of coupled strategy organizations) has four important characteristics. First, decoupled organizations exhibit rapid early performance gains relative to those organizations pursuing a coupled strategy. While holding the amount of search (two searches per period) constant, decoupled search increases the speed of technological progress. The result that allocating all search resources in one domain (technology) would lead to superior early performance across the combined technology-product market space is not obvious ex ante – as the two search strategies use identical levels of search resources

and there are declining returns to local search in a particular domain. The observed advantage accrues to the fact that, for decoupled organizations, early search in the technology domain is not impeded by the significant confounding effects of simultaneous search in the product domain (Baldwin and Clark, 2000).

----- Insert Figure 2 about here -----

Second, the developmental trajectory of decoupled firms is highly non-monotonic, exhibiting less inter-temporal stability than the trajectory of coupled strategy firms. Subsequent to period 15, when decoupled organizations commence search in the product-market domain, their overall progress slows substantially. While these decoupled firms are rather well adapted in technology space, early search in the product-market results in a significant necessary realignment in the technology space and a near-term drop in fitness.

Third, decoupled organizations exhibit superior asymptotic fitness. The superior asymptotic performance of decoupled organizations is driven by the on-line nature of search in the product domain. On-line product market search is costly and, as a result, firms sample each neighboring location to its current product location only once. As product-market search is subject to significant disturbances due to search in technology space, by refining the technology first, decoupled strategy firms do not exhaust their limited search of product-market positions in conjunction with immature technologies. In this manner, decoupled organizations' early technology refinement reduces the possibility of product-market search locking onto solutions that may be inferior given later technological advances. In contrast, organizations that engage in coupled search throughout are more likely to exhaust possibilities for incremental improvements in product space while the product technology is still at an immature state. However, while coupled search strategy firms obtain an inferior performance asymptote, they reach this asymptotic performance level much faster. This result is consistent with work that demonstrates the value of a rapid iterative development process that is similar to our coupled strategy (Eisenhardt and Tabrizi, 1995). In contexts where development time is critical, the delay associated with the decoupled strategy involves a significant cost.

In sum, in a selection free context, temporal decoupling of search across the two domains proves to be an effective means of ensuring superior fitness, both in the near term and in the long term. At the same time, the coupled strategy is not without merit as it leads to a developmental trajectory that is both faster with respect to the rate at which asymptotic performance is reached and more stable. These properties of more rapid ascent to the asymptotic value and greater period-to-period stability in performance are brought to the surface in the subsequent analysis in which selection forces are introduced.

5.2 *Continuous Selection*

In this section, we introduce a continuous selection process in the combined (technology and product-market) space. This model allows us to begin our analysis of the differential effect of selection on alternative developmental processes. We tune the selection parameter z across a range of values, from $z=0$ through $z=0.45$ which covers a range of selection pressure regimes from no-selection, through selection pressure that eliminates 99% of organizations over the 100 period simulation. Results are presented in Figure 3. In order to present results in a manner that enables comparisons across selection regimes, we display these and the subsequent results as the percentage by which coupled organizations' fitness differs from that of decoupled organizations.

----- Insert Figure 3 and Figure 4 here -----

The basic results of the no-selection model are redisplayed in the $z=0$ model in which decoupled organizations make significant early progress relative to coupled organizations and recover from the post period 15 slump to develop a small, but significant ($p<0.001$), asymptotic fitness advantage of approximately 1%.

As we tune up selection pressure, three results are of note. First, during the early stage of the search process, increasing selection pressure has the effect of magnifying the no-selection results – increasing the relative advantage of decoupled organizations to coupled organizations. Second, and more significantly, as we tune up selection pressure, we notice a significant change in the asymptotic results. As selection pressure increases, the fitness conditional on survival of coupled relative to decoupled

organizations quickly improves. Third, firm level fitness, averaged across all surviving organizations, increases from the no-selection level of 0.6525 to a maximum of 0.7321 when the selection pressure level is set at $z=0.45$, as increasing selection pressure increasingly removes less effective organizations from the population.

A complementary way of interpreting the interaction of developmental and selection-based processes is to examine the changing nature of the population as selection pressure increases. These results are reported in Figure 4. As noted earlier, selection out of the population is a stochastic function of an organization's fitness relative to the maximum fitness in the population of organizations at that time. Figure 4 reports the population results for the selection model above as selection pressure increases from 0% at $z=0$ through 99% at $z=0.45$. As selection pressure increases, the population becomes increasingly skewed towards coupled strategy organizations, with coupled organizations accounting for approximately 52% of surviving organizations with selection pressure of $z=0.1$ (a level of selection pressure that results in the elimination of 82% of firms). Asymptotically, as selection pressure comes to eliminate all but two organizations, coupled organizations come to account for, on average, 59% of these surviving organizations.⁹

The conditional fitness results demonstrate a significant deviation from the no-selection model, thus calling into question normative advice provided on the basis of interpreting developmental processes in the absence of selection. Increasing selection pressure leads to asymptotically superior fitness conditional on survival for coupled strategy organizations. This asymptotic fitness result in favor of coupled strategy organizations coincides with the demographic results which highlights a significant increase in the survival prospects for coupled strategy organizations as selection pressure is increased. In this sense, organizations undergoing development face a trade-off under a continuous selection regime that is not apparent when analysis is conducted only on asymptotic results in the absence of selection:

⁹ Recall that these results are an average across 100 runs of each population of organizations and therefore the results need not take on an integer value.

organizations can optimize on asymptotic performance by pursuing the decoupled strategy, or they can pursue a coupled search strategy that enhances survival under a continuous selection regime by improving intertemporal stability and the pace with which asymptotic performance is reached.

More generally, the problem facing organizations, that of balancing near term survival and long term performance, is analogous to the exploration-exploitation problem (March, 1991). In this model, in the absence of selection the decoupled strategy serves to *both* enhance near term fitness and asymptotic fitness – thus implying that there is *no* trade-off between near-term and long-term benefit. Under continuous selection, however, one observes that organizations with the coupled strategy trade-off asymptotic fitness for enhanced survival rates. The results presented here suggest that a discussion of the trade-off between the near-term and long-term requires consideration of the role of selection.

The central task in the remainder of the analysis is to disentangle the factors that account for the above results. In particular, two basic questions are highlighted in the discrete selection simulations that follow. First, why does selection result in a reversal of the no-selection conclusions. Second, why is the population of surviving decoupled organizations inferior to surviving coupled organizations? This is a puzzling result given that we know that decoupled organizations, if they are allowed to reach maturity, are on average superior.

5.3 Discrete Selection

We attempt to answer the above questions by conducting a number of additional simulations using a discrete selection event in place of the continuous selection implemented above. We do so for two reasons. First, implementing a discrete selection regime serves to usefully reduce the complexity of the results, while in no way taking away from the generalizability of our conclusions.¹⁰ By looking at a

¹⁰ For a continuous selection regime S, one can specify a discrete (one time) selection regime S' such that the effect of S' on conditional fitness of survivors and asymptotic population demographics is the same as that of S (although the specifics of which firms in particular survive may change). Changing continuous selection pressure under the S regime consists of changing two distinct elements under the S' regime: (a) intensity of selection, and (b) timing of selection. Increasing selection pressure S (in a

discrete selection event held constant in time, we can single out the effect of increasing selection pressure from the effect of changing the time of selection. Second, the use of discrete selection more closely resembles the discontinuous intermediate ‘milestone’ selection context typically facing new innovations. In considering discrete rather than continuous selection regimes, we also consider in more detail the ability of selectors (e.g., venture capital firms, organizations with portfolios of projects) to engage in selection on various characteristics of a firm’s or project’s performance. That is, we consider the role of intermediate performance milestones on sub-landscapes. In particular, we consider two types of discrete selection independently. First, we consider discrete selection in combined technology-product market space. Second, we consider the case of early selection in technology space alone.

5.4 Discrete Selection – Combined Technology-Product Market Domain

As an alternative to the continuous selection imposed in our first simulation, we look at the effect of a discrete selection event on the combined technology and product-market landscape. We model such a selection process as a discrete selection event at period 30. The results of fitness conditional on survival are presented in Figure 5. The outcome is qualitatively consistent with the outcome of continuous selection noted previously, but the actual magnitude of the result far exceeds the continuous selection regime in that coupled strategy organizations outperform decoupled strategy organizations contingent on survival by a magnitude of over 5 percent compared to a 2 percent differential in the continuous selection model.

----- Insert Figure 5 and Figure 6 about here -----

In order to understand why, both under conditions of continuous selection and discrete selection (at period 30), coupled organizations exhibit superior post selection fitness, one must focus on the nature of selection – the basis upon which organizations become at risk of failure and how fitness at the time of selection relates to asymptotic fitness. Recall that Figure 2 illustrated fitness versus time for the two

continuous selection regime) serves to change the discrete selection event S' both by increasing the intensity of selection, as well as by shifting the selection event earlier in time.

different search strategies in the combined technology-product space. By period 30, coupled strategy organizations are, on average, at or very near to their local fitness peak, decoupled strategy organizations, which first focused on enhancing their technology, lag significantly and therefore, on average, coupled strategy firms make faster progress along their developmental trajectory.

This observed difference in the speed with which firms approach their asymptotic performance level on their local peak has a strong influence on the efficacy of selection. The fitness of a firm at the time of selection provides important information about the expected asymptotic fitness – in particular, it provides information on the minimum height of the local peak. The faster (on average) speed of coupled relative to decoupled firms means that selection over coupled firms is more effective at identifying those firms that will be of high fitness asymptotically. In this sense, at the time of selection, the fitness of a coupled strategy organization is more informative about its asymptotic fitness than is the fitness of a decoupled strategy organization. This enhances ‘selectability’ of coupled organizations in the sense that at any time, t , selection processes will do a better job of identifying superior asymptotic performance in the context of organizations with coupled search strategies than organizations with decoupled search strategies

The population demographic results displayed in Figure 6 are consistent with the results of the continuous selection case in that coupled organizations are increasingly likely to survive as selection pressure increases. Given the fitness function implemented, the only factor affecting the probability of survival is fitness relative to the maximally fit organization. At period 30, coupled strategy organizations exhibit, on average, superior fitness and thus have an increased probability of survival, even though we know that on average they have a poorer asymptotic performance level than decoupled organizations in the absence of selection.

This highlights an important point – selection operates over firms using current fitness. The extent to which present and past fitness is a good indicator of asymptotic fitness is a matter of significant consequence, particularly when heterogeneity in organization strategy may directly affect the outcome of the selection process that creates the final pool of surviving organizations.

5.5 Discrete Selection – Technology Domain

Selection during the early stages of an innovation journey can, in some contexts, be difficult to conduct in combined technology-product market space. Decisions to recommit resources often must be made prior to the point at which an initiative is ready to take to market and therefore only the realization of the innovation with respect to technical criteria can be incorporated in the interim evaluation. In the following simulation, we implemented discrete selection in technology space at period 10.¹¹ By discrete selection, we mean a single period selection event at period 10, with no selection in the periods prior or subsequent to period 10.

The results of discrete technology selection, in terms of fitness conditional on survival, are presented in Figures 7 and 9, with Figure 7 presenting fitness in the technology subspace where selection takes place and Figure 9 presenting fitness with respect to the combined spaces.

----- Insert Figure 7 and Figure 8a,b,c about here -----

This analysis of technology performance based selection allows us to unpack the superior technology space asymptotic fitness, conditional on survival, of coupled organizations vis-à-vis decoupled organizations, as selection pressure increases. We conducted an analysis of the distributions of organization fitness in technology space in the time period surrounding the selection event (Figure 8a,b,c). Immediately prior to selection at period 10, decoupled organizations have superior fitness as demonstrated in Figure 8a and this is reflected in a distribution of decoupled organization fitness that sits to the right of the distribution of coupled organization fitness. Immediately post selection (period 11), the distribution of fitness of survivors of both search strategies is, as expected, now far to the right of its earlier position (see Figure 8b) as selection serves to eliminate from the population those organizations that have low fitness at the *time of selection*. Thus, given the fitness advantage of decoupled firms immediately prior to selection, the population of decoupled organizations far outnumbered that of coupled organizations immediately post selection.

¹¹ Consistent with the notion of selection based only on technological performance, discrete selection was implemented during the period in which firms using a decoupled search strategy still engaged in only technology search.

Post period 15, when decoupled organizations start product space search, the distribution of fitness for decoupled organizations degrades (see Figure 8c depicting technology space fitness at period 25). The degradation of the decoupled organization fitness distribution takes the form of a shift in the distribution to the left. This shift is driven by the interaction of the developmental process used by decoupled organizations and the selection regime. Decoupled strategy organizations initially search and optimize fitness in technology space based on their initial location in product space. Once product space search commences in period 15, the fitness value for a particular decoupled organization's location in technology space changes markedly. The technology landscape is reshaped by product space search in the sense that a particular bundle of technological attributes that were valuable for one product-market configuration are perhaps less valuable for another configuration. Therefore, fitness on the technology landscape of decoupled organizations immediately prior to selection is not highly correlated with decoupled organizations' asymptotic fitness. In contrast, coupled organization fitness at the time of selection is highly correlated with their asymptotic fitness. In addition, the coupled organization distribution continues to improve as coupled organizations climb towards their local peaks. Using contemporaneous fitness at period 10 as a guide, it is difficult to intelligently select over the population of organizations with decoupled search strategies and, as a result, early technology domain selection erroneously eliminates many decoupled strategy firms that would have been superior performers.

The implications of early technology based selection for combined technology-product market fitness, which mirror the technology space results, are presented in Figure 9. The demographic results, depicted in Figure 10, indicate that decoupled strategy firms are more likely to survive early technology space selection and, as selection pressure increases, organizations with a decoupled search strategy come to make up an increasing share of the surviving population – a result that is opposite to the earlier product-market selection models.

----- Insert Figure 9 and Figure 10 about here -----

6 Conclusion and Discussion

We have sought to address the central question of evolutionary inquiry: “how selection processes affect, and are affected by, the pace and path of strategic change” (Barnett and Burgelman, 1996: 6). In order to guide our enquiry, we have focused our attention on the period in which the intersection of selection-based and developmental forces is most pronounced - during the earliest periods in the lives of new organizations. It is during these early periods of flux and tumult that organizations undergo the most rapid development, and at the same time, are most vulnerable to selection forces. Our results indicate that some central phenomena lie at the intersection of developmental trajectories and environmental selection and that these phenomena can only be explained by considering them jointly.

Selection at points intermediate to the conclusion of the developmental process has an effect on both the demographic characteristics of the population of firms surviving selection and on the fitness distribution of survivors across search strategies. Under either continuous or discrete selection regimes that select on the basis of performance on the combined (technology and product-market) landscape, we observe a full reversal of the no-selection results. The average asymptotic fitness of surviving coupled strategy firms exceeds that of decoupled strategy firms *and* coupled strategy firms are more likely to survive. Thus, under selection, one might argue that *coupled* strategy firms are ‘superior’ whereas in the no-selection context, one might argue that *decoupled* strategy firms are ‘superior’.

Understanding the mechanisms that lead to the observed fitness distribution of survivors, and in particular why surviving firms pursuing a coupled search strategy come to outperform decoupled firms, highlights an important result of this study – the critical role of the information content embodied in contemporaneous fitness at the time of selection. While selection in biological systems and end-product markets focuses on contemporaneous fitness alone (“What can you do for me now?”), intelligent selection over firms undergoing developmental processes necessarily focuses on expected fitness (“What can you do for me when you are finished your development?”). The need to select over entities based on expectations of future performance is abundant in economic contexts and is a primary role of financial and venture capital markets – and also arises in other socially relevant contexts (e.g. educational testing).

An important result from this study is that the extent to which intermediate selection is effective – that is, it removes organizations that have low expected asymptotic fitness - is a function of the choices firms make vis-à-vis the allocation of resources to the developmental process. Our simulations highlight the fact that at any given time during the developmental process, the contemporaneous fitness of firms with a decoupled search strategy is less informative about expected asymptotic fitness than is the contemporaneous fitness of firms with a coupled search strategy. Conditional upon survival, firms using coupled search, on average, outperform those engaged in decoupled search, even though unconditional on survival decoupled firms have superior asymptotic fitness.

We refer to this differential informativeness of contemporaneous fitness in relation to asymptotic fitness as differential ‘selectability’. Firms that choose a coupled search strategy exhibit higher selectability. Two elements of developmental trajectories affect the level of selectability. First, the speed of development strongly influences selectability. At the extreme, very rapid development leads immediately to a stable local peak, after which point fitness at any future time t is perfectly informative about fitness at any subsequent time $t+x$. Second, the level of stability in the developmental trajectory affects selectability. In particular, the degree to which cross-sectional rank ordering across organizations is preserved as individual organizational development plays out enhances the degree to which early selection is informative of long-run performance. Instability in developmental trajectories results from extreme changes in the course of development.¹² In our simulation, decoupled firms experience an instability inducing event when they commence search in the product-market domain. Such an event reduces the information content in contemporaneous fitness (pre-event) by decoupling asymptotic fitness from its pre-event fitness level.

¹² In this context, it may be useful to distinguish what could be termed short-wave and long-wave stability. Short-wave stability refers to the what Hannan and Freeman (1984) call reliability ($Cov(F_t, F_{t-1})$). Long-wave stability relates to what we call informativeness ($Cov(F_t, F_{asymptotic})$). Intertemporal variance would be influenced by both types of stability, though our focus is on the so-called long-wave stability.

In the remainder of this discussion, we focus our attention on three considerations that arise from the joint examination of development and selection: (a) definitions of intermediate selection; (b) exploration and exploitation; and (c) applications to the empirical context of venture capital.

Intermediate Selection: The issue most salient to the discussion is that of the integration of developmental and selection-based modes of change. In our discussion, we highlighted the argument that developmental processes of local search give rise to stable heterogeneity in organizations – and this heterogeneity then serves as fodder for selection processes (Levinthal, 1991b). However, the truth of such a claim depends on the speed of the adaptive search relative to the intensity of the selection forces. This dual contingency is highlighted in our analysis by our tuning of selection forces and our examination of alternative search strategies that differ in the speed with which their asymptotic value is reached and the variability in performance along this developmental path. Our analysis of *intermediate selection* highlights the importance of these properties of development and selection. We argue that, in general, developmental processes do not happen quickly (Hannan and Freeman, 1984). Development is a slow process often driven by a problemistic search (Cyert and March, 1963) which leads to incremental change in organizational routines (Nelson and Winter, 1982; Levitt and March, 1988). Nevertheless, a definition of slow development can be made only relative to a specific comparison time frame. The time marker of relevance here is the timing of selection processes – that is, the definition of slow is endogenous in the sense that a developmental process is slow if the organization is at risk of selection prior to reaching a stable state. This view is supported by work on the relationship between environmental context (selection environment) and strategic decision speed which finds a positive relationship between speed and performance only in high velocity environments (Eisenhardt, 1989; Baum and Wally, 2003), that is, in those contexts where selection processes intersect most strongly with developmental processes.

Exploitation and Exploration: This study serves to add to the longstanding debate on the relative merits of exploitation and exploration (March, 1991). The trade-off has taken numerous forms in the literature, including the trade-off between the short and long term, static and dynamic, known and novel, and near and far (cf., Ghemawat and Costa, 1993; Levinthal and March, 1993; Christensen, 1997;

Tushman and O'Reilly, 1997; Sorenson and Stuart, 2000; Rosenkopf and Nerkar, 2001). The results of this study suggest that the multiplicity of understandings of the various trade-offs that fit under the rubric of exploitation and exploration derives from a lack of attention to the role of selection.

This issue can be seen most readily in the context of the decision theory literature on sequential decision-making (DeGroot, 1970), particularly work that focus on the now well known n-armed bandit problem (Holland, 1975), as well as work on R&D strategies (Evenson and Kislev, 1976). The general finding of these analyses is to suggest that a firm should follow a strategy of early exploration followed by later exploitation. Implicit in this literature is the complete absence of selection at intermediate periods – the objective function of actors in these models focuses solely on asymptotic performance. Consideration of the impact of early selection, however, has a large impact on the normative advice. In the presence of early selection, organizations that focus energy on exploitation first, in order to create a performance buffer, are more likely to survive. Therefore, under early selection pressure, the normative advice is, unconventionally, exploit first, and then explore – a notion that is consistent with a stream of the venturing literature that highlights the benefits of bootstrapping (Bhide, 1992). For instance, within our analysis, under early discrete technology domain selection, a type of selection that is strongly present in venture capital and corporate venturing contexts, decoupled firms trade-off inferior asymptotic fitness conditional on survival (see Figures 7 and 9) for enhanced early survival prospects (Figure 10). More generally, the nature of the trade-off between exploitation and exploration will be a function of *both* firm choices with regard to search strategy which defines the general nature of the developmental trajectory and the nature of the selection regime.

Our study further suggests that one might observe a trade-off between near-term fitness and long-term fitness - even though such a trade-off need not exist. That is, under early technology selection, decoupled firms have superior early fitness and, conditional on survival, inferior asymptotic fitness, even though in the absence of selection decoupled firms have superior fitness on both time scales. More generally, there exists combinations of developmental trajectories and selection regimes such that observation of the post selection sample leads to the naïve inference that some organizations are trading

off near term fitness for long term fitness when in fact these organizations have superior fitness in both time frames. While the general sample selection problem is well recognized in the management literature (Shaver, 1998), the curious result observed here suggests that observation across a selected sample may be biased by selection that is differentially effective across search strategies – that is, we do not observe the endogenous variable ‘selectability’.

Venture Capital: For the types of firms conceived of in this paper - new organizations undertaking an innovation journey, early product-market selection is typically infeasible, as such organizations exhibit relatively long developmental periods during which participation in end product markets is not possible. As a result, organizations in such settings compete in capital markets on the basis of expectations of expected future performance in product markets. In venture capital markets, organizations undergo an intentional selection process. Selection takes the form of the periodic evaluation of performance relative to milestones (Block and MacMillan, 1985) in order to assess the future prospects of the venture (Cornelli and Yosha, 2003). The timing of these selection events takes into account the need to both: (a) overcome informational problems (Arrow, 1962) in order to mitigate agency concerns and to defer resource commitments until more information is available (Gompers, 1995; Cornelli and Yosha, 2003), as well as (b) manage the costs associated with monitoring (Gompers, 1995; Kaplan and Stromberg, 2001).

In viewing the venture capital process as one of intelligent intermediate selection over a developmental path, additional insights are gained into the nature of the venture capital selection problem. The challenges VCs face in managing the sequential selection (investment) process are significant, both in terms of agency concerns and VC decision making bias (Guler, 2003). Our results provide additional insights into these issues in terms of the timing and efficacy of selection events. First, uncertainty resolution over the firm’s developmental path may not always be monotonic. The degree to which contemporaneous assessments of performance reflect asymptotic results may vary both with the time of selection and the nature of the firm’s R & D strategy (its selectability) - early assessments may be misleading. Second, our results suggest that the selectability of a firm’s search strategy may be an

important element of information that is asymmetrically distributed (Arrow, 1962). Moreover, even when the venture capitalist is armed with sufficient information on the selectability of the firm's search strategy, a low selectability search strategy (e.g. decoupled) adds additional costs to venture capital – either in the form of decreased selection effectiveness (which reduces total returns) or the necessity of delaying selection (which leads to higher opportunity costs).

Third, to the extent that a firm's choice of strategy is endogenous to the expected nature of the venture capitalist's chosen selection regime, the efficacy of selection processes may be negatively impacted. For example, new ventures expecting early technology domain selection would be likely to pursue a decoupled search strategy because such a search strategy increases their probability of survival. This result is costly from the perspective of the venture capitalist – as early selection is relatively ineffective on firms using a decoupled search strategy given that their early technology fitness is a very poor indicator of asymptotic fitness.

In addition, consideration of intermediate selection in a capital market context also raises important questions for work on industry evolution. Models of industrial evolution (Abernathy and Utterback, 1978; Nelson and Winter, 1982; Anderson and Tushman, 1990; Klepper, 1996) have long suggested important roles for technological development and population-level selection. This work has made significant progress under the simplifying assumption of natural selection based on contemporaneous product-market performance. In fact, in modern technology based industries where new innovations are often commercialized either by venture capital backed firms or multi-business corporations, forward-looking selection processes better describes the process by which firms enter and exit an industry. Consideration of selection as intentional and intelligent - based on expectations of asymptotic performance – raises a new question for scholars of industry evolution. How might firm developmental paths, and heterogeneity in them, affect the efficacy of selection and the observed outcomes of the intersection of development and selection in the evolution of industries? In this regard, our work does not provide answers– instead, our work opens up a new avenue for future exploration.

Development and selection are two phenomena that must be explained simultaneously. We contend that evolutionary arguments about change that rule out (or hold constant) the effect of one mechanism or the other do so at the cost of overlooking an important dynamic interaction that dramatically affects observed outcomes. The important conclusion to be drawn from this exercise is that firm level choices vis-à-vis search strategy affect not only asymptotic performance, but also the time path of development in terms of both the speed and shape of the trajectory. When selection takes place at points intermediate to the conclusion of the developmental process, these divergent developmental trajectories will materially affect the outcomes of the selection process – both which firms will survive, and the average performance of survivors. Both selection and development occur in “real time”. Selection operates over the current manifestation of latent forms and does not wait for the realization of future possibilities. Exploring the dynamics of developmental journeys and the impact of selection intermediate to the fulfillment of such journeys, provides a bridge between our theories of adaptation and selection and the twin challenges of development and survival that organizations face.

Figure 1: Landscape Interaction Structure

Technology							
a^t_1	a^t_2	a^t_3	a^t_4				
x	x	x					o
	x	x	x		o		
x		x	x	o			
x	x		x		o		
	o			x	x	x	
o					x	x	x
		o		x		x	x
	o			x	x		x
				a^p_1	a^p_2	a^p_3	a^p_4
				Product-market			

Figure 2: Combined Technological and Product Market Fitness – No Selection

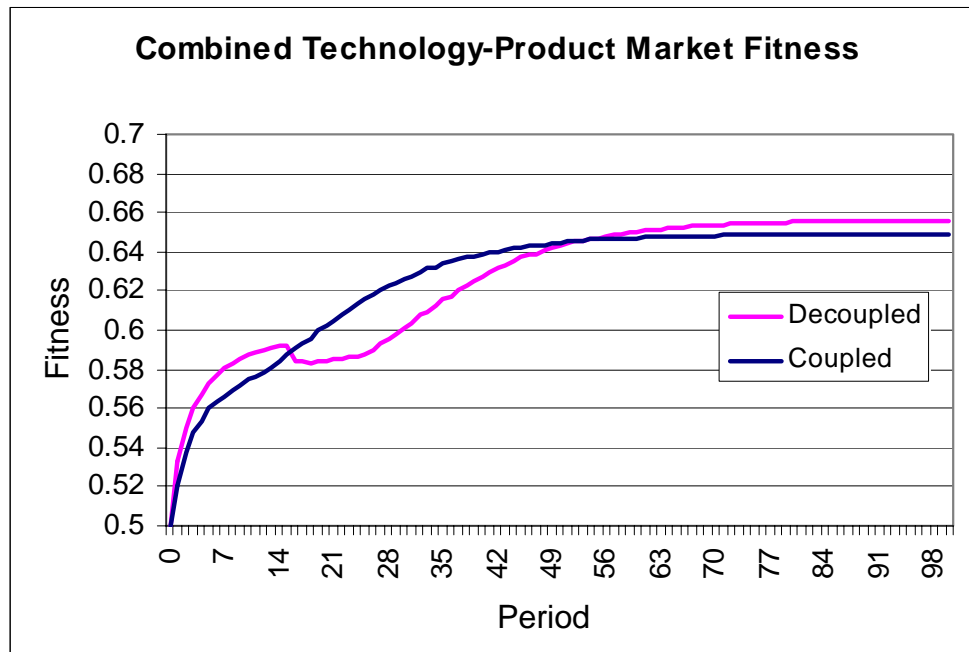


Figure 3: Combined Technological and Product Market Fitness - Continuous Selection in Combined Space

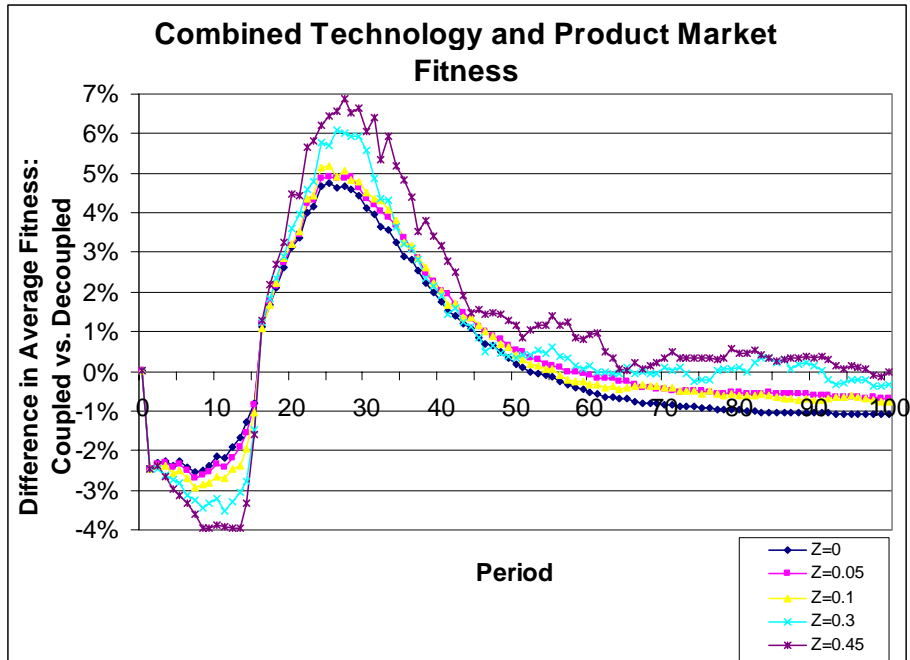


Figure 4: Population Demographics- Continuous Selection in Combined Space

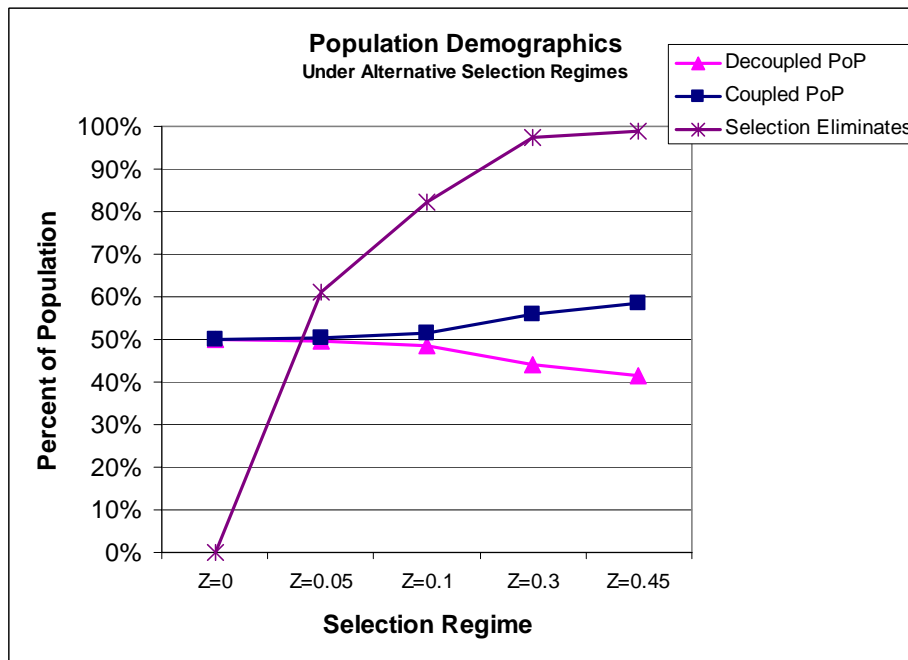


Figure 5: Combined Technological and Product Market Fitness - Discrete Selection in Combined Space at t=30

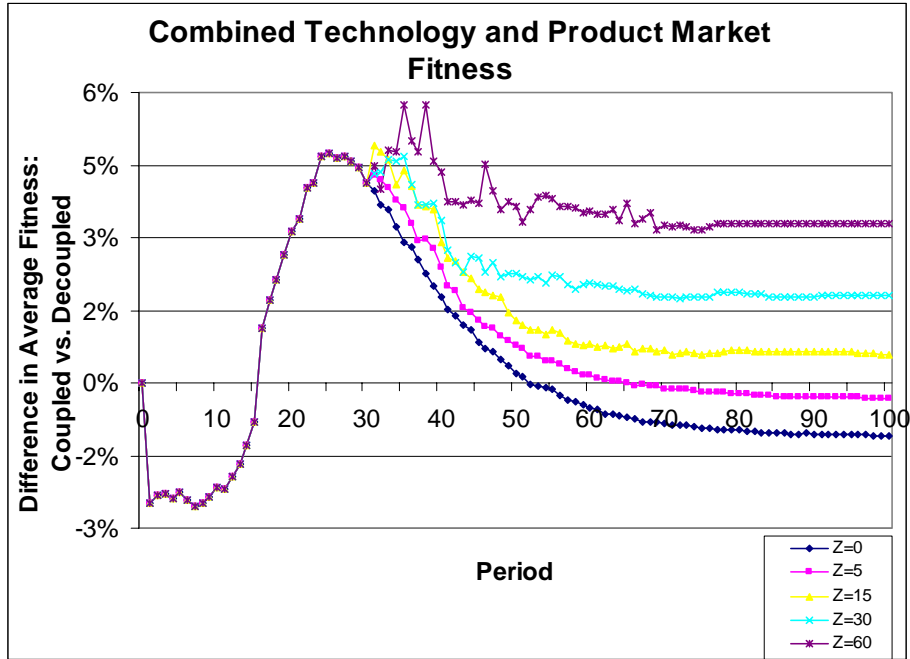


Figure 6: Population Demographics- Discrete Selection in Combined Space at t=30

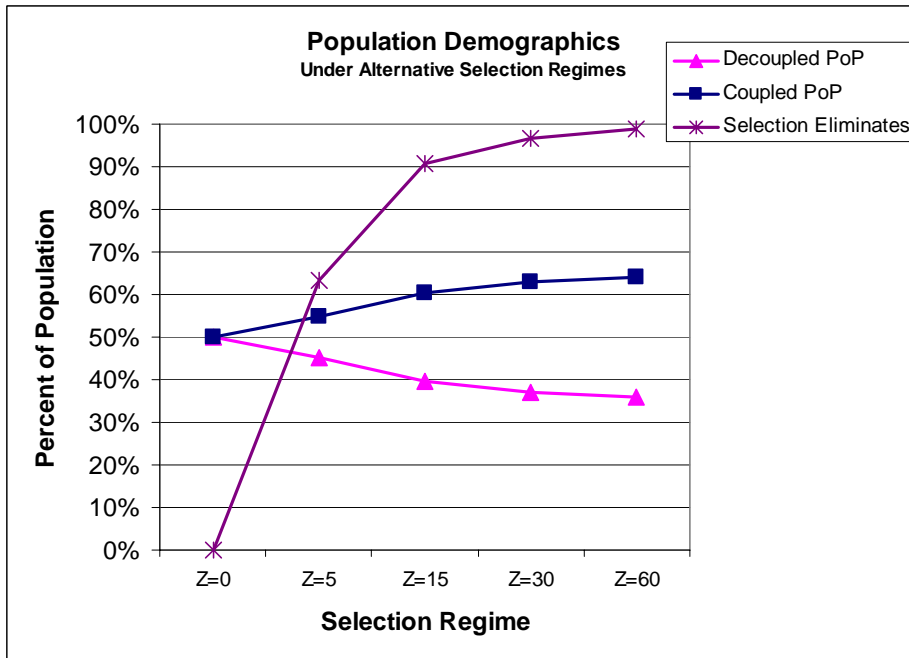


Figure 7: Technological Fitness - Discrete Selection in Technology Space at t=10

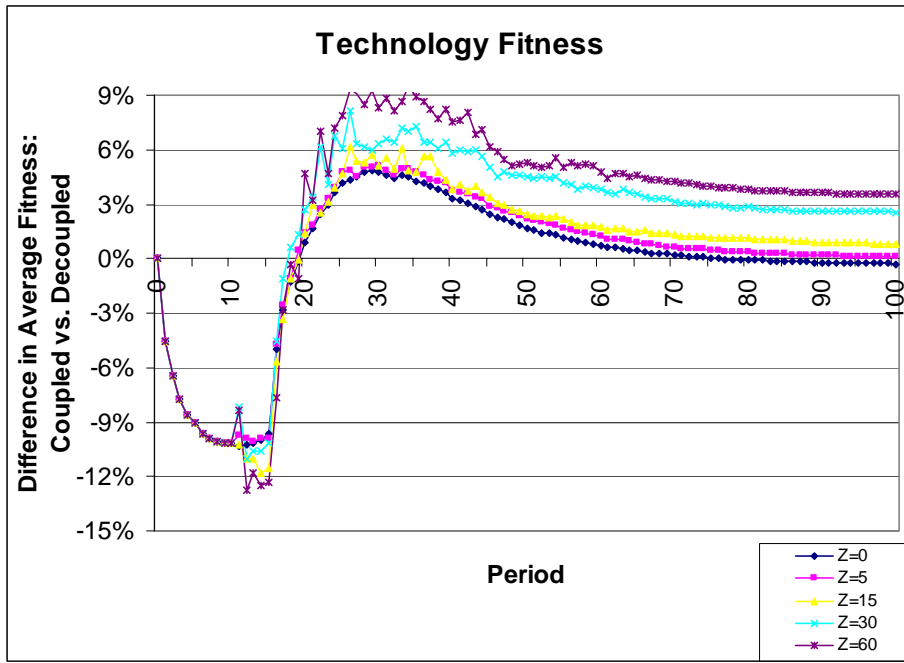


Figure 8: Technological Fitness Distributions - Discrete Selection in Technology Space at t=10

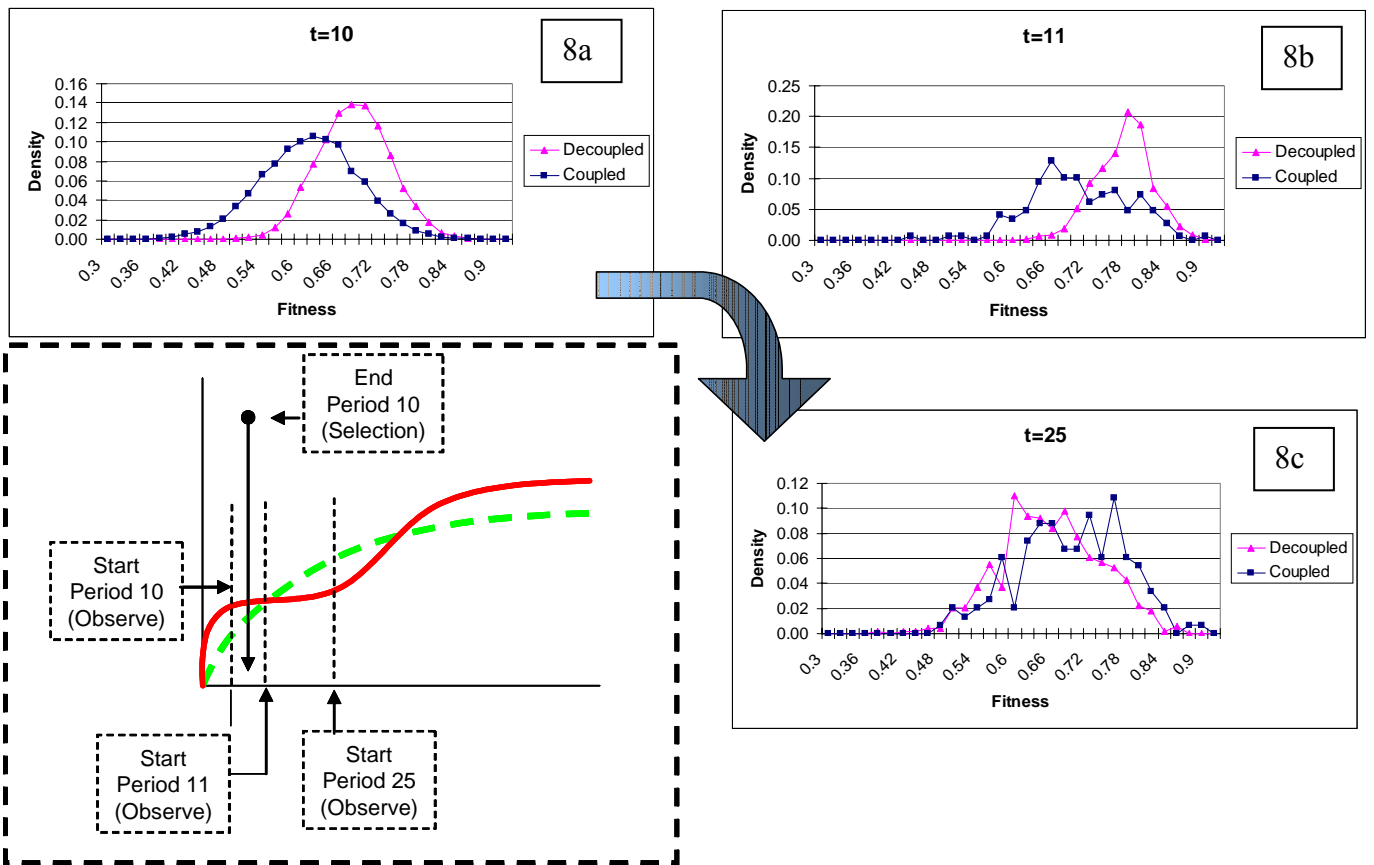


Figure 9: Combined Technological and Product Market Fitness - Discrete Selection in Technology Space at t=10

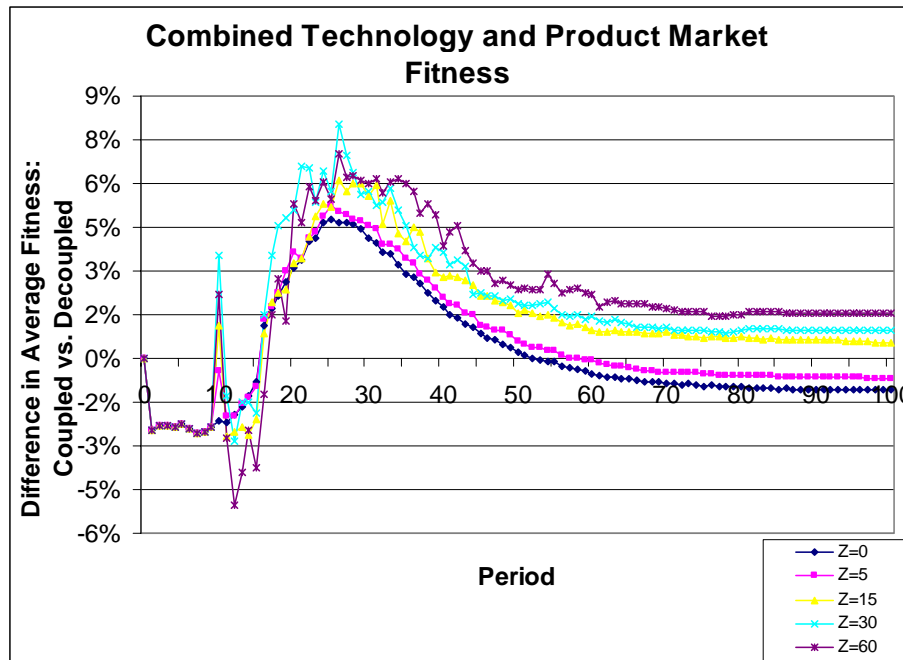
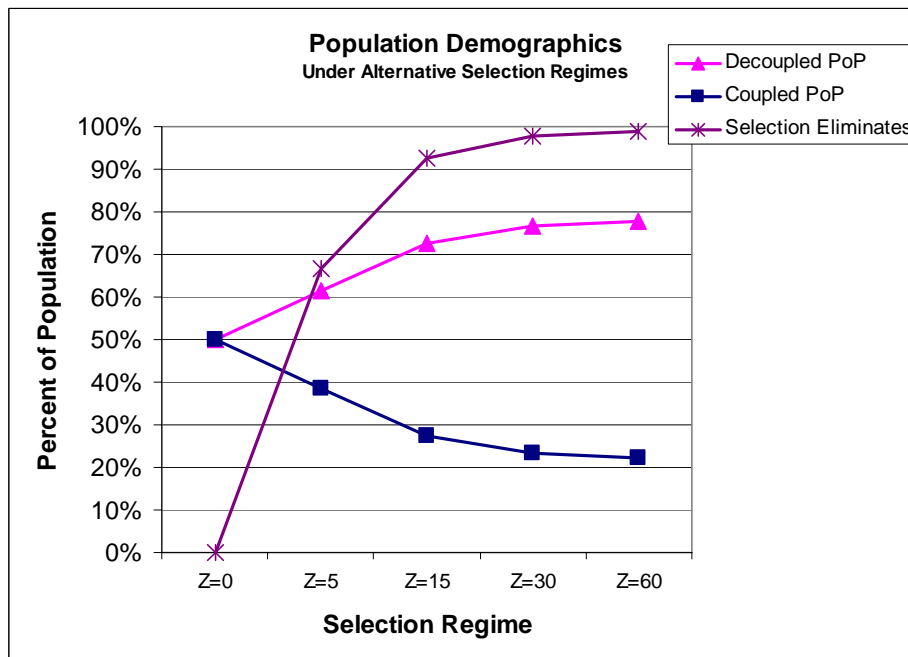


Figure 10: Population Demographics- Discrete Selection in Technology Space at t=10



Technical Appendix

In the following appendix, we provide a detailed explanation of the construction of the task environment, firm search behavior, selection, and the structure of the NK simulation.

Task Environment

Firms operate in a task environment consisting of two nearly decomposable problem spaces – technology space (T) and product-market space (P). A location in technology space is represented by the vector N^T (length n^T) of policy choice attributes, and similarly, a location in product-market space is represented by the vector N^P (length n^P). Taken together, a location in the combined technology and product-market space can be described by the row vector N^C (length n^C) of firm policy choice attributes such that:

$$N^C = \{N^T, N^P\} = (a_1^T, a_2^T, \dots, a_{n^T}^T, a_1^P, a_2^P, \dots, a_{n^P}^P). \quad (\text{A1})$$

For notational convenience, we have omitted the subscript denoting the firm, i , from the discussion that follows. Without loss of generality, we assume that each policy choice is binary (1 or 0) and therefore, there are 2^{n^C} possible combinations of organizational choices.

The topography of the landscape is a function of the number of interactions between policy choices. Interactions between policy choices affect the topography by influencing the degree to which the payoff of a *focal* policy choice depends on the value of *other* policy choices. Interactions can occur both within a landscape (technology or product-market space) and between landscapes (the upper right and lower left quadrants in Figure 1).

Consider a single policy choice j on landscape L , a_j^L . For notational convenience we let $L = T$ or P where $\neg L = P$ if $L = T$ and $\neg L = T$ if $L = P$. Let K_j^W represent the vector of policy choices of length k^W ($a_j^L \notin K_j^W$) within landscape L that affects the payoff to policy a_j^L . The k^W policies with which a_j^L interact are specified as the k^W adjacent elements such that:

$$K_j^W = \begin{cases} (a_{j+1}^L, \dots, a_{j+k^W}^L) & \text{if } k^W > 0 \\ 0 & \text{if } k^W = 0. \end{cases} \quad (\text{A2})$$

In addition, let K_j^B represent the vector of policy choices of length k^B on the *other* the landscape $-L$ that affect the payoff to policy choice a_j^L . Specifically, we randomly fill the vector K_j^B such that on average there are k^B policies with which a_j^L interact and thus:

$$K_j^B = \begin{cases} (a_{-1}^{-L}, \dots, a_{-k^B}^{-L}) & \text{if } k^B > 0 \\ 0 & \text{if } k^B = 0. \end{cases} \quad (\text{A3})^{13}$$

We define the fitness contribution of an individual policy choice j on landscape L , a_j^L , as π_j^L , such that:

$$\pi_j^L = \pi_j^L(a_j^L | a_-^L \in K_j^W, a_-^{-L} \in K_j^B) = \pi_j^L(a_j^L | K_j^W, K_j^B). \quad (\text{A4})$$

The fitness contribution of each policy choice, π_j^L , can take $2^{1+k^W+k^B}$ unique values which are assigned as i.i.d. draws from a uniform distribution $u[0,1]$.

When $k = k^W + k^B = 0$, the payoff to a policy choice depends only on that choice alone. As k increases, the pay-off to a policy choice depends not only on that choice alone, but also the value of k other policies. In general, low levels of interactions result in a smooth landscape (at the extreme, when $k^W = k^B = 0$ the landscape has only a single peak) and high levels of interactions result in very rugged landscape with many local peaks (i.e., a highly complex task environment). Asymmetry in the levels of within and between interactions – where $k^W \gg k^B$ - produces a landscape that can be described as nearly decomposable. In the extreme, when $k^B = 0$, the landscape is fully decomposable.

¹³ Note that this notation implies symmetry in above and below diagonal seeding. While I have implemented and run a model with symmetry, and the results are identical, the models in the paper do not possess symmetry.

The fitness of a firm with the policy choice (location) vector N^L on landscape L is defined as the average of the fitness contribution of each its N^L policy choices such that:

$$\Pi^L = \frac{1}{n^L} \sum_{j=1}^{n^L} \pi_j^L(a_j^L | a_-^L \in K_j^W, a_-^{-L} \in K_j^B) = \frac{1}{n^L} \sum_{j=1}^{n^L} \pi_j^L(a_j^L | K_j^W, K_j^B). \quad (\text{A5})$$

A firm's fitness on the combined (technology and product landscapes) landscape N^C is the average of its fitness on each individual landscape such that:

$$\Pi^C = \frac{1}{2}(\Pi^T + \Pi^P). \quad (\text{A6})$$

Search

Firm development is modeled as a local search process in which a firm selects an innovation from an alternative set consisting of all policy choice sets that vary from the current set by a single policy attribute (an innovation). Thus, at any location on an individual landscape ($L = T$ or P), there are n^L alternatives from which to choose.

Evaluation criteria define the rules used to judge the relative fitness of an alternative. Evaluation criteria vary along two dimensions: (a) evaluation type: on-line vs. off-line, and (b) evaluation domain: local vs. global – we specify each of these evaluation elements in more detail in the remainder of this section.

Search in technology space is conducted using off-line local evaluation. At the start of a period t , the firm selects at random one of its N_t^T policy choices for reversal. Consider the policy choice $a_{j,t}^T$, and its inverse $\hat{a}_{j,t}^T$ (recall that policy choices are binary such that a flip entails switching a 1 to a 0 and vice versa). Without moving to the new location in technology space, the firm compares its expected fitness in technology space after the flip to its fitness prior to the flip and moves to the new location (accepts the flip) only if the move results in an improvement in fitness. Evaluation of fitness is local such that the firm

considers only technology space performance in assessing the outcome of a search attempt. More formally, if:

$$\frac{1}{n^T} \sum_{m=1}^{n^T} \pi_{m,t}^T (a_{m,t}^T; a_{-(m,j),t}^T, \hat{a}_j^T | K_{m,t}^W, K_{m,t}^B) > \frac{1}{n^T} \sum_{m=1}^{n^T} \pi_{m,t}^T (a_{m,t}^T; a_{-(m,j),t}^T, a_{j,t}^T | K_{m,t}^W, K_{m,t}^B) \quad (\text{A7})$$

$$\text{then } \begin{cases} N_t^T = (a_{-j,t}^T, \hat{a}_{j,t}^T) & \text{otherwise,} \\ N_t^T = (a_{-j,t}^T, a_{j,t}^T). \end{cases}$$

Search in product-market space uses on-line global evaluation. At the start of period t , a firm selects at random one of its N_t^P policy choices for reversal. Consider the policy choice $a_{j,t}^P$, and its inverse $\hat{a}_{j,t}^P$. The firm immediately moves from its current location $N_t^P = (a_{-j,t}^P, a_{j,t}^P)$ in product-market space to its new location $N_t^P = (a_{-j,t}^P, \hat{a}_{j,t}^P)$. The firm then compares its fitness (after the flip) to its fitness prior to the flip. If its fitness at the new location is superior to its old fitness, it will accept the change. Otherwise, the firm remains at the new location for the remainder of period t , but returns to its original location immediately prior to the start of period $t+1$. Evaluation in product-market space is global such that the firm considers the effect of the proposed change on its fitness in combined technology and product-market space. More formally, if:

$$\left\{ \frac{1}{n^P} \sum_{m=1}^{n^P} \pi_{m,t}^P (a_{m,t}^P; a_{-(m,j),t}^P, \hat{a}_j^P | K_{m,t}^W, K_{m,t}^B) + \frac{1}{n^T} \sum_{m=1}^{n^T} \pi_{m,t}^T (a_{m,t}^T | K_{m,t}^W, K_{m,t}^B) \right\} > \left\{ \frac{1}{n^P} \sum_{m=1}^{n^P} \pi_{m,t}^P (a_{m,t}^P; a_{-(m,j),t}^P, a_j^P | K_{m,t}^W, K_{m,t}^B) + \frac{1}{n^T} \sum_{m=1}^{n^T} \pi_{m,t}^T (a_{m,t}^T | K_{m,t}^W, K_{m,t}^B) \right\} \quad (\text{A8})$$

$$\text{then } \begin{cases} N_{t+1}^P = (a_{-j,t+1}^P, \hat{a}_{j,t+1}^P) & \text{otherwise,} \\ N_{t+1}^P = (a_{-j,t+1}^P, a_{j,t+1}^P). \end{cases}$$

Firms do not conduct product-market space search in perpetuity. At any given location in product-market space, $N_t^P = (a_{1,t}^P, \dots, a_{n^P,t}^P)$, a firm will evaluate, over successive periods, all n^P single policy search options available in the alternative set. If, after the conclusion of n^P search attempts, no

superior location has been found, the firm concludes that it is at a local peak and ceases product-market space search for the remainder of the simulation.

Selection

We examine the outcome of the developmental process under selection regimes that vary in timing, intensity, and duration. In addition, selection varies in its landscape of application in that we implement selection that can occur in the technology subspace alone, or in the combined space (technology and product-market).

The probability of firm i surviving a selection event in technology space in period t is defined as:

$$s_{i,t}^T = \left(\frac{\Pi_{i,t}^T}{\text{Max}(\Pi_t^T)} \right)^{Z_t^T}, \quad (\text{A9})$$

where $\text{Max}(\Pi_t^T)$ is the maximum fitness exhibited in technology space at time t by all firms in the population. Z_t^T defines the strength of selection. As time is discrete, we treat Z_t^T as a vector of real numbers $[0, \infty]$ that define the strength of selection in each time period from $t = 0$ to $t = t_{\max}$ such that $Z_t^T = (z_t^T, \dots, z_{t_{\max}}^T)$. A random number is drawn from a uniform distribution $u[0,1]$. If $s_{i,t}^T$ is greater than or equal to the realization of the draw, then the firm survives. When $Z_t^T = 0$, the probability of survival for firm i in period t is $s_{i,t}^T = 1$ (100%). As Z_t^T increases, the probability of survival conditional on firm fitness declines. There is an analogous expression for the probability of surviving a combined space selection event:

$$s_{i,t}^C = \left(\frac{\Pi_{i,t}^C}{\text{Max}(\Pi_t^C)} \right)^{Z_t^C}. \quad (\text{A10})$$

Simulation Model

The simulation models 200 firms as they search under risk of selection for 100 periods ($t_{\max} = 100$). All firms are allocated two search efforts per period. We generate an equal number of coupled and decoupled strategy firms. Coupled strategy firms allocate one search effort to technology space and one to product-market space in each period. Decoupled strategy firms allocate both search efforts to technology space search in periods 1 through 14, and thereafter divide their search effort equally between technology space and product-market space.

The simulation proceeds as follows. At time $t=0$, each firm is randomly allocated an initial location in both technology space, $N_{i,0}^T$, and product-market space $N_{i,0}^P$. Each period is divided into two sub-period (parts a and b). Firms conduct search activity sequentially – conducting one search effort during period $t = t_a$ and a second effort in $t = t_b$. Decoupled strategy firms conduct one technology space search in $t = t_a$ and another in $t = t_b$. Coupled strategy firms (and decoupled firms post period 15) conduct one technology space search in $t = t_a$ and one product-market space search in $t = t_b$. Search in product-market space in period $t = t_b$, the outcome of which is a function of the firm's location in technology space, takes into account any search activity in technology space in $t = t_a$. At the end of each period (that is, after the conclusion of search activity in $t = t_b$), firms are subject to selection.

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