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SEARCHING AND SHAPING THE EXTERNAL ENVIRONMENT: TOWARD A GENERAL MODEL OF NICHE CONSTRUCTION AND ENDOGENOUS SELECTION

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Abstract

Bounded rationality underlies organizational routines, capabilities, and local search. Firms search complex combinatorial spaces incrementally for better profit opportunities in an external environment that selects for differential performance. But this picture is fundamentally incomplete. Firms do not limit themselves to search. Through their actions they may also shape their external environment. The strategy literature is replete with examples in which firms attempt to shape the external selection environment to their advantage, such as by introducing technological, product, and strategic innovations; influencing competitors' strategic moves; and altering relevant audiences' perceptions. Moreover, these actions can have long-lasting effects on the external selection environment that in turn affects the success or failure of subsequent strategic actions by firms. As a result, opportunities for profit are not only out there, more or less visible, ready to be plucked. They are also created, shaped, constructed. In this paper we present a model (derived from the broadly used NK models of search and selection) of firms both searching and shaping their environment.

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INTRODUCTION

The concept of bounded rationality is central to what is commonly recognized as the "evolutionary paradigm" of strategy research. Bounded rationality underlies organizational routines, capabilities, and local search. As firms search complex combinatorial spaces incrementally for better profit opportunities, performance heterogeneity within a given population of competing firms arises from a combination of happenstance (i.e., how favorable initial conditions were) and local learning and search processes. Critical to this image is a context, an external environment, a selection regime that penalizes the least fit organizations.

But this picture is fundamentally incomplete. Firms do not limit themselves to search. Through their actions they may also shape their external environment. The strategy literature is replete with examples in which firms attempt to shape the external selection environment to their advantage, such as by introducing technological, product, and strategic innovations; influencing competitors' strategic moves; and altering relevant audiences' perceptions. Moreover, these actions can have long-lasting effects on the external selection environment that affects the success or failure of subsequent strategic actions by firms. As a result, opportunities for profit are not only out there, more or less visible, ready to be plucked. They are also created, shaped, constructed.

Relatively little research in strategy has examined how, by shaping the external environment, the actions of firms currently in an industry affect the competitive success of firms in the future, and the interplay between these actions and search for profit opportunities. Given that firms undertake both shaping and searching activities, often in concert, this gap in the literature calls out for greater attention. Although some research has produced empirical findings that can inform our understanding of the relationship between shaping and searching of the external environment by firms, the evidence is sparse and comes from a variety of disparate literatures. There has also been relatively little modeling of the interplay between shaping and searching over time (with notable exceptions such as Barnett and Hansen, 1996 and Levinthal and Warglien, 1999). Our goal in this paper is to provide a general framework for understanding and analyzing the shaping of the external selection environment by firms – or what we call 'endogenous selection' – and its effects on subsequent firm performance. To do so, we draw on recent research in biology on niche construction, which offers a parsimonious and empirically-

grounded conceptualization of how organisms shape the selection environment and the impact on subsequent search and selection. We then use this conceptualization to inform an initial formal model that extends the basic NK apparatus to capture the interplay of shaping and searching behavior.

The biological theory of niche construction proposes that organisms shape their external selection environment in a manner that has long-lasting effects on the subsequent evolution of the population. In what follows, to motivate the analysis, we first provide an example from research in biology on niche construction. Then we give an example of how firms searching for profit opportunities in an external selection environment also shape it, and explain the analogy to the biological example. Following these examples, we summarize the key elements and mechanisms of the biological theory of niche construction, and adapt this theory to provide a framework for analyzing endogenous selection and the shaping-searching interplay in strategy. We then broaden this perspective to discuss prior research that has implications for the relationship between firm actions in search of profit opportunities and the external selection environment. This lays the groundwork for modeling endogenous selection and niche construction in strategy using NK methods. After presenting an initial model of this type, we conclude with a discussion of potential applications and extensions of the modeling approach.

NICHE CONSTRUCTION AND ENDOGENOUS SELECTION

A canonical example of biological niche construction is the case of Kwa-speaking yam cultivators in West Africa (Odling-Smee, Laland, and Feldman, 2003). In contrast to neighboring non-yam-cultivating populations, some 2000 years ago a large portion of Kwa-

speaking yam cultivators shifted from hunting and gathering to agriculture. Propelling this change was the initiation of the practice (unique to this population) of cutting clearings in the rain forest to grow yam crops. Absent this practice, the domestication of plants in the rain forest would have been impossible because of the absence of direct sunlight. The clearings created large areas of land that enabled yam crops to receive adequate amounts of both water and sun. Clearing the land of trees also had the inadvertent effect of increasing the amount of standing water when it rained, which increased the breeding ground for malaria-carrying mosquitos. As a result, selection for the sickle-cell allele intensified because of its malaria protection properties (Durham, 1991): the practice of cutting clearings in the forest generated an endogenous shift in the selection regime, which over time had the effect of changing the genetic makeup of the members of this population (whether they had transitioned to agriculture or were still gathering or hunting) -- with effects that are still visible today in comparisons of the genetic makeup of the descendants of this and neighboring populations.

Niche construction also occurs, in more or less subtle ways, in the world of organizations. A not-so-subtle example is Apple's introduction of the i-Phone in 2007, a result of Apple's search for new profit opportunities. Relative to the competition (PDAs and standard cellular phones, which represented the great majority of the market in 2007), the i-Phone broke many conventions. In essence, the i-Phone was designed as a tool that provided at once strong aesthetic appeal¹, Apple's traditional easy-to-use interface, and the

¹ When he unveiled the i-Phone 4, Steve Jobs compared it to the iconic Leica M camera, a symbol of design perfection and craftsmanship: "You gotta see this in person. This is beyond the doubt, the most precise thing, and one of the most beautiful we've ever made. Glass on the front and back, and steel around the sides. It's like a beautiful old Leica camera."

immediate access to the Apple multi-media world, a combination of entertainment and communication functionalities. The immediate success of the i-Phone, accompanied by Apple's hugely successful marketing campaign, quickly shifted the external selection criteria in the cellular phone industry away from phone functionality, pocketability, and barebones enterprise communication, precisely the selection criteria that had made companies such as Motorola, Nokia, and RIM leading forces in the industry. These firms were slow to recognize the changed selection criteria and adapt to them. In terms of the prior example, they neither had the analogue of a sickle cell allele that could protect them against Apple (the malaria virus in the prior example), nor did they manage to develop it. And Apple benefited directly from changing the selection criteria in the external environment to its advantage.

The cases of the Kwa-speaking yam cultivators and Apple's i-Phone are of course very different. In one case, a collective effort resulted in the modification of the selection regime; in the other, the change came from a new member of the population. In one case, the shift in selection criteria was the inadvertent effect of a fitness-increasing cultural change; in the other, it was arguably part of a deliberate strategy. In one case, there were no other competitors; in the other, there was intense competition. Yet both cases display the main features of our phenomenon of interest: niche construction.

The Theory of Niche Construction

In the standard theory of natural selection in evolutionary biology, an exogenous external environment in one time period acts upon the gene pool of populations of diverse phenotypes (observable traits and characteristics), and determines which genes are

inherited through “selection” of organisms whose genes fit the external environment well enough to enable the organisms to survive. In the next time period, the external selection environment (which may or may not have changed due to exogenous factors) acts upon the inherited gene pool, and the process of evolution through natural selection continues.

The biological theory of niche construction, which departs from the standard theory of natural selection, is relatively recent. A few early works appeared in the 1980’s (e.g., Lewontin, 1982, 1983; Odling-Smee, 1988), followed by significant works in the 1990’s (e.g., Laland, Odling-Smee, and Feldman 1996), and a flurry of research since 2000 (see e.g., Odling-Smee et al, 2003). “Niche construction refers to the activities, choices, and metabolic processes of organisms, through which they define, choose, modify, and partly create their own niches” (Laland, Odling-Smee, Feldman, 2000: 132-33). The characteristics of the resulting niche are then inherited in much the same way as genes are inherited, in what is termed a process of ‘ecological inheritance.’ That is, in addition to inheriting genes, each offspring inherits a modified niche from its ancestors. The critical element of this model is a feedback effect in which the modified local selection environment determines genetic fitness. Figure 1 depicts the biological model of niche construction.

The model incorporates three mechanisms through which populations can construct niches. First, genes may be directly responsible for niche construction. That is, genes can predispose organisms to behave in a manner that alters the external selection environment for the organisms in question and potentially for other organisms as well. For example, beavers’ genes lead them to build dams, and the repeated building of dams by beavers has a major effect on the external environment—and has a positive impact on the survival and reproduction rates of beavers. As in the case of beavers, the general concept of

niche construction encompasses any impact of genes responsible for niche construction on the subsequent inheritance of these genes through favorable external selection. Secondly, genes may indirectly affect niche construction through an effect on an organization's ability to learn. Although knowledge learned by an individual organism cannot be inherited, an organism may use its learned knowledge to guide niche construction and thereby affect ecological inheritance.

Beyond individual learning, a few species including humans have the capacity to learn from other individuals. In evolutionary biology, the term 'culture' refers to shared information (including beliefs and values) that is learned.² This information can be socially transmitted between individuals across generations, leading to 'cultural inheritance.' In addition, cultural activities that rely on shared information in a population may temporarily modify some selection pressures in the external environment and thereby affect the inheritance of certain genes. Shared knowledge and understanding can also be used to modify the external selection environment more permanently as a part of niche construction.

In addition to ecological inheritance, the biological model of niche construction incorporates genetic inheritance as in the standard model of evolutionary biology. An ecologically inherited selection environment acts upon the inherited genes of populations of diverse phenotypes. In human populations, the biological model of niche construction also includes cultural inheritance through social transmission of knowledge from one generation to the next (Laland et al, 2000).

² In a simpler formulation used in work on sociobiology, 'culture' is viewed as an expression of naturally selected genes like any other feature of the phenotype.

Niche Construction and Firm Strategy

There are several features of the biological model of niche construction that are helpful in motivating an analysis of firm strategy and endogenous external selection. Most obviously, if we consider firms as analogous to organisms, a model of niche construction as applied to strategy rests on the idea that firm actions in one period can affect the external selection environment in current and subsequent periods. However, extending the biological model of niche construction to strategy also requires modification, because the impact of firm strategy over time goes well beyond an impact on the inheritance of characteristics from firms to their offspring (although there are some situations such as spinoffs where this is relevant). Firms can and do survive for multiple periods.

We are interested in how the actions of firms in a particular external selection environment alter that environment over time, and how this affects which firms subsequently survive and prosper, including the firms that undertook the actions in the first place. Therefore, we can think of firm actions as taking place in one time period, which affects the external selection environment and associated payoffs in that period; firms then inherit this altered selection environment in the next period, which firms can again alter through niche construction, and the process continues over multiple periods. These actions may come from individual firms such as Apple, or from groups of firms taking joint action in an analogy to the yam cultivators.

The potential for firms to affect survival and performance over multiple periods through an impact on the external selection environment is analogous to the biological process of 'ecological inheritance' in which organizations bequeath the new selection

environment to the population as a whole in the next period, which in this instance may include the original organizations. That is, we can think of this ecological inheritance as endogenously modifying the external environment, or landscape in NK terms, in which firms take subsequent actions in search of profit opportunities. The three general mechanisms of biological niche construction are also relevant to strategic shaping of the external environment. First, routines, which comprise the 'genes' of firms in evolutionary economics, may shape the external environment just as genes affect niche construction in biology. That is, firms may have routines directed toward altering their external environment, much as beavers have genes that lead them to build dams. In addition, the niche construction mechanism of individual learning in biology is analogous to organizational search and learning, which in turn may affect the external selection environment. Finally, socially transmitted knowledge, an analogue to the biological concept of 'culture', may arise through social learning and search. This socially transmitted knowledge may also be used to alter the external environment, leading to ecological inheritance.

In addition to ecological inheritance, firms inherit learned routines (analogous to genes in biology) and socially transmitted knowledge (analogous to 'cultural inheritance' in biology) from one period to the next. Firms also inherit individually learned knowledge, unlike in biological models of niche construction.

The foregoing analogy to the biological model of niche construction suggests an organizational model of niche construction, depicted in Figure 2. Firms alter their external selection environment during one time period through their routines, individual learning and search, and/or social transmission of knowledge and learning. An external selection

process then takes place. One approach to modeling this process would be to set a predetermined fitness level, and whether firms exceed this would depend on the composition of routines, individually learned knowledge, and social knowledge that is in place subsequent to niche construction in each period. However, we are interested in capturing the interplay between shaping through niche construction and searching for new profit opportunities based on internal characteristics. Therefore, subsequent to niche construction, we include a process of firm search for new profit opportunities based on their internal routines, individually learned knowledge, and/or socially transmitted knowledge. Firms take actions that alter their internal characteristics if this yields higher payoffs, where the payoffs depend on the endogenously altered external environment. Firms then 'inherit' these internal characteristics in the next time period. The process begins again in the following period as firms engage in niche construction followed by search and external selection, in a cycle of shaping and searching that endogenously alters the environment in which firms compete and the characteristics of the firms themselves. This relatively direct analogue to the biological model of niche construction provides a useful starting point for our analysis, which can be altered to incorporate different or more complex processes of shaping and searching.

PRIOR RESEARCH ON FIRM-ENVIRONMENT INTERACTION

The concept of niche construction contrasts with the way in which research in strategic management often treats firm-environment interactions. The view of the external selection environment as exogenous to the actions of firms pervades prior research, either explicitly or implicitly. Most strategic analysis begins with the primitive that in order to

survive and prosper, firms must align their strategy with what are typically viewed as exogenous factors in the external environment such as prices, customer demand, and technology. This concept of fit with the external environment is central to the field of strategy (e.g., Andrews, 1987). Siggelkow (2001: 840) defines external fit as “the appropriateness of a set of [firm] choices given environmental conditions...[which] encompass all factors that affect the relative profitability of a firm’s set of choices, including competitors’ actions, customer preferences, and available technologies.”

In a stable external environment, firms that have survived the winnowing out process of competition by definition will have arrived at a strategy that is well adapted to the external environment. Literatures such as organizational ecology in its original form (Hannan and Freeman, 1977) and the resource-based view in its non-dynamic incarnation (e.g., Barney, 1991; Peteraf, 1993) have taken this approach. Research that allows for strategic change on the part of firms also tends to hold the external environment exogenous, focusing on firm adaptation to exogenous environmental changes such as new technology. The external environment then weeds out firms that cannot adapt to ‘disruptive’ or ‘discontinuous’ change (e.g., Bower and Christensen, 1995).

In contrast, a limited amount of strategy research uses the metaphor of firms shaping their external environment through capabilities and actions (e.g., Teece, 2007). Additional research has investigated the ‘coevolution’ of firms and industries. It is fair to say, however, that most of the research on firm-industry coevolution does not examine the shaping of the external environment by firms. Instead, the analyses tend to trace the adaptation of firms to changes in their external environment over time. Nevertheless, some research from a variety of different literatures does incorporate elements of the

relationship between shaping of the external environment by firms and internal search over time. In what follows, we synthesize research with implications for this relationship. Much of this research is not directed toward understanding the shaping-searching interplay. However, we reinterpret the research discussed below the lens of the shaping and searching. As part of this analysis, we identify mechanisms through which firms may shape their external selection environments, and link these mechanisms back to those proposed in our niche construction framework.

Research on industry evolution provides a useful starting point for our discussion because it aims to understand factors that determine the success and failure of firms over time in the context of the external environment. In an analysis of research on industry evolution, Audretsch (1997) argues that the survival and growth of firms in an industry depends on three factors: economies of scale (specifically, minimum efficient scale in the industry), demand conditions, and underlying technological conditions. These factors in combination have implications for the number, size, and capabilities of firms in an industry, which in turn affects the nature and extent of competition. In Audretsch's (1997) analysis, these factors are exogenous to the actions of firms, who can adapt to the external environment through learning. Subsequent research has suggested that industry evolution depends on additional factors, such as the availability and capabilities of suppliers and complementors (Helfat, 2015).

Suppose, however, that firms not only adapt to but also shape the external factors that have strong effects on firm survival and growth. Then we would be in the world of endogenous selection. For example, one might argue that firms use marketing to alter demand conditions such as customer preferences. Although marketing activity may bring

forth latent demand, if that demand would not have existed absent firm actions and if the demand persists over time, then we can say that firms have shaped their environment. Firms may also be able to shape minimum efficient scale through process innovation, which then shapes the subsequent evolution of the industry, the firms in it, and competition between them. And firms may be able to shape underlying technological conditions through the creation and accumulation of new knowledge, and subsequent technological innovations. As we will explain below, some prior research has suggested that firms may influence both underlying technological conditions and economies of scale. Additional research has suggested that firms may influence other factors in the external selection environment such as customer preferences, competitors' actions, and the availability of suppliers. We discuss this research below.

Shaping the External Environment

Shaping of the selection environment by firms can occur at the inception of a new industry or industry segment, and as the industry evolves. A natural starting point is to consider the shaping of an industry at its inception. For example, we might argue that firms shape the external environment of a new industry through their choice of technology or associated product, such as the commercialization of new technology (e.g., integrated circuits) or the creation of a new product category (e.g., online retailing). However, it is not entirely clear to what extent firms create these new external environments. A new technology that underpins a new industry might instead represent the discovery of an opportunity already present in the external environment, which firms merely tap into,

rather than the creation of new opportunities by firms. For example, when the integrated circuit and biotechnology industries first emerged, the underlying scientific advances had already occurred and the commercial potential was obvious.

Denrell, Fang, and Winter (2003) provide a clear theoretical analysis of the discovery by firms of unexploited opportunities in the external environment for new uses of their resources. In a somewhat similar spirit, in modeling entry into new industry submarkets (market segments), Klepper and Sleeper (2005) model entry into preexisting exogenous product demand space, using a Hotelling type of model. The concept of niche formation in the organizational ecology literature takes a similar approach in which new product niches arise from exogenous changes in customer preferences and technological discontinuities, to which entrepreneurs then respond (Delacroix and Solt, 1988; Swaminathan, 1998).

In contrast, the ecological theory of resource partitioning argues that new product niches arise because firms with large market shares ('generalists') are unable to take advantage of resources on the periphery of the market, enabling entrepreneurs to form 'specialist' firms in these niches (Carroll, 1985). Entry by specialist firms into these niches might be viewed as endogenous to the decisions of the generalists.³ In a similar spirit, in Klepper and Sleeper's (2005) model of submarkets, the types of firms (incumbents in the larger industry or de novo entrants) that choose to enter an unfilled product niche depends on which firms recognize the opportunity and how existing firms assess the risk that another firm will enter. In this model, the existing product demand space is exogenous but which types of firms enter is endogenous. More generally, tension regarding the exogeneity

³ Alternatively, or in addition, the inability of generalists to take advantage of smaller niches could be exogenously determined by other factors such as economies of scale.

versus endogeneity of the external environment in the formation of a new market is reflected in the heated and unresolved debate in the field of entrepreneurship about whether entrepreneurs 'discover' or 'create' opportunities (see, e.g., Alvarez and Barney, 2007).

Shaping the Selection Environment Early in the Industry Lifecycle

Regardless of whether firms that start a new industry or submarket discover or create the initial opportunity, it is useful to ask whether firms that enter new product markets early on subsequently shape the external selection environment of the industry. Certainly anecdotal evidence suggests this has occurred. In addition to the earlier example of the Apple i-Phone, consider the role of Southwest in pioneering the low-cost segment of nationwide airline travel in the United States. Southwest initially provided regional transportation within Texas, which shielded it from federal regulation. Eventually Southwest received a governmental exemption that enabled it to fly out of state, and its low cost short haul business model made it possible for the firm to charge lower prices and tap into latent customer demand for less expensive air travel. In addition, Southwest began to draw customers from nearby routes served by full fare carriers, putting pressure on incumbents in the full fare segment to reduce prices. This in turn led the incumbents to look for ways to reduce costs. In landscape terms, Southwest utilized a new configuration of activities, which dramatically changed the payoffs to not only their own activities but also those of the incumbent airlines (Porter, 1996).

Systematic empirical analyses of industry evolution also suggest that firm strategy decisions early in the life of an industry may shape the subsequent selection environment.

For example, in an analysis of the early Japanese cotton-spinning industry, Braguinsky (2015) demonstrates that technological knowledge generated by college-educated engineers combined with a tradition of knowledge sharing among firms led to knowledge diffusion that was critical for industry growth. Although the requisite technological knowledge was available in Britain, key firms made the decision to search for this knowledge, which other firms did not; moreover, the firms that obtained the requisite knowledge shared it with other firms in the industry. These strategic choices led to two major industry changes that were critical to the rapid industry growth that ensued: a large increase in minimum efficient scale of production and a new technological paradigm for cotton spinning (Braguinsky and Hounshell, 2016). Moreover, the actions of key firms to obtain and share new knowledge not only fundamentally shaped industry growth but also shaped the ability of these same firms to subsequently prosper. Here we see the endogeneity of minimum efficient scale and technological conditions to the strategic choices of firms, two factors in the external selection environment that Audretsch (1997) identifies as critical determinants of firm survival and growth. In addition, we see clear effects of both individual firm learning and social transmission of ideas that are analogous to the transmission mechanisms in biological niche construction.

Collective action by firms early in the life of an industry also can affect the selection environment through an impact on customers and resource suppliers as part of a process of building cognitive legitimacy for a new product category (Lant, 2003; Mezas and Kuperman, 2000). Mezas and Kuperman (2000) document how collective action by movie producers and distributors shaped the early movie industry. Lant (2003) also shows how firms in the early new media business in New York City worked through formal industry

organizations to structure the perceptions of customers and resource suppliers regarding categories of new products and services. In addition, firms jointly sponsored and organized events such as conferences that helped the industry and the firms in it gain cognitive legitimacy with customers and resource suppliers.

Another factor early in the lifecycle of many industries that affects subsequent firm survival and growth is the emergence of a dominant design. Nelson (1994) points out that a dominant design is not necessarily the best variant that wins out over other contenders. Instead, when technological advance is cumulative, a technology that gains an early lead in development, even if by chance, may end up as the dominant design due to positive feedback effects as firms focus their efforts on improving the leading design. Moreover, if investments in complementary products are required, this makes it more likely that lock-in to the dominant design will ensue (David, 1985; Arthur, 1989). Firms that take actions to promote this lock-in can tilt the selection environment in their favor (Katz and Shapiro, 1994). Thus, firms have joined standard setting organizations in order to shape the technological paradigm in an industry, such as the formation of SEMATECH in the semiconductor industry. As another example, Microsoft achieved technological lock-in of the market for personal computer operating systems through actions to promote its software as the industry standard, including charging low prices in order to build its network of users and obtaining contracts with key personal computer customers such as IBM and Compaq. In taking these actions in search of profit opportunities, Microsoft fundamentally shaped the external selection environment not only for operating systems but also for personal computers for many years to come.

Shaping the Selection Environment as Industries Evolve

Other research has investigated the relationship between firms' actions and the external environment as industries continue to evolve. A number of studies document ways in which organizational capabilities adapt to market environments, resulting in the co-evolution of capabilities and markets. For example, Levinthal and Myatt (1994) show how the capabilities of mutual fund processors developed in response to actual and anticipated changes in the market. Studies that document shaping of the external environment in concert with capability development and acquisition are rare, however. One study that begins to get at this issue analyzes the exit of firms in the Internet sector during 2001 after the stock market collapse. Fortune and Mitchell (2012) show that whether firms exit through acquisition or dissolution, and thus whether or not the capabilities of firms persist as part of other companies, depends on the nature of the capabilities themselves. This endogenous persistence of capabilities might in turn shape the competitive environment.

In a related vein, Henderson and Mitchell (1997) suggest that as firms react to changes in their environment, they may affect the competitive actions of other firms. That is, firms may shape the competitive environment through their actions. The theory of the 'Red Queen' is especially relevant here. Barnett and Hansen (1996) propose that organizations facing competition respond by searching for ways to improve performance, which results in learning that makes the firms stronger competitors. This leads competitors to respond through search and learning, and the competitors become stronger. The cycle continues as firms respond to search and learning on the part of competitors with additional search and learning. In this way, firms shape the competition that they face in the external selection environment. Empirical research provides evidence supportive of the

Red Queen hypothesis, including with respect to the impact on the external selection environment. For example, Barnett and Hansen (1996) find that Illinois banks generated stronger competition when they had more competitive experience, particularly recent experience. Barnett and Sorenson (2002) also find that through a Red Queen type of process, some Illinois banks grew more quickly, creating strong competitive pressure on their rivals and helping to create barriers to entry. Derfus, Maggitti, Grimm, and Smith (2008) also found evidence supporting a Red Queen effect on firm performance in 11 industries in the U.S.

A somewhat different approach to competition and rivalry suggests another aspect of endogenous selection. In particular, Porac and colleagues (Porac et al, 1989; Porac and Thomas, 1990; Porac et al, 1995) argue that rivalry is socially constructed. Who a firm believes its rivals to be in turn shapes its own competitive actions, such that firms compete more fiercely with firms they believe to be their most direct rivals. When these views are collectively held, this shapes which firms respond to the actions of which other firms. Porac et al (1989) find evidence consistent with this in the Scottish knitwear industry. This suggests that firms' perceptions regarding the external environment essentially 'shape' the environment, which in turn affects the competitive actions that firms take.

Social construction may shape the external environment in other ways. For example, Rosenkopf and Tushman (1998) document how, following a technological discontinuity in the flight simulator industry, voluntary cooperative groups, which included firms in the industry, selected specific technologies for the industry to pursue. Even though the initial discontinuity was exogenous, through a process of "social construction of technology," a

network of firms and other organizations definitively shaped the subsequent external selection environment (Rosenkopf and Tushman, 1998: 31).

In addition to shaping how discontinuities proceed, individuals and groups operating in an industry may create discontinuities during the evolution of the industry. For example, the chef Ferran Adria developed an entirely new approach to haute cuisine, creating a 'conceptual cuisine' that departed radically from the tenets of nouvelle cuisine. As customers and food critics began to flock to and rave about his restaurant, El Bulli, other top chefs visited El Bulli and incorporated some of Adria's innovations in their own offerings (Rao and Giorgi, 2006). This built legitimacy for the new 'product' and led to a change in the standards regarding what was considered haute cuisine.

The foregoing research has implications for two of the mechanisms of niche construction identified earlier: individual search and learning, and social transmission of knowledge and learning. We see the impact of individual learning and search on ecological inheritance in the actions by specific firms such as Apple, Southwest, Microsoft, the restaurant El Bulli, and key firms in the Japanese cotton spinning industry. We also see the impact of actions by individual firms in Red Queen analyses of competition. Other research has demonstrated an impact of social learning and group action on niche construction. This includes the sharing of technological knowledge among Japanese cotton spinning firms, collective action to gain legitimacy by shaping the perceptions of consumers and resource suppliers in the movie and new media sectors, and cooperative action to select technological standards in the flight simulator industry. Many of these analyses involve niche construction early in the life of an industry or when discontinuities occurred either exogenously or due to the actions of organizations or individuals in the industry. However,

shaping of the external environment also occurs throughout the lifecycle of an industry, as in the analysis of Red Queen competition throughout the history of the Illinois banking industry (Barnett and Hansen, 1996).

Models with Implications for Endogenous Selection

Beyond empirical evidence relevant to niche construction, a limited number of models have implications for some aspects of niche construction and endogenous selection. We review models other than those that use NK methods here, and defer a discussion of NK modeling to the next section.

Dosi, Marsili, Orsenigo, and Salvatore (1995) provide a simulation model with the purpose of predicting several features of industry evolution, including the entry and number of firms and their age distribution, the probability of firm growth and death, and persistence in the relative performance of firms. Most parameters of the model are set exogenously, including exogenous heterogeneity in the initial knowledge and capability of firms, with the exception that firms with better capabilities learn faster due to positive feedback effects of learning. Although firm survival and market shares are endogenous to firm capability because firms with better capabilities grow more quickly and become larger, if market share falls below an exogenously determined threshold value, firms exit. This mix of endogenous and exogenous selection pressures model is similar in spirit to that in the resource partitioning model and the Klepper and Sleeper model (2005) of submarkets.

LeMens, Hannan, and Polos (2011) propose a somewhat similar model with the purpose of explaining age dependence of firms as industries evolve. In the model, firm

survival depends on an exogenously determined fitness threshold, where fitness depends on the appeal of a firm's products in the external market relative to that of other competitors. Firms accumulate organizational capital over time if they exceed the fitness threshold and lose organizational capital if they are below it. The model also includes an assumption that the appeal of a firm's product increases with age, due in part to learning and other actions on the part of firms. Thus, whether firms exceed the fitness threshold is partly endogenous to learning and firm actions directed at the external marketplace.

A class of history-friendly simulation models that replicate stylized facts of the evolution of specific industries also incorporates elements of endogenous selection, in particular with respect to customer demand. In a history-friendly model of the computer industry, heterogeneous firms make strategic choices according to decision rules. Firms can undertake R&D to improve their competence in an existing technology, but the introduction of new technologies is exogenous. Consumer demand has both an exogenous component as well as an endogenous component in the form of brand loyalty/bandwagon effects that firms can shape through advertising, which in turn affects market shares (Malerba et al, 1999, 2008). This partial endogeneity of customer demand and market share to the marketing efforts of firms is also included in a history-friendly model of the pharmaceutical industry (Malerba and Orsenigo, 2002).

These models incorporate two sorts of endogeneity of the selection environment with respect to firm actions. First, relative performance serves as a selection criterion, and relative performance is endogenous due to positive feedback effects in which firms with better organizational capabilities in one period improve their capabilities and performance in the next period. Secondly, firms affect the appeal and demand for their products in the

marketplace. The models, which are relatively complex even though they have limited elements of endogeneity, also point to the difficulty of cleanly modeling endogenous selection. In what follows, we take a different approach to modeling endogenous selection and niche construction that incorporates search as well.

NK MODELING OF ENDOGENOUS SELECTION IN STRATEGY

In analyzing the interplay between search and endogenous selection, fitness landscape models (such as, prominently, Kauffman's NK model) are an obvious choice, because they feature boundedly-rational firms that search for improved profit opportunities over time. However, in standard fitness landscape models, firms search in an environment that is exogenously given and unchanging. In an exception to this approach, Levinthal (1997) investigates the impact of a change in the external environment, modeled as an exogenous change in the landscape to which actors adapt through renewed search. Levinthal and Siggelkow (2003) also analyze the impact of an exogenous environmental change on organizational structure.

Levinthal and Warglien (1999) go further and suggest that the co-evolutionary model of coupled fitness landscapes (NKC) proposed by Kaufman (1993, 1995) could help to address firm-environment interactions. In this type of model, the payoffs of one organization or actor depend on the attributes of other organizations or actors. For example, the product positioning of one firm may depend on that of another firm (Levinthal and Warglien, 1999). In this model, each organization searches on its own landscape, but the payoffs are affected by search and moves of other organizations on their respective landscapes. The payoff structure that links the outcomes of search by multiple

organizations is exogenous. Levinthal and Warglien (1999) provide a depiction of coupled landscapes using the common pool problem in which the payoff to one player in exploiting a common resource depends on the other player's exploitation of that resource.

Our challenge is to go further in bringing niche construction into the analysis of search on fitness landscapes. We seek to model how search by actors (organizations) modifies the external environment on which the same and other actors subsequently search, and how the extent to which actors modify the environment affects the outcomes of subsequent search. In this initial model of niche construction that is a close analogue to the biological model, we consider a population of agents that can engage in search for better fit both by modifying its own characteristics and by modifying the environment itself. The model is very similar to the so-called NKES model (Suzuky and Arita, 2005), which in turn is a variation of the coupled fitness landscape (NKC) model (Kauffman, 1993, 1995).

We do not employ a standard NK model with binary components and random fitness contributions but a "pseudo"-NK model with integer valued components and deterministic fitness function (Valente, 2014). This pseudo-NK (p-NK) model has the same fundamental properties of the standard NK in terms of complexity (ruggedness) of the search space, but some attractive additional features. First of all, the location and value of the global optimum can be decided by the experimenter, since the fitness function is deterministic; second e contrary to standard NK, the value of such global optimum does not depend on the K parameter, therefore we can compare results obtained on landscapes with different K's; third, the intensity of the interdependencies among components is a parameter which can be tuned and not the uncontrollable outcome of the extraction of random fitness contribution; fourth, the search space is not for each components is not

limited to either 0 or 1 but can take any integer value; fifth and finally, it allows more easily to experiment with large N and large K since the computation of fitness values amounts to finding the value of a deterministic function and does not require to store large matrices of random numbers in the computer memory.

We give here a rather informal and short account of our p-NKES model, more details can be found in Valente (2014) and in the appendix to this paper.

We have a population of agents/firms each of them fully characterized by a vector of integer-valued characteristics. For instance, firm i is described by the vector:

$$x^i = \{x_1^i, x_2^i, \dots, x_N^i\} \text{ with } x_j^i \in Z$$

Also the environment is also fully characterized by an integer valued vector of length W:

$$e = \{e_1, e_2, \dots, e_W\} \text{ with } e_j \in Z$$

There are two types of interdependencies among the components of the two strings. The former are the usual interdependencies among groups of K (with $1 \leq K \leq N$) elements that make up the agent's string.⁴ The latter are the interdependencies between elements of an agent's string and the components of the environment. The extent of these interdependencies is summarized by the parameter E (with $0 \leq E \leq W$), which indicates the fitness contribution of each x_i depends also on the value taken by E elements of the environment.

Alike the standard NK model, the fitness of a vector x is given by the average of the fitness contributions of its components:

⁴ We use the convention of assuming that K is at least equal to 1 (the fitness contribution of the bit g_i depends at least on its own value) and at most equal to N (the fitness contribution of a single bit depends on the value taken by all N bits).

$$f(x) = \frac{\sum_{i=1}^N \varphi_i(x)}{N}$$

Where φ_i is the fitness contribution of component i which, instead of being a random number, is computed as

$$\varphi_i(x) = \frac{f^{Max}}{(1 + |x_i - \mu_i|)}$$

where f^{Max} is the maximum fitness value (e.g. 1), and:

$$\mu_i(x) = c_i + \sum_{j=1}^N a_{i,j}x_j + \sum_{j=1}^W b_{i,j}e_j$$

The value μ_i defines a sort of “target” for component i that, when met by x_i , maximizes the fitness contribution of component i . However, the value of x_i maximizing φ_i may not be the most desirable, concerning the overall fitness value. In fact, x_i influences also all contributions φ_j for the variables, where $a_{j,i} \neq 0$. Therefore, it is well possible that moving x_i to maximize φ_i actually decreases the overall fitness value because of the deterioration generated in other fitness contributions φ_j 's where $a_{j,i} \neq 0$. In addition the target value for x_i also depends on the current state of the environmental vector, through the coefficients $b_{j,i} \neq 0$. The coefficients $a_{j,i}$ and $b_{j,i}$ represent the intensities of the interdependencies of component x_i on, respectively, the other components of vector x (i.e. the other internal characteristics of the organization) and the components of vector e (i.e. the environmental characteristics). The number of coefficients $a_{j,i} \neq 0$ corresponds to the parameter K which gives the extent of “internal” interdependencies, while the number of coefficients $b_{j,i} \neq 0$ corresponds to the parameter E which gives the extent of “external” interdependencies on the environmental characteristics. In this model however we can not only set the extent of such interdependencies, but also their intensities, by tuning the values of the $a_{j,i}$ and $b_{j,i}$.

Finally, c_i is a coefficient can be computed in such a way that the fitness function has its maximum value in a desired location. Suppose for instance that we want such a maximum value at vector:

$$x^* = \{x_1^*, x_2^*, \dots, x_N^*\}$$

This can be obtained by setting:

$$c_i = x_i^* - \sum_{j \neq i} a_{i,j} x_j^*$$

$$f = \frac{1}{N} \sum_{i=1}^N f_i$$

Search and Niche Construction

At the outset of each simulation, unless it is otherwise specified, all agents and the environment are randomly initialized. Each agent h is attributed random values for the parameters K_h and E_h and a structure of interdependencies is randomly constructed by picking for each component x_i K_h-1 other components x_j and E_h environmental elements e_h whose values will determine together its fitness contribution. Finally, each individual agent is randomly attributed a starting value for its vector x .

An initial value for the environmental vector $e_1 e_2 \dots e_w$ is also randomly chosen. This environmental vector is unique and common to all the agents.

In each iteration, a random permutation of all the agents is chosen which determines the order in which they can perform their search in order to improve individual fitness. Search is off-line and can either involve a mutation of the genetic string or a mutation of the environmental string.

We experiment with two types of search processes, known in the literature as “off-line” and “on-line” that we describe here.

Off-line search:

More precisely, suppose that agent j is called to perform search. Suppose that the agent’s vector is currently x , the current environmental vector is e and the agent’s fitness is now $f(x/e)$. The agent chooses randomly one component x_j and generates two new vectors:

$$x^+ = \{x_1, x_2, \dots, x_j + 1, \dots, x_N\}$$

and

$$x^- = \{x_1, x_2, \dots, x_j - 1, \dots, x_N\}$$

and observes the fitness values of the new vectors (computed holding constant the environment) $f(x^+/e)$ and $f(x^-/e)$.

Then the agent tests for a change in the environment: one environmental element e_h is chosen randomly and two new environmental vectors are generated:

$$e^+ = \{e_1, e_2, \dots, e_h + 1, \dots, e_W\}$$

and

$$e^- = \{e_1, e_2, \dots, e_h - 1, \dots, e_W\}$$

and the agent observes the fitness values that its current characteristic vector x would have in the new environments: $f(x/e^+)$ and $f(x/e^-)$.

Finally the agent compares $f(x/e)$, $f(x^+/e)$, $f(x^-/e)$, $f(x/e^+)$ and $f(x/e^-)$ and adopts the situation which maximizes fitness. If $f(x/e)$ is the highest value, the initial status quo is kept and the agent does not perform any mutation. If either $f(x^+/e)$ or $f(x^-/e)$ is the highest fitness, the agent either x^+ or x^- as its new characteristic vector but the environment

remains constant. Finally, if either $f(x/e^+)$ or $f(x/e^-)$ is the highest value the agent will keep constant its initial vector x and perform the environmental mutation. The new state of the environment will therefore become either e^+ or e^- and this new state will apply to all the agents in the population (whose fitness will be modified unless they have $E=0$).

On-line search:

Contrary to the off-line case, in on-line search new fitness values cannot be evaluated and compared in advance. Here the agent must implement the attempted mutation.

More precisely, at each iteration each agent, with equal probability, can either stay put, or modify one component of the characteristic string, or modify one component of the environment. In the two latter cases, the modification is always implemented, regardless the new fitness value it generates.

Thus, while off-line search always determines a immediate increase of fitness (though fitness may later decrease due to environmental changes performed by other agents), on-line search may result in lower fitness. On the other hand, while off-line search may stop in a local optimum, where no change of an individual component either of the characteristics vector or of the environment increases fitness, on-line search never comes to a halt.

SIMULATIONS RESULTS

We have conducted preliminary experiments with $N=W=20$ and 10,000 iterations, testing the properties of agents for different values of K and E .

Let us first of all concentrate on off-line search. It is well known that in standard NK models as K increases search tends to get stuck in local optima. With high levels of K search becomes almost powerless because there is a very high number of local optima and search always halts after a small number of mutations. The final outcome is very close to the initial condition and there is a strong path-dependency.

In our model, the presence of interdependencies with the environmental string modifies considerably this picture. If we consider only an individual agent, a high value of E makes the landscape more complex. If, for instance, $K=N$ and $E=W$ the agent is actually searching on landscape of dimension $N+W$ with maximum complexity, and therefore with a higher number of local optima.

However, if we consider a population of agents that can modify the environmental vector, lock-in into local optima tend to be transient, because local optima of the genetic code are conditional upon the state of the environmental string which gets modified by the action of other agents. If both K and E are large, the result of the interaction among a sufficiently large population of agents produces very erratic and unstable behaviour. Figure 3 shows a typical time series of the fitness of one agent.

Thus, at one extreme, high K with $E=0$ (and therefore no interaction in the population with the environment) produces almost no dynamics as a local equilibrium is quickly reached. At the other extreme, a large population of diverse agents with high K and E tends to produce highly volatile fitness, chaotic behaviour, and no equilibria. More interesting behaviours emerge for intermediate values of K and E . Figure 4 reports fitness values after 10,000 iterations for a low ($K=2$), an intermediate ($K=8$) and a maximum

($K=20$) value of K as E varies from 0 to 20. Highest fitness is reached when E is relatively low but not 0.

These results are also indicative of the properties of search and adaptation when environmental changes are not endogenously produced by agents but are the outcome of exogenous shocks.

Summary

This model illustrates some interesting aspects of niche construction by enabling us to evaluate the interaction between search that influences the external environment – or shaping – and search that modifies organizational characteristics. For example, as shown in the prior example of intermediate values of K and E , it is the environmental change produced by others – and not by the agent itself – that unlocks an agent from its local optima, similar in spirit to the Red Queen view of competition discussed earlier (cf. Barnett and Hansen, 1996). Moreover, the model shows that this effect holds for relatively low (but not zero) levels of interdependence between an agent's action and environmental change. This suggests that even in environments in which shaping by individual firms affects only a few elements of the external environment, individual firms can have a substantial impact on the selection environment, and thereby affect subsequent search outcomes. This is consistent in spirit with the examples given earlier of firms whose actions influenced one or a few key dimensions of their external environments, even though the details of those examples do not match our model precisely.

The model also suggests that when firms face high interdependence of characteristics in the external environment in addition to high interdependence of internal firm attributes, search becomes difficult and outcomes become unstable. In this type of setting, some have recommended that firms cannot hope to sort out the various permutations of possible actions and therefore should employ simple rules for making strategic decisions (Eisenhardt and Sull, 2001). We would add the simple rules might also help firms to narrow the choice set of actions to modify the external environment, potentially enabling organizations to better manage environmental volatility.

DISCUSSION

In this initial model, individual organizations can directly shape some characteristics of the external environment, which in turn affects subsequent internal search by all firms. The model explicitly captures the concept of 'ecological inheritance' from biological research on niche construction, in which 'shaping' actions by organizations in one period bequeath an altered external environment to organizations who then undertake additional search by altering their internal characteristics. Each time that firms modify the external selection environment, they change the landscape on which internal search takes place, providing a model of endogenous selection. At a minimum, the discipline imposed by the construction of the model offers a simple language and parsimonious intellectual structure for investigating niche construction and firm shaping of the external environment.

In the model, agents have bounded rationality and assess whether a move would improve their current payoffs without forecasting the impact of niche construction on

payoffs in the more distant future. The model has the benefit that it incorporates a likely aspect of bounded rationality in firm decision making, in that firms may find it difficult to simultaneously evaluate potential outcomes of shaping that alters the environment and search that alters internal characteristics. Instead, as in this model, firms may sequentially consider external shaping and internal search.

The model also captures one of the mechanisms of niche construction identified earlier, namely, the impact of individual firms on the selection environment through search and associated learning. There are myriad examples of individual firms that arguably have modified the external environment through search for improved payoffs, including the earlier examples of Apple and Southwest. Our model shows that even with search only at the individual (rather than group) level, the payoff structure can be much more complex than in standard NK models in which there are interdependencies only between the characteristics of each agent.

In contrast to most prior research using NK types of models, our initial approach explicitly incorporates shaping of the external selection environment by individual firms. We know that firms undertake many actions of this type, ranging from marketing to shape consumer preferences to R&D that can shape technological trajectories. Our model also explicitly separates shaping the external environment from search that alters internal firm characteristics. We believe that it is valuable initially to distinguish and model these two effects separately in order to gain a better understanding of how the external environment and firms co-evolve. This lays the groundwork for tailoring general mechanisms of niche construction to various contexts, which complements the approach used in history-friendly models of industry evolution that are specific to individual industries.

The initial model employed here can potentially be modified in a number of ways to incorporate more specific aspects of shaping and search by individual firms. In addition, we could consider somewhat different models, such as one in which the individual firm cannot act directly on the environment (direct niche construction) by mutating one or more bits of the environmental string, but can only perform search with respect to its own characteristics, i.e., flip one (or more) bit(s) of its characterizing string. Environmental bits would mutate when some configuration of this characterizing string is reached through search (indirect niche construction). As in our initial model, any mutation of environmental bits would determine a change of fitness contribution of the individual firm bits linked to it. And beyond search by individual organizations, future research could consider the even more difficult challenge of modeling group search and shaping of the external environment.

CONCLUSION

Our approach here is but a start on a much larger intellectual agenda with implications for the study of firm strategy, and indirectly, for firms involved in making strategy. By adapting the biological framework of niche construction and the associated concept of ecological inheritance, we propose a general framework for understanding the shaping of the external environment by firms. This framework has the advantage that it captures, in a realistic yet parsimonious fashion, key elements of how firms make strategic decisions over time, and in a manner that incorporates the impact of these decisions on subsequent strategic choices for all firms in the population. This relatively simple framework also has the potential to elucidate some of the mechanisms suggested by disparate prior research relevant to firm-environment interactions and co-evolution over

time. Moreover, we have shown how the niche construction framework can be modeled analytically using an NK type of approach in order to probe the implications of niche construction for firm strategy – providing a route forward to improved analytic understanding of endogenous selection.

REFERENCES

- Alvarez, S., Barney, J. (2007). Discovery and creation: alternative theories of entrepreneurial action. *Strategic Entrepreneurship Journal*, 1 (1-2): 11-26.
- Andrews, K.R. (1987) *The Concept of Corporate Strategy*, 3rd ed. Richard D. Irwin.
- Arthur, W.B. (1989) Competing Technologies, Increasing Returns, and Lock-in by Historical Events. *The Economic Journal*, 99: 116-131.
- Audretsch, D. B. (1997). Technological regimes, industrial demography and the evolution of industrial structures. *Industrial and Corporate Change*, 6(1): 49-82.
- Barnett, William P. and Morten T. Hansen (1996), The Red Queen in Organizational Evolution, *Strategic Management Journal*, vol. 17, pp. 139-157.
- Barnett, W.P., Sorenson, O. (2002) The Red Queen in organizational creation and development. *Industrial and Corporate Change*, 11(2): 289-325.
- Barney, J. 1991. Firm Resources and Sustained Competitive Advantage. *Journal of Management*, 17(1): 99-120.
- Bower, J.L., Christensen, C.M. (1995) Disruptive technologies: catching the wave. *Harvard Business Review*, Jan.-Feb.
- Braguinsky, S. (2015) Knowledge diffusion and industry growth: the case of Japan's early cotton spinning industry. *Industrial and Corporate Change*, 24(4): 769-790.
- Braguinsky, S., Hounshell, D. (2016) History and nanoeconomics in strategy and industry evolution research: lessons from the Meiji-era Japanese cotton spinning industry. *Strategic Management Journal*, 37(1): 45-65.
- Carroll, G. (1985). Concentration and specialization: dynamics of niche width in populations of organizations. *American Journal of Sociology*, 90(6): 1262-1283.
- David, P.A. 1985. CLIO and the Economics of QWERTY. *American Economic Review*, 5(1): 332-337.
- Denrell, J., Fang, C., Winter, S.G. (2003) The economics of strategic opportunity. *Strategic Management Journal*, 24: 977-990.
- Delacroix, J., Solt, M.E. (1988) Niche formation and foundings in the California wine industry, 1941-84. In G.R. Carroll (ed.), *Ecological Models of Organizations*. Ballinger, Cambridge, MA: 53-70.

- Derfus, P., Maggitti, P.G., Grimm, C.M., Smith, K.G. (2008) The Red Queen effect: competitive actions and firm performance. *Academy of Management Journal*, 51(1): 61-80.
- Dosi, G., Marsili, O., Orsenigo, L., Salvatore, R. (1995) Learning, market selection and the evolution of industrial structures. *Small Business Economics*, 7: 411-436.
- Durham, W.H. (1991) *Coevolution: Genes, Culture, and Human Diversity*. Stanford University Press, Stanford, CA.
- Eisenhardt, K., Sull, D. (2001) Strategy as simple rules. *Harvard Business Review*.
- Fortune, A., Mitchell, W. Unpacking firm exit at the firm and industry levels: the adaptation and selection of firm capabilities. *Strategic Management Journal*, 33(7): 794-819.
- Hannan, M.T., Freeman, J. (1977) The population ecology of organizations. *American Journal of Sociology*, 82(5): 929-964.
- Helfat, C. E. (2015). Vertical firm structure and industry evolution. *Industrial and Corporate Change*, 24(4): 803-818.
- Henderson, R., Mitchell, W. (1997) The interactions of organizational and competitive influences on strategy and performance. *Strategic Management Journal*, 18(summer special issue): 5-14.
- Katz, M., Shapiro, K. (1994) Systems Competition and Network Effects. *Journal of Economic Perspectives*, 8(2): 93-115.
- Kauffman, Stuart A. (1993). *The Origins of Order: Self-Organization and Selection in Evolution*, Oxford University Press, 1993.
- Kauffman, Stuart A. (1995). *At Home in the Universe: The Search for Laws of Self-Organization and Complexity*, Oxford University Press.
- Klepper, S., Sleeper, S. (2005) Entry by Spinoffs. *Management Science*, 51(8): 1291-1306.
- Laland, K.N., Odling-Smee, J., Feldman, M.W. (1996) On the evolutionary consequences of niche construction. *Journal of Evolutionary Biology*, 9:293-316.
- Laland, K.N., Odling-Smee, J., Feldman, M.W. (2000) Niche construction, biological evolution, and cultural change. *Behavioral and Brain Sciences*, 23(1): 131-175.
- Lant, T.K. (2003) Strategic capabilities in emerging fields: navigating ambiguity, leveraging social capital, and creating identity in Silicon Alley. In C. Helfat (ed.) *The SMS Blackwell Handbook of Organizational Capabilities: Emergence, Development, and Change*. Blackwell Publishing: Malden, MA: 110-118.

- LeMens, G., Hannan, M.T., Polos, L. (2011) Founding conditions, learning, and organizational life chances: age dependence revisited. *Administrative Science Quarterly*, 56: 95-126.
- Levinthal, Daniel A. (1997), Adaptation on rugged landscapes, *Management Science*, vol. 43, pp.934-950.
- Levinthal, D.A., Myatt, J. (1994) Co-evolution of capabilities and industry: the evolution of mutual fund processing. *Strategic Management Journal*, 15: 45-62.
- Levinthal, D.A., Siggelkow, N. (2003) Temporarily divide to conquer: centralized, decentralized, and reintegrated organizational approaches to exploration and adaptation. *Organization Science*, 14(6): 650-669.
- Levinthal, D.A., Warglien M. (1999) Landscape design: designing for local action in complex worlds. *Organization Science*, 10(3): 342-357.
- Lewontin, R.C. (1982) Organism and environment. In H.C. Plotkin (ed.), *Learning, Development, and Culture*. Wiley, New York.
- Lewontin, R.C. (1983) Gene, organism, and environment. In D.S. Bendall (ed.), *Evolution from Molecules to Men*. Cambridge University Press.
- Malerba, F., Nelson, R., Orsenigo, L., Winter, S. (1999) 'History-friendly' models of industry evolution: the computer industry. *Industrial and Corporate Change*, 8(1): 3-40.
- Malerba, F., Nelson, R., Orsenigo, L., Winter, S. (2008) Vertical integration and disintegration of computer firms: a history-friendly model of the coevolution of the computer and semiconductor industries. *Industrial and Corporate Change*, 17(2): 197-231.
- Malerba, F., Orsenigo, L. (2002) Innovation and market structure in the dynamics of the pharmaceutical industry and biotechnology: towards a history-friendly model. *Industrial and Corporate Change*, 11(4): 667-703.
- Mezias, S.J., Kuperman, J.C. (2000) The community dynamics of entrepreneurship: the birth of the American film industry, 1895-1929. *Journal of Business Venturing*, 16: 209-223.
- Nelson, R.R. (1994) The co-evolution of technology, industrial structure, and supporting institutions. *Industrial and Corporate Change*, 3(1): 47-63.
- Odling-Smee, F. J. (1988) Niche constructing phenotypes. In H.C. Plotkin (ed.), *The Role of Behavior in Evolution*. MIT Press: Cambridge, MA.
- Odling-Smee, F.J., Laland, K.N., Feldman, M.W. (2003) *Niche Construction: The Neglected Process in Evolution*. Princeton University Press: Princeton, NJ.

- Peteraf, M. (1993) The cornerstones of competitive advantage: a resource-based view. *Strategic Management Journal*, 14(3): 179-191.
- Porac, J.F., Thomas, H., Baden-Fuller, C. (1989) Competitive Groups as Cognitive Communities: The Case of Scottish Knitwear Manufacturers. *Journal of Management Studies*, 26(4): 397-416.
- Porac, J.F., Thomas, H. (1990) Taxonomic Mental Models in Competitor Definition. *Academy of Management Review*, 15(2): 224-240.
- Porac, J.F., Thomas, H., Wilson, F., Paton, D., Kanfer, A. (1995) Rivalry and the Industry Model of Scottish Knitwear Producers. *Administrative Science Quarterly*, 40(2): 203-227.
- Porter, M. (1996) What is strategy? *Harvard Business Review*, 74: 61-78.
- Rao, H., Giorgi, S. (2006) Code breaking: how entrepreneurs exploit cultural logics to generate institutional change. *Research in Organizational Behavior*, 27: 269-304.
- Rosenkopf, L., Tushman, M.L. (1998) The coevolution of community networks and technology: lessons from the flight simulation industry. *Industrial and Corporate Change*, 7(2): 311-346.
- Siggelkow, N. (2001) Change in the presence of fit: the rise, the fall, and the renaissance of Liz Claiborne. *Academy of Management Journal*, 44(4): 838-857.
- Swaminathan, A. (1998) Entry into new market segments in mature industries: endogenous and exogenous segmentation in the U.S. brewing industry. *Strategic Management Journal*, 19: 389-404.
- Suzuki, R. and T. Arita (2005), "How Niche Construction Can Guide Coevolution", *Proceedings of the 8th European Conference on Artificial Life*, pp. 493-496.
- Teece, D.J. (2007) Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance. *Strategic Management Journal*, 28(13): 1319-1350.
- Valente, M. (2014), An NK-like model for complexity, *Journal of Evolutionary Economics*, vol. 24, pp. 107-134.

Figure 1 Biological Model of Niche Construction

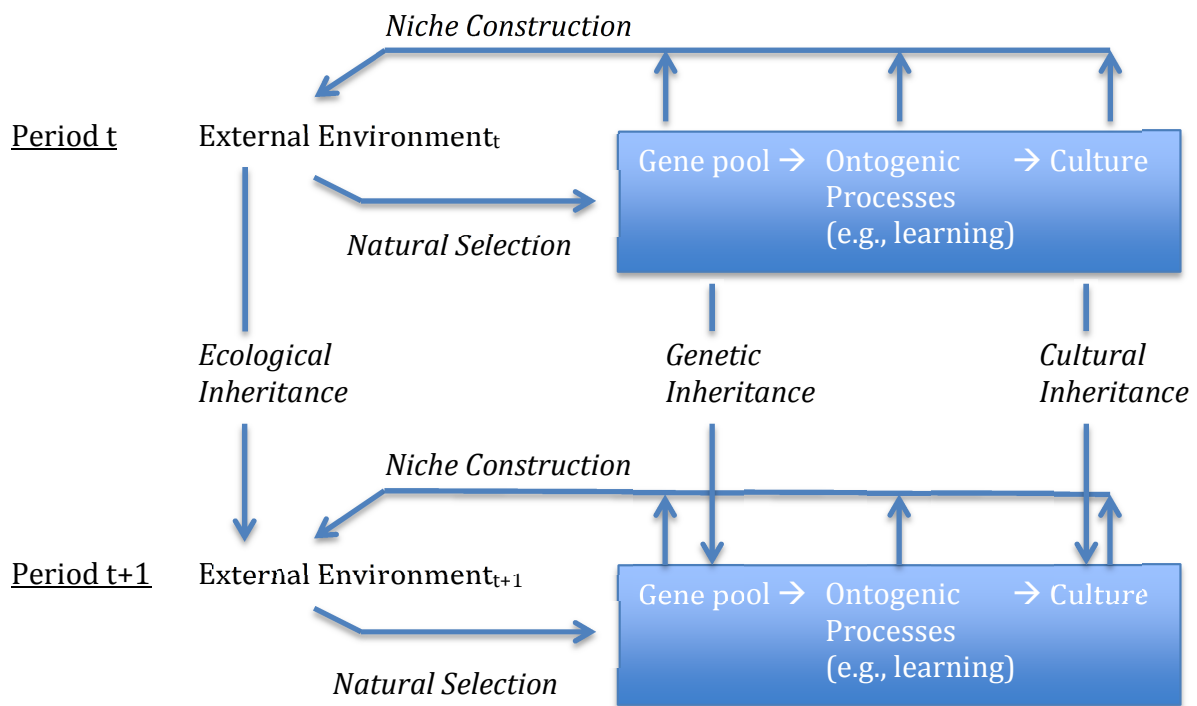


Figure is adapted from figures 2 and 3 in Laland et al (2000)

Figure 2 Organizational Model of Niche Construction

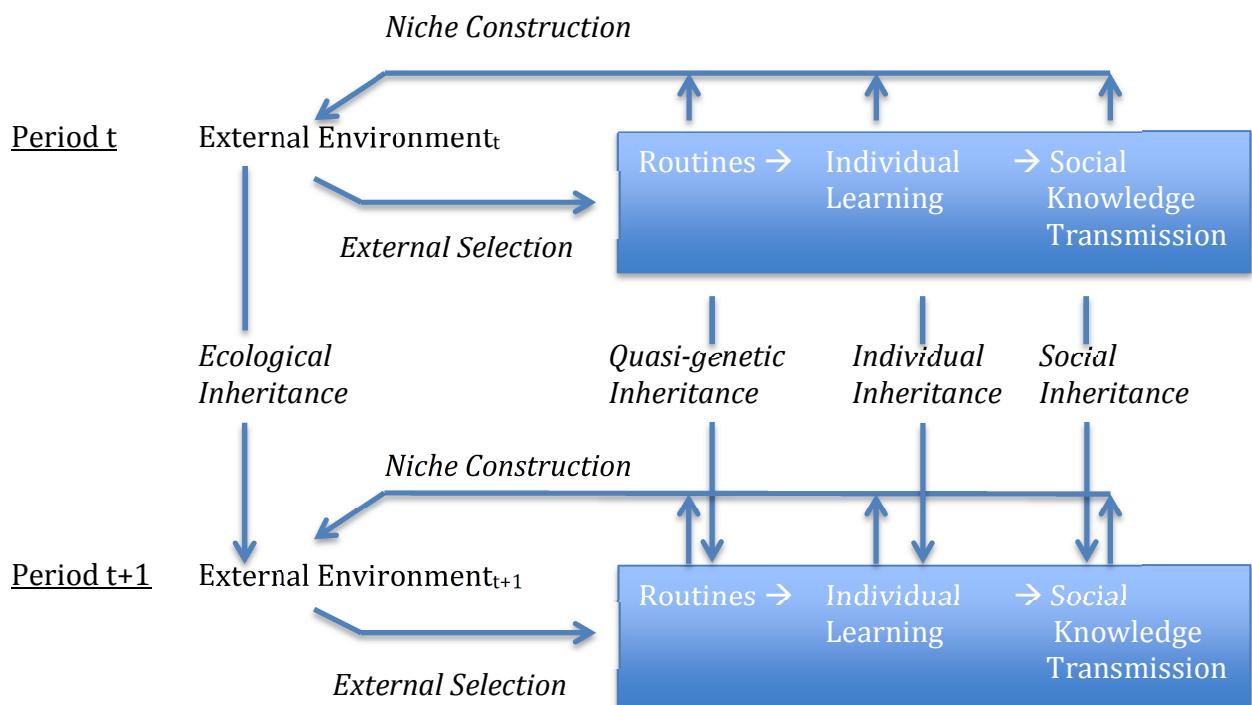


Figure 3 A typical agent's fitness with large K and E

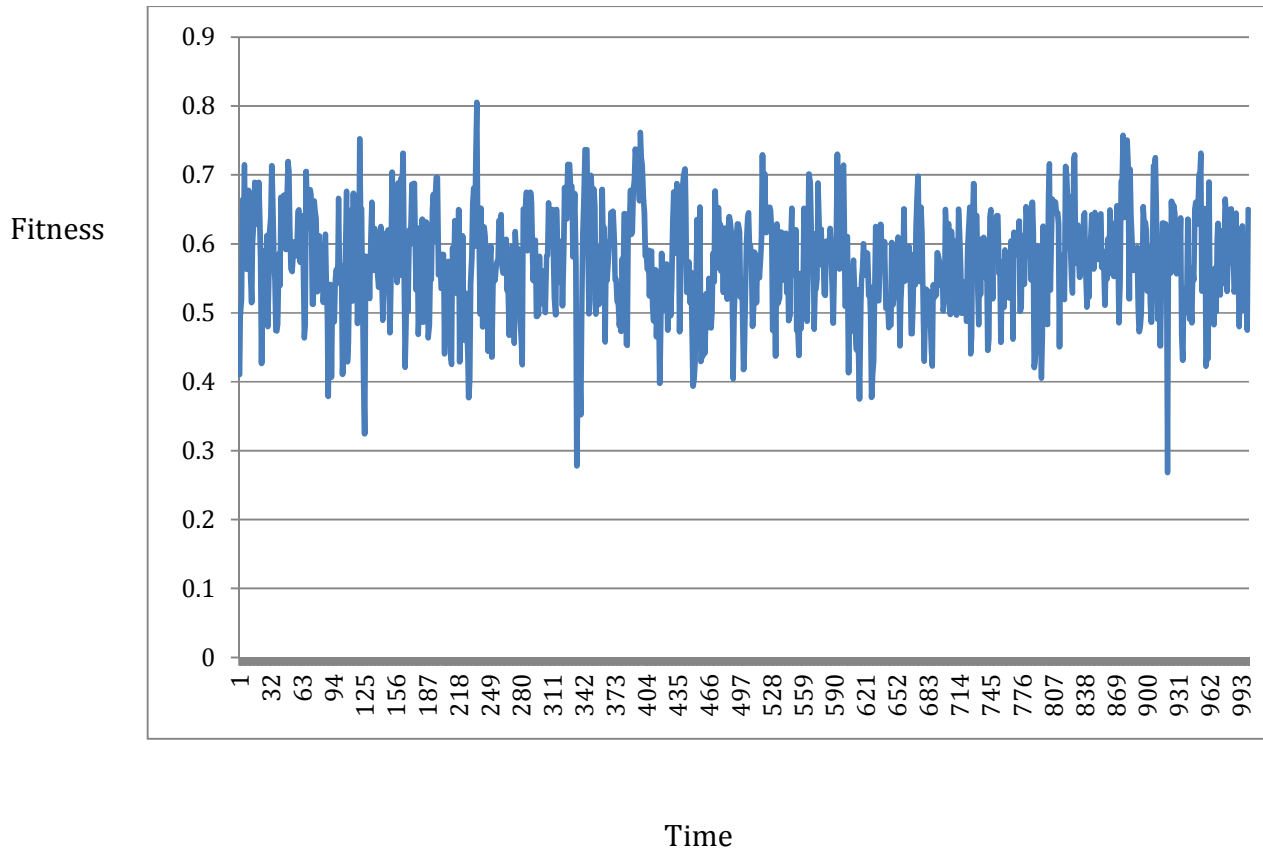


Figure 4 Fitness for different values of E when K=2, K=8 and K=20

