Interdependencies, Competition and Industry Dynamics

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Abstract

A fundamental connection between strategic outcomes and industry evolution is critical to strategy research. Across a number of literatures, a robust set of empirical regularities has been observed with regards to industry evolution and a number of theories have been advanced to explain these regularities. Despite early interest in explaining these industry patterns based on concepts central to strategy research such as the cognitive difficulties that firms encounter when trying to innovate or imitate one another (Demsetz 1973; Nelson and Winter 1982), the most prominent subsequent theorizing and models have focused on the role of convex adjustment costs and scale advantages in innovation and learning (Ericson and Pakes 1995; Klepper 1996). While these models are capable of explaining many of the stylized facts of industry evolution, their explanations are based on mechanisms that may be absent from many industries and more importantly mechanisms that abstract from the practical challenges of innovation and imitation. These practical challenges, however, are central to strategy since the complexity of real firms – where interdependent activities are managed by individuals who must learn rather than simply calculate or observe the best configurations of those activities – leads to variety in firms’ practices (Levinthal 1997) and places limits on imitation and on the expansion of successful firms (Dierickx and Cool 1989; Szulanski 2000; Argote 2000; Rivkin 2000). To connect these mechanisms to industry dynamics, we develop a model of industry evolution where firms make entry, exit, and output decisions to maximize current profits while seeking to improve their quality or efficiency through innovation and imitation of a highly interdependent set of practices. Even without the assumptions about convex adjustment costs or scale advantages in innovation that are central to other models of industry dynamics, the model reproduces many of the same widely observed patterns of industry evolution. Importantly, analysis of the model produces novel empirical implications for patterns of entry, exit, costs, output and profitability in industries over time.

(Keywords: industry evolution, complementarities, interdependencies)
1. Introduction

Critical to our understanding of contemporary differences in market share and profitability among firms within an industry is systematic knowledge of how those differences arose in the first place. The structural evolution of industries – the rate of change in output and prices, the rates of entry and exit (turnover), and the growth and decline of individual firms (mobility) – is fundamental to our identification of profitable market leaders who can sustain performance over time. Industry evolution provides important contingencies that affect the viability of various firm strategies. Without a keen grasp of the underlying mechanisms driving industry evolution and the resulting changes that occur at the industry level over time, we are less able to identify why certain firms are the winners and others losers in an industry (Aggarwal and Gort 2002). In this paper, we advance an alternative explanation for observed patterns of industry evolution based on interdependencies in productive activities (Milgrom & Roberts 1990; Rivkin 2000) and identify novel predictions based on this explanation.

Across a number of literatures, a robust set of empirical regularities have been observed about industry evolution (Gort and Klepper 1982; Caves 1998). For example, following the inception of an industry, new entrants rush into the industry often driving up the rate of innovation and leading to a diverse set of ways to deliver value. Over time the rate of entry decreases, eventually stabilizing at a low level. Meanwhile, the number of firms within the industry grows exponentially at first, peaks, and declines typically settling in with a few dominant firms. The most prominent explanations for these patterns rely on convex adjustment costs and scale advantages in innovation and learning (Ericson and Pakes 1995; Klepper 1996). For example, a firm with a small initial efficiency advantage or a chance innovative success may expand faster than rivals allowing it to learn more rapidly from subsequent experience and justify larger subsequent investments in innovation.

In contrast, we propose that interdependency in productive activities provides a robust, alternative explanation for stylized facts about industry evolution and provides novel insights into the nature of industry dynamics and the origins of competitive advantage. By “interdependency in productive
activities”, we refer to the potential for the value of one activity to depend on whether a firm engages in another activity (Levinthal 1997). In the presence of interdependent and potentially complementary activities, firms face barriers to search and often struggle to discover valuable configurations of productive activities (Rivkin 2000).

In this paper, we construct and analyze a model of industry evolution in the presence of interdependency. We demonstrate that such a model can explain many of the stylized facts of industry evolution. We explain why such an alternative explanation is valuable to those concerned directly with industry evolution and dynamics, and more importantly, discuss the implications for those concerned with cross-sectional differences among firms. We argue that these mechanisms provide an explanation for industry dynamics and differences in cross-sectional firm market shares and profitability that, while not contradictory to adjustment costs and scale advantages in appropriating returns to innovation, are at least as compelling and may explain industry dynamics in markets where adjustment costs are lower and innovation returns depend less on previous scale. In addition, in the presence of interdependencies, past innovation conditions future innovation, not because they affect the incentives to innovate as in Klepper (1996) and Ericson and Pakes (1995), but because they affect the things that will be learned from innovative effort. The key is not the amount of past innovative success, but the character of your past innovative successes that leads to different technological trajectories (Dosi 1982). Our model focuses attention on the importance of what firms learn rather than simply how much firms learn.

2. Industry Structure and Evolution

Over the years, a number of empirical regularities have been observed with respect to industry structure and evolution (see Table 1 for a summary). Gort and Klepper (1982) provide an early careful and rich characterization of industry dynamics. They based their findings on a study of the life cycle of forty-six industries originating between 1887 and 1960 and producing a diverse mix of consumer, industrial, and military products. They begin their analysis of each industry with the introduction of a
substantial new innovation. They first looked at patterns of industry participation and observed that industries for new products pass through a brief period with few firms, followed by a rapid increase in the number of firms which then falls rapidly down to a relatively stable level with on average forty percent fewer firms than existed at the peak (p.639). During the evolution of the industry they also observed that: output growth is initially high but declines steadily (p.645); prices fall rapidly but at a decreasing rate (p.647); the rate of both major innovations and minor innovations rise, peak and then remain stable over time with major innovations peaking earlier (p.648); and patenting rises steadily, plateaus when the number of firms peaks, falls, then surges when the number of firms becomes stable (p.650).

Caves (1998: p.1948) provided a more recent summary of empirical findings on industry dynamics including entry and exit as well as changes in the size and market share of incumbents. Entry and exit occur primarily among small firms. In general, variance in growth rates fall with firm size and mean growth rates decrease with both size and a units’ age. Though the negative correlation between firm size and growth rate causes regression toward the mean in size, the largest firms generally retain market share leadership for several decades. It is uncertain whether growth rates are serially correlated, but growth rates are clearly not very highly correlated among firms within an industry over any period of time. Caves cites one study showing that more than 0.6 jobs were lost for every job gained in growing industries and more than 0.6 jobs were gained for every job lost in contracting industries. Caves also notes that more concentrated industries have lower turnover of leaders due to entry and exit but that even in highly concentrated industries we can see significant change in market share among incumbents.

A number of theories have been advanced to explain various subsets of these patterns. Jovanovic (1982) provided a model to explain why small firms grow more rapidly and are more likely to fail than larger firms. The model is based around a “theory of noisy selection” where firms are initially and randomly endowed with different levels of efficiency but only learn and update their beliefs about their
type over time with noise in the signals. In this model, efficient firms recognize their efficiency over time and grow while inefficient firms become aware of their inefficiency leading them to contract and exit. In order to produce analytic results, the model assumes an infinite number of firms so firms are all price takers who limit their output due to convex production costs rather than strategic concerns about the effect of their own output prices and on the output of other firms. Though not discussed in the paper, the model likely produces both prices that fall and output that rises at a decreasing rate as more efficient firms expand and less efficient firms contract. The model also provides an explanation for the positive correlation between profits and both firm size and concentration (more efficient firms are larger), higher serial correlation in rates of return for larger firms (larger firms are updating their beliefs and changing their production levels less), and a higher correlation between industry concentration and firm profits for larger firms (larger firms do not keep prices up and thus concentration does not benefit smaller firms). Adding entry to the model would likely allow it to produce a rise then fall in industry participation (a shakeout) if the assumptions about an infinite number of firms and price taking behavior were also relaxed.

Utterback and Abernathy (1978) provided an alternative explanation for the shakeout of firms where firms take a more active role in determining their efficiency levels. Utterback and Abernathy based their explanation on a period of technological uncertainty that ends with the emergence of a dominant product design after which firms that are unable to produce this design exit the market. Klepper (1996) pointed out the appearance of a dominant design is far less predictable than the other regularities observed in industry life cycles and proposed and explored a more complete analytical model to explain these patterns along with an additional regularity involving a shift in emphasis from product to process innovation over time. Klepper’s model is based on (a) advantages of scale in exploiting product and process innovations that lead larger firms to innovate more and lead to a shift from product toward process innovation, (b) convex adjustment costs that limit the rate of firm expansion, (c) firms that make output choices to maximize current profits, (d) a pool of potential entrants, and (e) firms that make entry, exit, output, and R&D choices to maximize expected next-period profits.
Ericson and Pakes (1995) also provide a model of entry and exit among competing firms engaged in innovative efforts, though the model’s primary purpose is to explain the “great variability in the fate of similar firms” with some firms growing while others contract. Their model allows firms to make entry and exit decisions not only based on current profits but on expected future profits following later innovative efforts; entry and exit decisions are based on optimal stopping rules rather than current period profits. The model can produce a wide variety of behavior depending on parameterization, including a rise in the number of firms followed by a shakeout, high contemporaneous rates of both entry and exit and a skewed distribution of firm lifetimes and firm performance. Similar to Klepper’s model, convex adjustment costs allow for the expansionary period of high net entry while advantages of scale in innovation are key drivers of the eventual fall in the number of competitors.

In this paper, we advance an alternative approach based on the degree to which firm activities are interdependent or complementary with one another. Interdependency among firm activities is well documented at the product, process, and organizational levels (Demsetz 1973; Milgrom and Roberts 1990; Porter 1996; Rivkin 2000; Siggelkow 2001; Kaufman 1989; Cassiman and Veugelers 2006). Activities are interdependent to the extent that “the value of a particular [activities] depends on a variety of other [activities] (Levinthal 1997: p.936).” Interdependent activities are complementary when the marginal value of engaging in one activity is increased by engaging in another activity (Milgrom and Roberts 1990).

The potential for interdependency among a firm’s activities may lead firms to adopt a host of specific practices in concert and result in “distinctly separated clusters of firm characteristics (Milgrom and Roberts 1990: 527).” Early random differences in production decisions condition later choices potentially leading to quite different bundles of activities (and profitability) for even initially similar firms (Levinthal 1997). These differences in activity bundles may persist as lagging firms struggle to imitate the bundles of highly interdependent activities of leading firms (Rivkin 2000). To the extent that organizations are better at evaluating incremental rather than wholesale changes (Levitt 1975, Levinthal and March 1993, Nelson 2003) and limited in their ability to fully comprehend or recreate the practices of
rivals without such understanding (Lippman and Rumelt 1982, Rivkin 2000), the presence of interdependencies will only reinforce within-industry heterogeneity.

As an illustration, consider a previously untried distribution process that is well-suited to one firm but that creates costly complications or few benefits for a rival firm that uses a different set of manufacturing techniques. Due to its interactions with other practices, adopting the new distribution process may give the first firm a large performance advantage (Rivkin 2000) that persists because rivals: 1) fail to observe adoption or performance changes (Dierickx and Cool 1989); 2) make errors observing or changing interdependent differences among firms (Rivkin 2001); 3) cannot efficiently change some complementary difference or differences (Dierickx and Cool 1989; Oster 1982); 4) favor incremental evaluation and adoption of changes that provide immediate improvements (March & Levinthal 1991; Levit 1975; Christensen and Rosenbloom 1995).

The resulting limits to imitation and search are central to a number of streams of literature in strategy and economics. Fundamental to the resource-based view of strategy is the notion that heterogeneity in individual firm resources and capabilities may lead to performance differences among firms and that these advantages are not competed away due to the inability of competitors to perfectly imitate one another. Difficulty in imitation and search is also fundamental to Nelson & Winter’s (1982) evolutionary economics and behavioral theories of the firm (Simon 1961, Cyert and March 1963).

Some work has begun to map the existence of these interdependencies to firm and industry profits (Lenox, Rockart, and Lewin forthcoming), but no one has made the full mapping to industry dynamics. Using the model presented in the following section, we connect interdependencies in productive activities with industry dynamics. In doing so, we hope to not only explain known stylized facts about industry evolution, but to develop novel insights about when certain patterns may or may not arise.

3. The Model

For our model, we adopt the specification of Lenox, Rockart, & Lewin (forthcoming). Their specification provides a mechanism to determine how the relative cost or quality of firms within an
industry affects firm and industry dynamics. They make similar assumptions about potential entrants, exit, and output choices to those in Klepper (1996), but assume that innovative outcomes are conditioned not on the scale of current production but on the firm’s current organization of productive activities. Unlike Klepper (1996), they assume no advantage from past scale in appropriating innovation and no costs of expansion. By not modeling these advantages and costs, the model has predictive power in settings such as software development where firms can scale their operations quickly and with little expense. We do not disagree that such advantages and costs may exist, but we wish to demonstrate that many of the extant findings can be explained by a model absent these mechanisms. In particular, the main mechanism in the Lenox, Rockart & Lewin (forthcoming) model is the imperfect and time consuming nature of imitation (as opposed to the complete and relatively rapid imitation assumed by Klepper).

The overall model is composed of 1) a model of competition among firms that maps the distribution of firm cost or quality to industry outcomes and 2) a model of interdependencies among a firm’s resources and practices that determines firm performance in terms of cost or quality. For the model of competition, we consider an undifferentiated market where industry price depends on demand conditions and total industry output. Consumers are assumed to choose firms that maximize their own utility and firms act to maximize their profits. As a robustness test, we also consider a model of competition where competitors are differentiated in quality and thus each firm’s sales depend on demand conditions as well as the quality and price offered by that firm and every other competitor (see Appendix). For the model of interdependencies, we adopt a general representation of interdependencies among activities that allows for interactions consistent with Kaufman’s (1989) NK model which has been introduced into the strategic management field by Levinthal (1997) and Rivkin (2000). We consider each model in turn.
3.1 The Competitive Model

To formalize our setting of undifferentiated competition, we consider a market under Cournot competition (i.e., we assume price is set by the market and that firms choose their level of output). The Cournot model assumes that firms recognize their interdependence and choose output quantities that maximize their profits given the expected output of their rivals. This model generally leads to oligopoly but also produces monopoly as a special case when fixed costs are particularly high or one firm has a substantial variable cost advantage over all rivals.

To operationalize our model of competition, we first assume demand is a linear function of price:

\[ Q = \alpha - (1/\beta) p \]  
\[ \text{or alternatively, } p(Q) = \alpha - \beta Q, \tag{1} \]

where \( Q \) is total industry output, \( p \) is price, and \( \alpha \) and \( \beta \) are the intercept and slope of the inverse demand function. The profit function for any firm \( i \) is:

\[ \pi_i = p(Q)q_i - c_i(q_i), \tag{2} \]

where \( \pi_i \) are the profits for firm \( i \), \( q_i \) is the sales quantity for firm \( i \), and \( c_i(q_i) \) is the cost of producing \( q_i \).

For simplicity, we assume a linear cost function:

\[ c_i(q_i) = c_i q_i + c_f, \tag{3} \]

where \( c_i \) is firm-specific marginal cost and \( c_f \) represents fixed industry-specific costs.

Each firm chooses output to maximize profits:

\[ \max_q \pi_i = (\alpha - \beta \sum q_i)q_i - c_i q_i - c_f. \tag{4} \]

Given this decision problem, a rational oligopolist will set quantity such that:

\[ q_i^* = \left( \alpha + \sum c_i \right)/\beta(n+1) - c_i/\beta, \tag{5} \]

where \( n \) is the number of competitors and \( \sum c_i \) is the sum of marginal costs across all firms. Thus, firms with lower variable costs will have higher output and greater profits.
3.2 NK Model of Interdependencies

Rather than focus on input costs such as labor and capital or one-dimensional accumulations of efficiency based on past investments and cumulative output, costs in the competitive model are assumed to be driven by the details of what firms do. Specifically, costs are assumed to be driven by how firms conduct each activity in a large set of activities. The full model captures firms actively engaged in experimenting with existing operations and altering how they perform activities in an attempt to lower marginal cost (Lippman and Rumelt 1982). Appropriate decisions about how firms should perform each activity are complicated by interactions among those activities which, depending on how the other activities are conducted, result in complementarities or conflicts that increase or reduce efficiency.

Our analysis assumes that the extent of interactions among activities is a characteristic that varies among industries but not within industries over time. In other words, we define potential interdependencies as a latent property which remains constant within an industry over time. By this definition, many of the interactions will go unrecognized until firms try novel approaches to one or more activities (perhaps made possible by scientific discoveries) at which point it might appear that the interdependencies have changed. By defining interdependencies in this manner, we include in firm behavior changes in activities resulting from “breakthrough” ideas and scientific discoveries (e.g., new materials, contracting forms, or process technologies).

Incorporating the widely applied NK model of interdependencies allows the model to capture differences in the potential for interdependency in activities among industries (Kauffman 1993). This is a critical point for this analysis in this paper since our goal is to make predictions about how industry dynamics differ based on the potential for interdependency. The NK model as applied in management research can be viewed as a complex production function depending not only on aggregate supplies of capital and labor but also on a firm’s specific mix of activities, practices and resources. The “N” in the NK model refers to the number of potentially interdependent activities that a firm may adopt or employ and the “K” refers to the number of activities (including itself) that interact with each of the N activities.
Higher values of K lead to more expected combinations of activities that could complement or conflict with one another to produce a distinctly higher quality or lower cost than would be expected by a combination of independent changes. For example, whether to use just-in-time logistics, piece-rate payments, sampling techniques to control quality, work teams and stock options as incentives would naturally fall among the N decisions that a manufacturing firm needs to make. Researchers have found evidence that steel producing firms adopting incentive pay, teams, flexible job assignment, employment security and training enjoy higher productivity than would be expected from the sum of the individual gains to be generated from each of these activities (Ichniowski et al. 1997).

One of the desirable aspects of the NK specification is that it captures interdependencies in a more general sense than captured in analytical specifications (Ghemawat and Levinthal 2000). Milgrom and Roberts (1990) provide an analytical treatment of interdependencies where doing more of each activity enhances the value of doing more of every other activity. This fully-complementary assumption allows for closed-form comparative static results using the concepts of lattice theory and supermodularity. The NK specification, however, “avoids imposing a specific structure on the linkages among choices” and “allows the richness of such linkages to vary across situations” so that we can explore the effects of both complements and conflicts among activities (Ghemawat and Levinthal 2000, p.17). Conflicts are represented in the NK model whenever the value of an individual practice increases in the absence of another practice.

The NK model provides a backdrop for an agent-based model where each firm in the industry is an agent. Each firm is assigned a vector of N binary activity decisions, \( s_i \), which represents the way it does each activity. For example, a firm that adopts just-in-time supply logistics, forgoes piece rate payments, uses quality sampling, encourages integrated work teams, and refuses to offer stock-options may have an activity set as follows: \( s_i = [10110] \). For each activity decision, we randomly generate \( 2^{K+1} \) cost or quality values which that characterize the potential interactions within that industry. For example, if each activity decision interacts with three other decisions, there are sixteen \( (2^{3+1}) \) potential values for
each activity and those values are determined by random draws from a $U(0,1)$ distribution. Each activity in each firm is then assigned the value which corresponds to way that activity is carried out and how the K-1 related practices with which it interacts are conducted. The firm’s overall marginal cost or quality is determined by the average of the assigned values for all its activities.

The implications of interdependencies in activity sets captured by the NK model are perhaps most easily understood using the imagery of a three-dimensional physical landscape (Kaufman 1989). Imagine mapping all possible activity sets along a two dimensional plane and defining a surface or ‘landscape’ above that plane where the height of that surface represents the cost or quality corresponding to each activity set. The firm’s objective in such a world is to find the highest ‘peak’ in that landscape.iii When there are no interdependencies among activities the landscape is gently sloping with a single peak. Any firm will find this peak simply by altering activities one-at-a-time and making individual alterations that improve performance at each step. This is not true, however, when interdependencies are present. The greater the number of activities that each activity relies on, the more rugged the landscape becomes – local optima proliferate – and no rapid algorithmic solution is known that can find the highest peak under these conditions (Rivkin 2000).

If the firm knows the way every activity would interact with every other K activities, an optimal activity set could quickly be determined by exhaustive computational. In practice, this problem is that firms must discover the way activities interact. Firms must engage in costly and time consuming data gathering and trial and error discovery to determine the nature of the interdependencies among activities and how these interdependencies affect the cost or quality coefficients. Therefore, firms are unable to quickly calculate a globally optimal decision and are forced to rely on experience and experiments to evaluate how changes in activities will affect and be affected by other activities.

We specify a repeated evolutionary game to capture firms learning the nature of the landscape. Firms evaluate and implement changes in activities by determining how those activities would complement or conflict with their current activities and by observing choices made by other firms. We
assume that all firms within an industry choose an initial set of activities and observe their own cost relative to competitors. After that, firms search for activity sets that will improve their cost. Improvements in cost are likely but not guaranteed to lead to higher profits as improvements by competitors offset gains made by a firm.

We examine the two primary categories of search – innovation and imitation – employed in previous research (Nelson and Winter 1982; Massini et al. 2005). In any given period, firms generally search only a small fraction of the enormous number of possible changes to their activity sets and concentrate their search on ‘local’ alternatives that involve relatively incremental modifications. Since there are an infinite number of variants possible for capturing limited and local innovative search, we adopt the basic innovative search model employed by Levinthal (1997). Firms consider only one change in an activity at a time and adopt any change that represents an improvement.\textsuperscript{iv} Imitation occurs in a similar manner to innovation in that firms only evaluate a subset of all possible changes at any given time. When imitating, however, firms adopt changes that will make them more like the best firm even if doing so lowers quality or raises costs due to conflicts with other activities.\textsuperscript{v}

As a practical matter, imitation and innovation take place simultaneously (Westney 1987; Szulanski 2000). The model includes a parameter ($\gamma$) which represents the likelihood that a firm searches for innovations or possibilities for imitation. A firm with $\gamma$ equal to zero will rely purely on internal innovation, but as $\gamma$ rises toward a value of unity the firm becomes increasingly and eventually totally reliant on imitation. Prior to each time period each firm considers altering each individual activity with probability $\theta$.$^vi$ In each period, firms adjust their activity sets then we determine the marginal cost, quality, total cost, quantities produced, prices, and profits for each firm before firms consider changing activities again.

The computational steps proceed as follows. Firms are endowed with a randomly generated set of activities. One firm decides whether to update its activities before the next period based on a logic of imitation (chosen with probability $\gamma$) or a logic of innovation that will be applied to all activity decisions
for that period. Then with probability $\theta$ that firm considers changing its first activity using the chosen logic. If that firm considers changing the activity and is following an imitation logic, the firm will mimic the activity choice of the most successful firm in the previous period industry. If that firm considers changing the activity and is following an innovation logic, the firm changes its activity choice if and only if it will improve its profitability in the industry given the current state of the world. The same logic is reapplied to each activity considered, taking into account any changes made in the activity set so far. Each firm continues through all activities in this manner. Since the choices are probabilistic and independent, the firm may consider changing no activities, a few activities, or potentially all activities.

We assume that firms will enter and exit the industry depending on the attractiveness of the industry and their ability to compete effectively in the industry. At any time $t$, we assume that there exists a pool of potential entrants. Potential entrants attempt entry in a given time period stochastically:

$$P(\text{entry}) = \min(\lambda \pi^\tau, 1),$$  \hfill (11)

where $\pi$ is average industry profits and $\lambda$ ($\lambda \geq 0$) and $\tau$ ($\tau \in 0, 1$) are parameters. The parameter $\tau$ allows us to investigate the effect of profits in encouraging entry with $\tau = 0$ means that profits do not affect entry.

Attempting entry and producing are not the same. Upon attempting entry, a firm calculates its expected profits based on knowledge of its own marginal cost (or product quality) and the marginal cost (or product quality) of all other competing firms. Incumbent firms and firms attempting entry will remain in the market if they anticipate positive profits in the following period.

4. Analysis & Results

To analyze the model, we rely on computational methods. During the course of our computational experiments, firms compete on cost and search for more productive combinations of activities. We generate the variation and selection of activity sets for each firm in the population according to its updating heuristic. We calculate the marginal cost, quality, total cost, quantities produced, prices, and profits for each firm according to our competitive model. Finally, firms enter and
exit the industry according to the specification described above. For each test environment (i.e. industry), this process is repeated for 100 time periods.

Overall, we simulated 50,000 test industries. Across test cases, we varied the updating heuristics firms use ($\gamma$) and the potential for interdependency of the industry (K). For each test case, we assigned the rate of change ($\theta$), the number of activities under consideration ($N$), demand parameters ($\alpha$, $\beta$, and $\rho$) and entry parameters ($\lambda$, $\tau$). We generate an industry production function (i.e., a cost landscape) by randomly drawing marginal cost equation coefficients from a uniform distribution ranging from zero to one. Finally, we randomly initialized firms’ activity sets ($s_i$) such that at entry each activity decision of a firm was equally likely to assume a value of zero or one.

Below we consider the results from these computational experiments.

4.1 Costs, Prices, and Demand

Our first observation is that industry average marginal cost declines over time (see Figure 1 graph A). This is a result of firms learning and discovering over time more fruitful combinations of activities that drive down marginal costs. The decline however is less pronounced for higher levels of interdependency (K). This is due to the increasing difficulty of discovering the best combinations of activities that lower costs. In the absence of interdependency (K=1), firms quickly converge on the optimal configuration of activities that minimize costs. At higher levels of interdependency, the search space becomes highly non-linear, leading to more firms getting trapped on local optima far from the best configuration of activities.

Consistent with the findings of Gort and Klepper (1982: 647), prices fall over time at a decreasing rate (see Figure 1 graph B). Prices in our Cournot competitive environment are a product of both industry average marginal costs and the number of firms in the industry. The decline in marginal costs over time,
therefore, is partly responsible for the fall in prices. Similar to marginal costs, the decline in prices is less pronounced for higher levels of interdependency. These lower prices lead to an increase in demand (i.e. total output) for the industry (see Figure 1 graph C) in the same pattern of decelerating growth identified by Gort and Klepper (1982: 645). Demand is greater in low K environments because prices are lower.

As for the average output of individual firms, we observe a sharp drop-off followed by a recovery (see Figure 1 graph D). So while industry demand is increasing, average firm output is decreasing. This is a direct result of entry. As the market expands, firms rush into the industry driving down average firm output. Over time the average output of individual firms within the industry increases as a shakeout occurs and firms exit the industry. Interestingly, this recovery is greatest for industries with moderate levels of latent interdependency. In the next section, we explore why this is the case.

4.2 Entry and Exit (Turnover)

Consistent with Gort and Klepper (1982), we observe rapid entry of new firms in the early stages of the industry increasing total industry participation (Figure 2 graph A). For industries with low interdependency in activities, the number of firms continues to increase but at a decreasing rate, eventually stabilizing as the number of new entrants approaches zero (Figure 2 graph B). While exit rates increase at first, eventually both the entry rate and exit rate decline leading to a relative stable number of long-lived players, in other words, low interdependency industries tend to have less turnover (entry plus exit). In contrast, industries with moderate to high interdependencies the number of firms rises rapidly at first but eventually declines as high rates of exit overtake declining entry rates (Figure 2 graph C). At the highest level of interdependency, both entry and exit rates remain high leading to high turnover (Figure 2 graph D).

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The high rate of turnover for high levels of K is a novel model prediction that has a fairly straightforward explanation based on the combined effects of competition and interdependencies. The viability of an entrant depends on their cost position relative to current prices and how much current prices will fall if the firm enters and how efficient the entrant is relative to current competitors. Low K environments are difficult to enter since many firms discover the most efficient possible configuration of activities (a logical outcome of low interdependencies) thus bringing current prices very close to the best possible cost position for a new entrant. Additionally, in low K environments there is a relatively high number of incumbent firms. When the number of firms is high in Cournot competition, (or generally in a conjectural variations environment), each firm and the industry overall contracts its output only a very small amount in response to a new entrant. As a result, industry output rises more and prices fall farther for any given size of entrant. This later effect can be shown analytically, if we assume that the entrant comes in at an average cost position, the change in incumbent firm output is (from Equation 5):

\[
\frac{\partial q_i^*}{\partial n} = -\frac{(\alpha - \bar{c})}{\beta(n + 1)^2},
\]

Since the first derivative of incumbent firm output with rising number of competitors (n) is negative, average incumbent firm contraction is smaller for larger industries. With less contraction, prices fall further (except in the unlikely case that the elasticity of demand falls with output, i.e., unless prices fall at a slower rate as output rises). Moderate K environments are more conducive to entry since there are fewer incumbents so the fall in total output of incumbents will be greater and the fall in prices will be smaller. Furthermore, firms are less efficient on average increasing the likelihood that an entrant will have a competitive cost structure even after prices fall. High K environments generally have a slightly higher number of incumbents than moderate K environments causing prices to fall by a greater amount, but incumbents are even less efficient on average leading to even greater entry opportunities. The greater concentration and lower efficiency that result from the combination of high interdependencies and a conjectural variations output decision leads to greater sustained entry.
In general, the observed turnover in our model is consistent with the empirical observations of Caves (1998). In particular, Caves reports that entry and exit occur primarily among small firms. The model behaves similarly with entering and exiting firms being well below the average size of firms within the industry. Figure 3 graphs A and B, present the average deviation from industry average firm output for firms entering and exiting the industry respectively. The entry result follows naturally from the efficiency disadvantage entrants face (since they lack a history of incremental learning) and from the conjectural variations attribute of the Cournot model that less efficient firms produce less. The exit result follows from the same Cournot artifact that firms produce less when they are less efficient than others within the industry with exit being simply the endpoint of contraction.

As a result of these differences in turnover rates, industry concentration varies significantly over time and between different interdependent environments (see Figure 3 graph C for the average industry Herfindahl index). In low K environments, industry concentration falls as firms rush into the industry and stabilizes at a rather low concentration level. For more interdependent environments, industry concentration climbs back up after the shake-out though less so the higher the interdependency. This helps explain the differences in industry average output observed in Figure 1 graph D. For low levels of K, there is massive entry and competition, suppressing the output of individual firms even though efficiency and competition lead to high overall industry output. For moderate levels of K, even though overall industry efficiency and output is lower than at low levels of K, the shakeout leads to a small stable set of firms who grab large market shares. For higher levels of K, there is continued high turnover and low efficiency, leading to lower concentrations where more firms take a smaller share of lower total industry output.
4.3 Growth and Decline (Mobility)

High turnover would suggest that at any point in time, some firms within an industry will be growing while others are declining. Caves (1998) confirms that growth rates are clearly not very highly correlated among firms within an industry over any period of time. A consistent pattern is observed within the model. We see both a high percentage of firms growing and a high percentage of firms shrinking (see Figure 4 graphs A and B) even though overall output is increasing (Figure 1 graph C). This variance in growth rates increases at first but then declines though less so for higher K environments. This result is driven in part by turnover, but it is also driven by differences in improvement rates across firms. These differences in improvement rates arise because of the differences in the potential to improve given a firm’s current configurations of activities (e.g., is a firm “trapped” at a local optima?, is the firm at the base of a very big hill?). Firms that fail to improve see their market share decrease as other firms lower their marginal costs and expand their output. This explains why we see high variance in growth rates even in highly concentrated industries (such as moderately interdependent environments) – a finding consistent with empirical evidence and a source of puzzlement to Caves (1998).

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Insert Figure 4 about here
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Caves’ (1998) further observed that variance in growth rates falls with firm size and mean growth rates decrease with both firm size and firm age. These same patterns are observed in the model (see Figure 4 graphs C, D). In general, growth rates decline with size and age with very small, young firms the most likely to grow and large, old firms on average staying the same size. Notably, in high K environments, our model predicts that small to moderate size firms are on average likely to contract output. This effect may reflect a threshold for the efficiency of a configuration of activities where firms have peaked in their technological trajectories (i.e., they are unlikely to improve) and thus are likely to contract (due to a fall in relative performance as others improve). Also of note, in low K environments,
we observe that very large firms are likely to contract. This result is primarily driven by early entrants who take a large share of the market and later cede some of the market to entrants.

### 4.4 Profits and welfare

One can surmise from the results presented what the effects on profits will be. For low K environments, industry average profits begin high as a few firms discover profitable ways of organizing production but fall dramatically as entry occurs, stabilizing quickly at low levels (see Figure 5 graph A). In effect, low K environments rapidly become perfectly competitive markets that drive out economic rents. This is consistent with standard strategy ideas of the rapid imitation of resources (firms quickly discover the optimal configuration of activities) leading to a fall in profits. For moderate levels of K, industry average profits begin low as industry pioneers struggle to find good combinations of activities. They suffer further in the short run as additional firms enter the industry. Eventually, however, some firms discover better ways of organizing production. This results in a shakeout where the firms with the best marginal costs force out underperformers in the industry. Industry concentration and average profits increase over time as the industry is left with a handful of large, low cost firms. For high levels of K, firms struggle to find good configurations of practices. Over time industry average profits improve but slowly. There is high turnover as new entrants come up with alternative activity combinations that are marginally better than existing combinations.

Further evidence is found by looking at the variance in industry profits (see Figure 5 graph B). In low K environments, all firms quickly discover the optimal configuration of practices driving down intra-industry variance. In moderate K environments, variance increases quickly as some firms discover better (low cost) configurations of practices than their rivals. Variance begins to decline as higher costs rivals exit the market but does not fall completely as there continues to be new entrants trying to survive at the
margins. In high K environments, variance also increases over time but less so than in moderate K environments. This reflects once again the difficulty in finding good configurations of practices in these environments. While there is much heterogeneity in the ways firms organize production, the variance in marginal costs and hence the variance in profits is lower.

Closely following these patterns is the average profits of the industry leader (i.e., the firm with the highest profits at any point in time) (see Figure 5 graph C). The industry leader sees their profits collapse as entry occurs in low K environments. In moderate K environments, the profits of the industry leader increase dramatically as leaders separate themselves from the pack. In high K environments, we see a similar increase in profitability of leading firms but not as pronounced as in mid K environments.

Finally, from a policy standpoint, we may be interested in the welfare implications of different levels of interdependency. In Figure 5 graph D, we present the sum of consumer surplus and industry profits over time. In all cases, we see welfare increasing over time due to increasing efficiency. We observe this pattern even in moderate K markets where a shakeout reduces the number of firms and competitive intensity. Since the number of firms depends both on average efficiency and on the distribution of efficiency among firms, this indicates that changes in the distribution of efficiency levels among firms over time produced by interdependencies are not so great as to lead to a drop in welfare from period to period. This indicates that a society would not be better off if it could freeze the technological advance at some level to avoid a shakeout and subsequent decrease in competitiveness. Technological progress in this model is good even if it leads to greater concentration and monopoly power.

This last finding provides some interesting insight into the historic debate about the locus of innovation. Joseph Schumpeter in his early work proposed new entrants (entrepreneurs) were responsible for productivity gains. In later work, he argued that only large incumbent firms would have the scale to justify investment in R&D and consequently were more likely to drive innovation. Our model provides a potential resolution to the two sides of Schumpeter. In low K environments, incumbent firms contribute the vast majority of the overall industry efficiency improvement found during the period of simulation. This result occurs due to the low rate of entry, the high survival rate of incumbents, and the high
likelihood that all firms will quickly attain the most efficient possible set of activities. As K rises, increased entry and exit and the falling probability that early entrants will achieve highly efficient sets of activities means that incumbents account for a falling share of efficiency improvement. With the parameters chosen for the model, the drop off in the importance of incumbent innovation is quite dramatic. Incumbents contribute over 90% of the efficiency gains for low K, less than 70% of the gains for moderate K and less than 25% of the efficiency gains for high K.

5. Discussion

Across a number of literatures, a broad and robust set of empirical regularities have been observed with regards to industry evolution. This model is able to recreate the patterns observed in industry output (increasing at a decreasing rate), prices (steady decline at a decreasing rate), industry participation (rapid entry is followed by mass exit leading to a shakeout and stable number of competitors), inventive activity (continued but with less substantial innovations), and market shares (leading firm shares are more spread out) along with many and perhaps most of the other observed patterns summarized in Table 1. Notably, the model explains these patterns absent the central mechanisms of past models which relied on convex adjustment costs and scale economies in learning and instead gives center stage to a richer understanding of the managerial challenges involved in improving the internal workings of firms.

The results, particularly those that provide insights beyond known stylized facts, depend on the combination of a model of competition with a representation of interdependencies. This is clearest when we look at patterns that differ with the extent of interdependencies among activities. For example, understanding entry and exit requires us to know the profitability of entering and exiting which cannot be determined without a clear competitive model that generates output levels for competing firms and industry price levels. Entry and exit also differ substantially with the level of K which both provides a direction for empirical studies but potentially explains why not all industries undergo a shakeout and why
the shakeout in some industries is far more dramatic than in others. A model that only allowed for stochastic effects on learning and no interdependencies would be equivalent to the model when $K=1$ in which case no shakeout would occur, entry and exit would fall to zero, and all industries would have low concentration.

As a result, our model is able to provide explanations for a number of theoretical and empirical conundrums. For example, we provide an explanation for why we may observe high variance in growth rates even in highly concentrated industries: interdependencies create different potentials for improvement among firms, leading to contraction among leading firms as higher potential laggards and new entrants eventually improve and overtake leaders. This findings is consistent with empirical evidence, but is not explainable in models that rely on convex adjustment costs and scale advantages in innovation (e.g., Ericson and Pakes 1995; Klepper 1996). Our model also provides a potential resolution to the debate between the “old” and “new” Schumpeter about the growth contributions of incumbent firms versus new entrants. In low interdependent industries, incumbent firms are more likely to innovate and drive growth. In high interdependent industries, new entrants (entrepreneurs) are more likely to drive innovation and growth.

In general, our results emphasize the importance of experimentation relative to incremental learning in industries with high interdependency in activities. While new entrants lack the opportunity for incremental learning that results from past production, they have a greater likelihood of considering a novel configuration of activities than incumbents. While we’ve assumed a strong form of experimentation for entrants (they choose randomly), entrants will have an advantage as long as the pool of potential entrants are more likely to consider a broader set of configurations than incumbents. One might conclude that incumbents should widely experiment with configurations to replicate entrants’ proclivity for novelty. However, to the extent that there are costs to experimentation and limits to the amount of experimentation a firm can undertake in any given time period, a large population of potential entrants is at an advantage simply in the number of experiments they will run. This does not necessarily
mean it is better to be a potential entrant, only that potential entrants are a greater threat in high interdependency environments.

5.1 Limitations

For the sake of parsimony, there are a number of simplifying assumptions that we make that may not match with competitive reality. As we have highlighted throughout the paper, we assume that there are no adjustment costs or scale advantages in innovating and learning. We do this to isolate the mechanisms of interest to us (interdependencies) versus previous treatments by Klepper (1996) and Ericson and Pakes (1995). We do not want to suggest that such costs and scale advantages do not exist. We simply want to point out that interdependencies are sufficient absent these mechanisms to generate many of the stylized facts about industry evolution and that they provide additional novel insights not found in previous models.

For our analysis, we assume that managers are rather myopic. When deciding to enter or exit the industry, managers look at their current profitability relative to other firms within the industry. If firms have different expectations about their improvement rates vis-à-vis their rivals, firms may be willing to expect losses in the short run with expectation of higher profits in the future. Adding greater managerial foresight, however, is likely to exacerbate many of our findings. In low interdependency environments, new entrants will recognize that they are unlikely to catch incumbents and will be even less likely to invest in innovation or even enter the industry. In high interdependency environments, new entrants realize higher improvement rates than incumbents and thus will be willing to tolerate losses in the short run, increasing entrepreneurial entry and turnover.

As a result of these assumptions concerning managerial myopia and no adjustment costs and scale advantages, we choose not to explicitly model the inputs to search (e.g., R&D) as an endogenous choice of the firm. In our model, all firms are assigned a constant search strategy \( \gamma \). One could imagine allowing firms to adjust \( \gamma \) given their position relative to rivals. Furthermore, one could assign different
costs to different search strategies, e.g., the costs of innovation could be more or less than the costs of imitation. We choose not to model this process because such an addition should only have an effect on our results if we included adjustment costs or scale advantages to innovating (which we purposefully do not wish to include in the model). In future work, we plan to include such additions as they do allow us to explore a host of interesting questions about favorable search strategies in interdependent environments.

The desire to provide a simple model imposes some limitations on the phenomena that we can explain. There are a host of known stylized (and likely some yet undocumented) regularities that this model does not address such as patterns of change in ownership (Caves, 1998), diversification, and changes in the balance of research and development efforts on products and processes (Klepper, 1996). Small extensions to the model may allow the model to explain some of these patterns. However, more substantial extensions to the model are likely necessary to explain all of these patterns (such as changes in ownership). We leave these to future work.

5.2 Empirical Strategies

Analyzing the model reveals how industry dynamics vary given the underlying interdependency in the firm’s production function. To the extent that we can develop reasonable proxy measures for interdependency, each of these dimension on which industry dynamics vary becomes a potential target for empirical research. For industries with a moderate range of interdependency we expect: the greatest drop than rebound in average firm output; greater increases and later drop in the number of competitors; greater and more rapid increases in concentration during the shakeout; and the presence of highly profitable leading firms and early emergence of highly profitable firms. Perhaps most intriguing is the result that, in mid-range interdependency industries, variance in profits eventually falls even as average profits continue to rise (see Figure 5 graphs A and B). If carefully analyzed, this result would produce a negative correlation between industry profits and variance in profits apparently at odds with Demsetz (1973) argument that variance among firms is responsible for high industry profits.
Even without direct measures of interdependency, however, analysis of the model reveals interesting patterns of industry dynamics that can be explored. We expect that marginal cost declines will be considerably lower in some industries (those with greater interdependency among activities) and these industries will not only see slower price declines, smaller increases in output, and lower welfare gains as we would naturally expect when costs fall more slowly in a competitive setting, but these industries will also see higher turnover with greater rates of both exit and entry than other industries. This is in many ways a surprising result; the least technologically progressive industries attract the greatest apparent attention of new entrants despite average to poor profitability and in doing so create the greatest risk for incumbents of being replaced.

6. Conclusion

A fundamental understanding of industry evolution is critical to strategy research. The mechanisms that impart advantage for some firms over others should be evident in their effects on industry dynamics and their efficacy will likely be altered with the course of industry evolution. In this paper, we develop a model of industry evolution based on the presence of interdependencies among firm’s potential productive activities. We demonstrate that the model can explain many of the stylized facts that have accumulated about industry evolution. More importantly, our model provides novel insights into why patterns may vary across industries.

By providing a rival explanation for industry evolution based on interdependencies and complementarities rather than convex adjustment costs or scale advantages in innovation and learning, we have endeavored to create a closer link between key ideas stimulating work in business strategy and research on industry structure and dynamics. Strategy researchers have long relied on limitations to search and imitation to explain sustained heterogeneity among firms (Lippman and Rumelt 1982; Barney 1986; Carroll 1993; Levinthal 1995). Recent strategy research has provided a leap forward in formalism by using the NK model (Levinthal 1997; Rivkin 2000) to represent basic concepts such as
‘interconnectedness’ and ‘causal ambiguity’ (Dierickx and Cool 1989) that have long intrigued researchers in the strategy field. These concepts are a natural element of a field that originated with questions of how managers understand connections and make tradeoffs among narrower functional considerations.

The study of the effects of interdependencies on industry evolution provides a very useful mechanism for strengthening the connections between both past and future strategy research at the firm and industry level. The robust set of empirical regularities that have been observed with regards to industry evolution are a boon to strategy researchers only if the models to explain those behaviors contain the concepts at the center of strategy research. The marriage in this paper of a formal model of competition with an explicit representation of constrained search due to interdependency provides a bridge between firm-level theorizing in strategy with industry-level theorizing and empirical work on industry dynamics.
References


Lenox, M., S. Rockart, and A. Lewin (forthcoming) "Interdependency, Competition and the Distribution of Firm and Industry Profits" Management Science


<table>
<thead>
<tr>
<th>Stylized Facts</th>
<th>References</th>
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<tbody>
<tr>
<td>1. Rate of growth in output declines rapidly with time and tends to converge to zero</td>
<td>Gort &amp; Klepper (1982)</td>
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<tr>
<td>2. Prices decline fairly steadily and at a decreasing rate over time</td>
<td>Gort &amp; Klepper (1982)</td>
</tr>
<tr>
<td>3. Rapid entry of firms is followed by a mass exit (a “shakeout”)</td>
<td>Gort &amp; Klepper (1982)</td>
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<tr>
<td>4. Inventive activity does not seem to decline with time</td>
<td>Gort &amp; Klepper (1982)</td>
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<tr>
<td>5. Earlier innovations contribute more to industry growth than later innovations</td>
<td>Gort &amp; Klepper (1982)</td>
</tr>
<tr>
<td>6. A firm’s likelihood to exit the industry rises with the age of the industry</td>
<td>Gort &amp; Agarwal (1996)</td>
</tr>
<tr>
<td>7. A firm’s likelihood to exit the industry declines with its age and size</td>
<td>Gort &amp; Agarwal (1996), Caves (1998)</td>
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<td>8. Leading firm shares are more spread out</td>
<td>Caves (1998)</td>
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<td>10. A firm’s mean growth rate declines with size and age</td>
<td>Caves (1998)</td>
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<td>11. Entry is more likely in smaller size classes</td>
<td>Caves (1998)</td>
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<td>12. The likelihood of exit decreases with size</td>
<td>Caves (1998)</td>
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<td>13. Firms growth rates are largely uncorrelated within industries</td>
<td>Caves (1998)</td>
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<td>14. Firm size has a long run regression to the mean</td>
<td>Caves (1998)</td>
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<tr>
<td>15. Smaller firms have more variable shares</td>
<td>Caves (1998)</td>
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<td>16. Leading firms maintain their lead for long periods of time</td>
<td>Caves (1998)</td>
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<tr>
<td>17. Higher turnover has a greater effect on concentration when firm shares are similar</td>
<td>Caves (1998)</td>
</tr>
<tr>
<td>18. Changes in incumbent market share are high in labor intensive and product differentiated industries but low in scale-based industries</td>
<td>Caves (1998)</td>
</tr>
<tr>
<td>19. High net entry is correlated with industry profit</td>
<td>Caves (1998)</td>
</tr>
<tr>
<td>20. High turnover (entry and exit) is correlated with high industry profits</td>
<td>Caves (1998)</td>
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Figure 1: Cost, price, and output over time at varying levels of complementarity

Notes: To increase comparability, we graphed the results from simulations with firms making decisions about twenty critical business practices (N=20) where the practices range from completely independent (K=1) to completely interdependent (K=N). For the analyses presented, we set parameters $\gamma = 0.2$, $\alpha = 1$, and $\beta = 1$. Sensitivity analysis found that the general patterns presented persist at various parameter values.
Notes: To increase comparability, we graphed the results from simulations with firms making decisions about twenty critical business practices (N=20) where the practices range from completely independent (K=1) to completely interdependent (K=N). For the analyses presented, we set parameters $\gamma = 0.2$, $\alpha = 1$, and $\beta = 1$. Sensitivity analysis found that the general patterns presented persist at various parameter values.
Figure 3: Concentration and share of entrants and exiting firms at varying levels of complementarity

Notes: To increase comparability, we graphed the results from simulations with firms making decisions about twenty critical business practices (N=20) where the practices range from completely independent (K=1) to completely interdependent (K=N). For the analyses presented, we set parameters $\gamma = 0.2$, $\alpha = 1$, and $\beta = 1$. Sensitivity analysis found that the general patterns presented persist at various parameter values.
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Figure 5: Profits and welfare over time at varying levels of complementarity

Notes: To increase comparability, we graphed the results from simulations with firms making decisions about twenty critical business practices (N=20) where the practices range from completely independent (K=1) to completely interdependent (K=N). For the analyses presented, we set parameters $\gamma = 0.2$, $\alpha = 1$, and $\beta = 1$. Sensitivity analysis found that the general patterns presented persist at various parameter values.
Portions of this section are excerpted from Lenox, Rockart, & Lewin, forthcoming.

For the sake of simplicity, we refer to activities, practices and resources simply as activities and the possible combinations of the activities, practices and resources as ‘activity sets.’

We will refer to the highest peak as being the most efficient point in order to sustain the imagery, though in fact firms are seeking the lowest marginal cost in the undifferentiated competitive model.

Variants on this innovative search strategy have been employed by other researchers. Rivkin (2000) broadens the search and focuses changes by assuming firms evaluate all alternative activity sets with up to M changes from the current activity set and select the very best one. Levinthal (1997) also considers the possibility of innovative ‘long-jumps’ where a firm considers a single randomly drawn alternative where as many as all elements of the activity set may change. Rivkin and Siggelkow (2003) and others also consider the effects of organizational structures that divide search and evaluation into subsets of firms’ activities.

Imitation, like innovation, has been modeled in varying ways. For example, Rivkin (2000) allows firms to imitate on many dimensions at once but with error.

In each period, a firm has the potential to consider altering each of its resource decisions. Given the probability (θ) of considering one resource decision, the probability of considering all resource decisions is θ^N. Thus for θ = 0.10 and N = 10, the likelihood of considering altering at least one decision is 65% (1-(1-θ)^N) and all decisions is 0.00000001%. We emphasize that considering altering a resource decision does not necessarily mean a firm will alter a decision.

All else being equal, improvements in cost or quality will lead to increases in profits. Thus, the results are identical if firms choose activities that improve cost or quality rather than profits.

We experimented with profit hurdle rates greater than zero and found that they have no effect on the results presented in this paper. Higher hurdle rates decrease the likelihood of entry and increase the likelihood of exit, but do not affect the general patterns presented here.

One of the interesting features of NK environments is that the greater the potential for interdependency in activities, the better the best possible low-cost (or high quality) configurations of activities (Kaufman 1989). In other words, the best position achievable (the global optima) improves as the number of interactions (K) among activities rises. To increase comparability across industries, we decided to eliminate this feature of the NK specification by expressing individual firm marginal cost as one less the percent global attained plus a constant so that higher values indicate lower cost. A constant is included to assure that the best achievable marginal cost is greater than zero. Varying this constant has no bearing on our results.

We assume α=1 and β=1. Assuming α=1 is simply a scaling of the overall demand curve and does not, therefore, limit generalizability of the results. If one substitutes the individual production quantity function (equation 5) into the profit function (equation 4) it is clear that the slope of the demand curve β directly raises or lowers the output and gross margin for firms but does not change the relative output or relative gross margins among firms. By scaling gross margins up or down, however, more elastic demand will increase the disparity in profits among firms when there are positive fixed costs. This result will be revisited later in the paper as it becomes relevant to reported results.

For the results presented, we assume a pool of 20 potential entrants. Assuming a likelihood of attempted entry of 50%, the probability that all 20 firms would attempt enter simultaneously is 0.000001. We experimented with larger and smaller pools and found that they did not substantively affect the results reported.

It is important to note that the comparison we are noting is among industries with different levels of potential for interdependency. Casual conversation sometimes suggests that innovative firms or technologies “create” new complementarities. We treat such innovations as occurring within the model whenever three or more activities interact (K>2) and a firm changes one of these activities so that it is now more valuable to do two other activities in a given way than it was before.

We calculate the contribution of incumbents to efficiency by calculating the change in share-weighted average efficiency of firms who survived from the start of the industry and dividing this by the change in the share-weighted efficiency of firms at the start and end of the industry.