**DYNAMIC CAPABILITIES AND THE EMERGENCE OF
INTRA-INDUSTRY DIFFERENTIAL FIRM PERFORMANCE:
INSIGHTS FROM A SIMULATION STUDY** [*]

By

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Abstract

This paper explores how the dynamic capabilities of firms may account for the emergence of differential firm performance within an industry. Synthesizing insights from both strategic and organizational theory, four performance-relevant attributes of dynamic capabilities are proposed: timing of dynamic capability deployment, imitation as part of the search for alternative resource configurations, cost of dynamic capability deployment, and learning to deploy dynamic capabilities. Theoretical propositions are developed suggesting how these attributes contribute to the emergence of differential firm performance. A formal model is presented in which dynamic capability is modeled as a set of routines guiding a firm's evolutionary processes of change. Simulation of the model yields insights into the process of change through dynamic capability deployment, and permits refinement of the theoretical propositions. One of the interesting findings of this study is that even if dynamic capabilities are equifinal across firms, robust performance differences may arise across firms if the costs and timing of dynamic capability deployment differ across firms.

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1. INTRODUCTION

Despite at least two decades of empirical and theoretical research attempting to answer the question "Why are firms different?", a satisfactory answer continues to elude researchers in strategic management (Rumelt, Schendel, and Teece, 1994). A related, yet more focused, question is: "Why do firms perform differently?" These questions have captured researchers' interest because although economic theory predicts that differences among rival firms will be eliminated over time by competition, empirical evidence has shown this not to be the case. By disaggregating business-unit profits into components capturing industry effects, corporate-parent effects, and market share effects, Schmalensee (1985) demonstrated the importance of industry effects on firm performance. Extending Schmalensee's approach, Rumelt (1991), McGahan and Porter (1997a), and McGahan (1999) showed that business effects were approximately twice as important for performance as industry effects. Their results have contributed to a refinement of the original research question: "Why do firms *in the same industry* perform differently?", which is the focus of this study.

The resource-based view (RBV) of the firm broadly answers this question as follows. Firms in the same industry perform differently because, even in equilibrium, firms differ in terms of the resources and capabilities they control (Amit and Schoemaker, 1993; Barney, 1986; Dierickx and Cool, 1989; Penrose, 1959; Peteraf, 1993; Wernerfelt, 1984). Early explanations of why firms within the same industry had differential stocks of resources and capabilities included luck and/or superior information about the expected value of resources (Barney, 1986). More recently, strategy scholars have begun to explicitly acknowledge the importance of acquiring, developing, and maintaining differential bundles of resources and capabilities over time (e.g., Collis, 1994; Dierickx and Cool, 1989; Henderson and Cockburn, 1994; Iansiti and Clark, 1994; Kogut and Zander, 1992; Szulanski, 1996; Zander and Kogut, 1995). In particular, the dynamic-capability construct, which refers to "the firm's ability to integrate, build and reconfigure internal and external competencies to address rapidly changing environments" (Teece, Pisano and Shuen, 1997:516), has been used to explain why firms in the same industry are different. Yet, while strategic management research has

uncovered the characteristics of *resources and capabilities* and the market conditions that permit sustainable competitive advantage (e.g., Amit and Shoemaker, 1993; Barney 1991, 1997; Peteraf, 1993), little is known about the ways in which *dynamic capabilities* affect the emergence of differential intra-industry firm performance. In this paper, I attempt to address this gap in the strategic management literature by conceptually and analytically linking dynamic capability with firm performance. A model is presented that captures the system dynamics engendered by dynamic capability deployment and helps explain the emergence of differential intra-industry performance.

The basic premise adopted in this paper is that dynamic capabilities are indirectly linked with firm performance. It is argued that dynamic capabilities are embedded in routine organizational processes aimed at changing the firm's resources, operational routines, and competencies. These processes act as mediating constructs between dynamic capabilities and firm performance. Based on this argument, performance-relevant attributes of dynamic capabilities are identified by synthesizing insights from both strategic and organizational theory. These attributes include (1) the timing of dynamic capability deployment, (2) imitation as part of the search for alternative resource configurations, (3) the cost of dynamic capability deployment, and (4) learning to deploy dynamic capabilities. It is suggested that relative firm performance is affected by *when* a firm changes (timing), *how* it searches for viable alternatives (search direction), *how costly* the change is (cost), and *whether* the firm *learns* to change (learning).

The theory development in this paper is supported by the construction and simulation of a formal model. The model offers some insights into the process of change engendered by dynamic capability deployment and permits refinement of the theoretical propositions. One of the interesting findings of this study is that even if dynamic capabilities are equifinal[1] across firms, robust performance differences may arise across firms if the costs and timing of dynamic capability deployment differ across firms.

The paper is organized as follows. The following section consolidates the notion of dynamic capability and reviews the received literature on how dynamic capabilities influence the performance of firms. In section three, the performance-relevant attributes of dynamic capabilities are theoretically derived. Based on these attributes, several propositions are offered linking dynamic capability to the emergence of intra-industry

differential firm performance. A formal model of intra-industry competition is presented in section four. This is followed in section five by a description of how dynamic capabilities affect competition among the firms in the model. The model is subsequently analyzed using computer simulation; the simulation results are reported and discussed in section six. The paper concludes with a summary of the main results and several suggestions regarding future research.

2. DYNAMIC CAPABILITIES AND FIRM PERFORMANCE: AN INDIRECT LINK

2.1. What are dynamic capabilities?

Relatively little is known about how dynamic capabilities affect firm performance partly because the large number of definitions that have been proposed for the construct has made it difficult to reach any consensus on the issue. I therefore begin this section by identifying the key conceptual elements of dynamic capability that are consistent with the various approaches suggested in the literature. This consolidation of the various strands of the literature on dynamic capabilities facilitates the construction of the link between dynamic capabilities and firm performance and serves as the basis for the formal model presented below.

The emerging consensus in the field of strategic management suggests that dynamic capabilities are (1) embedded in organizational processes, (2) captured by firm routines and (3) directed toward effecting change. A possible framework for integrating these various elements is offered by evolutionary theory (e.g., Nelson and Winter, 1982) which suggests that dynamic capability is embedded in routine processes for variation, selection, and retention of a firm's resources, capabilities, and operational routines.

Dynamic capability as embedded in organizational processes. While Dierickx and Cool (1989) emphasize the importance of asset accumulation processes for achieving superior output market positions, Amit and Schoemaker (1993) focus on information-based processes to deploy, rather than accumulate, resources. These studies provide evidence that the essence of dynamic capability is rooted in the firm's organizational processes (Teece, Pisano and Shuen, 1997). Strategy scholars are in broad agreement that the overarching theme of capabilities is the importance of processes (e.g., Eisenhardt and Martin, 2000; Iansiti and Clark, 1994; Kogut and Zander, 1992; Nelson and Winter, 1982).

Dynamic capability as routines. Dynamic capabilities are learned, regular patterns of organizational

activity (Zollo and Winter, 1999), which can be termed "routines" (Nelson and Winter, 1982). Dynamic capabilities as socially complex routines (Collis, 1994) embody a firm's current stock of knowledge that constrains and shapes the development of new knowledge (Zander and Kogut, 1995). This view is consistent with the notion of path dependencies that arise in the context of dynamic capabilities (Teece, Pisano and Shuen, 1997).

Dynamic capability as directed toward effecting change. A striking common denominator of the theoretical and empirical work on dynamic capabilities is its strong emphasis on change. Dynamic capabilities serve to change a firm's capabilities, knowledge, and competencies (Kogut and Zander, 1992; Iansiti and Clark, 1994; Zander and Kogut, 1995; Teece, Pisano and Shuen, 1997), its operational routines (Collis, 1994; Zollo and Winter, 1999), and its resource configurations (Eisenhardt and Martin, 2000; Galunic and Eisenhardt, 2000). The growing body of empirical literature on firms' routinized change processes has even produced evidence of innovation routines within firms (e.g., Benghozi, 1990; Brown and Eisenhardt, 1997; Chapman Wood, Hatten and Williamson, 1999).

Dynamic capability as evolutionary learning. Taken together, the conceptual building blocks of dynamic capability identified above suggest that the construct is embedded in routine sub-processes or activities that guide the evolution of a firm's resources, capabilities, and operational routines (Helfat and Raubitschek, 2000; Nelson and Winter, 1982; Zollo and Winter, 1999). These routine sub-processes can be classified under the broad c ategories of variation,[2] selection,[3] and retention,[4] which, despite their connotation as drivers of an evolutionary process (Campbell, 1965), characterize *any* decision-making or problem-solving activity (for example, see Iansiti and Clark, 1994). Helfat and Raubitschek (2000:975) stress the importance of learning as an essential part of dynamic capability: "Systems of learning are prime examples of dynamic capabilities (Teece at al., 1997), since these systems are fundamental to the ability of organizations to innovate and to adapt to changes in technology and markets."

2.2   Dynamic capabilities and firm performance

There is increasing evidence demonstrating that dynamic capabilities are linked with firm performance. Henderson and Cockburn (1994) attest that "architectural competence" in the pharmaceutical

industry, that is, a firm's ability to integrate knowledge from external sources, is positively associated with research productivity as measured by patent counts. Iansiti and Clark (1994) studied "integration capability" in the automobile and computer industries and found broad empirical support for their hypotheses that a firm's knowledge integration capability in product development is positively correlated with positive firm performance and with performance improvements over time. Kale (1999) reports that knowledge articulation and codification, potentially important antecedents of dynamic capability, help explain higher joint venture success rates across various industries. Similarly, in their study of post-acquisition integration processes in the banking sector, Zollo and Singh (1998) found that acquirers who devoted more effort to codifying their integration processes significantly improved their return on assets relative to competitors.

Despite the progress made in the empirical investigation of the phenomenon, there are few theories on how dynamic capability affects relative firm performance. Collis (1994:149) suggests that higher-order organizational capabilities such as dynamic capabilities "allow firms to overcome the path dependency that led to the inimitability of the lower-order capabilities." This implies that dynamic capabilities undermine competitive advantage, since they erode the rents of successful firms stemming from valuable, rare, and inimitable "lower-order" capabilities by providing rivals with substitute or superior capabilities. Eisenhardt and Martin (2000) propose a different logic, albeit with similar implications. They argue that dynamic capabilities are typically valuable and rare (i.e., they are not possessed by all competitors equally), but are equifinal and hence neither inimitable nor immobile. They argue that this quality implies that dynamic capabilities can be a source of competitive but not sustainable advantage.

While the above studies offer valuable insights regarding the effect of dynamic capabilities on the *sustainability* of differential firm performance, little is known about how dynamic capabilities affect the *emergence* of the phenomenon. The framework used in the present study to address this gap is illustrated in Figure 1. The framework builds on the working definition of dynamic capability as routine processes directed toward change.

Dynamic capabilities create and shape a firm's resource positions (Eisenhardt and Martin, 2000), capabilities (Kogut and Zander, 1992), operational routines (Nelson and Winter, 1982) and activities (Porter,

1985, 1994). In turn, these mediating variables determine the firm's product market position and therefore its performance. This chain of causality implies an indirect link between dynamic capability and firm performance (see Figure 1). The processes by which firms accumulate their strengths and capabilities, which in this paper are referred to as dynamic capabilities, and which Amit and Schoemaker (1993) characterize as "intermediate goods" generated by the firm to provide enhanced productivity of its resources, are a logical prior to firms' resources and capabilities.

[INSERT FIGURE 1 ABOUT HERE]

Based on this framework, it is not immediately clear whether the conditions for creating and sustaining competitive advantage that hold at the level of product market positioning (Porter, 1985) or at the level of factor market sourcing (Barney, 1991; Peteraf, 1993) apply at the level of dynamic capabilities. At the level of factor market sourcing, several conditions for sustainable competitive advantage have been advanced: (1) resource heterogeneity or heterogeneity in output market positions, (2) ex-ante limits to competition, (3) ex-post limits to competition, and (4) imperfect factor mobility (Peteraf, 1993). Another set of criteria introduced by Barney (1991) suggests that only resources that are valuable, rare, and inimitable can serve as a basis for sustainable competitive advantage. Unfortunately, these conditions have only limited validity when applied to dynamic capabilities. Consider two firms that possess identical dynamic capabilities (thus leaving the condition of heterogeneity unfulfilled). Even under these circumstances firms may use their capabilities to build differential resource positions, which may then lead to differing firm performance. This follows directly from the framework outlined in Figure 1. For example, if a firm with strong transfer capabilities (Zander and Kogut, 1995; Szulanski, 1996) has a rival with similar capabilities, it may simply move into a different, more profitable market faster than its rival. Or if a firm with strong acquisition competence (Zollo and Singh, 1998) faces a competitor who is also an eager and skilled acquirer, it may simply locate a different target firm. Analogous reasoning shows that even if the conditions of inimitability and non-substitutability of dynamic capabilities are violated, firms may build differential resource positions that may account for differential performance. This raises two important questions that are addressed in the next section: (1) What are the attributes of dynamic capabilities that affect firm performance, and (2) How do they contribute to the

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emergence and sustainability of differential intra-industry performance?

3. DYNAMIC CAPABILITY ATTRIBUTES AND THE EMERGENCE OF DIFFERENTIAL INTRA-INDUSTRY FIRM PERFORMANCE

This section attempts to identify some performance-relevant attributes of dynamic capabilities. It is argued that the timing of change and the direction of search – either outward-focused imitation of rivals or inward-focused experimentation with firm-specific solutions – as well as the costs of dynamic capability deployment are relevant to understanding the emergence of intra-industry differential firm performance. The cost argument is further differentiated to distinguish among cost effects and learning effects. The theoretical anchoring of these ideas is presented, and theoretical propositions are developed linking dynamic capability to the emergence of differential intra-industry performance on the basis of the respective attributes.

3.1. Timing of dynamic capability deployment (Attribute 1)

Differential timing of dynamic capability deployment can result either from deliberate attempts to move first (Lieberman and Montgomery, 1988), or from the reluctance of firms to take action, which may, for example, be due to organizational inertia (Stinchcombe, 1965; Hannan and Freeman, 1977; Sastry, 1997). It may also result from "randomness in competition" (Porter, 1994), or from luck (Barney, 1986). Moving first in an industry can bestow powerful advantages on a firm — it can lead to technological leadership, preemption of strategically valuable assets, or the creation of consumer switching costs (Lieberman and Montgomery, 1988). Enacting adaptive change faster than rivals may also enable the first mover to earn Schumpeterian rents, that is, rents that occur during the period of time between the introduction of an innovation and its imitation or substitution by rival firms. Consistent with these arguments, Porter (1985, 1994) considers timing a fundamental value driver, and Teece, Pisano, and Shuen observe that it is important for firms "to scan the environment, to evaluate markets and competitors, and to quickly accomplish reconfiguration and transformation ahead of competition" (1997:521). Thus, timing appears to be an important characteristic of dynamic capability, especially with respect to relative performance outcomes.

Game theoretic models of intra-industry rivalry have established the importance of the timing of actions for the resulting equilibrium. For example, games in which rivals move sequentially (and hence can observe the other firm's choice prior to making their own decision) can have drastically different outcomes

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than games in which firms move simultaneously (see Tirole, 1988). While firms may compete simultaneously in output markets, they can trigger strategic moves, such as organizational change engendered by dynamic capability deployment, at different time intervals. Such differential sequencing of strategic moves, or "action timing" (Ferrier, Smithy, and Grimm, 1999), on top of simultaneous competition makes the game of business difficult to analyze. It may also have important consequences for diversity in firm performance. For example, scholars such as Eisenhardt (1989) and Ferrier, Smithy, and Grimm (1999) believe that firms may gain competitive advantage through taking fast action. Thus, it can be surmised that differential timing of dynamic capability deployment fosters the emergence of intra-industry differential firm performance, as stated in the following proposition:

Proposition 1:   *Differential timing of dynamic capability deployment fosters the emergence of intra-industry differential firm performance.*

3.2.   Imitation of rivals (Attribute 2)

Search is an essential part of variation (Levinthal, 1995) and therefore a central constituent of dynamic capability (see the definition of the variation stage of dynamic capability in endnote 1). A firm's search behavior can have an impact on performance (Amit and Schoemaker, 1993; Gavetti and Levinthal, 2000; Levinthal, 1995; Williams, 1994). Gavetti and Levinthal (2000), for example, demonstrate that experiential (i.e., backward-looking) search coupled with cognitive (i.e., forward-looking) search can outperform purely experiential search. Focusing on experiential search, March (1991) examines the tradeoff between global and local search, that is, between exploration and exploitation. He shows that competitive advantage defined as the likelihood of having the best performance within a group of identical competitors is a function of the relative mean and variance of the firm's performance distribution (see March, 1991:82, Figure 6).

While the search mode – experiential versus cognitive – has received some attention in the literature, another distinction can be drawn at the level of the search direction: imitative versus experimental search. The search direction may be more of a choice variable than is the search mode. Imitation and experimentation can be viewed as distinct alternatives to search that underlie a firm's "capability to adapt" (Teece, Pisano, and Shuen, 1997:515), or its dynamic capability. Indeed, imitation can be viewed as a pro-active strategic weapon

(Dutton and Freedman, 1985; d'Aveni, 1994). Some prior simulation studies of organizational change (e.g., Levinthal and March, 1981; March, 1991; Sastry, 1997) have focused on experimentation, while others (e.g., Lant and Mezias, 1990) have also considered imitation, albeit as an exogenous variable. In this paper, I make the choice between experimentation and imitation endogenous to the firm. This follows Dutton and Freedman's (1985) suggestion that such endogeneity can yield insights regarding the changing relative positions of firms over time.

Imitation may be difficult when rivals successfully establish "isolating mechanisms" (Rumelt, 1984). Such barriers to imitation may result from causal ambiguity (Lippman and Rumelt, 1982), that is, uncertainty regarding the sources of differences among firms, which prevents firms from knowing what or how to imitate. Peteraf (1993) observes that if the condition of causal ambiguity is coupled with non-recoverable costs, such uncertainty may limit imitative activity. Some isolating mechanisms such as trade secrets or property rights to scarce resources (Rumelt, 1984), time compression diseconomies, or asset mass efficiencies (Dierickx and Cool, 1989) may even prevent imitation altogether.

The presence of strong isolating mechanisms that make imitation all but impossible limits firms' search for new or improved operational routines, resources, and capabilities. In this situation, low -performing firms lose one strategy for bridging gaps with rivals. This could lead to the emergence of intra-industry differential firm performance, as stated in Proposition 2:

> _Proposition 2_: _Conditions that prevent firms from imitating rivals foster the emergence of intra-industry differential firm performance._

3.3   Cost of deploying dynamic capabilities (Attribute 3)

The resource-based view of the firm argues that it is costly to acquire or build valuable resources and capabilities (e.g., Barney, 1986; Dierickx and Cool, 1989). Since dynamic capabilities are embedded in routine processes that are involved, for example, in the acquisition, creation, modification, and transfer of valuable resources and capabilities, their costs are important to consider when discussing their performance implications. For example, the transfer of assets or best practice among firms is costly because of transaction and transfer costs (Szulanski, 1996; Teece, Pisano and Shuen, 1997). Additional costs of changing a firm's resource positions and operational routines include sunk investments in skills and working relationships under

the old system and the costs of mistrust between individuals within a firm (Ichniowski, Shaw, and Prennushi, 1997).

Imitation may be a costly search option because it often requires the acquisition, understanding, and assimilation of new know-how (Zander and Kogut, 1995). Before a firm is able to imitate a competing firm, it must gather information about what the rival firm is doing and how. Channels for acquiring this information include consultants, trade shows, industry publications, company statements, clients, suppliers, and other professionals. Accessing and exploiting these channels is costly. The exact costs of imitation hinge on factors such as the codifiability and complexity of the object of imitation (Kogut and Zander, 1992). For example, knowledge codification may entail direct and indirect costs, where "direct costs include the time, the resources, and the managerial attention to be invested in the development and updating of task-specific tools, while indirect costs refer to the increase in organizational inertia consequent to the formalization and structuration of task execution" (Zollo and Winter, 1999:16-17). Similar arguments can be made concerning the costs of experimental adaptation.[5]

The costs of dynamic capability deployment may have both direct and indirect effects on firm performance. The direct effect is the reduction of performance measures such as profit if the firm implements change. The indirect effect is that they may influence a firm's choice about how and when to change. Firms may anticipate the costs of a particular change option; if these are higher than the expected benefits, firms will not use that option. Consequently, if the costs of effecting change through deploying dynamic capability differ across firms, firms may reach different conclusions about the change paths. This may lead them to adopt different resource positions or business practices, which will likely increase differential performance outcomes. This leads to the following proposition:

> *Proposition 3:*   *Differential costs associated with the deployment of dynamic capabilities foster the emergence of intra-industry differential firm performance.*

3.4. Learning to deploy dynamic capabilities (Attribute 4)

In many industries, firms gain proficiency simply through repetitive actions. As a result of such learning by doing, the costs of carrying out these activities are reduced (Arrow, 1961). Learning-based

approaches to explaining sustainable competitive advantage build on this cost reduction argument by proposing that firms differ in profitability because of differences in their histories of operation. For example, Porter (1985, 1994) considers learning a fundamental source of competitive advantage that leads to differing activity costs across competing firms. A similar reasoning can be used for dynamic capabilities. Teece, Pisano and Shuen (1997:521) state that, "The capacity to reconfigure and transform is itself a learned organizational skill. The more frequently practiced, the easier accomplished." In a related vein, Zander and Kogut (1995) argue that, "The accumulation of experience in an activity leads to the facility to communicate and understand the relevant knowledge. This facility, in turn, should reduce the cost of acquiring new related capabilities" (1995:79). Sastry (1997) characterizes these costs as costs that result from the destruction of established organizational capabilities. She states that, "The higher the level of accumulated experience with reorientation, the less organizational competence is destroyed in subsequent reorientations" (1997: 262).

If learning effects lead to different cost patterns across firms, relative firm performance will likely diverge. A distinction can again be made between a direct and an indirect effect linking dynamic capability and relative firm performance. To illustrate the direct effect, consider a firm that engages frequently in costly experimentation, and hence moves down the learning curve in terms of effecting adaptive change through experimentation. This specialization in search direction may eventually give the firm a distinct cost advantage over rivals, who both imitate and experiment, and thus do not manage to drive down their change costs by as much as their specialized competitor.[6] However, given learning and an endogenous choice of search direction, an indirect effect may also occur since firms may embark on different trajectories of change. For example, one firm may initially choose to engage in costly experimentation. By doing so, it will move down the learning curve for effecting adaptive change through experimentation. It will become a specialist in the use of dynamic capabilities that involve experimentation. This will make future experimental adaptations cheaper, and the firm therefore has an increased incentive to change through experimental adaptation and a disincentive to change through imitative adaptation. For similar reasons, a firm that initially favors imitative change may find it increasingly attractive to change by imitating rivals. Learning how to change can thus trigger self-reinforcing dynamics that may lead firms to specialize in distinct variants of dynamic capabilities. This specialization will

likely lead to changes in relative firm performance, as the following proposition states:

> *Proposition 4:*   *Learning how to deploy dynamic capabilities both directly and indirectly fosters the emergence of intra-industry differential firm performance.*

The next section presents the formal model used to validate the logic and soundness of the theoretical propositions just stated, and to refine them by analyzing the model via computer simulation.

Using a simulation approach to support theory development is increasingly popular in the management literature. Particularly in the area of organizational learning, there is now an impressive number of simulation-based papers that have advanced the state of knowledge in the field (e.g., Levinthal and March, 1981; Lant and Mezias, 1990; Mezias and Eisner, 1997; Sastry, 1997). Computer simulations offer a range of features that make them an attractive theory development tool (Mezias and Eisner, 1997): (1) they force researchers to make assumptions explicit that might otherwise remain implicit, (2) they allow one to control for certain variables while systematically varying others, (3) they allow researchers to generate multiple historical trajectories emanating from the same set of initial conditions, thus enabling them to generalize about the mechanisms and processes that produce such histories (empirical studies, in contrast, must rely on the observation of one historical path), (4) they trace the unfolding of longitudinal processes over extended periods of time, and (5) they provide insight into complex relationships between organizational phenomena that one might not otherwise be able capture due to data limitations.

4. MODELING FIRM PERFORMANCE

Consider an industry in which n firms compete with a differentiated product. In each of p periods, a firm has to make decisions about how much output to produce, how strongly to differentiate its product from its competitors' products, and how intensely to pursue cost-reduction initiatives. A firm's decision variables are: $q_{j,t}$, the output quantity of firm j in period t; $r_{j,t}$, the resources devoted to product differentiation by firm j in period t (this variable will henceforth also be called "product innovation rate"); and $i_{j,t}$, the resources firm j expends in order to achieve process innovations in period t (this variable will henceforth also be called "process innovation rate").[7] These three decision variables are among the main determinants of firm performance (Milgrom and Roberts, 1995). They have to do with the day-to-day operations of a firm, which

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can be called "routines" (Nelson and Winter, 1982) when they are regular and predictable. Output quantity $q_{j,t}$ may be viewed as representing a firm's production, manufacturing, and sales routines; a firm's product innovation rate $r_{j,t}$ refers to its R&D capabilities; and a firm's process innovation rate $i_{j,t}$, alludes, for example, to its quality management practices, communication structures, and its financial accounting routines. In summary, a firm's vector of decision variables can be interpreted as representing its operational routines, resources, and capabilities.

Total production costs, $C_{j,t}$, are inversely related to accumulated efforts aimed at reducing costs ($\sum i_{j,t}$). Let v denote the asymptotic variable production costs that are constant over time and across firms. We then have the following relationship between total production costs ($C_{j,t}$) and cumulative process innovations ($\sum i_{j,t}$; note that a is a cost parameter):

$$C_{j,t}(q_{j,t}, i_{j,t}) = q_{j,t} * v * (1 + a/\sum i_{j,t}) \tag{1}$$

Total production costs are determined by total output multiplied by variable costs. Variable production costs decrease with cumulative process innovations over time. As t approaches infinity, the term $\sum i_{j,t}$ will likely increase, in which case total production costs are likely to approach $q_{j,t}*v$ asymptotically.

Efforts aimed at reducing production costs may themselves entail significant costs, I, which sometimes outweigh the expected benefits. Changes made at one point in the production process to improve workflow or coordination of activities, for example, might increase the workload at other points (Milgrom and Roberts, 1995). For the costs of process innovations of firm j at time t, $I_{j,t}$, I assume a quadratic relationship as follows:

$$I_{j,t} = i_{j,t}^2 \tag{2}$$

Examples of the steps a company might take in order to improve its cost structure include worker training, investment in more productive equipment, and the re-engineering of work processes. Variable $i_{j,t}$ can be interpreted as an indicator that summarizes these measures. It represents the operational routines that are maintained in order to effect the desired level of cost controlling efforts. For simplicity, it is assumed that all cost reduction initiatives bear the same unit cost and lead to the same result, and that a company can modify the level of intensity with which it pursues cost reduction.

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There is a similar tradeoff between the benefits and costs of product differentiation (represented by variable $r_{j,t}$). On the upside, many product innovations are likely to lead to a better fit between a company's product line and market needs. This enables the company to charge a higher price since customers have a higher willingness-to-pay. On the downside, efforts aimed at differentiating a firm's product are costly. Let ⋲, denote the aggregate exogenous unit price of all input factors (such as technology and human capital) that facilitate product differentiation. The total costs of product differentiation, $R_{j,t}$, can then be written as a function of ϵ, and $r_{j,t}$. In the model developed here, these costs take a simple quadratic form as follows:

$$R_{j,t} = (\epsilon * r_{j,t})^2 \tag{3}$$

The higher the exogenous price of inputs and the larger the amount of resources dedicated to initiatives to achieve product improvements, the more expensive these efforts are. Examples of measures a company might take in order to differentiate its products include increasing the number of R&D staff, investing in brand creation, improving after-sales service, or hiring marketing specialists that report back customer needs to the R&D group. Variable r thus represents the operational routines that are maintained in order to effect the desired level of innovation and differentiation. It is implicitly assumed that all product differentiation initiatives bear the same unit cost, ϵ, and lead to the same result, and that a company can modify the intensity with which it pursues product differentiation.

Theoretical research has established that Cournot competition can be modeled as a two-stage game in which firms set capacity levels in stage one and prices in stage two (for a summary of these results, see Tirole, 1988). Therefore, even when firms are price-setters, there are circumstances under which it is reasonable to regard them as quantity-setters. This supports the approach taken in the model developed here, in which the inverse demand function is partially specified as:

$$P_t(q_{j,t}) = (n * K - \textstyle\sum_i q_{i,t}) \tag{4}$$

Where K is a constant and P_t is the price of an undifferentiated product. A lower aggregate quantity, $\sum_i q_{i,t}$, translates linearly into a higher price, and vice versa.

In addition to the indirect influence that a firm exerts on price through its quantity decision, a firm can also directly affect price through its choice of product differentiation. If a firm puts more emphasis on

product innovation than do its competitors, for example, it may be able to demand a higher price; if it is less innovative or has a weaker brand than does the average player in the industry, the firm must accept a lower price. This relationship is captured by the following fully specified inverse demand function:

$$P_{j,t}(q_{j,t}, r_{j,t}) = P_t(q_{j,t}) * \{r_{j,t} / [(1/n) * \sum_i r_{i,t}]\} \tag{5}$$

Where $P_{j,t}$ is the price of a differentiated product. It is partially determined by output quantity through (4), and partially through the multiplier $\{r_{j,t} / [(1/n) * \sum_i r_{i,t}]\}$, which is greater than 1 if a firm's rate of product innovations at time t is greater than the average rate in the industry. Other firms co-determine the price firm j may ask for its products through their quantity choice, which affects equation (4), and through their choice of product differentiation, which affects the second part of the right-hand side of equation (5).[8]

Firm j's revenues, $M_{j,t}(q_{j,t}, r_{j,t})$, are given by:

$$M_{j,t}(q_{j,t}, r_{j,t}) = q_{j,t} * P_{j,t}(q_{j,t}, r_{j,t}) \tag{6}$$

In each period, firms compete on output quantity (through product quantity, $q_{j,t}$), on product quality (through the rate of product innovations, $r_{j,t}$), and on production costs (through the rate of process innovations, $i_{j,t}$). The model thus diverges somewhat from pure Cournot competition. It acknowledges a range of competitive behaviors that involve tradeoffs between benefits and costs. A higher output quantity, for example, tends to increase revenues through a higher sales volume, but it also depresses revenues through a lower price (see equation 4). These tradeoffs are captured by the profit function of firm j, $\pi_{j,t}$, which describes a company's profits (before it incurs any change costs):

$$\pi_{j,t} = M_{j,t} - C_{j,t} - R_{j,t} - I_{j,t} \tag{7}$$

Inserting equations (1)-(6) into (7) yields:

$$\pi_{j,t} = q_{j,t}(nK - \sum_i q_{i,t}) \{r_{j,t} / [(1/n)\sum_i r_{i,t}]\} - q_{j,t}v(1 + a/\sum_t i_{j,t}) - \epsilon^2 r_{j,t}^2 - i_{j,t}^2 \tag{7'}$$

This is the objective function (before change costs) to be maximized by firm j for period t. It is difficult, though perhaps not impossible, to compute an analytic solution to this optimization problem for all firms at all dates. For this purpose, one would have to solve a differential game with n*p*3 decision variables (since there are three decision variables per firm per period). It is relatively easy, however, to determine an asymptotic solution to (7') based on a period-by-period optimization approach (see Appendix I).

Thus far, even though most variables have been indexed by t, the discussion of the various economic relationships that determine firm profitability (7') has focused largely on static aspects, that is, on the effects of competition in a given period t. The next step is to explain how firms can change the basis of competition over time through the decision variables q, r and i. Firms are not assumed to solve the game theoretic problem of maximizing (7') analytically. Instead, they deploy dynamic capabilities to effect change. (For further model assumptions, see Appendix II.)

5. MODELING DYNAMIC CAPABILITY

The integration of the notion of dynamic capability into the above model relies on the conceptual elements of the dynamic capability construct distilled from the received literature in section 2. In particular, I make use of the evolutionary framework that views dynamic capability as a collection of processes geared toward variation, selection and retention of resources, capabilities, and/or operational routines.

The final dynamic model can be summarized as follows. At a given point in time, the process by which a firm determines its vector of decision variables (i.e., output quantity, product innovation rate, and process innovation rate) has three stages. In the first stage (the variation stage), the firm generates a number of alternative decision variable vectors. It does so by applying change routines to its current vector. Each change routine stipulates the search direction for each variable in the vector. In the second stage (the selection stage), the firm evaluates each alternative vector generated in the variation stage and picks the one that promises the highest improvement in performance. Finally, in the third stage (the retention stage), the firm decides whether or not to implement the solution identified in the selection stage. Firms then compete according to the industry dynamics that have been described in section 4 and subsequently enter another cycle of the evolutionary process. The various stages of the process (i.e., variation, selection, and retention) are described in more depth below.

5.1. Variation

As a firm's vector of decision variables is subject to change, this vector will be the unit of selection. When a firm searches for appropriate values of q, r, and i for possible implementation, it varies the current values. Prior work has examined the relationships and tradeoffs between cognitive and experiential search

processes (e.g., Gavetti and Levinthal, 2000; Lippman and McCall, 1976). In this paper, the search mode is held constant. It is assumed that firms use "off-line" (Lippman and McCall, 1976), cognitive choice processes in the variation stage of organizational change.[9] Nevertheless these cognitive processes, which may be viewed as thought experiments, are not ad-hoc, they are driven by routines (Zollo and Winter, 1999).

Each firm has a bundle of change routines that represents its body of wisdom regarding any potential modification of its business practices. A change routine stipulates precisely which search direction (i.e., experimentation or imitation) a firm should favor for changing each of its decision variables, and whether it should change a particular variable at all. Such a routine might, for example, stipulate: "Experimentally increase output quantity, do not change the product innovation rate, and imitate the industry leader's process innovation rate." This particular rule suggests a hybrid change strategy that selectively applies experimentation and imitation to particular decision variables. With three decision variables and four possible actions on each variable (retain, imitate, experimentally increase, experimentally decrease) there are sixty-four possible change rules for each firm.[10]

The change rules represent the fundamental choices, or resource positions, that a firm has for generating alternative modes of operation. They summarize the complex sub-processes that are involved either in the imitation of competitors (e.g., collecting and making sense of information, assessing the requirements of organizational transformation, evaluating the costs of implementation, and so forth.) or in the experimental modification of business practices. In the same way that the firm's vector of decision variables can be interpreted as a simple representation of its operational routines, resources, and capabilities, its change rules can be interpreted as a simple representation of the processes that underlie imitation and experimentation.

The modeling approach chosen here is consistent with the assumption of bounded rationality. Organizations and their members lack the comprehensive and sophisticated information processing and computation capabilities required to derive a precise analytical solution to their complex inter-temporal optimization problems (Simon, 1955). They may also not possess all the information necessary to find such a solution. Consequently, decision-making in organizations is riddled with uncertainty, complexity, and conflict (Amit and Shoemaker, 1993). Recent empirical evidence confirms the importance of change routines that are

regularly deployed (Brown and Eisenhardt, 1997) and suggests the existence of strategy innovation routines (Chapman Wood, Hatten and Williamson, 1999).

It should also be noted that by including imitation as a means of generating variation, the model presented here combines cultural and genetic principles of evolution, as advocated by Boyd and Richerson (1985). The study thus contributes to developing more realistic evolutionary models of organizations.

5.2. Selection

In this stage, each alternative vector of decision variables generated in the variation stage is subject to an evaluation of its potential usefulness. This evaluation involves the calculation of a so-called fitness value. This value is used to derive the probability with which the alternative vector of business practices will be selected. Under stochastic selection, the higher a vector's fitness value, the greater is its likelihood of selection (Arthur, 1991). Under deterministic selection, the vector with the highest fitness value will be selected with certainty. In this paper, the focus is on the deterministic case in order to examine the proposed attributes of dynamic capabilities unperturbed by random effects.

Fitness values are calculated on the basis of an assessment of the potential performance implications of the suggested alternative. Unable to anticipate whether and how its rivals will change in the next period, a firm makes the simplifying assumption that all other players will "stick to their knitting." It then computes the fitness value as the expected net present value of the incremental profits resulting from the prescribed organizational change, minus any associated change costs. Fitness is thus the expected net present value of change.

Selection is part of the off-line cognitive evaluation process that also characterizes variation (Lippman and McCall, 1976; Gavetti and Levinthal, 2000). A firm selects values of decision variables that, if adopted, promise to increase performance. Once a favored solution has been determined, the firm must decide whether or not to implement the suggested changes. This decision implies a switch from an off-line to an on-line mode.

5.3. Retention

Selected alternative values of decision variables are retained (i.e., implemented) with a probability p_r,

which reflects a firm's propensity to move first (Lieberman and Montgomery, 1988), organizational inertia (Stinthcombe, 1966; Hannan and Freeman, 1977), luck (Barney, 1986) and/or randomness (Porter, 1994). If the firm refrains from modifying its current vector of decision variables, which happens with probability $1-p_r$, then it will simply keep the values it had installed in the previous period.

Retention, or more specifically, implementation of change, usually bears costs (see Attribute 1). In the model, a range of eight parameters defines the structure of a firm's change costs. It should be noted that there are three decision variables and two basic search directions, namely experimentation and imitation. The cost of applying a specific search direction to a specific decision variable is captured by a distinct parameter. This implies that there are at least six cost parameters to be considered. In addition, it is assumed that organizational change becomes more disruptive, and thus more expensive, with increases in the number of variables that are changed simultaneously. The model therefore includes two additional parameters that describe the higher costs of undertaking the simultaneous change of more than one decision variable (see also assumption A12 in Appendix II). These eight cost parameters determine the costs associated with the implementation of a selected vector of decision variables.

Once the selection and retention decisions have been made, firms compete with each other. They simultaneously announce their chosen levels of output quantities and innovation rates. A firm's payoff from competition in the marketplace is contingent on the decisions made by all firms in the industry. At the end of a period, firms receive their payoff and observe other firms' choices. The evolutionary cycle of variation, selection, and retention then starts again. Firms may enter into a new round of search, possible organizational change, and competition in the marketplace. At the end of the last period, the simulation terminates. (Further model assumptions are presented in Appendix II; the source code for the simulation algorithm, written in Delphi 2.0, is available upon request from the author.)

Taking a firm's vector of decision variables as the unit of selection, the model of dynamic capability delineated above has all the ingredients that characterize an evolutionary model: variability, selection pressure, and inheritability (more precisely, differential retention) (Campbell, 1965). Thus, the model bridges strategy process research (by focusing on evolutionary change processes) and strategy content research (by

considering content variables as units of selection). It also links discussions of firm capabilities and industry dynamics, thus offering a basis with which to explore the diversity in performance among firms (Levinthal, 1995). Finally, the model presents a dynamic view of strategy, as called for, for example, by d'Aveni (1994) and Porter (1994).

6. SIMULATING THE MODEL

In the above sections, four performance-relevant attributes of dynamic capabilities were identified and conjectures as to why and how they may be important for understanding the emergence of differential intra-industry firm performance were presented. At this point, it is necessary to verify the logic of the earlier conjectures and test their robustness by simulating the model. The two main goals of the simulation are first to understand the impact of dynamic change processes on the long-term performance of firms, and second to offer refined theoretical propositions. Where suitable, it will be noted to what extent the resulting dynamic performance patterns are consistent with empirical evidence. This is done for the sake of emphasizing the plausibility of the model.

In the simulation analysis that follows, the performance-relevant attributes of dynamic capabilities as described in section 3 are coded as on/off variables (see Table 1). This allows one to analyze model specifications in which several attributes hold concurrently.

[INSERT TABLE 1 ABOUT HERE]

The level of competitive advantage is defined in the model as the amount by which a firm outperforms the average firm in the industry. If a firm performs worse than the industry average, it is at a competitive disadvantage. An industry leader is the best performer in an industry. Sustainable competitive advantage or disadvantage can then be defined as "the tendency of abnormally high or low profits to continue in subsequent periods" (McGahan and Porter, 1997b:2). The notion of sustainability is defined in this study as the average number of periods that industry leadership lasts.

6.1. Setting up the experiment and initializing variables

To simulate the model, specific assumptions are made about the initial values of variables and parameters (see below). Further assumptions are embedded in the program code (see Appendix II). As these

assumptions characterize a specific industry environment, the simulation can be interpreted as a series of longitudinal case studies in a particular industry. The conclusions drawn and propositions offered in this section must therefore be carefully interpreted. As discussed below, however, the sensitivity analyses conducted confirm that the insights gained are fairly robust and would therefore carry over to other industries as well.

For simplicity, I consider an industry with only two firms (n=2) and a stable exogenous environment.[11] Exogenous parameters such as input prices and variable costs remain constant [$\epsilon=1$, v=3, $a=3$ in equations (1) and (3)] and there are no demand shocks [K=5 in equation (4)]. In addition, functional forms (e.g., firms' profit functions) do not change over time. Only decision variables and (if applicable, i.e., if A2-on) change cost parameters are subject to endogenous change. The probability of retention, p_r, is one third. The analytic asymptotic solution to the firms' inter-temporal optimization problem is $q_\infty^*=3$, $r_\infty^*=3^{1/2}$, $i_\infty^*=0$. It yields an asymptotic profit of 6 per firm. (For the derivation of the asymptotic solution, see Appendix I.)

Initial change rules, fitness values, and decision variables are identical across firms. Hence, the analysis focuses on the conditions under which heterogeneous firm performance may arise from initially homogeneous firms. This approach is adopted for two principal reasons. First, this approach avoids any confusion of the effects of initial asymmetries (asymmetric endowment of firms with dynamic capabilities, resources and organizational routines, asymmetric product market positions, etc.) on performance outcomes with the effects of Attributes 1-4 on those outcomes. Unlike empirical analysis, the simulation analysis provides a strictly controlled experimental environment in which these restrictions can be imposed. Performance differences among firms in this strictly controlled environment would have to be considered as evidence for the important role that Attributes 1-4 play in generating intra-industry firm heterogeneity.

Second, the assumption of initial homogeneity is empirically relevant; empirical evidence exists indicating that there are firms that are strikingly similar at one point in time and then take different paths in their development. Consider, for example, the so-called "Baby-Bells," that is, the companies that resulted from the break-up of AT&T in 1983. Noda and Collis (1999) show how these almost identical firms became competitors in the cellular phone market and subsequently evolved very distinct cellular phone businesses. As

a result, at the end of the 10-year period between 1983-1993, there were vast differences in the number of subscribers among the seven Baby Bells (see Noda and Collis, 1999, Figure 5). The assumption of initial homogeneity of firms is also consistent with Eisenhardt and Martin's (2000) observation that dynamic capabilities are equifinal.

The initial values of firms' decision variables are $q_0=1$, $r_0=1$, $i_0=1$. Thus, at the beginning of a simulation run, each variable is far from its asymptotically optimal level. This provides for endogenous instability. The chosen initial settings can be interpreted as indicating a young industry with two fiercely competing entrants. Each simulation is run for 200 periods. A firm can experimentally change a variable by increasing or decreasing its value by a fixed proportion (the "step size of experimental change," which is set equal to 5%). When imitatively changing a decision variable, a firm implements the respective value that the best performing firm had in place in the previous period (recall that only values from previous periods can be observed since firm choice is simultaneous).

For all results shown and discussed below, sensitivity analyses were conducted. The following parameters were varied, both separately and concurrently: initial values of the decision variables, the random seed, the step size of experimental change; the propensity to implement change (see Attribute 1), change costs (see Attribute 3), and the speed of learning (see Attribute 4). Simulation results are only discussed in depth for those cases that proved robust to some moderate variation of these parameters, for cases in which differential intra-industry firm performance emerged, and for cases that allowed for a refinement of Propositions 1-4. For example, in the model in which A2, A3 or A4 were coded as "on" and A1 as "off," no variation in performance could be observed, so the case is not reported here.

6.2. Exploring the effects of timing: differential performance due to differential timing of change

Consider the model with A1-on, A2-off, A3-off, and A4-off. This particular specification of the model focuses on the effect of the timing of dynamic capability deployment on differential performance. Change costs are zero (A3-off); the fact that firms do not learn how to reduce change costs (A4-off) is consequently of no importance. Firms can imitate each other (A2-off), but they do not always implement their selected change alternative (A1-on). Such uncertainty about implementation implies that one firm might

change when the other firm remains inert. In this case, the changing firm may gain or increase a competitive advantage or lessen a disadvantage because it adopts its best alternative vector of decision variables (i.e., the one with the highest fitness value).

Impact of change processes on performance. As a result of the ensuing competitive dynamics in this simple model, firms, at least temporarily, exhibit differential performance patterns. This interesting outcome is illustrated in Figure 2. As can be seen from the figure, Firm 2 manages to command an early lead and is able to stay ahead of its competitor for most of the early stages of the competition. Eventually, however, the two firms' profit curves converge.[12]

[INSERT FIGURE 2 ABOUT HERE]

The intuition behind the emergence of heterogeneous firm performance in this example is as follows. When initial values of decision variables differ greatly from the asymptotic solution, differential temporal sequencing of moves effects different organizational changes. Firms engage in a race with lags and leads toward the asymptotic equilibrium. Before converging to this solution, the under performing firm is often unable to catch up with its rival for relatively extended periods of time despite its potentially powerful capabilities of experimentation and imitation. The frequency with which experimental adaptation of decision variables is implemented is limited by Attribute 1 (differential timing due to stochastic retention). Imitation, on the other hand, is an imperfect change strategy here because it aims at a moving target. An imitating firm can only copy the decision variables that the industry leader had in place in the previous period. In the meantime, the leader may already have made further changes. This limits the potential of a lagging firm to catch up with the industry leader.

Implications for theory. The simulation results depicted in Figure 2 support Eisenhardt and Martin's conjecture that the potential for long-term competitive advantage "lies in using dynamic capabilities sooner, more astutely, or more fortuitously than the competition to create resource configurations that have that advantage" (2000:1117). They are also consistent with d'Aveni's (1994) argument that long-term competitive advantage is best thought of as a series of temporary advantages. These scholars claim that competitive advantage derived from the deployment of dynamic capabilities is related to their timing. The model presented

in this paper confirms the importance of timing for gaining and sustaining competitive advantage. Indeed, the simulation of the model supports Proposition 1 developed earlier.

The results also reveal that the asymptotic convergence of firm performance need not occur if equilibrium conditions change exogenously. Schumpeter believed that disequilibrium in an economy was the rule rather than the exception. He stated that, "The position of the ideal state of equilibrium in the economic system, never attained, continually 'striven after'…changes" (1934:62). If this were the case, then differential timing of dynamic capability deployment might explain the persistent diversity of firm performance. Suppose that the asymptotic equilibrium in an industry suddenly changes because, for example, input prices unexpectedly shoot up, or because consumer tastes shift. Technological discontinuities may alter the rules of competition. As a result, q_∞^*, r_∞^*, and i_∞^* will change and firms will find themselves poorly adapted to the new situation. Consequently, they must start searching for new ways of conducting business in order to improve performance. In an industry where this happens often, firms are continuously subjected to new equilibrium conditions, and their performances need not necessarily converge (as they do in Figure 2). A race towards equilibrium may be quickly followed by a race towards a new equilibrium. In other words, performance differences may not be temporary, but rather a normal characteristic of a continuously evolving economy.

Consistency with empirical evidence. The results obtained in this simple case are consistent with empirical evidence on the importance of action timing. In a study of the effects of nearly 5000 competitive moves implemented by 41 market share leaders and challengers over seven years, Ferrier et al. find that the industry leaders "were more likely to maintain their market share leads and avoid dethronement by moving swiftly against competitive challenges. Conversely, challengers who acted faster than leaders tended to gain share" (1999:384). The simulation results are also consistent with d'Aveni's (1994) account of the competition between Coke and Pepsi. For decades, the rivalry between these firms was characterized by frequent initiatives in new products, technical and organizational innovations, and advertising. D'Aveni (1994) points out that Coke's self-assessment that it was in a dominant position made the firm more interested in defending its position than in innovating. This gave Pepsi the opening to innovate and capture new market

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share. Thus, there is empirical support for the model's prediction that attribute A4 in and of itself can be sufficient for explaining differential firm performance, and for explaining the closing of the gap between a follower and a leader.

6.3.   Exploring the effects of precluded imitation: increased sustainability of differential performance due to barriers to imitation

Let us consider the model used previously, but with A2 -on, that is, there is no possibility of imitation. Consequently, a firm that performs poorly relative to its rival is not able to use imitation as a means of catching up. Figure 3 shows the results of this case.

[INSERT FIGURE 3 ABOUT HERE]

Impact of change processes on performance. The basic intuition behind the emergence of heterogeneous firm performance remains the same as in the previous case. Differential timing of moves causes some firms to fall behind in a now purely adaptive race towards an asymptotically optimal solution. The impossibility of imitating rivals slows the convergence of firms' decisions and performances, and serves to widen and sustain the performance gaps (see Figure 3).

Implications for theory. While barriers to imitation (Lippman and Rumelt, 1982; Rumelt, 1984; Dierickx and Cool, 1989) are important for explaining the sustainability and magnitude of a firm's competitive advantage (compare Figure 2 with Figure 3), they do not account for its emergence. Further simulations of models that preclude imitation support this result: barriers to imitation do not serve to generate differential firm performance. Instead, they are purely defensive in nature and contribute to sustaining and possibly reinforcing a competitive advantage that has been achieved through other means. This simulation suggests that Proposition 2, which states that the conditions that prevent firms from imitating rivals foster the emergence of intra-industry differential firm performance ought to be refined as follows:

> *Proposition 2':   Barriers to imitation tend to enhance the sustainability, in terms of both duration and magnitude, of intra-industry differential firm performance. They do not, however, account for the original emergence of the phenomenon.*

It is interesting to note that while RBV addresses imitation from the point of view of the firm, asking whether a firm can defend itself against imitation from competitors, the dynamic capability perspective also

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takes into account *what rivals do* in order to prevent imitation.

Consistency with empirical evidence. One of the factors cited by Barney (1997) that may make imitation of a particular resource or capability prohibitively costly, and thus virtually impossible, is unique historical conditions. Barney (1997) gives the example of Caterpillar, a heavy-duty construction firm, which was selected by the United States government during the Second World War to become the single supplier of construction equipment for U.S. military purposes throughout the world. Subsidies from the U.S. government enabled Caterpillar to build the first worldwide service and supply network in its industry. For several years after the war, Caterpillar was able to capitalize on its timing advantage and on the difficulty competitors had in imitating or substituting its global network. As a result, Caterpillar remained dominant in its industry (Barney, 1997).

6.4   Exploring the effects of costs: differential performance sustained by cost effects

The impact of change costs is analyzed next; the assumption is made that effecting organizational change by deploying dynamic capabilities is costly (see Attribute 3). Consider a model with A1-on (i.e., firms are likely to deploy dynamic capabilities at different times), A2-on (i.e., imitation is not possible), A3-on (i.e., the deployment of dynamic capabilities is costly), and A4-off (i.e., no learning). This model differs from that discussed above in that A3 is now switched on. Figure 4 shows relative firm performance gross of change costs in this case. Figure 5 depicts relative firm performance net of change costs.

<div align="center">[INSERT FIGURES 4 & 5 ABOUT HERE]</div>

Change costs are often not captured by accounting measures of firm performance. For example, the costs pertaining to the acquisition, understanding, and assimilation of new know-how (Zander and Kogut, 1995), or the costs of mistrust between individuals within a firm (Ichniowski, Shaw, and Prennushi, 1997) often do not show up in a profit-and-loss statement. Figure 4, which shows firms' profits before change costs, is an approximate graphical representation of accounting measures of firm performance. Figure 5 (which depicts profits after change costs) shows the real economic implications of change. [13]

Impact of change processes on performance. When A1, A2 and A3 concurrently hold, firms' initially diverging performance curves no longer converge in the long run. There are not only temporary

performance differences (as in the case where only A1 holds) that are increasingly sustainable (as in the previously discussed case where both A1 and A2 hold), but now firms fail to converge asymptotic ally.

The situation characterized by this model is that of a purely adaptive race between two firms in which the presence of positive change costs alters firms' incentives to strive for asymptotically optimal values of decision variables. For example, if at a certain point in time a firm produces more output than the amount prescribed by the asymptotic optimum, it may have little incentive to subsequently lower its output stance to the asymptotically optimal level. The associated costs of change may more than offset the expected benefit from implementing the alternative production policy. In the example depicted in Figure 4, if change costs were zero, Firm 2 would benefit from lowering its output quantity after period 80 since this would reduce overproduction in the industry, raise prices, and thus lead to higher profits. However, the costs of changing the production schedule outweigh the expected net present value of future performance improvements that would result from this change.

As a result of the existence and persistence of costs associated with the deployment of dynamic capabilities, firms may get "stuck" with decisions that are suboptimal in the long run. Since this effect is due to the introduction of change costs, it will be denoted as the "cost effect." Figure 6 illustrates the cost effect on the level of the decision variables (in contrast to the level of performance outcomes shown in Figures 4 and 5). The graph depicts the evolution of each firm's decision variables during the simulation.

[INSERT FIGURE 6 ABOUT HERE]

Implications for theory. Simulation of the model shows that the costs of dynamic capability deployment have both direct and indirect effects on firm performance. They reduce performance directly whenever the firm implements change (see Figure 5). But they can also have an indirect effect on firm performance by influencing a firm's choice as to how and when to change. If the costs of a particular change option are higher than the expected benefits, a firm will not select that option. Consequently, performance differences that arise in the course of the simulation due to differential timing of change (A4-on) may be sustained in the long run (see Figures 4 and 5). This holds even though firms' dynamic capabilities are equifinal (which is the case in all simulations since the firms are endowed with the same change algorithm and

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the same set of change routines). The results contrast with Eisenhardt and Martin's (2000) prediction that sustainable heterogeneous firm performance does not emerge under this condition.

Again, the simulation allows for refining the theoretical conjectures. Proposition 3 states that the likelihood of diverse performance outcomes increases if the costs of effecting change through deploying dynamic capability differ across firms. The simulation leads to a refinement of this proposition for two reasons. First, it shows that even if firms incur the same level of change costs, there may still be a cost effect that leads to sustained performance differences. Second, performance differences cannot emerge from Attribute 3 (dynamic capability deployment cost) alone; the attribute can only contribute to sustaining differential performance patterns that have arisen for other reasons (in the example given earlier differences arose because of A1, differential deployment timing). Hence, Proposition 3 is refined as follows:

> *Proposition 3':* *The costs associated with the deployment of dynamic capabilities foster the long-term sustainability of intra-industry differential firm performance ("cost effect").*

Consistency with empirical evidence. The simulation results are consistent with empirical evidence. Ichniowski et al. (1997) observe that certain innovative business practices are not adopted in existing firms even when they promise productivity gains. The authors suggest that "nonpecuniary barriers to change beyond the direct costs of the work practices," that is, economically relevant costs that may not be captured by accounting measures, might explain seemingly suboptimal decisions made by existing firms.

6.5. **Exploring the effects of learning: differential performance emerging from path dependencies**

Lastly, consider a model where Attributes 1 (timing), 3 (costs) and 4 (learning) hold concurrently, but Attribute 2 does not (in other words, imitation is possible). It is assumed that firms incur moderate change costs and that they learn moderately quickly.[14] Figure 7 shows the firm performance patterns in this example.

[INSERT FIGURE 7 ABOUT HERE]

Impact of change processes on performance. Figure 7 illustrates the fact that sustainable performance differences obtain in this case. Can the cost effect discussed above explain this result? In other words, do firms get stuck with certain decisions because it is too expensive to modify them? This is certainly part of the explanation. But the case being considered is slightly more complex. It is important to bear in mind

that the cost effect has been introduced above in a model in which both firms focus on a particular search direction, namely experimentation. However, in the present model, firms are allowed to imitate each other, and are also allowed to experiment with their decision variables. This means that firms now make an endogenous choice between two distinct search directions. By choosing one or the other, they realize a learning effect (enabled by A4-on) which makes the selected search direction even more attractive for future use. Such positive feedback dynamics can lead to path dependencies in applying change routines.

An analysis of the evolution of some selected change cost parameters demonstrates that path dependencies do indeed obtain. Consider, for example, the costs of experimental change and of imitating the rate of innovation (see also Assumption A12 in Appendix II). Because these cost items may vary for each firm, four distinct cost parameters must be considered. Figure 8 shows how they evolve.

[INSERT FIGURE 8 ABOUT HERE]

The above graph shows that firms differentiate their internal change cost structures endogenously. Consider first Firm 2. Early on, its *process adaptation cost* falls below that of its competitor and then rapidly approaches zero. Its *process imitation cost*, on the other hand, remains at its original level. Considering the performance chart Figure 7, it behooves the company to be indifferent to the strategy of imitation since it would not want to mimic an under-performing competitor. Over the course of the simulation, Firm 2 thus becomes a skilled adaptor that largely ignores the possibility of imitation. Firm 1, in contrast, pursues a more hybrid strategy in which it also emphasizes imitation. Its *process imitation cost* gradually declines; its *process adaptation cost* is also reduced early on but not to the same extent as that of its rival. With these observations regarding cost structures, a more complete account can be rendered of how and why the firms' performances in this example evolve (see Figure 7).

Attribute 1 (differential timing) creates an initial asymmetry between the firms. Firm 2, toward the beginning of the simulation, makes a few more positive moves relative to its rival who, more often than not, remains inert. Through such high relative decision speed, luck, or randomness at the outset, and the self-reinforcing effect of cheaper experimentation (brought about by Attribute 4 - learning), Firm 2 manages to quickly build a strong position in its industry by achieving a high output quantity and favorable innovation

rates. Firm 1, the follower, imitates its rival quite effectively on a number of occasions, but must eventually recognize that imitation becomes more and more unattractive. Alternative output quantities and innovation rates suggested by imitation have a lower and lower fitness level. At first glance, this might seem somewhat counterintuitive: if the industry leader does things correctly, would it not make sense to imitate its behavior? Part of the answer to this question is that mimicking a rival's high output level is likely to contribute to overproduction in the industry, and may therefore lead to falling prices in the near future. A firm may anticipate this effect and consequently shy away, if possible, from imitation. Moreover, imitating a high product innovation rate leads to better products and thus higher prices, but the imitating firm must also incur the related high R&D expense, which reduces profits. This tradeoff can be anticipated. If it is negative (i.e., if costs outweigh benefits), a follower will not want to imitate the best performing firm.

Hence, in the example just shown, imitation loses its appeal because the leading firm has too much market power. It would be too expensive to imitate its business practices. The follower (Firm 1 in this case), having failed to sufficiently hone its adaptive skills, falls behind in terms of performance in the long run. It "gets stuck" between its imitative and experimental modes of adaptation, both of which are only half-developed.[15] By contrast, Firm 2, the astute adaptor, manages to hold on to its competitive advantage because, as it turns out, adaptation is the superior strategy. It outperforms the hybrid strategy adopted by Firm 1 because of combined cost and learning curve effects.

To summarize this discussion, in a model with A1-on, A2-off, A3-on, and A4-on, endogenous learning may lead to a differentiation of internal change costs that catapults firms onto different trajectories of change through triggering positive feedback dynamics. Cost effects may then preclude the trailing firm from effectively catching up with the industry leader through a strategy of imitation, or from switching to a pure strategy of experimentation.[16] Simulations of the model with A1-off, A2-off, A3-on, and A4-on (i.e., a model in which imitation is possible and firms reduce their change costs through learning, but in which they deploy dynamic capabilities simultaneously), reveal that learning, in and of itself, does not cause differential firm performance. Learning can only reinforce pre-existing performance patterns; it cannot *cause* firms to develop different patterns either of activities or costs.

Implications for theory. This case highlights two points. First, imitation may not always be an attractive search option, especially if it implies crowding a niche. As Porter (1996) states, strategy is about successful differentiation from rivals, not about imitation. Second, learning is important not only because of its direct effect on firm performance by way of decreasing change costs, but because of the trajectories it shapes that then determine the firm's resource manipulation paths. This argument extends RBV by showing that differences among firms regarding the level of dynamic capabilities, particularly in terms of differences in their costs of imitation and experimentation, may translate into differences in resources and capabilities, which then cause differential performance. Thus, the simulation confirms the earlier theoretical conjectures about the direct and indirect effect of learning on the emergence of differential intra-industry firm performance. However, it also shows the incompleteness of the assertion that firms may perform differently because of path dependencies arising from learning-by-doing. With Attributes 3 and 4, heterogeneous firm performance only obtains if Attribute 1 holds concurrently. Furthermore, the resulting performance differences are sustained by firms' possibly differing change costs, not by learning per se. In fact, the less pronounced the learning, the less reduced are change costs, and the stronger the cost effect. The simulation leads to the following revisions to Proposition 4:

> *Proposition 4a':*   *Learning how to deploy dynamic capabilities directly and indirectly fosters the emergence of intra-industry differential firm performance, but does not trigger the phenomenon.*

> *Proposition 4b':*   *Learning how to deploy dynamic capabilities affects the long-term sustainability of intra-industry differential firm performance indirectly through determining the magnitude of the cost effect.*

CONCLUSIONS

In this paper, the construct of dynamic capabilities was linked with the phenomenon of intra-industry differential firm performance. New theory was developed in two ways. First, an emerging consensus in the strategy literature regarding the dynamic-capability construct was highlighted. Dynamic capabilities can be viewed as embedded in routine organizational processes aimed at effecting change. The sub-processes that constitute dynamic capability can be classified as routines for variation, selection, or retention, which are ingredients to a system of evolutionary learning (Helfat and Raubitschek, 2000; Zollo and Winter, 1999).

Dynamic capabilities are thus more than a simple addition to RBV since they manipulate the resources and capabilities that directly secure rents. There is a clear need for distinct criteria that allow for linking dynamic capabilities with firm performance. This paper identified a number of performance-relevant attributes of dynamic capabilities that are anchored in prior theory: (1) the timing of dynamic capability deployment, (2) imitation as part of the search for alternative resource configurations, (3) the cost of dynamic capability deployment, and (4) learning to deploy dynamic capabilities. While this set of attributes may not be exhaustive, it allows us to deduce four propositions that link dynamic capabilities to the emergence of intra-industry differential firm performance. The theory development showed that even if dynamic capabilities are equifinal across firms, performance differences may arise between firms due to both the costs of dynamic capability deployment and the differential timing with which they are deployed. Differential timing of dynamic capability deployment may be rooted in the cognitive biases of managers that cause them to make decisions at different points in time (Amit and Schoemaker, 1993). In contrast to conventional wisdom, dynamic capabilities may thus serve to gain and sustain competitive advantage.

A second path for theory development adopted in this paper was the formal and rigorous modeling of dynamic capabilities, and an analysis of a computer simulation of the model. The simulation helped test and refine the soundness of the propositions developed on the basis of prior theory. In addition, the simulation facilitated an assessment of the emergence of differential firm performance when several attributes are assumed concurrently.

Several effects based on the attributes of dynamic capabilities that affect the emergence and sustainability of differential firm performance were identified through a simulation of various model specifications. The analysis revealed that performance differences may arise from differential timing of dynamic capability deployment. In other words, it does matter when firms change. However, competitive advantage gained in this way is not sustainable in stable industries where decisions eventually converge to their asymptotic equilibrium. The costs associated with applying dynamic capabilities promote the sustainability of differential intra-industry firm performance. This effect occurs when a firm refrains from implementing change because of related costs. The analysis also revealed that path dependencies associated

with the application of dynamic capabilities emerge under specific circumstances, but they do not always obtain. Yet, once they occur endogenously, they present a case for divergence: some firms become astute experimentors, while others become skilled imitators, and their performance differs. The study thus showed that it is useful to make a distinction between different search directions (imitation versus experimentation) when discussing how dynamic capabilities are linked to relative firm performance.

This paper has begun to describe and disentangle the complex relationships that link dynamic capabilities, resources/competencies or operational routines, and firm performance. A wide range of theoretical questions awaits further clarification: What additional performance-relevant attributes of dynamic capabilities do exist? Can predictions be made about which of the firms competing on the basis of dynamic capabilities will win? At which inflection points can, or should, managers intervene, and how might intervention occur? More generally, what roles do leadership and culture play in the context of dynamic capability? By applying simulation analysis to one of the most puzzling and interesting questions that define the field of strategy -"Why do firms perform differently?"- this study has offered insight into how dynamic capabilities provide part of the answer, and it may inspire further theoretical and empirical research on the role of dynamic capabilities in bringing about heterogeneous intra-industry firm performance.

REFERENCES

Amit R, Shoemaker PJH. 1993. Strategic assets and organizational rent. *Strategic Management Journal* **14**:33-46.

Arrow K. 1961. Economic welfare and the allocation of research for invention. In R. Nelson, ed. *The Rate and Direction of Inventive Activity: Economic and Social Factors*, Princeton University Press, Princeton.

Arthur B. 1991. Designing economic agents that act like human agents: A behavioral approach to bounded rationality. *American Economic Review* **81**:353-359.

Barney J. 1986. Strategic factor markets: Expectations, luck, and business strategy. *Management Science* **32**:1512-1514.

Barney J. 1991. Firm resources and sustained competitive advantage. *Journal of Management* **17**:99-120.

Barney J. 1997. *Gaining and Sustaining Competitive Advantage,* Addison-Wesley Publishing Company, Reading, MA.

Benghozi PJ. 1990. Managing innovation: from ad-hoc to routine in French Telecom. *Organization Studies* **11**:531-554.

Brown S, Eisenhardt K. 1997. Art of continuous change: Linking complexity theory and time-based evolution in relentlessly shifting organizations. *Administrative Science Quarterly* **42**: 1-34.

Boyd R, Richerson PJ. 1985. *Culture and the Evolutionary Process,* University of Chicago Press.

Campbell DT. 1965. Variation and selective retention in socio-cultural evolution. In *Social Change in Developing Areas*, Barringer HR, Blanksten GE, Mack RW (eds.). Schenkman Publishing Company: Cambridge, MA.

Chapman Wood R, Hatten K, Williamson P. 1999. Strategy innovation routines and organizational change processes that generate them. *Paper presented at the Strategic Society 19th International Conference in Berlin* (October 4, 1999).

Collis DJ. 1994. Research note: How valuable are organizational capabilities? *Strategic Management Journal* **15**:143-152.

Cyert R, March J. 1963. *A Behavioral Theory of the Firm*, Prentice-Hall, Englewood Cliffs.

Dierickx I, Cool K. 1989. Asset stock accumulation and sustainability of competitive advantage. *Management Science* **35**:1504-1511.

Dutton J, Freedman R. 1985. External environment and internal strategies: Calculating, experimenting, and imitating in organizations. In R. Lant and P. Shrivastava, eds. *Advances in Strategic Management*, JAI Press, Inc., Greenwich.

Eisenhardt KM. 1989. Making fast strategic decisions in high-velocity environments. *Academy of Management Journal* **32**:543-576.

Eisenhardt KM, Martin JA. 2000. Dynamic capabilities: What are they? *Strategic Management Journal*

21:1105-1122.

Ferrier W, Smithy K, Grimm C. 1999. The role of competitive action in market share erosion and industry dethronement: a study of industry leaders and challengers. *Academy of Management Journal* **42**:372-388.

Galunic C, Eisenhardt KM. 2000. Architectural innovation and modular corporate forms. *Academy of Management Journal* (forthcoming).

Gavetti G, Levinthal D. 2000. Looking forward and looking backward: cognitive and experiential search. *Administrative Science Quarterly* **45**:113-137.

Hannan M, Freeman J. 1977. The population ecology of organizations. *American Journal of Sociology* **82**: 929-964.

Helfat CE, Raubitschek RS. 2000. Product sequencing: co-evolution of knowledge, capabilities and products. *Strategic Management Journal* **21**:961-979.

Henderson R, Cockburn I. 1994. Measuring competence? Exploiting firm effects in pharmaceutical markets. *Strategic Management Journal* **15**:63-84.

Iansiti M, Clark K. 1994. Integration and dynamic capability: evidence from product development in automobiles and mainframe computers. *Industrial and Corporate Change* **3**:557-605.

Ichniowski C, Shaw K, Prennushi G. 1997. The effects of human resource management practices on productivity: A study of steel finishing lines. *American Economic Review* **87**:291-313.

Kale P. 1999. *Building An Alliance Capability: A Knowledge-based Approach.* Unpublished Dissertation, University of Pennsylvania.

Kogut B, Zander U. 1992. Knowledge of the firm, combinative capabilities, and the replication of technology. *Organization Science* **3**:383-397.

Lant T, Mezias S. 1990. Managing discontinuous change: A simulation study of organizational learning and entrepreneurship. *Strategic Management Journal* **11**:147-179.

Levinthal D. 1995. Strategic management and the exploration of diversity. In C. Montgomery, ed. *Resource-based and Evolutionary Theories of the Firm: Toward a Synthesis* Kluwer Academic Publishers, Boston, pp. 19-42.

Levinthal D, March J. 1981. A model of adaptive organizational search. *Journal of Economic Behavior and Organization* **2**:307-333.

Lieberman M, Montgomery D. 1988. First-mover advantages. *Strategic Management Journal* **9**:41-58.

Lippman S, McCall J. 1976. The economics of job search: A survey. *Economic Inquiry* **14**:155-187.

Lippman S, Rumelt R. 1982. Uncertain imitability: An analysis of interfirm differences in efficiency under competition. *Bell Journal of Economics* **13**:418-438.

March JG. 1991. Exploration and exploitation in organizational learning. *Organization Science* **2**:1-13.

McGahan A, Porter M. 1997a. How much does industry matter, really? *Strategic Management Journal* **18**:15-30.

McGahan A, Porter M. 1997b. The emergence and sustainability of abnormal profits. Harvard Business School Working Paper 97-103.

McGahan A. 1999. The performance of U.S. corporations: 1981-1994. *The Journal of Industrial Economics* **47**:373-395.

Mezias S, Eisner A. 1997. Competition, imitation, and innovation: an organizational learning approach. *Advances in Strategic Management* **14**:261-294.

Milgrom P, Roberts J. 1995. Complementarities and fit: Strategy, structure, and organizational change in manufacturing. *Journal of Accounting and Economics* **19**:179-208.

Nelson R, Winter S. 1982. *An Evolutionary Theory of Economic Change*, The Belknap Press of Harvard University Press, Cambridge.

Noda T, Collis DJ. 1999. The evolution of intra-industry firm heterogeneity: Insights from a process study. *INSEAD Working Paper* 99/19/SM.

Penrose E. 1959. *The Theory of Growth of the Firm*, Basil Blackwell, London.

Peretaf M. 1993. The cornerstones of competitive advantage: A resource-based view. *Strategic Management Journal* **14**:179-191.

Porter M. 1985. *Competitive Strategy*, The Free Press, New York.

Porter M. 1994. Toward a dynamic theory of strategy. In R. Rumelt, D. Schendel and D. Teece (eds.), *Fundamental Issues in Strategy: A Research Agenda.* Harvard Business School Press, Boston, MA, pp. 423-461.

Porter M. 1996. What is strategy? *Harvard Business Review* **74**:61-79.

Rumelt R. 1984. Toward a strategic theory of the firm. In R. Lamb, ed. *Competitive Strategic Management*, Prentice Hall, Engelwood Cliffs.

Rumelt R. 1991. How much does industry matter? *Strategic Management Journal* **12**:167-185.

Rumelt R, Schendel D, Teece D. 1994. *Fundamental Issues in Strategy*, Harvard Business School Press, Boston.

Sastry A. 1997. Problems and paradoxes in a model of punctuated organizational change. *Administrative Science Quarterly* **42**:237-275.

Schmalensee R. 1985. Do markets differ much? *American Economic Review* **75**:341-351.

Schumpeter J. 1934. *The Theory of Economic Development.* Transaction Publishers, New Brunswick.

Simon H. 1955. A Behavioral Model of Rational Choice. *Quarterly Journal of Economics* **69**:99-118

Stinchcombe A. 1965. Social structure and organizations. In James G. March (ed.), *Handbook of*

Organizations:153-193. Chicago: Rand McNally.

Szulanski G. 1996. Exploring internal stickiness: impediments to the transfer of best practice within the firm. *Strategic Management Journal* **17**:27-44.

Teece D, Pisano G, Shuen A. 1997. Dynamic capabilities and strategic management. *Strategic Management Journal* **18**:509-533.

Tirole J. 1988. *Industrial Organization*, MIT Press, Cambridge.

Wernerfelt B. 1984. A resource-based view of the firm. *Strategic Management Journal* **5**:171-80.

Williams J. 1994. Strategy and the search for rents: the evolution of diversity among firms. In *Fundamental Issues in Strategy*, Rumelt R, Schendel D, Teece D (eds.). Harvard Business School Press: Boston, MA:229-246.

Zander U, Kogut B. 1995. Knowledge and the speed of the transfer and the imitation of organizational capabilities: an empirical test. *Organization Science* **6**:76-92.

Zollo M, Singh H. 1998. The impact of knowledge codification, experience trajectories and integration strategies on the performance of corporate acquisitions. *The Academy of Management*, Best Paper Proceedings: San Diego, CA.

Zollo M, Winter S. 1999. From organizational routines to dynamic capabilities. INSEAD Working Paper.

APPENDIX I: ASYMPTOTIC SOLUTION

The goal of the model is to find an asymptotic solution that yields a maximum for (7') with the decision variables i, q and r as maximands. Assuming that t? ∞, the first simplification one can make is to cancel the term $a/\sum_t i_{j,t}$, which, for a large t, is likely to become negligible. The optimal asymptotic solution for $i_{j,\infty}$ is obviously zero. Second, firms are initially symmetric, so one would expect a symmetric optimal value of $r_{\bullet,\infty}$. Simplifying (7') along these lines yields

$$\pi_{j,\infty} = q_{j,\infty}(nK - \sum_i q_{i,t}) - q_{j,\infty}v - \epsilon^2 r_{j,\infty}^2 \tag{8}$$

which is to be maximized with respect to $q_{j,\infty}$. The first order condition for $q_{j,\infty}$ is

$$?\pi_{j,\infty}/ ?q_{j,\infty} = (nK - v) - 2q_{j,\infty} - \sum_{i \neq j} q_{i,\infty} = 0 \tag{9}$$

Solving equation (9) for $q_{j,\infty}$ one obtains

$$q_{j,\infty}* = nK - [n/(n + 1)][(nK - v)] - v \tag{10}$$

where $q_{\infty}*$ denotes an optimal asymptotic value for the quantity decision variable if the second order conditions for a maximum hold. Inserting $q_{j,\infty}*$ back into (7') and again setting $i_{j,\infty} = 0$ and $a/\sum_t i_{j,t} = 0$ yields yet another expression for asymptotic profit, namely

$$\pi_{j,\infty}' = \alpha(r_{j,\infty} / \sum_i r_{i,\infty}) - q_{j,\infty}v - \epsilon^2 r_{j,\infty}^2 \tag{11}$$

where

$$\alpha = [n/(n + 1)]^2(nK - v)(K + v) \tag{12}$$

Taking the derivative of (11) with respect to $r_{j,\infty}$ yields the first order condition for $r_{j,\infty}$

$$\partial \pi_{j,\infty}'/\partial r_{j,\infty} = \alpha \ [(\sum_i r_{i,\infty} - r_{j,\infty})/(\sum_i r_{i,\infty})^2] - 2\epsilon^2 r_{j,\infty} = 0 \tag{13}$$

Solving equation (13) for $r_{j,\infty}$ one obtains

$$r_{j,\infty}* = [\alpha(n - 1)/2]^{1/2} / (n\epsilon) \tag{14}$$

$r_{j,\infty}*$ denotes the optimal asymptotic value for the product innovation rate, provided that the second order conditions for a maximum hold. These second order conditions stipulate that $\partial^2 \pi_{j,\infty}/\partial q_{j,\infty}^2 < 0$, $\partial^2 \pi_{j,\infty}/ \partial r_{j,\infty}^2 < 0$ and that the determinant of the Hessian matrix of $\pi_{j,\infty}$ with respect to $q_{j,\infty}$ and $r_{j,\infty}$ be positive. It may be assumed that this system of inequalities holds for some combinations of the parameters n, K, v and ϵ.

APPENDIX II: FURTHER MODEL ASSUMPTIONS

Assumptions about competition

(A1)   Firms seek to maximize profits.

(A2)   Firms are able to adjust their production rates, product innovation rates, and process innovation rates instantaneously.

(A3)   There is no noise or exogenous uncertainty in consumer demand.

(A4)   There is no entry of firms to, or exit from, the industry. Existing firms do not go bankrupt.

(A5)   If firms overproduce (i.e., they collectively produce more output than can be sold at a minimum price in the marketplace) they will be rationed. The rationing rule is proportional allocation. Suppose collective output, $\sum q_i$, exceeds n*K-m, where n is the number of firms, K reflects the strength of consumer demand, and m is a certain margin (when m>0, rationing will take place before the price drops to zero). Denoting the number of output units produced as q_i, a firm is then able to sell q_i*(n*K-m)/$\sum q_i$ units.

Assumptions about variation

(A6)   Firms know all their change rules. They apply these rules to their current vector of decision variables to generate a set of alternative vectors.

Assumptions about selection

(A7)   In each period, a firm selects exactly one alternative vector of decision variables.

(A8)   The fitness value of an alternative vector of decision variables is calculated according to the following formula:

> [(Expected Profits Assuming That The Alternative Values Are Implemented
> And All Other Firms Stick To Their Previous Vectors Of Decision Variables –
> Expected Profits Assuming That No Firm Will Make Any Changes) / Discount
> Factor – Respective Change Costs]

Thus a vector's fitness is the net present value of the incremental future benefits that it promises to achieve.

(A9)   In the case of stochastic selection, the fitness values of the generated alternative vectors of decision variables will be scaled so that they all become non-negative. Scaling is done by multiplying the smallest negative fitness value by (-1) and by adding the resulting positive number to all fitness values. Thus, scaling is additive and linear.

(A10)   Selection of an alternative vector of decision variables is costless.

Assumptions about retention

(A11)   Selected alternative values are implemented and thus retained with a certain probability p_r that reflects organizational inertia. If the firm refrains from modifying its current vector of decision variables (which happens with probability 1- p_r) then it will simply keep the values from the previous period. [Note that Cyert and March (1963) and Mezias and Eisner (1997) argue that change is either

"problemistic," i.e., driven by under performance relative to an aspiration level, or "opportunistic," i.e., motivated by the perception of opportunities to improve performance. I have run simulations under this alternative assumption and found that, in general, divergence of firm performance was less likely to result. The intuition for this is that the industry leader's speed of change slows, whereas the follower has an increased incentive to deploy dynamic capabilities in order to improve performance. This tends to foster convergence.]

(A12) The costs of implementing alternative values of decision variables are determined by the company's change cost structure, consisting of eight parameters (p1, the cost of adaptively changing the output quantity; p2, the cost of imitating a rival's output quantity; p3, the cost of adaptively changing the product innovation rate; p4, the cost of imitating a rival's product innovation rate; p5, the cost of adaptively changing the process innovation rate; p6, the cost of imitating a rival's process innovation rate; p7, the cost of changing two decision variables simultaneously; p8, the cost of changing three decision variables simultaneously). For example, the total cost of applying change routine "130" is equal to p2+p3+p7.

(A13) If firms learn to change, then the implementation of change entails a reduction of future change costs. In the above example, p2, p3 and p7 would be reduced.

(A14) Whether a decision variable is increased or decreased has no impact on the magnitude of related change costs. For example, increasing the product innovation rate is costly because it involves overcoming organizational barriers, using additional r esources, building new operational routines, and so on. But reducing the product innovation rate does not come for free, either. Taking away resources from research and development may create conflict and, at least temporarily, demotivate and thus reduce the productivity of workers. Similarly, sales teams may have to be dissolved and their members integrated into other parts of the organization. This involves either training costs or severance payments to fired employees.

(A15) Following a change, a new cyc le of competition, variation, selection and possible retention will immediately start.

TABLE 1: Each attribute of dynamic capability coded as "on" or "off"

	On-coding*	Off-coding
Attribute A1 (Timing)	**A1-on**: The selected decision variables are implemented with a probability smaller than 1; that is, firms are likely to deploy dynamic capabilities at different times	**A1-off**: The selected decision variables are always implemented; that is, firms deploy dynamic capabilities simultaneously
Attribute A2 (Imitation)	**A2-on**: Imitation of rivals is impossible	**A2-off**: Imitation of rivals is possible
Attribute A3 (Costs)	**A3-on**: Deployment of dynamic capability is costly	**A3-off**: Deployment costs are zero
Attribute A4 (Learning)	**A4-on**: Dynamic capability deployment costs decrease through learning by doing	**A4-off**: Dynamic capability deployment costs remain constant as there is no learning by doing

* The wording of the on-coding is such that the condition of the respective proposition is fulfilled. For example, Proposition 3 only holds under A3-on, never under A3-off.

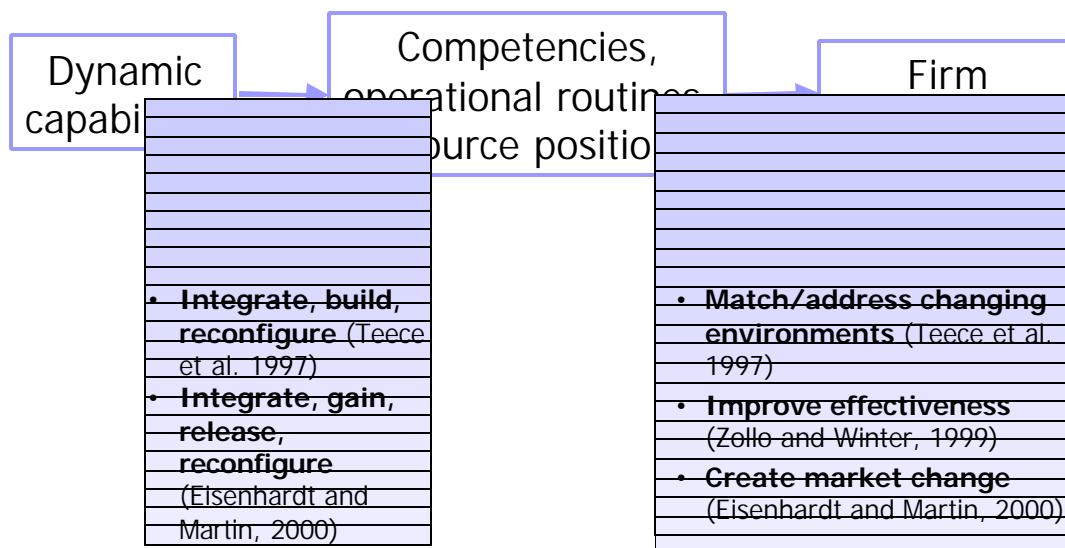**FIGURE 1:** Emerging consensus regarding dynamic capabilities and their link to firm performance

FIGURE 2: Firm performance in a model with differential timing of dynamic capability deployment
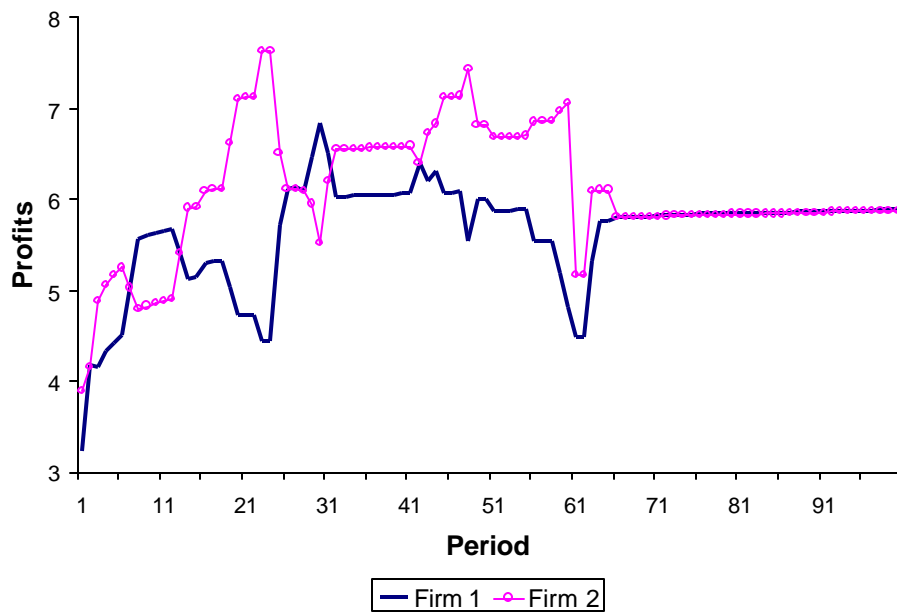

FIGURE 3: Firm performance in a model with differential timing of dynamic capability deployment and no imitation
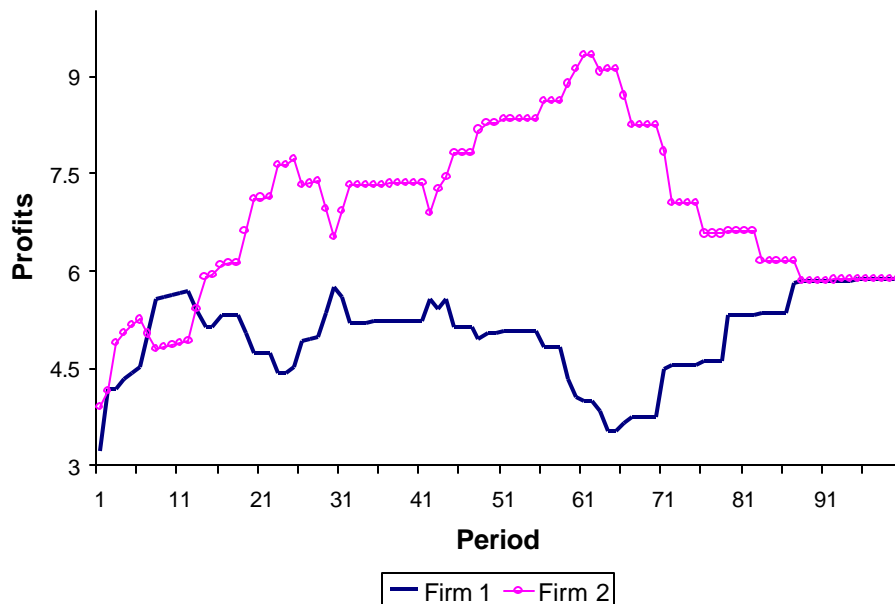

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FIGURE 4: Firm performance (measured as profit gross of change costs) in a model with differential timing of dynamic capability deployment, no imitation, and deployment costs
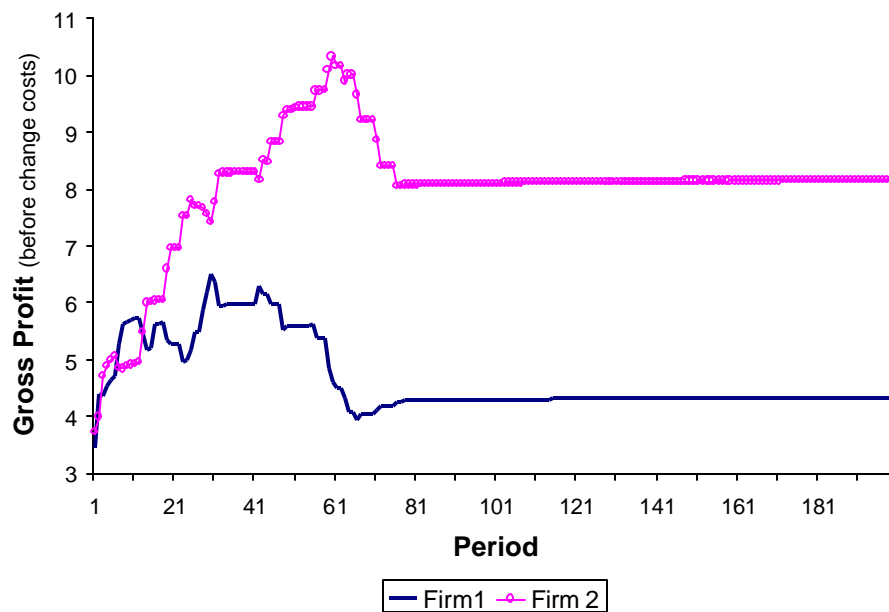

FIGURE 5: Firm performance (measured as profit net of change costs) in a model with differential timing of dynamic capability deployment, no imitation, and deployment costs
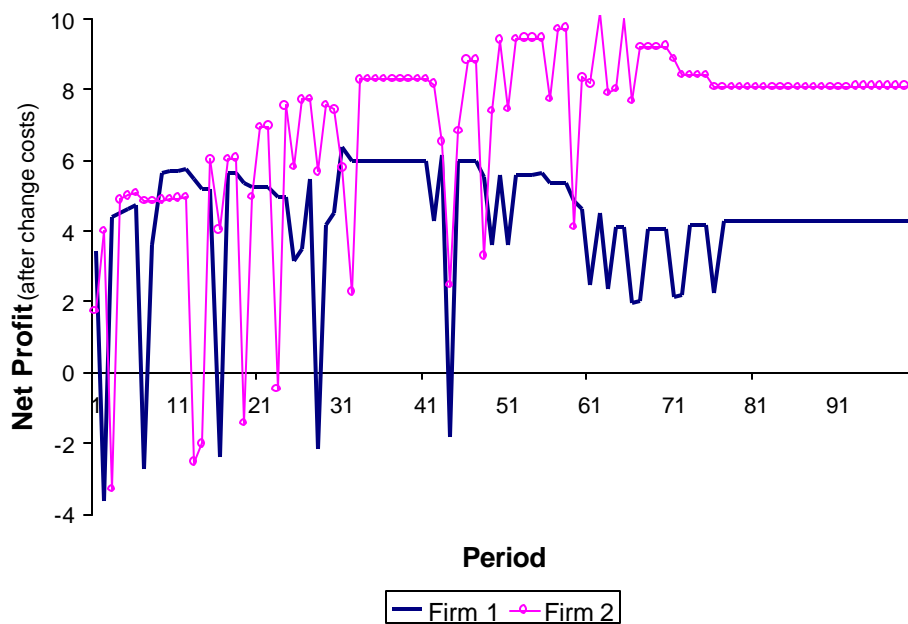

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FIGURE 6: Evolution of firms' decision variables in a model with differential timing of dynamic capability deployment, no imitation, and deployment costs
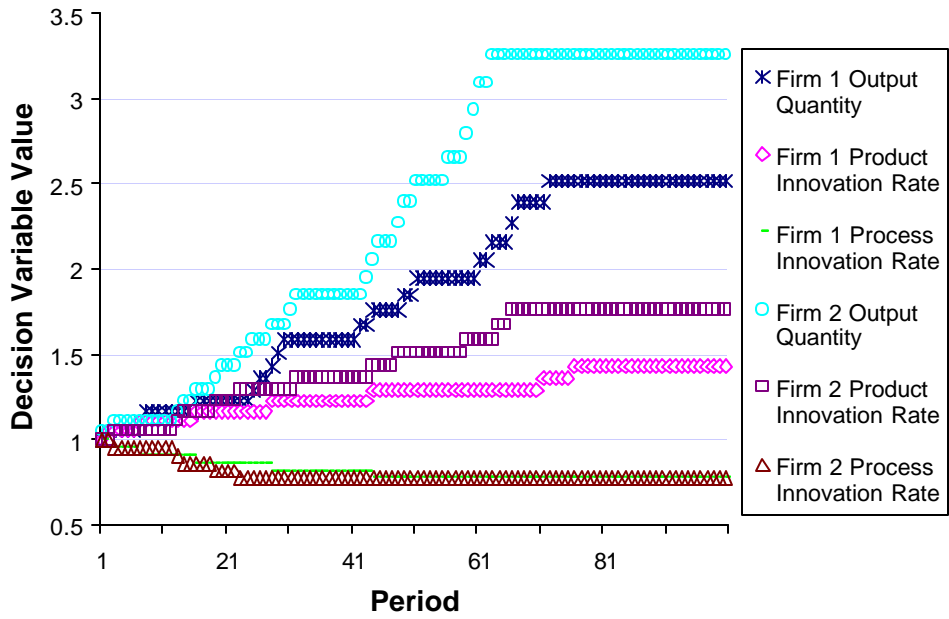

FIGURE 7: Firm performance in a model with differential timing of dynamic capability deployment, deployment costs, and learning
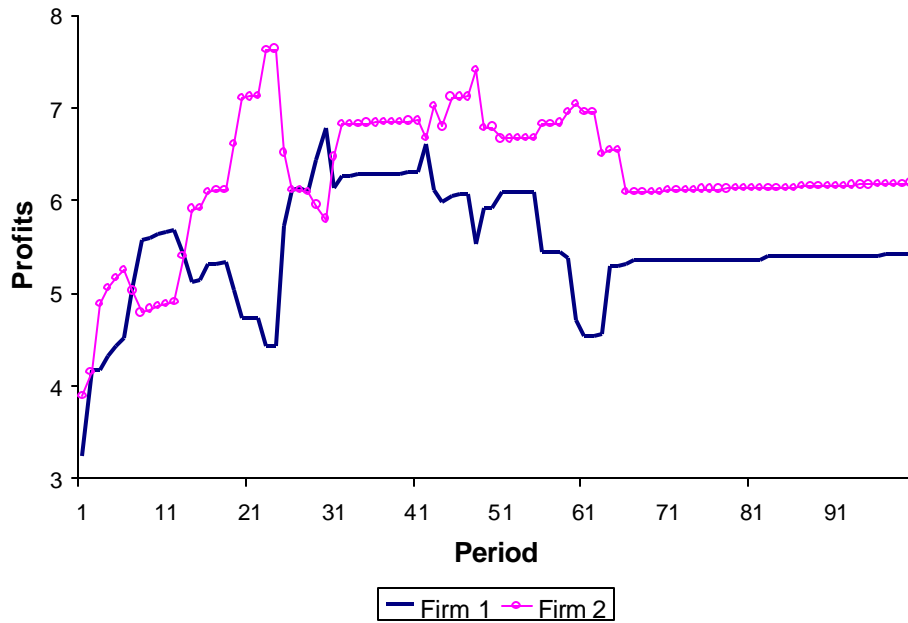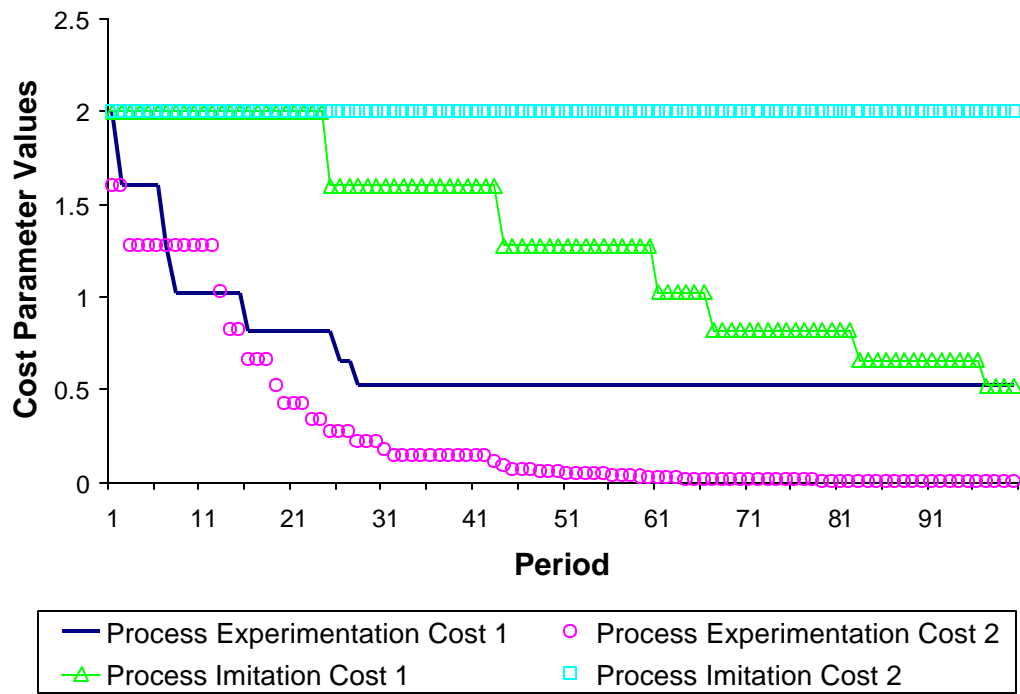
FIGURE 8: Evolution of selected cost parameters in a model with differential timing of dynamic capability deployment, deployment costs, and learning

Endnotes

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[1] A dynamic capability is equifinal if it is similar across firms in terms of key attributes, and if "managers of firms that develop an effective dynamic capability … very probably begin the development of that dynamic capability from different starting points, and take unique paths" (Eisenhardt and Martin, 2000:1109).

[2] *Variation* includes all processes and activities concerned with searching for, and identifying, alternative solutions to a problem, and sharing them among the members of an organization. Search can be exploratory or exploitative (March, 1991), cognitive or experiential (Gavetti and Levinthal, 2000), or imitative or experimental (Dutton and Freedman, 1985). A firm's search behavior may explain diversity among firms because organizational search is usually characterized by uncertainty, complexity, and conflict (Amit and Shoemaker, 1993). As a consequence, some firms may possess superior search routines (Williams, 1994).

[3] *Selection* refers to those organizational activities or processes, such as the evaluation of alternatives, involved in identifying a preferred alternative for organizational change. An example is the selection of a new product development process (Iansiti and Clark, 1994). Based on the premise that a firm can only select what it has learned from a previous search, selection logically follows a search. Knowledge articulation and codification appear to be important antecedents to selection (Kogut and Zander, 1992; Zollo and Singh, 1998; Zollo and Winter, 1999).

[4] *Retention* refers to the actual implementation of organizational change. It includes, for example, the management of changes in skills and systems, the coordination and communication across sub-units, and the establishment of direction and focus (Iansiti and Clark, 1994). It also refers to the transfer of operational capabilities (Zander and Kogut, 1995) or best practice (Szulanski, 1996) between different units of a firm.

[5] The costs of imitation and experimentation may differ substantially. While inward-focused experimentation may immediately yield insights about the linkages between actions and outcomes, there may be much less clarity about these causal linkages in the case of imitation. Hence, it may be costlier for the imitating firm to gain an adequate knowledge of these action-outcome linkages relative to an experimenting firm.

[6] Consider the following thought experiment. Let A be a firm that only experiments, and B a firm that alternates between experimentation and imitation, that is, in one period B experiments, in the next period B imitates, then B experiments again, and so on. Let the initial costs of experimentation and imitation be equal to 1. These costs are reduced by 50% whenever a firm engages in their respective activity. After two changes, A will have reduced its experimentation costs to 0.25, whereas B will have reduced both experimentation and imitation costs to 0.5. In other words, in the third round of change, A will have a cost advantage over B. This may translate into a performance advantage.

[7] I assume that the more resources devoted to product innovation, the higher the number of product innovations. A similar proportional relationship is assumed to hold for process innovations.

[8] Note that the inverse demand function specified by (5) has no memory – it ignores the total stock of product innovations and thus applies predominantly to markets where being current is important, that is, to so-called "fashion markets." Equation (5) can, however, be easily reformulated to include a memory of the past.

[9] Firms that use an "on-line" variation mode rely on feedback-based, experiential processes. This implies that they can explore only one alternative at a time (Gavetti and Levinthal, 2000).

[10] Change rules are coded as strings of length three, with elements of the string drawn from the set {0, 1, 2, 3}. "0" encodes the prescription "retain value," "1" represents the action "imitate industry leader's value," "2" stands for the action "experimentally adjust value downward," and "3" represents the action "experimentally adjust value upward." The first of the three letters in a string refers to how a firm should change the value of the quantity variable, the second element refers to a recommended change of the product innovation rate, and the third element defines a change action with respect to the process innovation rate. For example, the rule "120" calls for imitating the product quantity of the industry leader, experimentally lowering the rate of product innovations, and retaining the rate at which process innovations are realized. (Note that the decision variables in the model are flow variables, and can therefore be adjusted instantaneously. For a discussion of flow and stock variables, see Dierickx and Cool, 1989.)

[11] A stable industry has two main characteristics. First, there is little exogenous change -- for example, there is little technological change or changes in consumer preferences. Second, there is little endogenous change, which means that rivals' behavior is stable and predictable. In the simulation, I model an industry with a stable exogenous environment, but with a lot of endogenous change.

[12] Although the simulation was run for 200 periods, results are only shown for the first 100 periods. This was because the patterns did not change after period 100. The same is true for most of the other figures.

[13] Due to their tacit nature, change costs are often difficult to observe and verify. Therefore, one assumption made in the model is that firms benchmark against other firms using profit, gross of change costs, as a performance metric. The industry

leader is the firm with the highest accounting profits, which are assumed to be proportional to profits before change costs.

[14] More specifically, all change cost parameters are set equal to 2, and the learning discount is supposed to be 20%. In other words, whenever a firm invokes a particular search and change direction (either imitation or experimentation), the associated costs drop by 20%.

[15] Porter (1985:16-17) introduced the notion of firms getting "stuck in the middle" in the context of generic strategies.

[16] These results are robust to moderate changes in initial cost parameters and decision variable values. However, they are sensitive to the step size of experimental change. With a smaller step size, the qualitative results remain the same, but they are less pronounced (e.g., performance differences are smaller). In addition, with a higher probability of retention, or with different random seeds, these results may not obtain at all. An important precondition for the findings is that one firm should have a series of quick, adaptive changes towards the beginning of the simulation, whereas the other firm remains relatively passive (i.e., imitates or stay s inert), otherwise cost structures do not differentiate to a sufficient degree for path dependencies to arise.