

**The Significance of Capability Distribution in the Race to Enter Emerging Markets:
Telephony Communications and Computer Networking, 1989–2001***

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PRELIMINARY DRAFT

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Abstract

The objective of the paper is to explain the effect of a firm's capabilities on the speed at which the firm enters an emerging product market, when the firm is under the pressure of technological convergence as the boundaries between initially distinct industries become blurred. This paper develops a theoretical framework and a general methodology to build a dynamic model and analyze the evolution of a firm's product portfolio, so as to estimate the probability of firm entry and the amount of time it takes a firm to enter a product market. Three important questions addressed are: (1) which emerging product markets should a firm enter? (2) from what industries do potential entrants arise? and (3) why do some firms enter an emerging market faster than others? The basic proposition is that the heterogeneity of firms' timing of market entry can be explained by the firms' capabilities inferred from their pre-entry product portfolio. The proposed model aims to make the proposition precise and provide specific predictions. Using a multi-population panel of firms over a thirteen-year period from 1989 to 2001 collected from a natural experiment, I found strong empirical support for my hypotheses in the case of technological convergence between telephony communications and computer networking technologies.

* This paper is a part of my dissertation, which is entitled "The Competitive Consequences of Technological Convergence in an Era of Innovation: Telephony Communications and Computer Networking, 1989-2001."

** I would like to recognize the generous support of the Lucent Fellowship in Management of Technology. I would also like to thank the participants at the UC Berkeley Seminar on Innovation, the Haas Business and Public Policy Workshop in Institutional Analysis, and the Haas Organizational Behavior and Industrial Relations Colloquium for their comments and suggestions.

I. Introduction

In the last two decades, boundaries between many initially distinct industries have become blurred as a result of technological convergence. The convergence of data communication and voice communication industries is a prominent example, as the Internet becomes the dominant platform of communication. When previously disparate technologies converge, a firm's existing products, which may be aimed at rather different customer groups, might suddenly develop common technological and production roots for the development of emerging products (Teece et al., 1994). Established firms with seemingly different origins, thus face the decision of whether to enter emerging product markets as well as the challenge of quickly developing the capabilities necessary to enter the new markets. Researchers and business managers are naturally interested in knowing (1) what the conditions are under which a firm should enter the market when a new product market emerges; (2) which firms or groups of firms are more likely to enter and how fast they may enter; and (3) why certain firms have more competitive advantage in market entry and upon which the advantage may depend. These questions are fundamental to our understanding of firm growth/ renewal, corporate strategy, and industry evolution.

A popular framework for understanding the context of an organization's strategic position with respect to entry is "industry and competitive analysis" (e.g., Porter, 1980). This framework of industrial competition helps researchers and business analysts to assess which industries are more or less attractive environments to enter, and how a firm's strategy positions it with respect to other firms. However, much of the analysis using this framework has drawn on fairly static concepts of industry structure. The static, or "equilibrium," nature of the framework does not allow researchers or analysts to address why certain entrants are better positioned than others to enter an emerging market. There are, for example, circumstances in which first movers have advantages over latecomers. Also, the equilibrium assumption does not permit researchers or analysts the possibility to investigate the industries from which potential entrants arise, address whether their threats are equally formidable, or answer whether their pre-entry backgrounds have performance implications. In general, this framework does not differentiate one

potential entrant from another as long as potential entrants face the same form of competition or industry structure.

By contrast, the “resource-based” view of the firm (RBV) pays attention to the underlying resources and capabilities that are heterogeneously distributed across firms (e.g., Wernerfelt, 1984; Barney, 1986; Rumelt, 1991; Dosi and Teece, 1993).¹ The emphasis of the RBV is on a firm’s efficiency in deploying firm-specific physical assets (e.g., specialized equipment), human assets (e.g., expertise), and intangible assets (e.g., brand) to shape its external environment and improve its strategic position. Under the RBV framework, one firm occupies a more favorable position than another firm because it has better capabilities to deploy resources for a desired end result. Proponents of the RBV view strategic investments directed towards a firm’s capabilities as an instrument to generate supranormal returns. These capabilities include the ability to develop new products quickly, to thoroughly understand customers’ needs, and/or to take advantage of new technologies more effectively. Nevertheless, RBV addresses so broad a range of factors correlating firm behavior with performance outcome across various contexts, to the extent that a researcher can hardly use the theory to make specific predictions on important issues such as entry into a particular product market.

More seriously, the existing literature in RBV provides conflicting predictions on the merits and impediments of a firm’s existing capabilities. On the one hand, a firm’s existing capabilities provide opportunities for transferring learning and best practice across markets and industries (see Prahalad and Hamel, 1990, on core competencies). On the other hand, a firm’s existing capabilities may simultaneously enhance and inhibit the development of new capabilities (see Leonard-Barton, 1992, on core rigidities). This paradox of capabilities, consequently, yields little to guide practitioners. Even worse, managers bear the dear cost of making wrong decisions based on unsound prescriptions. Without a better understanding of the origin and evolution of capabilities, one who applies the RBV framework is

¹ Resources are defined as stocks of knowledge, financial assets, physical assets, human capital, and other tangible and intangible factors that a firm owns or controls (e.g., Penrose, 1959; Amit and Schoemaker, 1993).

just as handicapped as another who employs the industry and competitive analysis to identify potential entrants and analyze whether competitors differ in the threat they pose. More fundamentally, it is unclear what effect, if any, a firm's pre-entry capabilities have on its timing of entry into an emerging market.

Despite the enthusiasm for studying a firm's capabilities (Kogut and Zander, 1992; Foss, 1993; Teece and Pisano, 1994; Dosi, Nelson, and Winter, 2000; Eisenhardt and Martin, 2000; Helfat and Lieberman, 2002), critics of the capabilities approach challenge researchers to eradicate tautological, *ex post* rationalization and to operationalize the capabilities construct with rigorous empirical testing (e.g., Williamson, 1999; Porter, 1994). In response to the difficulties encountered by prior research, this paper limits the concept of capabilities to focus on a firm's product-embodied capabilities in deploying knowledge about technologies and customers that underpin the development of a product. These are the capabilities a firm uses to enter a product market of interest. By choosing this definition of capabilities, I allow researchers to draw inference from a firm's existing product mix as a representation of firm capabilities by examining the evolution of a firm's product portfolio. This definition is consistent with "organizational capabilities," a term used by evolutionary economists to refer to a firm's "ability to perform and extend its characteristic output actions – particularly, the creation of a tangible product or the provision of a service, and the development of new products and services" (Dosi, Nelson, and Winter, 2000: 1).

The goal of this paper is to study the evolution of a firm's product portfolio so as to understand how and why certain pre-entry capabilities confer more competitive advantage than others in terms of speed of market entry.² I view a firm as a set of product-embodied capabilities that evolve over time. Each firm occupies a certain position in the multi-dimensional "capabilities space" at a given time. The distance from the target in the "capabilities landscape" represents "the degree of relevance," or

² I recognize that the existence of a firm's product is not purely exogenous and I address the concern of endogeneity in the dissertation and extensions to this paper.

applicability, of a firm's initial capabilities to the new capabilities it seeks to develop.³ When the distance is short, or when the degree of relevance is high, it is easier for a firm to extend to the new capability from the existing ones. In other words, firms closer to the focal market of interest will be able to enter the market more quickly than firms that are farther away. My main proposition is that heterogeneity of firms' timing of market entry can be explained by firms' capabilities inferred from their product portfolio. The difference in the degree of relevance with respect to a focal capability distinguishes the competitive positions of firms and has significant performance implication. One of the main tasks of this paper is to develop such a notion of degree of relevance and identify a valid measure.

To develop the notion of degree of relevance and identify a valid measure, I establish a dynamic, path-dependent model that is consistent with theories on firm capability development. Specifically, I (1) develop a theory that allows the use of a firm's product portfolio to infer a firm's capabilities and to generate falsifiable hypotheses *a priori*; (2) build a Markov model to analyze the evolution of a firm's product portfolio so as to predict the probability of firm entry and the amount of time it takes a firm to enter a product market after the emergence of the market; (3) create a general methodology to estimate the parameters in the proposed model and apply analytical techniques to significantly reduce the complexity of the data structure; and (4) validate the proposed model with empirical evidence that I collect from a natural experiment over a thirteen-year period during which initially distinct technologies converge.

I begin the next section with a brief review of the literature on the origin and dynamics of capability development. I then discuss the techniques for analyzing a firm's timing of entry as a function of its pre-entry capabilities by characterizing a firm's position in the capabilities landscape relative to a strategic target (an emerging product market). Finally, I apply the proposed model and the associated analytical techniques that I developed to a case of technological convergence for hypothesis testing,

³ I propose the degree of relevance as a measure of relatedness for inter-business activities. For a more detailed discussion on measuring the coherence of business firms, see Teece et al., (1994).

where the origins and the dynamics of the development of technological capabilities are particularly important in this context.

II. Theory and Hypotheses: The Origin and Evolution of Capabilities

The literatures on evolutionary economics, the management of technology, and organizational theory posit that innovations are history dependent. That is, organizations often search for new capabilities in areas that allow them to build on their established technological base. The logic of this view assumes that a firm's prior capabilities condition the pattern of evolution and branching of its subsequent capability development. However, what is less understood is how the heterogeneity of a firm's existing capabilities affects the speed at which a firm develops the new capabilities of interest. My focus in this paper is the subtler difference in product markets at the level of industry segments under the light of evolutionary technological change. The theory and model that I develop explain the evolution of product portfolio by estimating the probabilities of firms' market entry and market exit, as well as the timing of entry, at the firm level and the industry segment level.

Quite the opposite, earlier studies mainly address entry into new industries that arise as a result of discontinuous technological shifts, as opposed to emerging industry segments that develop as a consequence of technological convergence (Abernathy and Clark, 1985; Tushman and Anderson, 1986; Henderson and Clark, 1990). These studies neither analyze which product markets a firm should enter nor estimate how fast firms with different backgrounds would enter. More recent studies have not comprehensively addressed why differences in pre-entry backgrounds lead to variations in performance or analyzed the industries from which potential entrants are likely to emerge, either (Klepper and Simons, 2000; Carroll et al., 1996). Exactly how the composition of the potential entrants' backgrounds influences entry and performance is unclear. Even less clear is what effect, if any, the firm's heterogeneous capabilities have on the intensity of competition and the structure of an emerging market. Additionally, given the heterogeneity in pre-entry conditions, researchers know little about how a firm's

adaptations in capabilities prior to entry influence the speed of market entry. Neither of the aforementioned studies, however, examined how a firm's subsequent strategic choice to adapt affects the timing of entry. These gaps in the existing literature highlight the process of capability development, which is affected by initial conditions and by subsequent adaptive changes.

Origin of Capabilities: Initial Conditions

Established firms that wish to enter an emerging product market in which they have not participated must develop new capabilities that meet the demands of the market. The management of research and development (R&D), however, challenges decision makers to perform in the context of uncertain technical, economic, and social environments in which the actions of competitors are particularly difficult to anticipate (Tushman and Rosenkopf, 1992). In such ambiguous and uncertain settings, a heavy reliance on historical experience is the norm (March, 1988). In other words, the results of past searches become natural starting points for initiating new searches (Nelson and Winter, 1982). As such, the development of new capabilities is likely to be constrained by local search, which is guided by previous, related experience. At the individual level, decision makers are boundedly rational so they cannot consider the universe of possible applications and technological opportunities. Instead, they engender local search and look to the firm's previous development decisions for guidance. Under the condition that prior investments are applicable to the new areas of endeavor, consistent investments in one domain to develop facilities, personnel, intellectual property, inter-organizational relations, and tacit organizational knowledge are critical to the development of new areas in that domain (Teece, 1988). Because organizational learning is a cumulative activity, a firm's pre-entry capabilities affect both the direction and the speed of subsequent development.

The constraint of local search plays a central role in conceptual frameworks that emphasize the difficulties incumbent firms have in adjusting their technology strategies to major environmental shifts (Abernathy and Clark, 1985; Tushman and Anderson, 1986; Henderson and Clark, 1990). These studies have discussed and documented the effects of "competence-destroying" technical changes, which are

defined as major technological changes that obviate the technical competencies of established firms. Although the generalizability of case studies is limited, a key finding from these in-depth case studies is that when radical technological developments significantly change the basis of competition, the path-dependent nature of firms' capabilities prevents the incumbents from responding quickly. In other words, these studies show that the severity of environmental shift moderates the persistence effect of initial conditions on the timing of response.

While it is important to investigate the role of the environment as a moderator in the "competence-destroying vs. competence-enhancing" framework, it is more important to understand the main effect of a firm's existing capabilities on the timing of entry into an emerging market. Drawing from Stinchcombe's (1965) idea of imprinting, I emphasize the role of initial conditions in the development of path-dependent capabilities.⁴ Indeed, the changing nature and mix of search routines in a population is a consequence of the context in which the strategy-making process takes place. So, I propose that an established firm's industry of origin before entering an emerging market may serve as the initial condition that bears potential in competitive advantage. Recent studies on industry of origin have shown empirically that firms diversifying from different industries of origin have different survival chances in the new product market (Carroll et al., 1996) and that having experience (compared to no experience) related to the emerging product market leads to faster entry (Klepper and Simons, 2000). Therefore, I expect firms diversifying from different industries of origin to enter an emerging product market at different rate. More specifically,

Hypothesis 1: The speed of entry into an emerging product market is significantly different among firms that diversify from different industries of origin.

⁴ The concept of imprinting refers to a process by which events at key developmental stages in an organization's life have persisting effects on the organization's survival chances. Although Stinchcombe's scholarship emphasizes founding event to set the initial condition of an organization's life, I extend the logic of the concept to treat a firm's activities as the initial conditions when the environment experiences significant shifts.

Evolution of Firm Capabilities: The Degree of Relevance

A firm's industry of origin, in my view, represents a firm's pre-entry capabilities at a coarse level. It serves as the initial condition that affects the rate at which an established firm enters an emerging product market. However, why do some initial conditions confer more competitive advantage than others? Carroll and his associates (1996) suggest that relevant theories are not very specific in making predictions about the sources of advantage, except to imply that they will vary from industry to industry. The rationale they use to explain their empirical findings is that firms generally differ in their levels of applicable capabilities. Having analyzed the specific context of the empirical setting, they identify that it is the deployment of assembly knowledge and expertise that propelled both bicycle and carriage manufacturers into automobile production with an advantage over engine producers. Klepper and Simons (2000) also point to relevant experience as a key factor that enabled firms with radio production experience to enter the emerging market of television (TV) receivers earlier than those without that experience. Radio producers were well positioned early to learn about technological developments in televisions because they had experience in R&D and distribution that was likely to be useful in televisions. They noted that (home) radio producers that entered the TV industry used their experienced radio engineers to direct their production-oriented R&D in TVs.

In addition, Brittain and Freeman (1980) argue that an organization is quick to expand when there is a significant overlap between its core capabilities and those needed to survive in a new market. Therefore, I propose that the timing of a firm's entry depends on the extent to which a firm's initial capabilities are applicable to the capabilities that it seeks to develop. That is, the degree of relevance in pre-entry capabilities with respect to a product market of interest affects a potential entrant's speed of developing products to compete in emerging markets. More specifically,

Hypothesis 2: The greater the relevance of a firm's capabilities to an emerging product market before entry is, the more quickly a firm will enter the market.

Although these hypotheses to be empirically verified are seemingly “intuitive,” the contribution of this paper is to quantify these predictions and enhance the predictive power of the theory with a formal model. Moreover, the proposed model provides a precise framework to generate more falsifiable hypotheses for rigorous empirical testing. Of course, the correctness and applicability of the proposed model are subject to the ultimate test of reality. This is why modeling alone without industry knowledge or qualitative analysis is less useful than complementing a formal model with case studies. As such, in Section III, I will build a formal model and then verify its usefulness empirically in Section IV with the case of voice/data convergence.

III. A Dynamic, Path-dependent Model: How to Estimate Timing of Entry as a Function of a Firm’s Pre-entry Position(s) in the Capabilities Landscape

Researchers do not yet have a set of comprehensive tools to quantify the relevance of a firm’s pre-entry capabilities with respect to an emerging product market. Thus, they cannot predict quantitatively the effect of relevance on the timing of market entry into the product market of interest. In this section, I develop a general methodology to analyze a firm’s timing of entry into an emerging market as a function of a firm’s pre-entry, product-embodied capabilities. My approach is to characterize a firm’s pre-entry strategic position or niche in the capabilities landscape with respect to a focal market of interest. The proposed methodology allows each firm to occupy a position in the capabilities landscape that reflects the distribution of a firm’s product portfolio. As discussed in the previous section, a firm’s position in this landscape derives from its existing capabilities, which partly shapes its competitive advantage.

It is important to note that my proposed theory and model focus solely on diversifying entry of established firms into emerging product markets and I purposely ignore the capability development of startups, except to account for the competitive pressure startups exert in the emerging market. Prior research establishes that a firm’s entry mode (de novo vs. de alio) uniquely distinguishes firms and it has

implications on a firm's length of survival (Carroll et al., 1996). Researchers find that diversifying entrants (*de alio*) enter at a larger scale than startups (*de novo*) and they have higher rates of survival than startups (Carroll et al., 1996; Caves, 1998). In addition, researchers find that the influence of diversifying entrants is often greater than their number, although the rate of *de novo* entry often exceeds that of diversified firm entry (Geroski, 1995). Therefore, I choose to focus on the capability change of diversifying entrants in this study.

A. Inferring Firm Capabilities From Product Portfolio

As defined in Section I, a firm's capabilities are the abilities to deploy knowledge about technologies and customers that underpin the development of a product. Several streams of research have contributed to the study of capabilities by examining various aspects of the capability construct, including "distinctive competence" (Selznick, 1957), organizational routines (Nelson and Winter, 1982), absorptive capacity (Cohen and Levinthal, 1990), architectural knowledge (Henderson and Clark, 1990), combinative capabilities (Kogut and Zander, 1992), and dynamic capabilities (Teece et al., 1997). However, the operationalization of the capabilities construct and rigorous empirical tests are underdeveloped.

The challenge is to identify robust statistical measures for capabilities that allow an analyst to examine the link between capabilities and revealed organizational performance. The representation of the capability construct remains difficult to analyze because capabilities are not directly observable, although many researchers have provided numerous definitions and taxonomies of capabilities (see Dosi, Nelson, and Winter, 2000). As such, most empirical studies do not measure firm capabilities directly. Instead, researchers examine relatedness and applicability by measuring the relative similarity of resource profiles across industries. That is, industry A is more closely related to industry B if the two industries share common resources. Researchers have used various resource profiles such as materials (input-output tables) and human capital (patent data and occupational employment survey data) (e.g., Chang, 1996). Other studies use a distance measure based on a company's R&D expenditure and/or advertising intensity

in a particular industry as a measure of relatedness between two industries (Montgomery and Hariharan, 1991).

In contrast, the novelty of my analytical strategy is to study observable changes in capabilities demonstrated by an organization's entry into product markets.⁵ Importantly, a prior study has demonstrated the positive correlation between a firm's range of products and its profile of technological capabilities (Patel and Pavitt, 2000) and established the validity for examining a firm's capabilities with its product portfolio. In other words, the choice of using product portfolio for my study is justified because it captures the range of a firm's ability to create tangible products and develop new products. Moreover, the degree of relevance derived from a firm's annual product portfolio is consistent with the *survivor principle* (see Stigler, 1968; Teece et al., 1994). In developing such a measure, I maintain the following key assumptions: (1) A potential entrant has some non-zero level of relevant and transferable capabilities applicable to the development of the desired capabilities; (2) Each of a firm's existing capabilities has a different strength of applicability to the development of the desired capabilities; and (3) Product-embodied capabilities that are more applicable to one another will more frequently co-exist within the boundary of the same firm. That is, if firms, which produce product A, almost always produce product B, I infer from the joint occurrence that A and B are likely to be related and the degree of relevance between the two products is high.⁶ I interpret my measure as a representation of a firm's capabilities and it provides researchers and managers a sense of how to develop entry strategy based on where firms are in the capabilities landscape prior to entry.

Furthermore, the uniqueness of my approach is to measure the distance from a firm's pre-entry position to a strategic target of interest. When firms have a common strategic target, the relative distance

⁵ I recognize that in the case of product line proliferation, a firm's capabilities may not change even if its product portfolio changes. However, in high-tech industries and particularly in the context of technological convergence, the ability to innovate and deploy knowledge about new technologies and customers is critical to compete in merging product markets.

⁶ Of course, products can co-occur in a firm's range of activities because they are complementary to one another, not merely applicable to one another. However, existing theories on bundling do not adequately explain how firms innovate under the pressure of technological convergence when their existing capabilities are partially threatened.

between firms can be defined, and so can that between industries of origin. In comparison, related research that examines a firm's technological position uses common lineage to explain the relative distance between two firms, not with respect to a common target. Applying cluster analysis to the distribution of firms' patents across the patent classes assigned by the U.S. Patent Office, Jaffe (1989) proposed that two firms are more related technologically if there is a higher degree of overlap between their research interests. Similarly, Stuart and Podolny (1996) defined two firms as technologically related if their search paths cite the same patents. However, these formulations lack a strategic target in their design.

In addition, my measure is more economical and parsimonious in terms of the requirements of information and data collection. One approach to study the degree of relevance between products is to conduct detailed case studies through fieldwork and interview industry experts. However, this approach is both costly and subject to severe sampling and recall bias. Another approach is to use technometrics derived from archival data sources. Examples of archival data sources used in related studies include patent data (e.g., Mowery et al., 1998; Silverman, 1999; Patel and Pavitt, 2000) and Standard Industry Classification (SIC) code (e.g., Teece et al., 1994; Montgomery and Wenerfelt, 1988).⁷ In comparison, patents are an intermediate output of R&D activities, not a full characterization of a firm's capabilities. In particular, patenting does not fully measure capabilities in software technology, which are essential in designing networking and communications equipment, since copyright law has until recently been the main means of protection against imitation for software technology (see Samuelson, 1993; Barton, 1993). By contrast, the SIC system captures more product characteristics than the patent system, but the measure based on 2-digit SIC codes is too coarse and it rests on strong assumptions about the order of the SIC system and the distance between each SIC code (see Silverman, 1999). Although the organization of a firm's product portfolio also employs a hierarchical structure where the product classification maps to

⁷ See Griliches (1990) and Patel and Pavitt (1995) for recent views on technometrics.

traditional SIC, the details in my data source provide much more fine-grained groupings of products for a rich and complete picture of each industry segment.⁸

B. Dynamic Modeling of Product-embodied Capability Evolution

I develop a dynamic, path-dependent model to test the significance of pre-entry capabilities in explaining a firm's timing of entry into an emerging market. The purpose of using a dynamic model is to connect the evolution of organizational capabilities to the strategic outcomes of market entry. It allows theory testing without resort to untenable assumptions such as temporal equilibrium or negligible friction associated with organizational change. In comparison, studies that are based on cross-sectional design cannot predict the timing of entry, which potentially has performance implications for first-movers. Although related research has confirmed that idiosyncratic firm capabilities both shape diversification strategy and drive the performance of diversified firms (e.g., Montgomery & Wenerfelt, 1988), its focus has been on the *spatial* relationships between the characteristics of the firm and the properties of the target market. Since Rumelt (1974), diversification research has favored a typology that defines a firm's strategy in terms such as related or unrelated diversification. Unfortunately, such a typology shows only a snapshot picture of a firm's evolution because cross-sectional studies ignore the dynamics and timing of entry. The *temporal* sequence of market entry, however, remains unexplored.

I propose the model to follow a multiple discrete state space process where the number of subsequent states that can be entered is finite. A state space is a one-to-one match from a firm's annual product portfolio to a location in the capabilities landscape. It can also be enlarged to include environmental conditions and firm characteristics (see Lancaster, 1992). Mapping a firm's annual product portfolio to a discrete state space, I specify the probability law governing the passage of the firm from one state to another as a semi-Markov chain of multiple-cycle, multiple-destination process (Lancaster, 1992: 108-118). Consistent with the theory of path dependency, the Markov chain is a

⁸ Nevertheless, because a firm's product portfolio captures the firm's ability to deploy knowledge about both technology and customer, I cannot differentiate a firm's technology-related from market-related capabilities.

general model of computation that consists of a set of states, which can include the initial conditions and subsequent changes of a firm's capabilities. The most important assumption in the proposed model is that the underlying data generation process allows the transition to a future state to depend only on the current state. Since the research questions and hypotheses emphasize the path-dependence of capability evolution, the choice of Markov model is appropriate because in the model, the initial condition and transition probabilities together give a complete description of the evolution trajectory. By contrast, a model based on logit regressions ignores the amount of time that elapsed before censoring (end of study) occurred because it does not distinguish slower moving cases from faster moving cases.

Suppose the process begins at calendar time $t = 0$ with entry to a state, and imagine that at some subsequent time the firm occupies state m . Let the time from entry to arrival at a particular state be s . At any time, a firm must occupy exactly one of M possible states. I define that given the history of the process to $t+s$, for small ds ,

$q_{mq}(t, s) ds \equiv$ Probability of departure from state m to state q in $s, s+ds$, given that the firm entered state m at t and has remained in state m for duration s

$$m, q = 1, 2, \dots, M. \quad m \neq q \quad (\text{eq. 1})$$

By the history of the process, I mean the list of states previously occupied, the dates when the firm entered and left those states, and the values and paths of any, possibly time-dependent, regressor variables. q is the transition intensity of the previous section with the original state (m) and the original date (t) brought explicitly into the notation. For subsequent states that are mutually exclusive, there is a corresponding destination-specific rate of transition (see Petersen, 1995: 481-483).

Let $\{X(t), t \geq 0\}$ be the stochastic process identifying the state occupied by a firm at each time t . The process is such that

$$\begin{aligned} P(X(t+s) = q \mid X(s)=m, X(u)=x(u), 0 \leq u < s) \\ = \text{Probability} (X(t+s)=q \mid X(s)=m) \end{aligned} \quad (\text{eq. 2})$$

for all $s, t \geq 0$, and $q, m, x(u) = 1, 2, \dots, M$. In essence, Equation 2 shows that the probabilities of the states, which may be occupied by a firm at $t+s$, depend only upon the state occupied at s and not at all upon the prior states.

C. Techniques to Reduce Model and Data Complexity

The main objective of this section is to fit the model to empirical data. Specifically, the parameters in the proposed model need to be estimated and the transition rate function needs to be identified. What type of aggregation, then, should be used to model the composite effect of the “capability bundle” on the speed of entry? The concept of “industry origin” is too broad as a level of aggregation because it assumes that a “core” industry origin is identifiable and that the distribution of capabilities in an organization is homogeneous. Consider the extreme case of conglomerates, where diversification spans across industries, not simply product lines. The notion of core capabilities is thus not useful.

An important issue to discuss before turning to the estimation of parameters is that of data management and dimension reduction. Table 1 shows an example of firms’ product portfolio for three product categories across three firms in year 2001. I record firms’ annual product portfolio as a K by N matrix where the rows are product categories and columns are firms. Each entry in the matrix is binary, taking the value of 1 to indicate that the firm is a producer of a particular product category, and 0 otherwise. There is one matrix per year where the row vector is $\mathbf{P}_{i,t}$ and the column vector is $\mathbf{F}_{j,t}$ for each year. In the subsequent discussion of the paper, however, I will drop the temporal subscript, t , for the purpose of notation simplification.

When the number of product categories is small, for each potential initial and subsequent state, I can easily use a categorical (dummy) variable to represent the distribution of a firm’s pre-entry, product-

embodied capabilities. However, as the number of product categories increases, the total number of combinations of initial and subsequent states are then $2^K \times 2^K = 2^{2K}$, where K is the universe of product categories that a firm can ever produce. The high dimensionality makes it difficult to use all the possible combinations as categorical covariates in regression analysis. For instance, if the number of product categories equals 3, there are a total of eight (2^3) possible discrete state spaces that a firm can occupy at time t . There are also eight potential subsequent states at time $t+1$. Together, there are $(2^3) \times (2^3) = 64$ possible combinations of initial and subsequent states a firm can potentially transition from time t to $t+1$. See Figure 1 for an illustration. Thus, the combinatorial problem aggravates and leads to challenges in the empirical analysis.

To reduce data complexity, I apply a set of simplifying assumptions as well as statistical techniques. The foremost challenge, however, is to select a subset of product categories (industry segments) that are most relevant to the development of an emerging product market. To make specific predictions, researchers need to identify which dimensions of a firm's existing capabilities provide a platform for developing a specific, often different yet related, capability. More importantly, the subset of product categories identified helps researchers to define the population, which is likely to enter the market (the risk set), as firms that have ever produced at least one product in this subset. I propose to use the joint occurrence of a product with the focal product in the same firm to identify the dimension of a firm's existing capabilities that is relevant and applicable to the development of the product of interest. In particular, the frequency with which an existing product category, P_i , and the targeted product category, P_x , jointly occur in an entrant's portfolio at the year of entry can be interpreted as the strength of the applicability from P_i to P_x . Another challenge is to select which entrants to include in the sample. The most straight-forward approach is to include all entrants that have ever entered the focal market. This option, however, picks up too much noise from entrants whose entry decisions are based on random imitation; thus it may be difficult to infer the relationship between P_i and P_x . A better option is to select only the entrants that succeed in surviving for an extended period of time. Together, the subset of product

categories produced by entrants with reasonable survival chance provides researchers a guideline to identify product categories not only have applicability to the development of P_x , but also sustain the vitality of a firm in the market of P_x .

To reduce the number of subsequent states, I make the simplifying assumption that separates the subsequent states into two categories: one where the product of the emerging market is present, and another where the focal product is absent. This assumption ignores changes in other parts of the portfolio where existing products can be dropped or new products can be added. Additionally, to reduce the number of initial states, I apply cluster analysis to classify a firm's pre-entry capabilities into groups. This technique extends prior research on the effect of industry origin. Clustering firms according to their pre-entry capabilities identifies where entrants come from; potential entrants in each cluster cohere because they have similar degrees of relevance with respect to the development of the desired capabilities.

A short summary of the cluster analysis is as follows (see dissertation for more detailed discussion). Because the data are binary, the class of similarity measures is the association coefficient. The coefficient is computed based on a 2×2 association table comparing the column vector F_j and F_g , which is the group average. With binary data, a group average is interpreted as a proportion. Each entry in F_g , also called the group proportions vector, is the corresponding fraction of the observations in the group for having a particular product category (StataCorp., 2001: 76). Among many candidates of association coefficients, I choose Jaccard's binary similarity coefficient, which avoids the use of joint absences of a variable in the calculation of similarity, because I am mainly concerned with features that have positive matches (see Aldenderfer and Blashfield, 1984; Everitt, 1980). I also choose iterative partitioning as the clustering method and the specific algorithm applied is k-means. In k-means clustering, the algorithm begins with k seed values, where k is the specified number of groups to create. Each observation (firm) is assigned to the group whose mean of the similarity measure is closest. New group means are then determined on the basis of that categorization. These steps continue until no observation (firm) changes groups. The groups can be interpreted as clusters of firms with different

industries of origin. Each cluster conceptually functions as a strategic group and occupies a different distance from the target in the capabilities landscape.⁹

Alternatively, another option to reduce the number of initial states is to transform the discrete state spaces into a continuous variable, R_j , which I call the “composite degree of relevance” for each firm j . R_j is a transformation of F_j and it locates a firm’s pre-entry position by summing the weights assigned to each product in a firm’s portfolio according to the product’s degree of relevance with respect to the focal product of interest. The steps involved in the transformation are as follows: First, for each year t , I define a vector P_i that shows the distribution of product category i across j firms. Using P_i , I then examine the joint distribution of product categories in a firm to measure the degree of relevance a firm’s existing capabilities have to the desired capabilities. Using the subset of product categories identified as discussed at the beginning of Section III C, I proceed to measure the degree of relevance with respect to the focal market. Among many potential measures for the degree of relevance, I choose the cosine index of similarity (for other measures that I experimented with, see dissertation for more detail). The cosine index of similarity measures the angular separation between two vectors, and is equal to the cosine angle between them. This measure meets the selection criteria because it is independent of the number of observations (it captures the direction the vectors are pointing, but disregards the absolute length) and can be formulated for binary data. For each product category chosen, the degree of relevance, S_{ix} of P_i with respect to P_x is calculated as:

$$S_{ix} = \frac{P_i \bullet P_x}{|P_i| |P_x|} \quad (\text{eq. 3.1})$$

⁹ The application of clustering technique to firm capabilities potentially connects the research in strategic groups and the RBV (see Lant and Phelps, 1999).

$$= \frac{\sum_{i=1}^{i=K'} C_i C_x}{\sqrt{\sum_{i=1}^{i=K'} C_i^2} \sqrt{\sum_{i=1}^{i=K'} C_x^2}} \quad (\text{eq. 3.2})$$

The value of $S_x = (S_{1x}, S_{2x}, \dots, S_{K'x})$, where K' is the subset of product categories identified, is equal to unity when P_i and P_x have identical distribution of co-occurrences across all samples. S_x goes to zero when P_i and P_x do not co-occur at all. In essence, the measure is the normalized count of firms that produce both product i and product x . An example of S_x where the focal product is network switching equipment is provided in Table 2-1.

The last step of the transformation is to use S_x as weights assigned to F_j and collapse the vector of binary data into a continuous measure by calculating the dot product of S_x and F_j . The higher the value of R_j , the more relevant a firm's pre-entry capabilities are with respect to the development of the desired capabilities, and the closer the firm is to the focal market. See Table 2-2 for examples.

$$R_j = S_x \bullet F_j \quad (\text{eq. 4})$$

D. Fully Parametric Inference

Before I discuss the estimation of parameters and functions, it is necessary to establish that they are identifiable. For a multiple destinations process, identifiability has been proved when the joint survivor function is a member of some parametric family, for example, the bivariate Normal or various types of multivariate Exponential distribution (Lancaster, 1992: 154-155). I now discuss issues related to parameter estimation and fully parametric inference. In building a dynamic model, I first assume that the entry events under study follow a continuous-time, discrete-state stochastic process (Carroll & Hannan,

2000).¹⁰ The principal methods for analyzing such a process empirically are called event-history and event-count methods. Event histories can be described using a number of parameters (or functions of the underlying stochastic processes) such as hazard, waiting time, and so forth. I choose to concentrate on hazard, which describes the rate at which events occur very near (just after) some time point. By definition, the hazard of entry is the probability of firm entry in year t for firms that have not yet entered by year t . When the hazard is destination-specific, I call it transition intensity.

My second assumption is that the hazard function takes the form

$$\theta(t,x,v) = v\underline{\theta}(x,t), \tag{eq. 5}$$

where x is a known regressor vector and v a scalar representing unmeasured (unobserved) heterogeneity that is firm-specific, time-invariant, and regarded as a realization of a random variable V with distribution function $H(v)$. However, unmeasured heterogeneity in multiple-cycle data remains under-studied, particularly with regard to the role of endogenous time-varying covariates and to the possibilities of instrumental variable type estimators. I address this issue in the dissertation, but I do not formally examine unmeasured heterogeneity in this paper. Instead, I address the issue of unmeasured heterogeneity for fully parametric inference by using a sampling scheme where I draw samples from the flow of entrants to and leavers from a state, and observe only one complete cycle. In order to obtain consistent estimates of the parameters, I need to eliminate unmeasured heterogeneity from the likelihood function. One way is to eliminate by integration, in which I form the joint distribution of the data and the firm-specific effect, and then integrate out the latter. This then gives me a likelihood based on a mixture model (Lancaster, 1992: 194).

¹⁰ Although the entry events under study are observed annually and there is loss of information that comes from not knowing the exact time of the event, this loss usually makes little difference in the estimated standard errors (see Alisson, 1984: 22). Thus, the choice between discrete- and continuous-time methods should generally be made on the basis of computational cost and convenience.

Third, I assume that the hazard of entry depends on time/duration and covariates that are both time-invariant and time-varying. That is, the hazard of entry is duration dependent and is a function of environmental conditions, such as legitimation and competition, and organizational properties, such as age and size. I consider the hazard to vary with time after the emergence of the focal market; the analysis thus follows an external clock because the origin of the time scale is relatively unambiguous. Because I assume the hazard to be duration dependent, the underlying process that I specified earlier as a semi-Markov chain is time-inhomogeneous. This leads me to assume further that the hazard can be estimated piecewise, and within each time period the hazard is constant.

So, the fourth assumption on model specification follows: I assume the so-called piecewise-exponential constant rate specification based on maximum likelihood. This specification is a flexible and widely used strategy for representing temporal variation in transition rates by breaking the relevant temporal dimension into pieces and fits constant rates within segments (Tuma & Hannan, 1984; Blossfeld and Rohwer, 1996). This kind of specification constrains temporal variation in the rate to a step function in duration; the researcher sets the width of the steps and allows the data to determine the height of each step (Carroll & Hannan, 2000: 136, 283). While much research makes parametric assumptions about the form of duration dependence by using the Gompertz, the Weibull, or the log-logistic models, I prefer the piecewise-exponential specification, which is less restrictive in representing temporal variation in transition rates. It allows the hazard of entry to change as the industry evolves. More importantly, the piecewise-exponential specification estimated by maximum likelihood has a decided advantage because it (1) accommodates non-proportionality of effects; (2) does not require strong assumptions about the exact forms of duration dependence; and (3) provides information about duration dependence (Carroll & Hannon, 2000: 140).

In contrast, Klepper & Simons (2000) and other studies on market entry rates use the Cox proportional hazards model based on partial likelihood in their empirical analysis. However, the Cox model has several drawbacks. First, the proportional hazards specification imposes a strong assumption

of proportionality of effects. That is, the model forces the estimation to be based on a product of two components, one that gives the effect of duration (the baseline hazard) and a second that gives the effect of the covariates (the proportionality). More specifically, the model assumes that the ratio of the hazards between any two subjects at any point in time is a constant, and it conditions out the baseline hazard. No econometrician has provided an economic -theoretical justification for why hazards should be proportional, or even approximately so (Lancaster, 1992: 57). Second, instead of forming a likelihood for the full model, the Cox model only maximizes the partial likelihood involving the effects of the covariates as if it were a genuine likelihood. Because it does not seek to obtain high-quality estimates of duration dependence, the Cox model is used much less frequently in research on the demography of corporations (Carroll & Hannon, 2000: 140). Third, the applicability of the Cox model is restricted to cases when an analyst knows the exact date of each market entry event and therefore can order them exactly (Hall, 2001: 5). On the contrary, when data are aggregated to a quarter or year, which is often the case if the data source is an annual directory, the dating of market entry events is imprecise. Therefore, it is inappropriate to use the Cox model in cases where time-aggregation bias is a concern.

Let v denote the set of time-constant covariates. Let $z(t)$ be the vector of explanatory variables at time t , where $z(t)$ may include lagged values (elements of the past history) of the explanatory variables and is approximated by a step function of time. For piecewise-exponential specification with time-varying covariates, I also impose the assumption that the parameters are constant within each time period. With a set of time-invariant variables, v , and a set of time-varying variables, $z(t)$, the hazard rate of entry is defined as follows in which the hazard depends log-linearly on v and $z(t)$ across P time periods (see Carroll & Hannan, 2000; Petersen, 1995):

$$\theta_p = h(t | v, z(t)) = \vartheta(t) \cdot \exp [\beta v + \gamma z_p(t)] \quad t \in I_p \quad (\text{eq. 6})$$

$$I_p = \{t | \tau_p \leq t < \tau_{p+1}\}, \quad p = 1, \dots, P. \quad (\text{eq. 7})$$

Recall in Section III C that I reduce the total number of possible subsequent states to two so as to simplify data management issue (entry into the focal market vs. no entry). So, on the left-hand side of Equation 6 is the hazard of entry into the focal market. To be clear, though, the dependent variable is not the hazard or transition intensity, but the amount of time that elapsed after the emergence of the focal product market and before a firm's entry, or censoring (end of study). On the right-hand side of Equation 6, the main explanatory variable is the composite degree of relevance, R_j . The control variables at the environmental level are organizational density in the emerging market in the year prior (a proxy for degree of crowding) and a quadratic term of organizational density to capture the curvilinear effect established in prior literature. The control variables at the organizational level include a firm's age (a proxy for structural rigidity), a firm's annual size (a proxy for the pool of human resources), and the annual level of investment in research and development (a proxy for input to innovation). A list of the variables and their data sources is presented in Table 3.

In summary, the set of techniques developed in this section provides a general methodology that estimates a firm's timing of entry as a function of its pre-entry, product-embodied capabilities. By applying data reduction methods, I show in detail how to use a firm's history in terms of its annual, observable product portfolio to predict its timing of entry into an emerging product market. This general methodology presents a dynamic, path-dependent model where the future state is a function of the current state. It can be applied more generally to predict the evolution of firm capabilities based on the states a firm has occupied previously. It potentially can be extended to incorporate information on vehicles of entry to analyze whether a diversifying entrant acquired the capability to produce an emerging product via internal development, merger/acquisition, joint venture, or technology licensing. So, the model is useful to quantitatively analyze whether, when, and how a firm enters an emerging product market.

IV. Empirical Evidence: The Case of Technological Convergence

To conduct the empirical test, I take advantage of a natural experiment that sets up a race between two populations and provides an excellent context to study changes in capabilities. That setting is technological convergence, which is the integration of previously disparate technologies. Technological convergence significantly influences business strategies and industry structure because it pressures a firm to incorporate a wider range of technologies into their systems and creates gaps in a firm's existing product portfolio. In particular, I choose voice/data convergence as the empirical context in which to examine the speed at which firms that have been active in different industries develop emerging capabilities and make lateral entrance to an emerging product market when initially distinct industry boundaries become blurred.

A. Conceptual Framework of Technological Convergence

The phenomenon of technological convergence is prevalent, not limited to any particular industry. The evolution of the medical equipment, life science discovery, bio-infomatics, semiconductor, consumer electronics, computer, telecommunications, and content industries over the past fifteen to twenty years clearly exemplify the impact of technological convergence on organizational capabilities, firm boundary, and industry structure (see Adner and Levinthal, 2000; Lei, 2000; Cockburn et al., 1999; Yoffie, 1996; Kodama, 1992).

Consistent with Adner and Levinthal (2000), I define technological convergence as the unification of formerly distinct technologies into a common application domain, in which one of the antecedent technologies is already applied (cf. Yoffie, 1996; Kodama, 1992). For example, the development of the CAT scanner for medical imaging drew on X-ray technology, which was already applied in that domain, and computer technology, which had been applied to data processing (see Figure 2-1). The combination of these two technologies created a new technology that was applied to the same domain as X-ray technology (Adner and Levinthal, 2000). In this case, only the computing technology is applied to a different domain (from data processing to medical imaging), but the result was a radical shift

in the technology application (Teece, 1987). Alternatively, technologies may undergo fusion, in which the resulting technology is applied to a new domain. For example, magnetic recording technology and the technology of optical signal processing, which had been applied extensively to audio tape recorders and television broadcasting, respectively, for some time, were brought together in the new domain of fiber-optic communications technology (see Figure 2-2).

B. Voice/Data Convergence

The particular context I choose is the technological convergence of voice and data communications on a packet network. Voice/data convergence is the technological convergence of telephony communications and computer networking technologies for the development of new products and applications on networks based on the Internet Protocol (IP). As shown in Figure 3, voice and data communications technologies are both applied to the network based on the IP, which is the common application domain. It is a specific case among the more general convergence between the telecommunications and computer industries where the main driving force is the evolution from centralized to networked computing. These new products and applications for the IP-based network infrastructure promise to deliver multi-media (voice, data, and video) services that, for example, would enhance distance learning, enable just-in-time professional training, and improve worker productivity.

Among the many product markets that emerged from voice/data convergence, I select the networking switches as the focal market (see Figure 4). A networking switch is a high-performance internetworking hardware component that is used to connect local area networks (LANs) to one another and to the Internet.¹¹ Historically, the telephony and data networks served different markets and had dissimilar functions. However, the popularization of the Internet and Web-based technologies changes the mix of traffic flow in the network. As data traffic overtakes voice traffic on most networks, network operators and service providers look to reduce cost and increase efficiency by purchasing switching

¹¹ A LAN is a group of data devices such as computers, printers, and scanners that can communicate with each other within a limited geographic area such as a floor, department, or building.

equipment that tightly bundles logic control and forwarding function into one physical unit for the provision of multi-media services. Initially, a networking switch receives and transmits data packets, but the technologies evolve to deliver quality of service for the transmission of multi-media traffic (voice, data, and video) through the network. As such, a networking switch is intelligent because it is capable of transferring and directing traffic flow based on traffic content.

Circuit- vs. Packet-Switching

Significant changes in network demand in the second half of the 1990s included: (1) an increase in the number of users, with increasing use of mobile devices connecting through wireless networks; (2) an increase in session time on the Web; (3) an increase in multi-media transmissions as users transmit more phone calls, emails, faxes, graphics, audio files, video streams, Web pages, medical images, and multi-media teleconferences through the Internet; and (4) an increase in application file sizes. In response, telecommunications equipment suppliers (henceforth, “telecoms”) and computer networking equipment suppliers (henceforth, “datacoms”) needed to learn the capabilities applied in each other’s domains in order to develop innovative products that will meet shifting demands and serve new customers. Prior to convergence, telecoms’ technological trajectory was on the telephone network (public telecommunications networks and private branch exchanges). Telecoms made mostly telecommunications equipment, such as telephone network hardware, designed to carry voice mainly for telecommunications service providers (e.g., long-distance telephone service providers). Examples of large telecom vendors are Lucent Technologies, Nortel Networks, and Siemens AG. By contrast, the technological trajectory of datacoms was on networking components, such as routers and hubs, mainly for corporate enterprise customers to transfer data within LANs and/or wide area networks (WANs). Prominent datacom vendors include Cisco Systems and 3Com.

From my fieldwork, I find that the associated scientific and engineering knowledge requires a significant leap when the telecoms change their application domain from the telephone network to the IP network (see Figure 3 for an illustration). Transporting voice and/or video on a packet network requires

an understanding of how to deal with quality of service at the system level to minimize packet loss and delay and to facilitate interoperability, system scalability, and reliability. Telephony communications technologies are based on circuit-switching, which is connection-oriented. Unlike the connection-less packet networks of IP, circuit networks that connect telephone calls maintain a dedicated path for the duration of the call. So telecoms, which are experienced in designing telephone systems to deliver high voice quality, have an advantage in delivering quality of service. The challenge for telecoms, however, is to extend their strength in voice and incorporate computer networking technologies for the IP network. In contrast, datacoms may have an advantage because computer networking technologies are based on packet-switching, not circuit-switching. The challenge for them is to extend their strength in packet-switching and incorporate multi-media communications for the IP network.

According to Henderson and Clark's definition (1990), the type of innovation required for datacoms is architectural because the core design concept behind each component—and the associated scientific and engineering knowledge—remains the same when datacoms add voice capabilities to a networking component. All computer networking equipment shares a common framework and associated Internet Engineering Task Force (IETF) networking protocols, which is the Open System Interconnection (OSI) seven-layer model of networking. The OSI model is the core design concept behind each component. In comparison, the type of innovation required for telecoms is radical because core concepts are overturned (the OSI model for data network vs. proprietary systems for telephony network) and linkages between core concepts and components are changed (packet- vs. circuit-switching). Unfortunately, existing frameworks, theoretical or empirical, do not allow a researcher to quantify and compare the differential effect of technological change (architectural vs. radical) on the speed of firm entry into an emerging product market.

C. Unit of Analysis, Data Sources and Sampling Scheme

The unit of analysis is a firm that is a potential entrant into an emerging product market. All operating units and subsidiaries, including those that come from mergers and acquisitions, are rolled up to

the level of the parent company or holding company. The empirical examination covers all market entry events into the networking switches market to which many firms from multiple industries have diversified. I investigated the period from 1989 to the end of 2001, that is, from the beginning of market emergence to the latest date covered by the data source. Complete coverage over the thirteen-year period allows me to investigate how change unfolds as the environment undergoes significant shifts.

The main data source is the CorpTech database “Who Makes What,” which provides product portfolios by firm, by product code, and by year for about 50,000 high-technology manufacturing companies in the United States, including those that are domestic - and foreign-owned, public and private, parent companies, subsidiaries, and divisions. I use the CorpTech database to construct annual product portfolios for each firm on the panel. This allows an analyst to determine a firm’s industry of origin as well as its historical capability distribution prior to entry. (See Appendix A for CorpTech’s data collection methodology.) However, one drawback of CorpTech is that a researcher cannot identify from the data directly the extent to which a firm may function as a reseller or original equipment manufacturer (OEM). To resolve this concern, I verify CorpTech’s data against IDC’s database of communications and networking equipment vendors and various trade journals such as *Network World* to confirm company names, products, R&D activities, and industry trends. Other data sources include Standard and Poors’ Compustat accounting measures for publicly traded firms.

Using entrants’ product portfolio, I create the populations in the risk set that could be potential entrants as follows: (1) Analyze the distribution of product portfolios of all the entrants into the networking switches market at the year of entry. The frequency distribution by product code shows a set of product categories that coexist with the focal product at the year the firm enters the product market. (2) Perform the analysis described in (1) only for entrants that survive for more than five years (see dissertation for more detailed discussion on various experimentations I performed on the selection of entrant samples). (3) Compare the two lists and examine the extent to which they overlap. This comparison leads to the identification of a set of core products that are particularly relevant to the

development of the focal product. In this case, the product categories that co-occur most frequently with networking switches are network components/ Internet equipment, data communications equipment, telephone/voice equipment, and telecommunications distribution equipment (see Table 4 for detailed distribution). (4) Use the products under the identified categories to create the risk set from the flow of vendors, which are listed as producers of products in this subset over the thirteen-year period. (5) Among the firms identified in (4), select the ones that were founded before the emergence of the networking switches market. Note that on the chart listed on the bottom of Table 4, the core product categories (the top 4) are the same for all entrants, which have ever produced a piece of networking switch equipment, and for more vital entrants, which have a length of survival in this market longer than five years. As shown, this subset of core products is the most relevant one to the development of networking switches.

D. Analysis: Entry Patterns in the Emerging Networking Switches Market

Figure 5 shows the annual count of firms in the networking switches market. Figure 6 shows the number of entrants, by their time of founding, in the networking switches market. The early entrants into the networking switches market are the diversifying firms that already existed prior to the emergence of the market. In comparison, most of the firms founded after 1990 entered after 1997. More importantly, Figure 7, which is the estimated hazard rate of market entry using the piecewise-exponential model across the thirteen-year period of observation, shows that there is a point of inflection in year 1994 and the hazard of entry increases sharply in 1995 and 1999. The entry rate peaked in 1996 and dropped significantly in 2000, after the collapse of the stock market. However, once firm age, firm size, and level of competition (organizational density) are introduced as covariates in the baseline model, the hazard rate of entry started high but dropped as a step function.

I also used the Cox, Gompertz and Weibull specifications to model the entry pattern, however, the piecewise-exponential specification provides the best fit based on likelihood ratio tests (see dissertation for more details and the results are available upon request). Although the other model

specifications do not fit as well, the estimators in both models are statistically significant and show that the longer a firm waits, the more likely it is to enter the market.

Timing of Entry

I apply cluster analysis as described in Section IV and identify two groups of potential entrants: those that have pre-entry capabilities from the computer networking industry, and those that have pre-entry capabilities from the telephony communications industry. Results of the cluster analysis are available upon request. Model 1 of Table 6 shows the results from the piecewise-exponential hazard model for parameter estimation. The estimated coefficient for industry of origin is statistically significant. Therefore, Hypothesis 1 is supported. Firms that have different industries of origin differ significantly in the speed of entry into an emerging product market. The group of firms that have pre-entry advantage from the computer networking industry commands a higher speed of entry than the group of firms from the telephony communications industry. The control variables behave as prior literature has established: the larger and younger the firm is, the faster the speed of entry; the hazard of entry is density dependent and the relationship follows an inverted U.

The composite degree of relevance with respect to networking switches is found to be an even more important predictor of entry hazard than industry of origin. As shown in Model 2 of Table 6, the estimated coefficient is statistically significant and positive, so Hypothesis 2 is supported. The greater the relevance of a firm's capabilities is, to an emerging product market before entry, the more quickly a firm will enter the market. The estimated coefficient for the composite degree of relevance remains significant even after controlling for industry of origin (Model 3). Within each industry of origin, the greater the relevance of a firm's capabilities is, the more quickly a firm will enter the market.

To integrate the findings from the test of both hypotheses, I plot the degree of relevance by industry of origin to illustrate the distribution of capabilities of potential entrants in year 2001 (see Figure 8). The average composite degrees of relevance between the two groups of firms are 0.60 for firms with pre-entry advantage from the computer networking industry and 0.14 for firms from the telephony

communications industry. This difference in the average composite degrees of relevance between the two groups of firms explains why certain industry of origin confers more competitive advantage than others in terms of speed of entry into emerging product markets.

The Advantage of Early Entrants

After showing the analysis of entry timing, I would like to examine potential performance implications that may be associated with entry timing. Entry order analysis often shows that early entrants to an industry or technical subfields of an industry outperform late entrants. Some studies, however, have found that fast followers prevail. In the empirical context under study, there is strong network externality. Because the larger the installed base of a firm's product is, the more the firm's product will sell, I expect the early entrants to have more competitive advantage than late entrants.¹²

The two performance measures that I examine are length of stay in the networking switches market (hazard of exit) and share of market attained in terms of end-user revenue.¹³ Compared to late entrants, early entrants (those that entered before 1995, which is the year that the Internet became increasingly popular) reduce their hazard of exit by 0.01, but the estimated coefficient is not statistically significant (see Table 5).¹⁴ Also, according to the market share data collected by IDC, pre-1995 entrants generated 49.6%, 50.0%, and 57.4% of the worldwide local area network (LAN) switch end-user revenue in years 1998, 1999, and 2000, respectively. These two pieces of evidence together show that early entrants do not have the decided advantage, and fast followers do not suffer from significant disadvantage, either. I interviewed several industry experts why entry timing does not correlate with post-entry performance in a product market where network externality is high. Possible reasons given

¹² While my research examines the influence of entry timing on firm performance for entrants diversifying from different industries of origin into an emerging product market, related studies such as Mitchell (1991) focus on the effect of specialized assets on the value of entry order for incumbents entering new technical subfields within the diagnostic imaging industry. My study does not test the effect of specialized assets explicitly.

¹³ I also experimented with using firm value (e.g. Tobin's q) as a performance measure and the results are available upon request.

¹⁴ The year 1995 is chosen because the hazard of entry increased sharply in 1995 and the point of inflection occurred in year 1994.

include the rate of product commoditization, the dominance of standards, and the efficiency of operation.¹⁵ Although I do not show empirically that early entry leads to longer survival or higher market share, the issue of entry timing is nevertheless important by itself to theory, practice, and policy development, and therefore deserves further investigation.

E. Managerial and Policy Implications

Firms have ways of doing things that persist strongly over time, and the development of capabilities is path-dependent, according to evolutionary perspectives (Dosi, Nelson, and Winter, 2000; Nelson, 1991; Nelson and Winter, 1982; Hannan and Freeman, 1984; Stinchcombe, 1965). However, for firms that may wish to break away from the constraints of structural inertia and modify their course of development (make path-breaking changes), my research specifies the conditions that would allow them to first recognize and then respond to unfavorable positioning. Equally important, for firms that may wish to maintain their current course of development to capture increasing returns, the methodology developed in this paper is useful to managers in first identifying and then exploiting the opportunities offered by the environment.

Although the empirical test described in this paper addresses a particular product market of interest, the proposed model can also be applied to estimate the long-run probability predicting when a firm is observed to occupy state m , $m = 1, 2, \dots, M$. Specifically, the model can quantify the rate at which firm capabilities emerge, develop, and change over time in different product markets across industry settings. Therefore, the proposed model and its associated analytical framework provides a rigorous way of inferring a firm's capabilities with respect to emerging product markets. It also provides a general methodology for industry competitive analysis in entry behavior. Managers applying the analytical tools are able to predict from which industry segments potential competitors will arise and how fast their entry will happen. In addition, the results discussed in this paper help managers understand a firm's strength

¹⁵ One industry expert even suggests that the determinants of entry timing are entirely decoupled from those of post-entry success.

and weakness in the structure of its product portfolio. Further more, by changing a firm's capabilities in a coherent manner by adapting product mix, managers can widen the scope of a firm's absorptive capacity and set up a platform for further branching of capabilities (Cohen and Levinthal, 1990; Kogut 1983, 1989).

For policy development, my research clarifies the conditions under which a pro-competition policy, such as The United States Telecommunications Act of 1996, can increase levels of competition in the context of technological convergence. The findings potentially contribute to the development of more informed public policy, presuming that a pro-competition policy enhances public welfare by increasing the rate of innovations, decreasing the price of products and applications useful to learning, and improving the accessibility of technologies so as to minimize the "digital divide." In the long run, I expect my work to improve people's quality of lives by uncovering the links among developments in information technology, process of innovation, and economic/social benefits.

V. Discussion and Future Research Agenda

This research examines the origin and the dynamics of capability development. In this paper, I quantitatively estimate the effect of a firm's pre-entry capabilities on the speed at which the firm enters an emerging product market. Here I propose a couple of extensions to this paper so as to further understand how established firms, which initially followed different technological trajectories, navigate through the landscape of capabilities in an effort to occupy an optimal position.

One extension is to rule out some alternative explanations, such as customer trap (see innovator's dilemma by Christensen, 1997) and strategic intent (see Stinchcombe's criticism, 2000). Both customer trap and a firm's strategic intent are examples of unmeasured heterogeneity. On the issue of choice vs. chance, the basis of my current model-building implicitly stresses the chance character of a firm's movement between states of capability. However, the element of strategic choice cannot be ignored. It may be luck that a potential entrant has the pre-entry advantage relevant to a particular product market,

but the firm must decide whether or not to enter. Since the development, as opposed to the deployment, of capabilities entails intent and deliberation (Dosi, Nelson, and Winter, 2000: 12), a firm's strategic choices in how to adapt naturally have performance implications. So, both choice and chance need to be incorporated to model the transition process. Extending the proposed model, I can adopt a different approach where the choice element in each transition is emphasized (see Lancaster, 1992: 122). In the extended approach, firms at all times are assumed to occupy the state that they prefer, given the opportunity set that they currently face. The element of chance enters into the transition process because both the desirability of different states and the opportunities open to the decision maker vary in a partly probabilistic way over time. However, the extended approach makes a strong assumption that decision makers are highly rational and constantly engaged in optimizing their utility in a dynamic programming sense that requires solving mathematical and computational problems. This assumption, nevertheless, contradicts against the behavioral model that I assume in the theoretical framework where decision makers are boundedly rational. Therefore, more careful investigation is warranted.

Another extension is to take advantage of the composite-degree-of-relevance measure that I developed to make causal inferences between diversifying entry and the returns to diversification. The use of this measure, as an instrumental variable in a dynamic panel to estimate the within effect, addresses concerns of firm-specific, unmeasured heterogeneity. This measure also addresses the concern of self-selection bias because a firm's capabilities may vary with a firm's decision to enter an emerging market. More specifically, it allows an analyst to cleanly estimate the effect of a firm's pre-entry capabilities on entry and performance in an autoregressive-distributed lag model with first-differenced Generalized Method of Moments (GMM) estimators. One key underlying assumption in this application, naturally, is that the control group and the treatment group are identical before treatment. However, this assumption may not hold between groups with different industry origins. Although the concern over the validity of such an assumption looms large and needs to be addressed carefully, this extension potentially contributes to an empirical test to inform the debate over whether diversification leads to firm value discount.

Appendix A: CorpTech Data Collection Methodology

Source: CorpTech Directory of Technology Companies, 1987–2002, Woburn, MA: Corporate Technology Information Services, Inc.

Phases of Data Collection (CorpTech, 1999: 1–vii)

New Companies

Phase 1 – Company Identification

CorpTech identifies firms from a variety of sources, including technology newsletters, industry (vertical) trade associations, technology-related press clipping services, economic development agencies, manufacturer's directories, other databases, and interviews with related manufacturers. When previously unknown companies are identified from these sources, known information is entered into the system for potential profile.

Phase 2 – Interview

Phase 1 records are printed up on a questionnaire and are distributed for contact. The interviewer calls the company and conducts a fifteen- to twenty-minute interview, typically with a senior member of the sales or marketing staff. After the interview is completed, the interviewer takes the information and formulates a profile, coding the products with the CorpTech Technology Classification System.

Phase 3 – Data Entry

The interviewer enters the data from the questionnaire into the computer system.

Phase 4 – Computer Checks

Each profile is run through a series of over 200 computer checks.

Phase 5 – Editing

Phase 4 records are printed out in their entirety for manual proofing, with the detailed computer-generated error codes. An editor reviews the data to ensure that the assigned codes match the company's products and corrects any textual errors or omissions of data.

Phase 6 – Faxed Confirmation

Phase 5 records are then faxed or mailed out to the company, requesting that any errors be reported to CorpTech.

Phase 7 – Error Correction

Errors notified as a result of confirmation are entered and the result records re-edited.

Updates

Phase 1 – Confirmation Fax

On a scheduled basis, previously published records are selected and the known data are faxed to the listed contact person for revision. (CorpTech updates about 1/12th of the company profiles each month).

Phase 2 – Confirmation Interview

Phase 1 records that are not returned with corrections after 3 requests are printed and the company telephoned. An interview is conducted, typically with the previous contact or a senior member of the sales and marketing staff.

Phases 3–7 – Same as for New Companies

Figure 1. Example of State Transition

An Example of Product Portfolio Across Three Years

- State transitions of firm j from t_0 , t_1 , to t_2

	t_0	t_1	t_2
Router	1	1	0
Central Office System	0	0	1
Networking switch	0	1	1

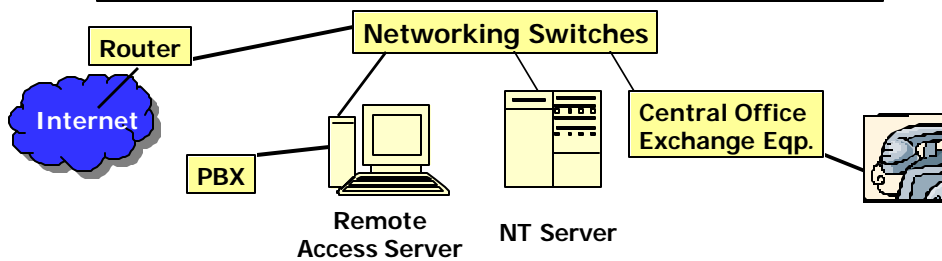


Figure 2-1. Technology Convergence in CAT Scanning

Source: Adapted from Figure 3.2 (Adner and Levinthal, 2000: 65)

Technological Convergence in CAT Scanning

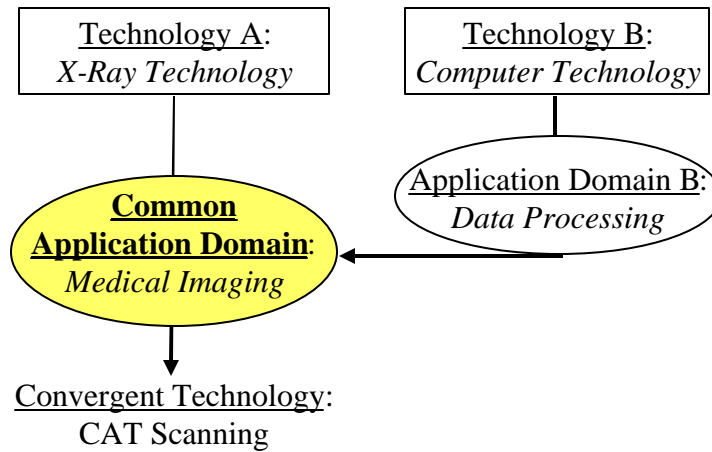


Figure 2-2. Technology Fusion and Video Recorders

Source: Adapted from Figure 3.3 (Adner and Levinthal, 2000: 66)

Technological Fusion and Video Recorders

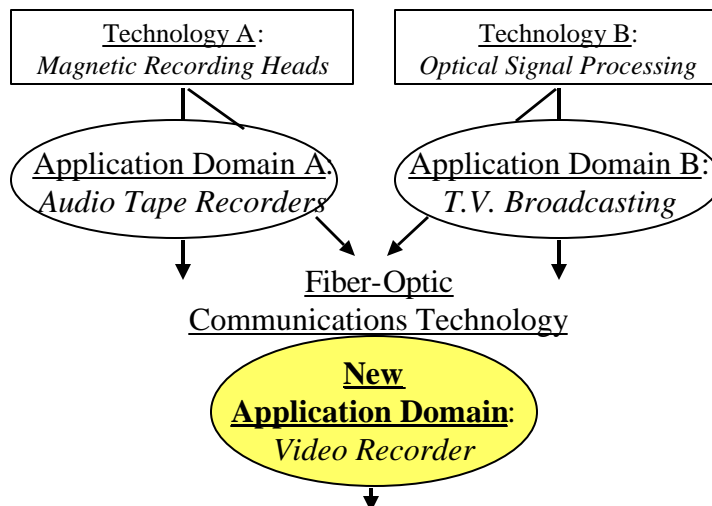


Figure 3. Technology Convergence in Voice/Data Communications
Source: Adapted from Figure 3.2 (Adner and Levinthal, 2000: 65)

Technological Convergence in Voice/Data Communications

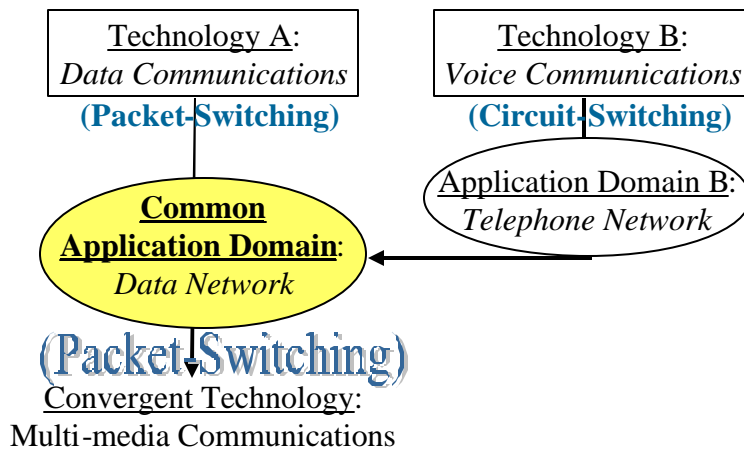


Figure 4. Aspects of Voice/Data Convergence
Source: Adapted from Bell Labs Technology Trends & Developments (Lucent Technologies, 1997: 4)

Aspects of Voice/Data Convergence

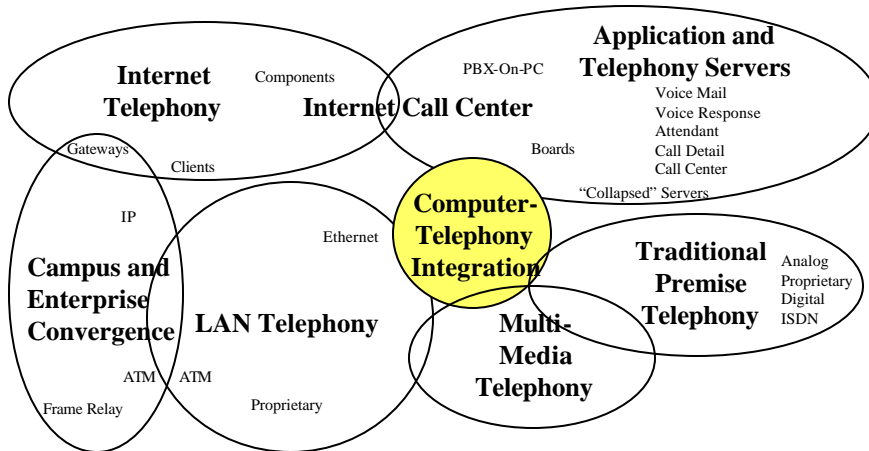


Figure 5. Annual Count of Firms in the Networking Switches Market

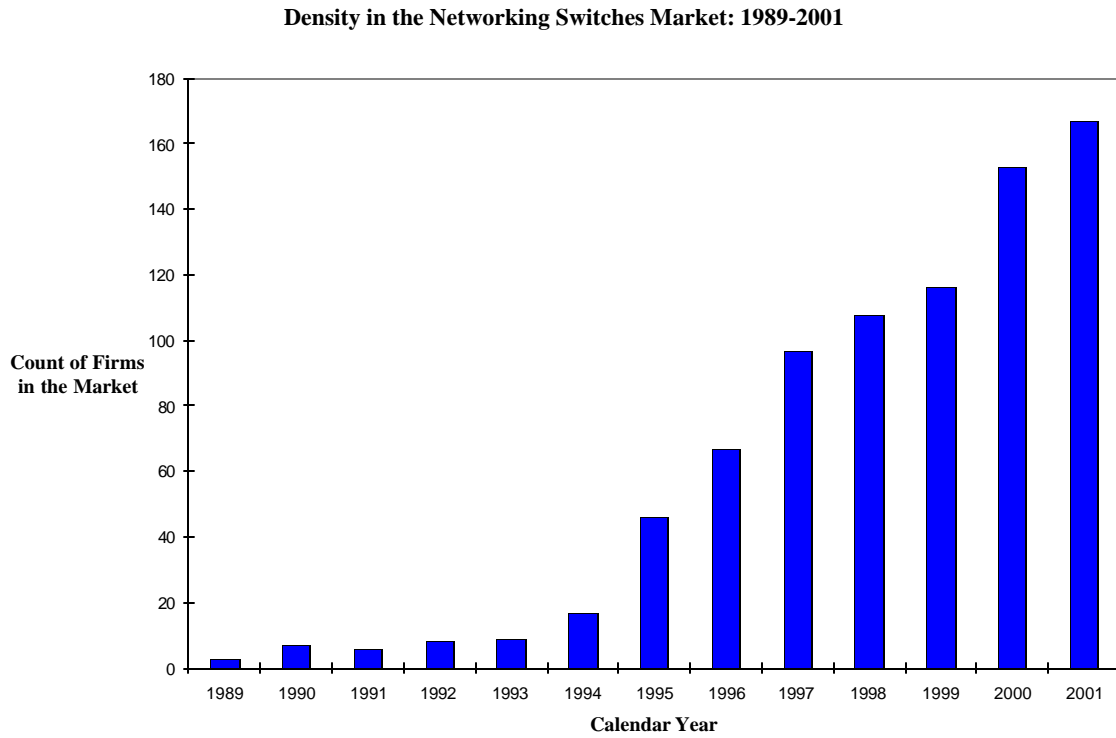


Figure 6. Annual Count of Entry Events in the Networking Switches Market

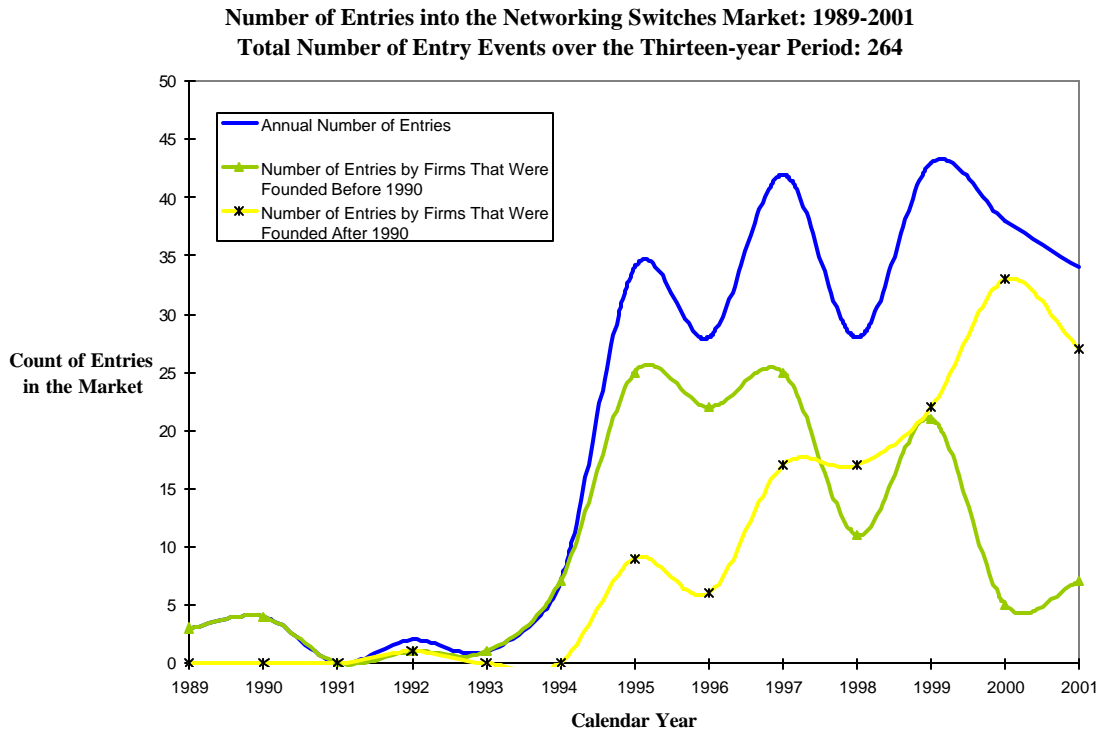


Figure 7. Estimated Hazard Rate of Market Entry – Piecewise-Exponential Model

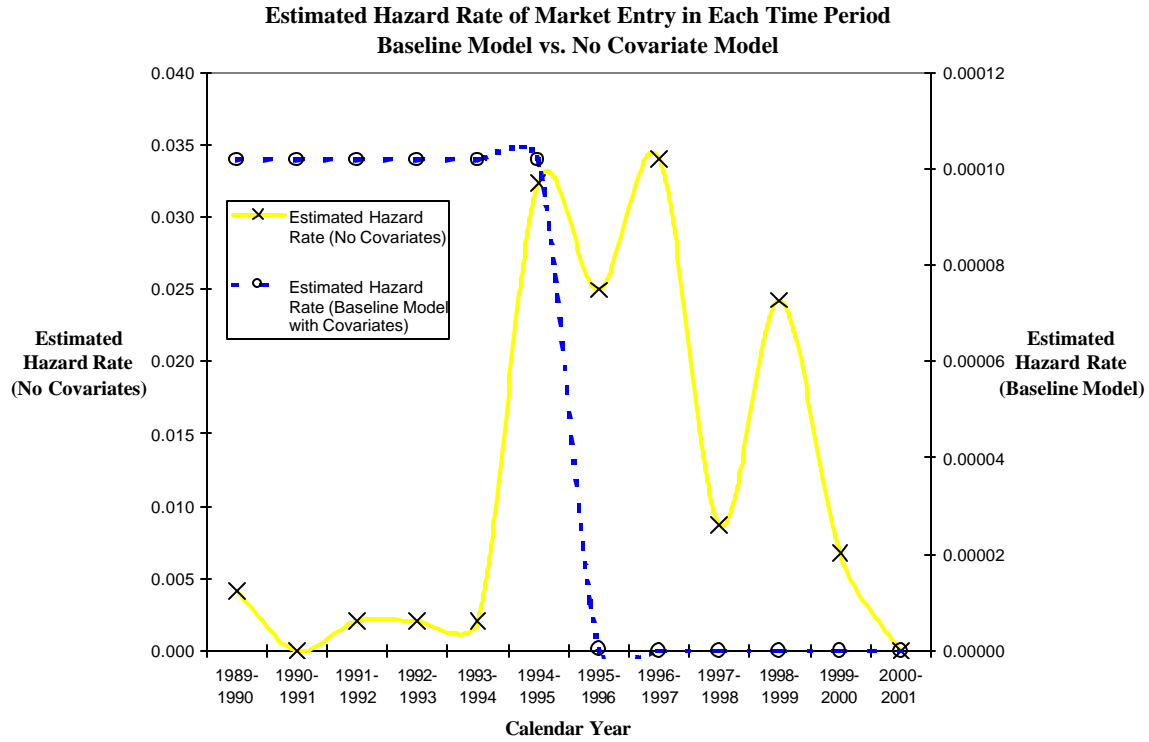


Figure 8. Pre-Entry Capability Distribution: The Composite Degree of Relevance

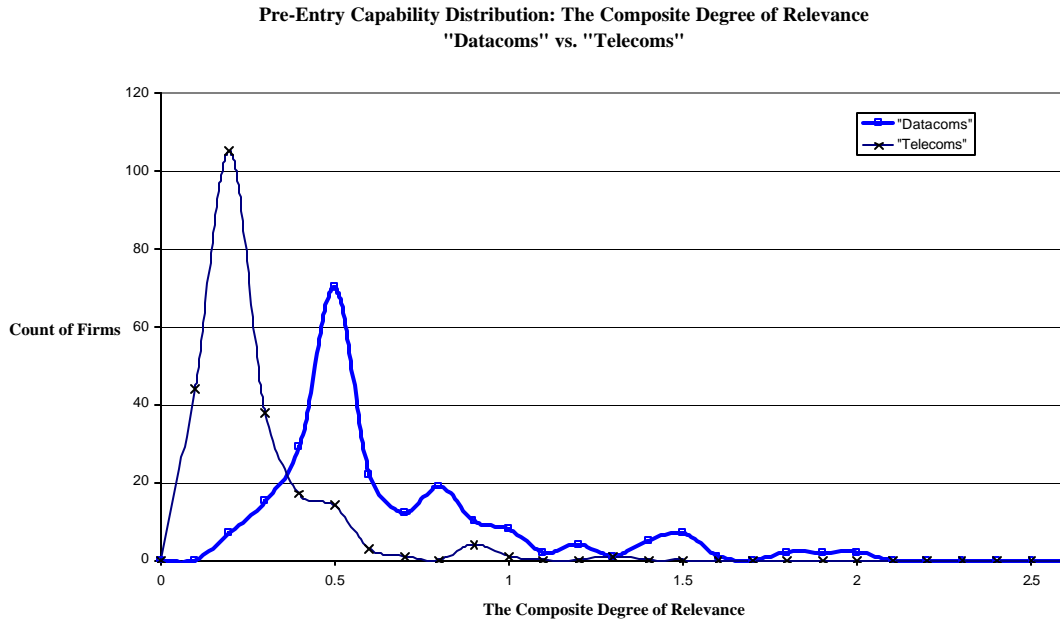


Table 1. Examples of Product Portfolio of Lucent Technologies (LU), Nortel Networks (NT), and Cisco Systems (CSCO) in Year 2001

Product code	SIC code	Product description	LU	NT	CSCO
TEL - NW - CB	3669	Data bridges and routers	0	1	1
TEL - NW - CH	3669	Hubs	1	0	1
TEL - NW - CP	3669	Repeaters/Network adapters	0	0	1
TEL - NW - CS	3669	Network switches	1	1	1
TEL - NW - CX	3669	Extenders	0	0	1
TEL - NW - LF	3669	Intelligent distributed network	1	0	0
TEL - NW - LR	3669	ATM internetworking systems	1	0	0
TEL - NW - W	3669	WAN interconnect devices	0	0	1
TEL - TD - R	3669	Communications trunks	0	1	0
TEL - TD - S	3669	Network servers	0	0	1
TEL - TE - M	3661	Network management systems	0	0	1
TEL - TE - NP	3661	Telephone Packet network switching systems	0	1	1
TEL - TE - NT	3661	Tandem network switching systems	0	1	0
TEL - TE - NZ	3661	Programmable switching systems	0	0	1
TEL - TE - PE	3661	Cellular mobile telephone switching systems	0	1	0
TEL - TE - SCC	3661	Digital central office systems	1	1	1
TEL - TE - SPX	3661	PBX equipment	0	1	0
TEL - TE - Z	3661	Data/voice phone/computer systems	0	1	0

K x N Product-Firm Matrix

		Firms				
Products	<u>Product code</u>	<u>SIC code</u>	<u>Product description</u>	<u>LU</u>	<u>NT</u>	<u>CSCO</u>
	TEL-NW-CB	3669	Data bridges and routers	0	1	1
	TEL-TE-SCC	3661	Digital central office system	1	1	1
	TEL-NW-CS	3669	Network switches	1	1	1

NOTE: Lucent Technologies (LU) Nortel Networks (NT) Cisco Systems (CSCO)

Table 2-1. Degree of Relevance by Product (in the core subset)

CorpTech Product Code	Detailed Product Description	The Degree of Relevance, Sx
1 TEL-NW-CB	Data bridges and routers	0.504
2 TEL-NW-CH	Hubs	0.465
3 TEL-TD-S	Network servers	0.435
4 TEL-ZD-C	Communication controllers	0.364
5 TEL-TD-R	Communication trunks	0.308
6 TEL-NW-CP	Repeaters	0.268
7 TEL-NW-W	Wide area networks	0.246
8 TEL-TE-NP	Telephone packet switches	0.238
9 TEL-TE-SP	PBX/PBX-related equipment	0.222
10 TEL-NW-LB	Baseband-based LANs	0.204
11 TEL-ZD-X	Data transceivers	0.204
12 TEL-NW-LR	Broadband-based LANs	0.195
13 TEL-TE-SC	Switching equipment for use in central telephone office systems	0.185
14 TEL-TD-T	T-1 equipment	0.185
15 TEL-NW-LF	Fiber optic-based LANs	0.174
16 TEL-TE-M	Network control telephone management systems	0.174
17 TEL-NW-CX	Extenders	0.163
18 TEL-TE-NT	Telephone tandem switches	0.163
19 TEL-TE-B	Telephone bridging equipment	0.151
20 TEL-TE-PE	Cellular phone equipment	0.151
21 TEL-ZD-L	Line termination systems	0.151
22 TEL-TE-CC	Telephone transceivers	0.138
23 TEL-ZD-M	Voice mail/message equipment	0.138
24 TEL-NW-CA	Annunciators	0.107
25 TEL-TE-PM	Telephone call management systems	0.107
26 TEL-TE-PP	Personal paging systems	0.107
27 TEL-TE-CT	Telephone transmitters	0.087
28 TEL-TE-KZ	Other telephone circuit/communications carriers not elsewhere covered	0.087
29 TEL-TE-NM	Phone message switches	0.087
30 TEL-TE-PT	Telephone sets	0.087
31 TEL-ZD-Z	Other data communications equipment not elsewhere covered	0.087
32 TEL-TE-PC	Telephone distribution equipment	0.062
33 TEL-TE-Z	Other telephone/voice equipment not elsewhere covered	0.062

Table 2-2. Examples of Composite Degree of Relevance with Respect to Networking Switches

<u>Firm Name</u>	<u>Rj</u>
3Com Corp.	2.146
Lucent Technologies	2.051
Nortel Networks	1.415
Cisco Systems	1.336
IBM	0.900
GE	0.883

Table 3. Variable List, Data Source, Summary Statistics and Pair-wise Correlations

Variable Description	Variable Name	Data Source
Natural log of employee head count	ln_size	CorpTech
Firm age as of 1990	Age_1990	CorpTech
Count of firms in the networking switches market in the year prior	CS	Corp Tech
Count of firms in the networking switches market in the year prior, squared	CS_sq	CorpTech
Categorical variable: 1 if the firm is classified as having a pre-entry background in computer networking, 0 otherwise (The base category is a firm that is classified as having a pre-entry background in telephony communications)	D_1_V_0	Cluster Analysis on CorpTech Product Portfolio
The composite degree of relevance	Sum_R	My Analysis
Annual investment in research and development of public firms as a percentage of sales	R&D_ratio	Compustat

Table 3. (continued)

Variable Name	Number. of Obs.	Mean	Std. Dev.	Min	Max
Employee headcount	5,655	6,103	34,543	1	382,000
Firm age in year 1990	5,655	16	19	2	125
Organizational density	5,655	51	50	3	154
Org. density squared	5,655	5,166	7,099	9	23,716
1=computer networking	5,655	0.509	0.500	0	1
Composite degree of Relevance	5,655	0.442	0.391	0.062	2.580
R&D_ratio	1,659	0.186	2.604	0	1.06

Table 3. (continued)

	ln_size	Age_1990	CS	CS_sq	D_1_v_0	Sum_R
Natural log of employee headcount	1					
Firm age in year 1990	0.442*	1				
Organizational density	0.001	-0.000	1			
Org. density squared	-0.002	-0.000	0.962*	1		
1=computer networking	0.090*	-0.133*	-0.000	-0.000	1	
Composite degree of Relevance	0.241*	0.006	0.000	0.000	0.639*	1

* p < .05, two-tail test

Table 4. Product Categories Used to Identify Potential Entrants And Their Degrees of Relevance

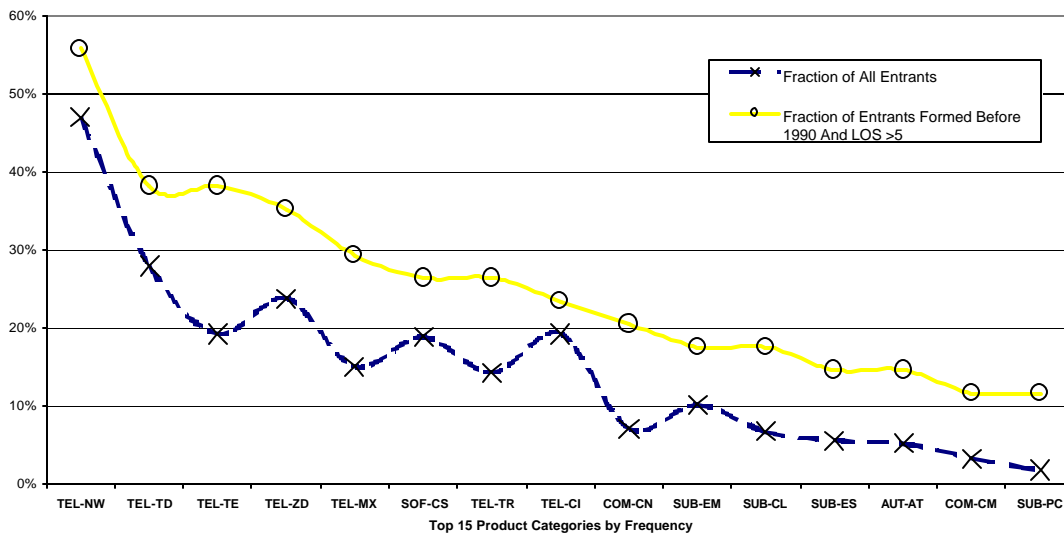
Description of Product Categories and the Associated CorpTech Codes	Count of Networking Switches Entrant with this Particular Pre - entry Capability	The Degree of Relevance to Networking Switches
Internet Equipment/ Networks and related equipment (TEL-NW)	124	0.685
Telecommunications Distribution Equipment (TEL-TD)	74	0.529
Other Data Communications Equipment (TEL-ZD)	63	0.489
Telephone/voice Equipment (TEL-TE)	51	0.440

Table 4. (continued)

Description of Product Categories and the Associated CorpTech Codes	Fraction of All Entrants	Fraction of Entrants That Survived Longer Than Five Years in the Networking Switch Market	Fraction of Entrants That Survived Longer Than Five Years in the Networking Switch Market and Were Founded Before 1990
Internet Equipment/ Networks and related equipment (TEL-NW)	47%	53%	56%
Telecommunications Distribution Equipment (TEL-TD)	28%	39%	38%
Other Data Communications Equipment (TEL-ZD)	24%	33%	35%
Telephone/voice Equipment (TEL-TE)	19%	36%	38%

Identifying An Efficient Subset of Product Categories

% of Networking Switch Entrants Producing this Product Category



Note: LOS is the length of survival in the emerging product market.

Table 5. The Hazard Rate of Exit Estimation – Piecewise-exponential Model

(Estimated Robust Standard Errors, Adjusted for Clustering on Subjects, in Parentheses)

	Estimated Coefficients
Time period: Years 1989 – 1995	***-2.964 (0.608)
Time period: Years 1996 – 2001	*-2.284 (1.152)
Natural log of employee head count	-0.077 (0.094)
Firm age as of 1990	0.022 (0.012)
1 if the firm entered before 1995, 0 otherwise (The base category is a firm that entered after 1995)	-0.014 (0.714)
Log likelihood	-45
Number of subjects (firms) at risk	99
Number of subjects (firms) exited	15
Number of observations at risk	304
Prob > chi2	0.0000

Dependent variable: The amount of time between firm entry into the networking switch until firm exit, or censoring (end of study).

*** p < .001, ** p < .01, * p < .05 two-tail test

Table 6. Pre-entry Advantage in Industry of Origin: The Hazard Rate of Entry Estimation

(Estimated Robust Standard Errors, Adjusted for Clustering on Subjects, in Parentheses)

	Estimated Coefficients (Baseline Model)	Estimated Coefficients (Model 1)	Estimated Coefficients (Model 2)	Estimated Coefficients (Model 3)
Time period: 1989 – 1995	***-9.227 (0.940)	***-9.781 (0.970)	***-9.822 (0.954)	***-9.871 (0.961)
Time period: 1996	***-15.05 (2.43)	***-15.59 (2.43)	***-15.52 (2.41)	***-15.57 (2.41)
Time period: 1997	***-16.88 (3.06)	***-17.42 (3.06)	***-17.28 (3.03)	***-17.33 (3.03)
Time period: 1998	***-19.05 (3.65)	***-19.58 (3.65)	***-19.30 (3.61)	***-19.36 (3.62)
Time period: 1999	***-17.66 (3.72)	***-18.19 (3.72)	***-17.90 (3.68)	***-17.96 (3.68)
Time period: 2000 – 2001	***-18.48 (3.88)	***-19.00 (3.88)	***-18.68 (3.83)	***-18.73 (3.84)
Natural log of employee head count	***0.292 (0.042)	***0.279 (0.049)	***0.229 (0.047)	***0.230 (0.047)
Firm age as of 1990	** -0.025 (0.008)	* -0.023 (0.009)	***-0.029 (0.007)	***-0.029 (0.007)
Count of firms in the networking switches market in the year prior	***0.290 (0.064)	***0.290 (0.064)	***0.287 (0.063)	***0.287 (0.063)
Count of firms in the networking switches market in the year prior, squared	***-0.002 (0.0003)	***-0.002 (0.0003)	***-0.002 (0.0003)	***-0.002 (0.0003)
1 if the firm's pre-entry background is in computer networking, 0 if the firm's pre-entry background is in telephony communications		**0.916 (0.283)		0.098 (0.324)
The composite degree of relevance			***1.521 (0.174)	***1.486 (0.211)
Log likelihood	-179	-174	-156	-156
Number of subjects (firms) at risk	517	517	517	517
Number of subjects (firms) entered	67	67	67	67
Number of firm-year spells	5655	5655	5655	5655
Prob > chi2	0.0000	0.0000	0.0000	0.0000

Dependent variable: The amount of time between the emergence of the networking switches market until firm entry, or censoring (end of study).

*** p < .001, ** p < .01, * p < .05, two-tail test

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Latest revision: 11/27/2002

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