Strategic Management Journal
Strat. Mgmt. J., **21**: 961–979 (2000)

PRODUCT SEQUENCING: CO-EVOLUTION OF KNOWLEDGE, CAPABILITIES AND PRODUCTS

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This article provides a conceptual model that explains how the coevolution of organizational knowledge, capabilities, and products over long time spans can result in competitive advantage through innovation and strategic linkage of products at a point in time and over time. At the heart of the model are sequences of products within and across markets, supported by an underlying system of knowledge and systems of learning. This dynamic model brings the importance of the products themselves, supported by vertical chains of activities, into the analysis of resource and knowledge-based competitive advantage. The model also suggests that we can think about the evolution of firms, and by implication the evolution of industries, not only in terms of knowledge and capabilities, but also in terms of vertical chains and products. Short company histories illustrate the workings of the model.

INTRODUCTION

Why are firms different? This is one of the fundamental questions in strategic management, because the sources of firm heterogeneity underlie competitive advantage (Rumelt, Schendel, and Teece, 1994). The resource-based view (Barney, 1991; Peteraf, 1993; Wernerfelt, 1984) and knowledge management approaches (Grant, 1996) suggest that capabilities and knowledge form the basis for differential firm performance. But how do successful firms get to the point where they have superior resources and knowledge, and how do firms maintain this superiority through time? Dynamic capabilities that enable firms to introduce new products and processes and adapt to changing market conditions play an important role (Teece, Pisano, and Shuen, 1997; Helfat, 1997). But exactly how do firms build and deploy capabilities? We provide a conceptual model that explains how organizations can successfully build and utilize knowledge and capabilities, over long time spans, in single and multiple product markets, for continuing competitive advantage. The model further highlights the importance of products, supported by vertical chains of complementary assets and activities, to the development and exploitation of capabilities and knowledge. That is, we bring the role of products back into the analysis of resources, capabilities, and knowledge. We also provide an explicitly dynamic framework that tracks stages of organizational evolution through time, across markets, and in the context of products and vertical chains. This in turn yields a model of the *coevolution* of knowledge, capabilities, and products.

At the heart of the model are sequences of products within and across vertical chains, supported by an underlying system of knowledge and systems of learning. At any given point in time, an organization's portfolio of products serves as a platform for future product sequences.

Key words: innovation; knowledge; capabilities; competitive advantage; evolution
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These product platforms evolve over time in concert with knowledge and capabilities, and provide opportunities for competitive advantage through the strategic linkage of products up, down, and across vertical chains.[1]

The paper proceeds as follows. We first set up some basic building blocks for the model. Next we explain the components of the model: the *system of knowledge* that underpins vertical chains of activities, and supports *product sequencing* within and across vertical chains over time, based on *systems of learning*. Then we present three company case histories that illustrate the model. The paper concludes with an explanation of the contributions of the model to several related literatures, including the resource-based view, dynamic capabilities, and knowledge management.

BASIC SETTING AND BUILDING BLOCKS

The model applies to technology-intensive companies, and to firms that require complex coordination of knowledge and activities more generally. Such firms include those in high-technology industries, as well as businesses that are not considered to be high-technology but require complex or technologically sophisticated knowledge in order to design and operate plant, equipment, and services. For example, an oil refinery consists of many complex, interrelated pieces of equipment requiring substantial technological know-how to design, build, and deploy. Our analysis also applies to companies that rely heavily on information technology, even if the companies themselves are not in high-technology industries (e.g., retailers such as Wal-Mart). Additionally, the analysis encompasses service businesses that make less use of information technology, but nevertheless require complex coordination of activities (e.g., financial services prior to the widespread use of computers). Thus, the model applies to a wide range of companies.

Within this setting, we focus on *organizational* knowledge and its relation to *organizational* capabilities, activities, and products. Tacit knowledge, for example, has the characteristic that it is not easily communicated in words, numbers, or pictures, but instead requires people, and often teams of people—that is, organizations—to effect knowledge transfer and utilization (Winter, 1987; Leonard and Sensiper, 1998). The creation of tacit organizational knowledge also generally requires repeated interactions between people over time. Because we are interested in organizational knowledge and capabilities, we do not analyze the sort of knowledge that can be easily transferred independent of people. Thus, we do not seek to explain phenomena such as the decoupling of semiconductor chip design and manufacturing fabs, enabled by the codifiability of chip designs.[2] We do, however, analyze more complex coordination of codified knowledge that requires organizational mechanisms.[3]

The product sequencing model utilizes two well-established concepts. The first is that of complementary assets and resources surrounding a core technology (Teece, 1986). The second closely related concept is that of a value chain (Porter, 1985). Teece (1986) points out that capturing value from what he terms 'core technological know-how' frequently requires complementary assets that reside in different stages of a vertical chain, such as finance, manufacturing, and marketing. A separate literature on vertical chains is associated with Porter (1985) in particular, who focuses on the 'value chain' within firms.[4] The stages of the value chain are 'activities' such as manufacturing and marketing, and we adopt that terminology here.

The basic unit of analysis in our model is a vertical chain in combination with the product it supports.[5] To simplify the exposition, we use the

[1] Kim and Kogut (1996) use the term 'platform technologies' to denote technologies that form the basis for diversification over time. The product platforms in our model serve a related purpose.

[2] Grant (1996: 330) notes that more advanced chips require closer coordination of design and fabrication, which has reversed some of the separation of the design and fab stages.

[3] Moreover, simply because knowledge is codified does not mean that it is necessarily well understood by all recipients of such knowledge. For example, most nonphysicists would have difficulty understanding a highly technical physics journal article. We thank Bruce Kogut for pointing this out. See also Zander and Kogut (1995) on the transfer of knowledge.

[4] In operations management, a vertical chain is referred to as a 'supply chain' that may involve more than one firm (Flaherty, 1996).

[5] Our analysis is in the spirit of Porter's (1996) recent focus on the entire activity system, with multiple linkages between different stages of the vertical chain. Fine (1998) also refers to 'capability chains.'

term 'product' to denote either a product or a service. We do not analyze the internal workings of individual stages in a vertical chain (e.g., research, manufacturing) or factors related to design of the product, nor do we deal with issues of organizational design. Additionally, we abstract from boundary of the firm issues. Our analysis requires only a long-term relationship between stages of vertical (or horizontal) chains, in order to build and utilize knowledge, regardless of whether this takes place in a single firm or in multiple firms (see, for example, Dyer and Singh, 1998). Figure 1 provides an overview of the model.

To begin the analysis, we describe the *system of knowledge* that underlies a set of activities and products in a vertical chain. Then we analyze *product sequencing* within and across vertical chains, as well as the required *systems of learning*.

SYSTEM OF KNOWLEDGE

The system of knowledge[6] in our model is composed of *core knowledge* and *integrative knowledge*. A more detailed explanation of each follows.

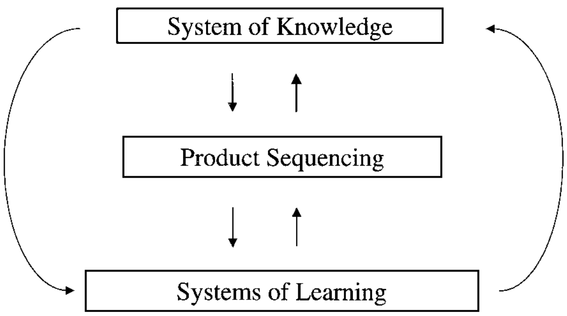

Figure 1. Product sequencing model

Core knowledge

In technology-intensive industries, a fundamental resource of the firm is its technology base.[7] We define *core knowledge* as knowledge—often scientific or technological—that is at the heart of, and forms the foundation for, a product or service. Core knowledge also is specific to a particular vintage of technology or state of knowledge development. For example, knowledge of integrated circuit technology formed the basis for semiconductor chips beginning in the 1960s. This vintage of electronics technology was preceded by transistors, and vacuum tubes before that.

Henderson and Clark (1990) note that an individual product consists of multiple components, each of which has a separate 'component knowledge' consisting of the basic knowledge underlying the component. In order to talk about basic knowledge for a product rather than a component, we focus on the critical aspects of the knowledge underlying a particular product. Such aspects of core knowledge for a product frequently relate to technology, and may include component knowledge underlying critical components of the product, as well as architectural knowledge that links components.

Core knowledge in vertical chains has the following characteristic:

> *Proposition 1: Core knowledge can form the foundation for multiple products and stages not only in different vertical chains, but also within vertical chains.*

The logic behind this proposition is similar to the rationale for related diversification, involving expansion into different product-markets (and vertical chains) based on shared knowledge, resources, and capabilities (see, for example, Montgomery, 1994). As an example of this phenomenon within a vertical chain,[8] rather than across vertical chains as in related diversification, consider the relationship between refined oil products and basic petrochemicals (Helfat, 1988). A basic petrochemical plant converts a refined oil

[6] Leonard and Sensiper (1998: 121) refer to 'system knowledge' as 'collective tacit knowledge ... developed communally, over time, in interactions among individuals in the group.' Our use of the term 'system of knowledge' also incorporates an important role for tacit knowledge between individuals, in our case involving stages of vertical chains that support specific products.

[7] For this reason, Teece (1986) makes 'core technological know-how' the centerpiece of his wheel of complementary assets, although he doesn't explicitly define the term.

[8] Argyres (1996) refers to the idea of shared knowledge that is common to adjacent stages of a vertical chain but does not elaborate on the concept.

or natural gas product into ethylene, propylene, and by-products. The core knowledge underlying both refined oil products and basic petrochemicals has to do with the process technologies used to refine crude oil and to process refined oil products into petrochemicals, respectively. In particular, production of basic petrochemicals utilizes a refining process that relies on technological knowledge similar to that used to refine crude oil. Additionally, both oil refineries and petrochemical plants consist of complex, interrelated pieces of equipment (no two oil refineries are exactly alike) that require considerable tacit knowledge in order to operate the equipment together smoothly. As this example demonstrates, oil refining and basic petrochemicals production take place within a vertical chain, yielding separate products that rely on similar core technological knowledge and core capabilities.

Integrative knowledge

In addition to core knowledge, we define *integrative knowledge* as: knowledge that integrates, or knowledge of how to integrate, different activities, capabilities, and products in one or more vertical chains. Integrative knowledge enables organizations to coordinate activities within a vertical chain or across vertical chains, to obtain market feedback from customers about products, and to obtain feedback either from within vertical chains or from external markets regarding technology.[9]

The nature of coordination within and across vertical chains depends in part on the sorts of knowledge that must be coordinated, such as tacit vs. codified knowledge. For example, Monteverde (1995: 1629) refers to 'unstructured technical dialog' involving the 'unstructured, uncodifiable, generally verbal, and often face-to-face communication demanded by integrated project management' of product design and manufacturing (see also Wheelwright and Clark, 1992). In this situation, coordination of tacit knowledge that resides in multiple stages of a vertical chain requires somewhat tightly coupled organizational mechanisms.[10]

In contrast, the product and organizational design literature on modularity (Baldwin and Clark, 2000; Sanchez and Mahoney, 1996) suggests that coordination often can take place via standardized rules when the knowledge in different activities that must be coordinated is codified and well understood. Coordination of codified knowledge, however, does not necessarily preclude the need for integrative knowledge. As an example, consider 'just-in-time' manufacturing and distribution of goods to final sales outlets that requires close coordination between suppliers, manufacturers, and distributors (Flaherty, 1996). Although the information that flows between the various stages of the supply chain is largely codified (e.g., number of widgets needed), the complexity of coordinating these information flows may require integrative organizational mechanisms and knowledge. More generally:

> *Proposition 2: Integrative knowledge is required not only for coordination of tacit knowledge, but also for complex coordination of codified knowledge, within and across vertical chains.*

As an example, consider the ways in which Wal-Mart uses information technology to help integrate multiple stages of a vertical chain (Bradley and Ghemawat, 1995). The company obtains daily information from its stores about shelf-stocking needs (derived from cash register scanner information), which it then relays to its suppliers, who deliver the requested goods to Wal-Mart warehouses within 24 hours. Then a portion of the supplier delivered goods is immediately cross-docked directly onto company trucks for store delivery, without any holding of inventory in Wal-Mart warehouses. All of this greatly reduces inventory costs at Wal-Mart stores and warehouses, and improves customer satisfaction (and presumably leads to repeat customers) because store shelves are more fully stocked.

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[9] Integrative knowledge, as defined here, is in part a firm-level analogue to architectural knowledge (Henderson and Clark, 1990) that links components of a product.

[10] We note that 'learning by monitoring' (Helper, MacDuffie and Sabel, 1999) can mitigate pitfalls of tightly coupled systems. Learning by monitoring includes simultaneous engineering across groups (e.g., sharing of designs in real time), as well as error detection and correction systems (e.g., stopping the assembly line when a worker spots a defect). These continuous adjustments prevent problems in one part of the chain from continually causing problems throughout the chain. Additionally, greater experimentation can take place, because the system provides a means of resolving potential consequences of experimentation in one stage of a chain for other stages in the chain.

Wal-Mart's system, which requires underlying knowledge of how to integrate activities and sales in a vertical chain, has several aspects that merit attention. First, the system involves complex coordination of codified information. Second, the system has feedback from customers built into it, in the form of daily information about what consumers are buying at each store. Third, information about the 'product' itself (i.e., retail sales) affects other activities in the chain. Fourth, Wal-Mart gains valuable information that it can use to forecast future coordination needs and consumer buying for its complete network of suppliers, distribution centers, and stores. Finally, Wal-Mart provides an example of how integrative knowledge can be embodied in organizational mechanisms and routines—in this case, facilitated by the use of information technology—that link activities and products.

Many other companies have made similar use of information technology to coordinate multiple stages of a vertical chain, including Federal Express (Rivkin, 1998) for example. We note that Wal-Mart and Federal Express are service companies. Their core products are retail sales and express delivery service respectively, and therefore the core knowledge underlying these products has to do with the attributes of the products themselves (e.g., knowledge of customer needs). But in addition, integrative knowledge and integrative capabilities allow the companies to more cost effectively deliver their products and to gain more information about their customers' needs, which the companies can then use to improve their core knowledge.

PRODUCT SEQUENCING

Both core and integrative knowledge can lead to economies of scope. Core knowledge reduces joint costs of production via sharing of intangible assets such as technological know-how (Bailey and Friedlander, 1982; Teece, 1980), not only across product-markets (in different vertical chains) as in related diversification, but also across product-markets within a single vertical chain. Integrative knowledge also reduces joint costs of production between stages of a single vertical chain and across vertical chains via improved coordination and consequent cost reductions, as illustrated by Wal-Mart's lower inventory costs.[11] But perhaps more importantly, in the spirit of Penrose (1959), firms can utilize core and integrative knowledge to introduce sequences of new products that in turn may provide new bases for economies of scope and platforms for future expansion.

Proposition 3: A system of core and integrative knowledge provides the basis for a matrix of product-market expansion paths, traced out by a series of new product introductions which we term product sequencing.

We classify product sequencing strategies into the following types: (1) new generations of an existing product, (2) replacement products, designed to partially or fully supplant customer usage of a company's prior product, (3) horizontal expansion (e.g., related diversification), (4) vertical expansion, and (5) complex sequences that combine two or more of the prior sequencing strategies.

The simplest product sequencing strategy involves new generations of a product, in the same product-market, generally using the same vertical chain. This strategy builds most directly on prior core knowledge, and likely requires the least alteration of the associated activities and integrative knowledge in the vertical chain. Manufacturing techniques frequently are similar, the distribution channels often remain the same, and marketing usually occurs to similar groups of customers. Additionally, integrative knowledge that links activities in the vertical chain facilitates the launching of new product generations in an organization's current market.

Like new generations of a product, some replacement products may be introduced in an organization's current market. Other sorts of replacement products, however, may be introduced in a separate market, essentially involving horizontal expansion. For example, the market for televisions differs from the market for radios,

[11] For products in two contiguous stages of a vertical chain, economies of scope occur when: $C(y_i,y_j) < C(y_i,0) + C(0,y_j,p_i) - p_i y_i(y_j,p^*)$, where y_i = upstream output, y_j = downstream output, p_i = market price for the intermediate product, $y_i(y_j,p^*)$ = derived demand for the intermediate product, and p^* = vector of all input prices at the downstream stage (including p_i). This formula comes from Kaserman and Mayo (1991), who focused on avoidance of transactions costs and of monopoly pricing mark-up as an explanation of vertical integration, rather than on core and integrative knowledge.

which televisions partially replaced. As this example also makes clear, a replacement product need not fully displace the prior product. Although replacement products may utilize previous core knowledge, they also may require new core knowledge and may require changes in manufacturing techniques. Distribution, marketing and sales, and customer service also may require changes to accommodate new customers and ways to reach them. Integrative knowledge in turn may need to adapt as well.

Opportunities for product sequencing in markets new to the organization encompass not only some forms of replacement product sequencing, but also horizontal expansion, as in related diversification, as well as product expansion up or down a vertical chain.[12] Consistent with Proposition 1, vertical product sequencing generally extends core knowledge underlying a product in one stage of a vertical chain to the introduction of a product in another stage of the same vertical chain. Horizontal product sequencing also extends core knowledge to another market, but across vertical chains. Like replacement product sequencing, both vertical and horizontal product sequencing may entail changes to integrative knowledge as well.

At some point of course, organizations may reach limits of integrative knowledge to coordinate across vertically and horizontally related markets, potentially with multiple generations of products in each. Moreover, expansion into new product-markets, including perhaps different customers, may require additions to core and integrative knowledge.[13] Additions to knowledge in this system, and product sequencing based on the system of knowledge, require learning, as we next explain.

SYSTEMS OF LEARNING

Proposition 4: Accumulation of core and integrative knowledge can be conceptualized as consisting of two systems of learning that run in parallel, each linked to one another and to the current system of knowledge and portfolio of products. The first system involves incremental learning, and the second system involves what we term step function learning.

We next explain the two systems of learning in more detail.[14]

Incremental learning

Incremental learning improves upon but does not fundamentally depart from current knowledge. Incremental learning in core knowledge may underpin new product generations, as in, for example, Sony's continual introduction of new Walkman and Discman models. These new models involved incremental improvements in the underlying technological knowledge of personal tape recorder and CD player technology and hardware design.[15] Incremental extensions of core knowledge also can involve new product development in another stage of a vertical chain, or in closely related horizontal markets.

Incremental learning also applies to integrative knowledge. As an example, consider Wal-Mart's addition of cross-docking (the unloading of supplier deliveries directly onto Wal-Mart store delivery trucks) to its distribution system. The integrative mechanisms linking supplier and company trucks changed, since Wal-Mart required greater coordination between supplier deliveries and store deliveries.

Rosenberg (1982, chapter 6) focuses on two forms of incremental learning: learning by doing and learning by using. The learning curve, where production costs decline as cumulative volume increases, typifies learning by doing in manufacturing. Additionally, learning by doing about productive processes can lead to alterations in the design of the product (Monteverde, 1995). In this instance, integrative knowledge that links manufacturing and product design activities facilitates incremental learning in core knowledge of the product.

With regard to learning by using, customer

[12] Winter (1993) briefly discusses the possibility that knowledge may form the basis for the growth of firms via vertical integration.

[13] We note also that integrative knowledge itself can provide the basis for horizontal product-market expansion. Federal Express, for example, is developing a new business as a logistics supplier, based on integrative knowledge developed in its express mail business (Smart, 1999).

[14] The concepts of incremental and step function learning are similar to March's (1991) exploitation and exploration in organizational learning, respectively.

[15] This statement is based on information in Patton (1999).

experience with a product can provide information about the relationship between specific product characteristics and product performance. Firms then can incorporate this information into design modifications (Rosenberg, 1982), including in new models or generations of a product (Von Hippel, 1976, 1986). Here again, incremental learning in core knowledge benefits from integrative knowledge, in this case involving feedback from customers that is linked to product design.

Incremental learning by doing and using is cumulative (Cohen and Levinthal, 1990) and also relies on local search for new knowledge in the neighborhood of existing knowledge. In general, cumulative learning combined with local search creates path dependence in the direction of organizational learning (Nelson and Winter, 1982; Helfat, 1994). Incremental learning therefore is path dependent, as are the product sequences that result. For example, as new generations of a product evolve, learning becomes more engineering and user oriented and specific to the particular product (Rosenberg 1982: 122). Improvements typically require familiarity with the product (Gomory, 1987; Gomory and Schmitt, 1988). Thus, incremental learning, the knowledge underlying the product, and the product itself are inextricably linked to one another, and to the history of product sequencing over time.

Step function learning

In contrast to incremental learning, what we term 'step function learning' involves fundamental changes to core or integrative knowledge. Step function learning presents difficult challenges for organizations, and the literature is replete with examples of firms that failed because they could not adapt to new technologies in particular. But some firms have successfully managed to accomplish step function learning, with regard to both core knowledge and integrative knowledge, using processes that we next describe.

Step function learning at a minimum requires ongoing feedback about products, markets, and technologies that points to the need for new and different knowledge. For example, Kao, a leading Japanese household and chemical products maker, has developed what it calls the ECHO system for processing and analysis of customer questions and complaints about Kao products (Nonaka and Takeuchi, 1995). Phone operators in Kao's customer service organization enter customer questions and complaints into a computer system that in turn generates reports used in various activities throughout the vertical chain. Kao also uses this feedback system directly in product refinement, involving incremental learning in core knowledge. But in addition, Kao obtains information regarding shifts in customer desires (Quinn, Baruch, and Zien, 1997), which provides a basis for step function learning in core knowledge and for new product development.[16]

As with core knowledge, step function learning in integrative knowledge requires ongoing feedback mechanisms that point to the need for new knowledge. Benchmarking of competitors, for example, can provide feedback such that wide gaps in performance may signal the need for a major rethinking of integrative mechanisms.

In addition to recognizing the need for fundamentally new knowledge, organizations must acquire and learn to utilize the knowledge. This may require teams and organizational units dedicated specifically to the learning effort. For example, with regard to core knowledge, when Sony decided to develop what became the Trinitron color TV, the firm set up a team of researchers focused on this effort.[17] As an example involving integrative knowledge, the opportunity for GM to learn from Toyota about just-in-time supply chains came about through a new organizational unit in the form of the NUMMI joint venture between the two companies (Badaracco, 1988).[18]

Product sequencing and linked systems of learning

The product sequencing strategies outlined earlier rely on incremental and step function systems of

[16] Kao's use of its customer service organization provides an example of Christensen's (1997) point that information from companies' less attractive customers (such as those that complain) may point to the need for what we term step function learning.

[17] We are grateful to James Brian Quinn for suggesting the Trinitron TV example. The references for the Sony example here and elsewhere in the paper are given at the end of the paper.

[18] GM, however, had difficulty taking full advantage of the opportunity NUMMI presented. For example, GM had difficulty transferring knowledge gained at the NUMMI plant throughout the rest of the company (Badaracco, 1988).

learning, upon which the system of core and integrative knowledge is built. Not only are the systems of incremental and step function learning linked to the current system of knowledge, but also the two systems of learning are linked to one another in the following ways. First, incremental learning is likely to build upon step function learning. For example, incremental learning in core knowledge that leads to new generations of a product builds upon step function learning in core knowledge embodied in the initial product. Additionally, step function learning may build upon prior incremental learning. For example, although Sony required new core knowledge to develop the Trinitron color TV tube, which differed fundamentally from black-and-white TV tubes, Sony also adapted the new tube to the company's prior TV design, which embodied incremental learning related to black-and-white TVs.

By employing the two parallel linked systems of incremental and step function learning, organizations learn to effectively manage the product sequencing process within markets, as well as up, down, and across vertical chains and product-markets, based on a system of core and integrative knowledge. The systems of learning create an understanding of the potential as well as the limitations of core and integrative knowledge, of the nature of the family of products that can be developed using the underlying system of knowledge, and of the markets for these current and potential products. Products are linked to one another at a point in time in different markets and through time, and coevolve with the underlying knowledge and capabilities.

PRODUCT SEQUENCING AND COMPETITIVE ADVANTAGE

The system of knowledge and portfolio of products, in combination with the two systems of learning, provide 'real options' (Kogut and Kulatilaka, 1997; Brown and Eisenhardt, 1997) for future product sequences. As Bowman and Hurry (1993: 762) state, 'options come into existence when existing resources and capabilities allow preferential access to future opportunities.' In creating access to new opportunities, however, the history of product sequencing also constrains options for future product sequences.[19] More specifically, creation of new products and new knowledge depends on existing products, along with the underlying path-dependent knowledge and capabilities. This dependence on history matters not only for incremental (and hence, path-dependent) learning and the products it supports, but also for step function learning. For example, integrative mechanisms in the current system of knowledge often alert the organization to the need for step function learning: existing integrative knowledge therefore shapes the direction of step function learning. Moreover, step function learning in turn may build on some aspects of existing core knowledge.

Over time, a system of core and integrative knowledge may generate more real options than an organization has the organizational, productive, and financial resources to pursue.[20] Managers must make choices of paths to pursue and place bets (Raubitschek, 1988a), and the choices made will alter the options for future product sequencing, due to built-in path dependence. There is no certain 'right' path to future success, since feedback that occurs in the process of developing, making, and selling each new product is not known ahead of time.

The product sequencing model implies differential firm success and competitive advantage. Different organizations rarely enter a market at the same time with the exact same initial sets of knowledge, products, and systems of learning, nor do these organizations necessarily make the same choices of product sequences over time. Therefore, due to path dependence, organizations will evolve different systems of knowledge, systems of learning, and portfolios of products. Furthermore, successful bets on products provide a richer set of real options and product platforms upon which to base future product sequences than do unsuccessful bets. Success may breed success and failure may make future success more difficult. And superior systems of learning that form the basis for continued product sequences can turn short-term competitive success into longer-term advantage.

[19] Ghemawat *et al.* (1999) make the more general point that investments in resource commitments and capabilities are often irreversible.
[20] An essential element of options is that less promising options can be allowed to expire.

EXAMPLES OF PRODUCT SEQUENCING STRATEGIES

To illustrate the product-sequencing model, we next provide abbreviated histories of new product introductions over time in three technology-intensive Japanese firms: Sony, Canon, and NEC. These histories rely on publicly available sources of information and, as a result, the histories contain more information about core than integrative knowledge. Where possible, we identify the types of knowledge (core or integrative) and learning (incremental or step function) in the product sequences. Following the three histories, we discuss their implications as a group for the product sequencing model.

Sony[21]

When incorporated as Tokyo Telecommunications Engineering Corporation (also called Totsuko) in 1946, Sony repaired radios and made radio upgrade kits that converted AM radios into short-wave receivers, among other products. By 1950, Sony produced magnetic audio tapes as well as tape recorders (step function learning related to audio magnetic recording for the company). Like radios, tape recorders were electromagnetic audio devices with mechanical parts.

In 1953, Sony licensed the basic technology underlying transistors from Bell Laboratories, and building on this technology developed a high-frequency transistor for radios (step function learning in electronics for the company). Sony went on to introduce the first Japanese transistor radio in 1955 (horizontal product sequencing from audio tapes and recorders into radios), as well as a 'pocket-size' transistorized radio in 1957. Then in 1958, after having further developed transistors so that radios could receive FM signals, Sony introduced the first portable AM/FM transistor radio (replacement product sequencing in radios). For both its radios and the transistor inputs (vertical product sequencing), Sony utilized and extended its core knowledge of electronics. Additionally, with its transistor radios, Sony developed core knowledge involving miniaturization of electronic products.

Continuing its transistor research, in 1958 Sony developed a portable transistorized video tape recorder (VTR) (horizontal and vertical product sequencing), followed by new lower-priced VTR models throughout the next decade (new-generation product sequencing). With the VTR, Sony added to its core knowledge of electronics and also fundamentally extended its knowledge of audio magnetic recording to video magnetic recording (step function learning).

Then, extending its research in transistors even further,[22] Sony developed a semiconductor type of television receiver. Sony combined this development with its core knowledge of miniaturization, and by 1960 introduced the first all-transistor, black-and-white, portable, small-screen television set (horizontal product sequencing into TVs and vertical product sequencing of semiconductor inputs for TVs, based on core knowledge of electronics). Then in 1969 Sony introduced its extremely successful Trinitron color TV (replacement product sequencing in televisions), which produced a superior picture due to its unique technology. In order to develop a color TV, Sony had initially licensed a new TV tube technology based on the work of Nobel Prize-winning physicist O. E. Lawrence, but its efforts to commercialize the technology were unsuccessful. These efforts, however, aided Sony in its subsequent development of the Trinitron technology (step function learning), which the company also combined with its knowledge of TV design from black-and-white TVs (incremental learning). While Sony's first Trinitron TV was again a small set, utilizing its core knowledge of miniaturization, this product was extremely successful, and Sony subsequently introduced a series of new models with larger screens (new-generation product sequencing).

In 1971, building on its experience with televisions, video recording, tapes, radios, and semiconductors, Sony developed a video recorder that played bulky video cassettes (replacement

[21] The sources for this history of Sony are: Bartlett (1992), *Broadcasting* (1983), Browning (1986), Burgess (1999), *Business Week* (1987), Cieply (1983), Cusumano, Mylonadis, and Rosenbloom (1992), *Economist* (1982, 1983a, 1983b), Gerson (1978), Ibuka (1975), Lyons (1976), Morita, Reingold, and Shimomura (1986), Nathan (1999), Pollack (1999), Rosenbloom and Cusumano (1987), Rubinflen, Ono, and Landro (1988), and Smith (1987).

[22] Semiconductors, made of substances that are between conductors and insulators, are the class of devices that replaced the use of vacuum tubes. Transistors were the first generation of semiconductor microelectronics technology.

product sequencing for reel-to-reel VTRs). This 'U-Matic' machine became the standard format in the institutional market,[23] and formed the basis for Sony's subsequent Betamax video cassette recorder (VCR) and for competing VHS machines, both sold to the home market. Sony introduced its Betamax type VCR in 1975, and in 1976 JVC introduced the VHS-type VCR, which was not compatible with Betamax and had a longer recording time. This began the Betamax–VHS video war, which lasted until the early to mid-1980s, when VHS emerged as the industry standard (Cusumano *et al.*, 1992).

Sony's failure with Betamax provides a cautionary tale that core technological knowledge alone cannot support effective product sequencing. Early on, JVC worked to line up other consumer electronics firms that would sell VHS-format VCRs. JVC's partners, especially its parent Masushita, provided technical feedback and assistance to JVC during development of the VHS machine, which led to improvements in product features such as longer recording and playback time (suggestive of integrative knowledge). Masushita also pursued large market share for the VHS format in order to obtain economies of scale, and therefore produced VCRs for other consumer products companies to market using their own brand names—which Sony refused to do. Additionally, Masushita held a dominant share of the retail appliance store market in Japan, giving the company guaranteed distribution outlets for its VCRs.

Masushita's large share of retail outlets in Japan also provided the company with good information about consumer reaction to its VCRs. In addition, JVC and Masushita, through their partners, gained early knowledge of the evolving importance to consumers of compatible prerecorded video software. JVC and Masushita had several partners in Europe, where video rentals become popular more quickly than in the United States. And one of Masushita's earliest partners in the United States was RCA, which saw consumer video software as important due to its videodisk business. As demand increased for prerecorded video tapes, consumers purchasing VCRs had to choose between two different video tape formats, and constraints on shelf space made stores reluctant to carry both formats. Masushita sped acceptance of the VHS format as a standard not only by manufacturing VCRs for other consumer electronics companies, but also by developing high-speed VHS video tape duplication equipment that it supplied at low cost to producers of prerecorded video tapes, which in turn increased availability of VHS tapes in stores.

In summary, throughout its history, Sony established strong links among its products based on core technological knowledge. With the VCR, however, Sony lagged JVC and Masushita in understanding customer needs and building market share in a market with network externalities, where small players often lose. Here we see the importance of feedback from consumers, feedback from partner companies, and integrative knowledge that facilitates this.

Canon[24]

Founded in 1933 as the Precision Optical Research Laboratories, Canon relied on core technologies of precision optics (involving the grinding of lenses to exact specifications) and mechanics to produce mechanical cameras.[25] During the next half century, Canon introduced new camera models and further accumulated skills in precision optics and mechanics (incremental learning and new-generation product sequencing).

One of Canon's relatively early ventures beyond mechanical cameras involved photocopiers, which essentially are cameras that take a picture in a different way. To introduce its first copier in 1965 (horizontal product sequencing), Canon used technology licensed from RCA. Then in 1968 Canon announced that, based on its own research on plain paper copiers, it had developed a new process technology that provided the first

[23] In 1970, Sony, Masushita, and JVC entered into a cross-licensing agreement for video recording patents that allowed the U-Matic to be adopted by all three companies as the standard for institutional use.

[24] The sources for this history of Canon are: Beauchamp (1988), Blum (1978), Cavuoto (1984), Canon, Inc. (2000), *Economic World* (1976), *Electronic Business* (1984), Heller (1983), Helm (1985), Hof and Gross (1989), Ishikura and Porter (1983a, 1983b), Johansson (1986), Kraar (1981), Meyer (1985), Moore (1982), Port (1987), Sutherland (1988), Trachtenberg (1987), and Yamanouchi (1989).

[25] This abbreviated history includes many but not all of Canon's product areas. The history does not, for example, cover Canon's optical products (semiconductor production equipment, broadcasting equipment, and medical equipment), which also utilize Canon's core knowledge.

alternative to Xerox's patented technology (step function learning). This new process reflected Canon's development of core knowledge in chemicals, which the company combined with its core knowledge of precision optics and mechanics to introduce a copier with dry toner in 1970 (replacement product sequencing). Canon then introduced a second-generation copier with liquid toner in 1972 (new-generation product sequencing) and a color copier in 1973. Because Canon lacked strong industrial marketing, the company licensed the technology to Japanese and foreign competitors. While providing royalty income, licensing inadvertently strengthened the competition, which gained manufacturing experience and brand recognition.

During the same time period, Canon entered the calculator business. In 1964, Canon introduced the world's first 10-key pad electronic desk calculator, which utilized the company's core knowledge of mechanics and which contributed to the development of core knowledge of electronic circuitry. Then in the early 1970s, Canon introduced hand-held electronic calculators, but was bested by Sharp's superior 'thin' calculator, which it could not quickly duplicate. Nevertheless, with its hand-held calculator initiative, Canon developed knowledge of miniaturized electronic circuitry that contributed to the company's platform for future product sequencing, as we next explain.

In 1976, Canon revolutionized the 35 mm camera market by introducing the AE-1 camera—the world's first electronically controlled, fully automatic, single-lens reflex (SLR) camera with a built-in microprocessor unit (replacement product sequencing in cameras). In developing the AE-1, Canon combined its core knowledge of precision optics and mechanics (from cameras) with that of miniaturized electronic circuitry (from hand-held calculators) in a completely new way, to essentially put an electronic brain into what previously were mechanical cameras (step function learning).[26]

Improving on its marketing performance with copiers, Canon spent over a million dollars for a spectacular promotion on American television to introduce the AE-1 camera—the first time that 35 mm cameras were advertised on TV. Canon also priced the camera at more than $100 below other cameras. Relying on experience gained in producing electronic calculators, the AE-1 used 20 percent fewer parts than conventional SLR cameras, resulting in significant cost reductions. In addition, Canon drew on knowledge it had gained in manufacturing mechanical cameras to construct new automatic equipment that helped to lower production costs. This learning in manufacturing from electronic calculators and mechanical cameras, and learning from copiers about the need for effective marketing, suggests that Canon may have had integrative mechanisms to facilitate knowledge transfer. The AE-1 became the world's best-selling 35 mm SLR camera, which Canon followed with new models that continued to attract consumer interest for many years (incremental learning and new-generation product sequencing).

Following the AE-1, Canon again hit the jackpot, this time with a personal copier introduced in 1979 and sold to the office market (replacement product sequencing in copiers). Canon had developed a new photocopying process, which the company did not license, and which it incorporated into the typewriter-size copier (step function learning). Then, in 1982, Canon introduced another personal copier (replacement product sequencing) that combined its new copying process with a disposable cartridge that incorporated the toner, developing assembly, and photoconductive drum, thus utilizing the company's core knowledge of chemicals. The cartridge eliminated the need for Canon to build a service network, a major barrier to entry in this market, by putting all parts that are likely to break down into a disposable cartridge.

To market the copier, Canon expanded its distribution channels and launched a major marketing campaign resembling its previous successful campaign for the AE-1 (suggestive of integrative knowledge in marketing across products). The company set a low price for the copier as well, relying in part on cost reductions obtained from redesign of the copier production line. These cost reductions in turn benefited from integrative mechanisms that facilitated knowledge transfer, in that Canon's copier product development group worked closely with the production engineering unit to utilize its camera-manufacturing know-how. Over time, Canon introduced new generations of personal copiers with features never

[26] This provides an excellent example of the power of combinative capabilities (Kogut and Zander, 1992).

before offered in the low-end price segment (new-generation product sequencing).

As yet another example of Canon's complex product sequencing strategy, in the early 1980s the company introduced a personal printer for desktop computers (horizontal product sequencing) that had higher speed and better quality text and graphics than existing daisywheel and dot matrix printers. Canon's personal printer relied on a copier-like printer engine and, like the copier, used a disposable cartridge. Canon offered the printer engine to other (original equipment) manufacturers of printers at a price such that, when configured with the necessary control electronics, the printers were priced competitively with the inferior daisywheel and dot matrix machines. Canon achieved this price breakthrough by using its experience in high-volume manufacturing of small copiers, and by employing common components in its copiers and printers, again suggestive of integrative knowledge across products in manufacturing. The Canon printer engine became an industry standard, used by many original equipment manufacturers including Apple and Hewlett-Packard.

In summary, Canon evolved from a simple new-generation product sequencing strategy in mechanical cameras to a complex product sequencing strategy in many markets. To introduce new products, Canon built on and extended its core knowledge of precision optics and mechanics, and developed completely different areas of core knowledge in electronics and chemicals (step function learning). Additionally, the evidence suggests that integrative knowledge across products in marketing and manufacturing may have played an important role in Canon's product sequencing strategy.

NEC Corporation[27]

NEC was formed in 1899 as a joint venture between Japanese investors and Western Electric, the manufacturing arm of AT&T, to produce telecommunications equipment in Japan. In its long and complicated history, NEC also enjoyed strong ties to ITT and Sumitomo.

Using Western Electric technology, NEC initially built telephone communication equipment and later using this expertise entered radio communication systems (horizontal product sequencing). Both sets of products relied on electromagnetic waves, although at different frequencies with different carrying mediums, and utilized electronics technology. Subsequently, NEC integrated backwards into vacuum tubes (step function learning in electronics), an important input to its telephone and radio broadcasting equipment (vertical product sequencing based on core knowledge of electronics). NEC also established its own radio research unit, and later began research on microwave communication systems. Over time, the company grew to the point where toward the end of the Second World War, it was a major producer of radio equipment, vacuum tubes, telephone equipment, and telephone carrier transmission equipment (complex vertical and horizontal product sequencing). At the conclusion of the war, however, NEC's operations came to a standstill due to bombing of its facilities and severe shortages of personnel and materials.

Following the war, Japan enacted two reforms aimed at restructuring and remaking its communication infrastructure, which allowed NEC to quickly rebuild. One reform permitted commercial broadcasting, and the resulting boom in broadcasting created a huge demand for broadcasting equipment. The other reform created Nippon Telegraph and Telephone Public Corporation (NTT) as the monopoly provider of domestic telecommunications in Japan, although NTT was not allowed to manufacture its own equipment.

NEC reentered the communications business, providing broadcasting equipment and telephone communication systems, and became NTT's lead supplier. By 1950, NEC had begun research on transistors (the semiconductors of the time) out of concern that the transistor would replace the vacuum tube. After the war, NEC also resumed work on microwave communication technology involving extremely high-frequency transmissions used in both telephone and broadcasting systems. And in 1954, the necessity for complex calculations in telecommunications spurred NEC to enter computer research.

All of these efforts converged as follows. In

[27] The sources for this history of NEC are: Browning (1985), *Business Week* (1982), *Economist* (1984, 1986), Hayashi (1987), IEEE spectrum (1986), Joseph (1986), Kobayashi (1986), Mead (1985), NEC (1984), Smith (1984), and Sullivan (1988).

1958, NEC began mass production of transistors, primarily for industrial applications with some internal consumption (step function learning in electronics and replacement product sequencing whereby transistors replaced vacuum tubes). This advance in transistor development benefited in part from NEC's R&D and production of silicon diodes for its microwave communication systems. And NEC's advances in transistors further enabled the company by 1959 to develop the first Japanese transistorized computer targeted for the general public (step function learning, resulting in complex vertical and horizontal product sequencing involving core knowledge of electronics).

During this period, again building on core knowledge of electronics, NEC in 1955 invented a method for improving the FM receiver threshold. This led to over-the-horizon microwave communications systems used to connect telephone networks, which NEC produced in 1959, and ultimately to NEC's highly successful entry into satellite communication systems (horizontal product sequencing), which essentially involve microwave relay links in space.

In 1960, NEC also began development of integrated circuits, the vintage of semiconductors that followed transistors. By 1962, NEC had developed its own integrated circuits (step function learning in electronics for the company and replacement product sequencing in semiconductors), and over a period of two decades the company introduced a series of semiconductor devices (new-generation product sequencing). By the mid-1980s, NEC was the world's biggest producer of semiconductors.

NEC continued its development of computers as well. In 1965, NEC unveiled the Series 2200 family of computer systems sharing a common hardware and software architecture, which made it easy for users to connect the machines to one another and to trade up to more expensive machines. With these products, each linked to one another at a point in time and over time, NEC became a major computer manufacturer in its domestic market. Then, in 1972, NEC became the first Japanese company to develop a microcomputer (horizontal product sequencing), utilizing its semiconductors as inputs (vertical product sequencing based on core knowledge of electronics), and which it followed with even more powerful versions (new-generation product sequencing).

In the early 1970s, NEC also increased its output of consumer electronics products, building on an electrical household appliance business originally established in the 1950s. Once again, NEC employed vertical product sequencing in electronics, incorporating microelectronic control functions into new consumer products, such as a color TV set with an electronic tuning system introduced in 1973.

In 1977, Koji Kobayashi, then Chairman of the board of NEC, expressed the concept behind the strategy that NEC pursued through the 1980s. He called it C&C—integration of computers and communications. Kobayashi early on recognized trends whereby advances in semiconductors supported the development of computers and communications networks throughout the world. NEC, with its strong presence and core knowledge of electronics in all three markets, could utilize the company's knowledge and product base to capitalize on integration of these markets and technologies. By the mid-1980s, NEC was the only company in the world to achieve the 'Triple Crown' in electronics. NEC alone ranked among the top 10 companies in the world in the three most important markets of the electronics industry: semiconductors, computers, and telecommunications.

DISCUSSION

The histories of Sony, Canon, and NEC highlight several aspects of the product sequencing model. First, per Proposition 1, NEC's and Sony's core knowledge provided the foundation for upstream as well as downstream products in vertical chains. For example, core knowledge of electronics underlay NEC's businesses in vacuum tubes (upstream) and telephone and radio communication systems (downstream). NEC also utilized core knowledge of a later vintage of electronics to produce semiconductors (upstream) as well as computers, consumer electronics, and telecommunication and broadcast systems (downstream). Similarly, Sony's core knowledge of electronics underlay semiconductors (upstream) and radios, VTRs, VCRs, and TVs (all downstream).

The company histories also demonstrate the importance of integrative knowledge, per Proposition 2. For example, Canon's copier product development group worked closely with the camera production engineering group to redesign the copier production line. Canon also benefited from learning across products in manufacturing and marketing for its electronic cameras and printers, suggestive of integrative knowledge. Sony's failure and Masushita's success in VCRs points to the importance of integrative knowledge as well.

Per Proposition 3, each of the companies' product sequences traces out a matrix of product-market expansion paths across or within vertical chains, building on previous core and integrative knowledge. For example, knowledge of audio and video technology, combined with core knowledge of electronics and miniaturization, are key links in Sony's horizontal product sequencing in radios, VTRs, TVs, and VCRs, supplemented by vertical integration into semiconductors. Canon built on its initial core knowledge of precision optics and mechanics in mechanical cameras, and combined this knowledge with core knowledge of electronics and chemicals to develop calculators, electronic cameras, copiers, and printers. And NEC's expansion based on core knowledge of electronics made it a leading player in the markets for semiconductors, computers, and communications.

Step function learning, per Proposition 4, also plays an important role in the product sequences. We see the importance that being in a market and making a product had in pointing to opportunities for related products and to the need to deal with emerging technologies. For example, by virtue of being in the markets both for vacuum tubes and for downstream communication systems that used vacuum tubes, NEC understood the threat posed by transistors. As a result, NEC undertook semiconductor research and made the leap from vacuum tubes to transistors.

Also with regard to step function learning, the desire to make a new type of product sometimes led the companies to combine previous areas of core knowledge and extend them in fundamentally new ways. For example, Canon's development of the electronically controlled AE-1 camera combined and extended the company's prior knowledge of precision optics and mechanics and electronic circuitry in a fundamentally new way. We also see how companies learned from their mistakes, as in Canon's ill-fated hand-held calculator initiative. From this endeavor, Canon gained a great deal of knowledge regarding miniaturized electronic circuitry, which it then employed in its highly successful AE-1 electronic camera.

Finally with regard to step function learning, we see how firms adapted to radical changes in technology and markets, and also shaped the evolution of products and markets. For example, NEC successfully managed the transition from vacuum tubes to transistors, a 'radical' shift in technology and the underlying core knowledge. And Canon's development of the AE-1 camera, along with its aggressive marketing, shifted the consumer camera market away from mechanical cameras to electronically controlled cameras.

A critical element in the product sequencing of these companies, but not brought out in the histories, has to do with the role of top management. In Sony, the founders Morita and Ibuka often initiated and played a large role in decisions regarding product sequencing and acquisition of any new knowledge required. In NEC, Kobayashi was critical to the company's product sequencing strategy involving integration of computers and communications. Notably, these leaders played important integrative roles within their organizations, as well as scanning the environment for new technologies and generating new ideas.

Overall, the product sequencing histories illustrate the continued coevolution of knowledge and products through time, involving both incremental and step function learning. We also see how these systems of learning essentially constitute dynamic capabilities that enabled the firms to continually introduce new products and adapt to changing technological and market conditions.

CONCLUSION

The product sequencing model provides a dynamic framework that enables us to track, step by step, how knowledge, capabilities, activities, and products coevolve over time and across markets. Admittedly, this is a large undertaking, and the model is a first step in unpacking the evolution of capabilities and products.

The model has several features that differ somewhat from existing models. As noted previously, the concept of knowledge shared across products is a well-known explanation for related diversification, but is not usually applied to vertical expansion. The oil–petrochemical example used earlier, as well as the histories of the electronics companies, suggest that not only does core knowledge form the foundation for multiple products and stages in a vertical chain, but it also applies to industries that contribute large shares to the world economy and that can be highly profitable. With regard to integrative knowledge, although the concept has been applied to linkages of activities within a vertical chain (e.g., Armour and Teece, 1980; Clark and Fujimoto, 1991; Iansiti and Clark, 1994), it has not been applied frequently to expansion into new product-markets either vertically or through diversification across vertical chains. More generally, the literatures on diversification and product development have not focused on the dynamic aspects of how expansion into new product-markets unfolds over time,[28] or on the importance of product platforms.

The product sequencing model has implications for several closely related literatures, including the resource-based view, knowledge management, dynamic capabilities, organizational learning, firm and industry evolution, and business history. First, the model highlights the importance of products to the resources and capabilities of firms. The analysis also helps to make the idea of resource and activity bundles (Rumelt, 1984; Conner, 1991) more concrete,[29] particularly with regard to knowledge and learning. The model further draws attention to the role of knowledge as a resource that supports capabilities, activities, and products, and that in turn arises from experience gained in making and selling products. Additionally, the model relates specific types of knowledge in specific ways to vertical chains of activities, and further suggests that it is useful to characterize the evolution of firms and industries in terms of vertical chains and products.[30] Thus, we may be able to gain greater understanding of changes in scale and scope (Chandler, 1990) over the course of business history by asking questions about exactly what types of knowledge and systems of learning formed the basis for expansion, and how these were linked to specific products. We also can examine deficiencies in knowledge and learning over the course of history.

With regard to change over time, the product sequencing model extends the analysis of dynamic capabilities as well. As noted earlier, the parallel systems of learning in the model are prime examples of dynamic capabilities (Teece *et al.*, 1997), since these systems are fundamental to the ability of organizations to innovate and to adapt to changes in technology and markets, including the ability to learn from mistakes. We also bring in the role of products that coevolve with, and contribute to, specific systems of knowledge and learning.

With regard to organizational learning and innovation more generally, step function improvement in integrative knowledge is akin to architectural innovation (Henderson and Clark, 1990), but at the firm rather than the product level. The model also contributes to the limited literature that points to the possibility that firms can achieve both evolutionary and revolutionary change (Tushman and O'Reilly, 1996). Our analysis highlights the dual systems of incremental and step function learning that facilitate evolutionary and revolutionary change, respectively.

The product sequencing model does not necessarily yield generic predictions about the appropriate direction of expansion for broad categories of firms.[31] As an example, consider the costs of learning required for product sequencing. These costs depend in part on how 'close' the new knowledge that must be acquired is to current knowledge, as well as on the extent of technological opportunity (or opportunity for knowledge advancement more generally) in a particular market. Although in general we would expect lower costs for incremental than step function learning, it is not clear *a priori* whether horizontal or vertical expansion, for example, will have lower costs of incremental learning, since both forms of expansion may build on current core and integrative knowledge. Nor is it clear *a priori* whether step function learning is less costly for vertical or horizontal expansion. Instead, costs of learning depend on the situation of the individual

[28] Teece *et al.* (1994) and Kim and Kogut (1996) are notable exceptions.

[29] As an alternative approach with a somewhat different focus, Milgrom and Roberts (1990) provide a model of strong complementarities between groups of activities. See also Cockburn, Henderson, and Stern (1999).

[30] Thus, the model adds a dynamic element to the literature on activity systems and value chains, which heretofore have often been analyzed in static terms (with notable exceptions of Ghemawat *et al.*, 1999; McKelvey, 1999; and Siggelkow, 1999).

[31] In this, we depart from Teece *et al.* (1994). We also differ somewhat from them in our explanation of vertical linkages.

firm, and more specifically on how 'close' the knowledge base required for a product expansion is to the current knowledge base of the firm, regardless of the direction of expansion.

In focusing on the knowledge bases and product sequencing of individual firms, the model alerts managers to factors to consider when making decisions regarding innovation, new product introduction, and market entry. Managers must consider the firm's core technological knowledge, as well information regarding the likely future trajectories of technologies and markets (gained from integrative knowledge), the firm's learning capabilities (systems of learning), and any new knowledge and capabilities the firm may need to acquire. Given this information, managers in essence place bets on product sequences, and scenario analysis can help managers plan in such situations (Raubitschek, 1988b).

In addition, using the model retrospectively, we can trace the progression of organizational knowledge and products through time using both qualitative historical analysis and statistical techniques if we can obtain appropriate data. The model predicts that, for each individual firm, successful product sequencing builds on and also augments the knowledge and capability base of the firm. More generally, we can start to unpack the evolution of firms (and other long-term organizational arrangements), and by implication the evolution of industries, into the evolution of the underlying systems of knowledge and learning, capabilities, and products.

ACKNOWLEDGEMENTS

This paper has benefited from discussions with Paul Almeida, Betsy Bailey, Therese Flaherty, Rob Grant, Quintus Jett, Bruce Kogut, Dan Levinthal, Marvin Lieberman, David Mowery, Yiorgos Mylonadis, C. K. Prahalad, James Brian Quinn, Dick Rosenbloom, Lori Rosenkopf, Nicolaj Siggelkow, Harbir Singh, and Sid Winter. We also benefited from presenting the paper at the 1999 annual meetings of the Academy of Management and INFORMS, the Tuck/CCC conference on the Evolution of Firm Capabilities, and the Helsinki School of Economics and Business Administration. The views expressed herein are not purported to represent those of the U.S. Department of Justice.

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