Strategic Management Journal, Vol. 13, 137–161 (1992)

THE ROLE OF EXECUTIVE TEAM ACTIONS IN SHAPING DOMINANT DESIGNS: TOWARDS THE STRATEGIC SHAPING OF TECHNOLOGICAL PROGRESS

RITA GUNTHER McGRATH
Sol C. Snider Entrepreneurial Center, The Wharton School, University of Pennsylvania, Philadelphia, Pennsylvania, U.S.A.

IAN C. MacMILLAN
Sol C. Snider Entrepreneurial Center, The Wharton School, University of Pennsylvania, Philadelphia, Pennsylvania, U.S.A.

MICHAEL L. TUSHMAN
Graduate School of Business, Columbia University, New York, New York, U.S.A.

The purpose of this paper is to argue that the destiny of the firm is closely linked to the evolution of product class in the industry and show that product-class evolution is driven by the variation, retention and selection of dominant designs in the context of lumpy markets. The paper demonstrates that business strategy decisions cannot be undertaken without an intimate understanding of the relationship between the firm's technology trajectory and the opportunity space created by lumpiness in the market. The paper identifies where the major choices facing the executive team, and the processes they implement in response, significantly influence the scope direction and quality of technology strategy decisions.

INTRODUCTION

The purposes of this paper are threefold. The first is to argue that to develop a comprehensive business strategy, the top management of an organization needs an intimate understanding of product class evolution, particularly of the ways in which dominant designs emerge. The second purpose is to offer a perspective on the evolution of dominant designs, which suggests that they may be explained in terms of 'lumpiness' of markets which have finite and limited customer bases. The third purpose is to identify the mechanisms through which executive teams shape technology strategy, and to identify the processes which significantly affect the scope, direction and quality of technology strategy decisions. It is our hope that this discussion will illuminate worthwhile new areas of inquiry into the strategic utilization of technology.

Current strategic management study can be thought of as drawing upon two parallel and complementary research streams. The first, deriving from Penrose (1959) and represented by Wernerfelt (1984) and by Teece, Pisano, and Shuen (1991) explains changes in industries primarily through the ways in which firms mobilize idiosyncratic resources to obtain excess profits. The second, exemplified by the work of Porter (1980, 1985), focuses on market forces as the driver of competitive outcomes. In considering the role of *technology* strategy as part of the overall business strategy of the firm, however, both strategic perspectives leave a number of key questions unaddressed.

The resource-based view suggests that unique

Key words: Strategy, technology, executive teams, top-management teams

0143–2095/92/100137–25$17.50

value can be obtained by the way in which technology is used, reinforcing the central importance of technology decisions in the repertoire of the firm. Unfortunately, as yet it offers little theory which would help a strategist make a particular technology deployment decision, let alone establish a sufficiently consistent stream of such decisions as to be termed 'strategic.' The market forces approach, on the other hand, offers more in the way of guidance for the strategist. Thus, it suggests specific areas in which technology can be used to support a given strategy (by using technology investments to drive down costs, for example). This approach, however, fails to address the necessity of firms to make decisions in a situation in which technologies are not stable and predictable, and in which technological development leads, rather than supports, the strategy of competitors in a product-class. Firms in such situations need a different framework for thinking through their approach to technology than can be obtained by looking primarily at competitive forces. Management will find little in this approach which explains the impact upon a marketplace of the introduction and proliferation of new technologies, in particular of technologies with the potential to represent a major discontinuity.

We suggest that a third stream of literature, one that addresses the evolution of technology and concomitant evolution of product classes, can do much to help the strategist bridge the above gaps. In this way, we hope to illustrate that bringing concepts from the technology literature into research in strategic management offers the potential for opening fruitful new areas of inquiry. We begin the discussion of these concepts with a perspective of how industries emerge and evolve, and how this understanding is strategically central to firm performance.

INDUSTRY EVOLUTION VIA PUNCTUATED EQUILIBRIA

We suggested above that informed technology strategy must seek to create both valuable, firm-specific assets and to position the firm advantageously with respect to competitors and a changing technological playing field. Let us begin our discussion by summarizing what we think we know about how technologies, industries and product-classes emerge, evolve and disappear.

The technology cycle and product-class evolution

Drawing from work in sociology, history, economics, and industrial engineering, Anderson and Tushman (1990) argue that technological change can be characterized by socio-cultural evolutionary processes of variation, selection and retention (Campbell, 1969). Variation is driven by stochastic technological breakthroughs which initiate substantial technological rivalry between alternative regimes (Jenkins, 1975). For example, the introduction of continuous-wave radio components led to competition between alternator, arc, and vacuum-tube transmitters (Aitken, 1985). Positively selected variants then evolve through retention periods marked by incremental technical change and increased interdependence and enhanced competence within and between communities of practitioners. For example, as the aeronautical community grew with the dominance of the turbojet engine its subcommunity of gas turbine practitioners also designed gas turbines for ships and offshore oil production platforms (Constant, 1987).

A technology cycle can be viewed in terms of four components: technological discontinuities in which a revolutionary breakthrough disrupts the industry, eras of ferment in which many designs compete for industry dominance, the emergence of dominant designs, and eras in which competition centers around incremental changes to dominant designs (Anderson and Tushman, 1990). Technological discontinuities and stabilization of dominant designs are events that mark the transitions between eras of ferment and eras of incremental change, as illustrated in Figure 1.

The technology cycle model is a useful frame for understanding both the development of simpler components or subsystems of larger products or technologies. A focus on simpler components was utilized by Anderson and Tushman (1990), who described the technological development of cement manufacture by focusing solely on cement kiln throughput, and the technological development of minicomputers by focusing solely on central processing unit speed. An extension of these ideas, which does not involve the same sacrifice of understanding of

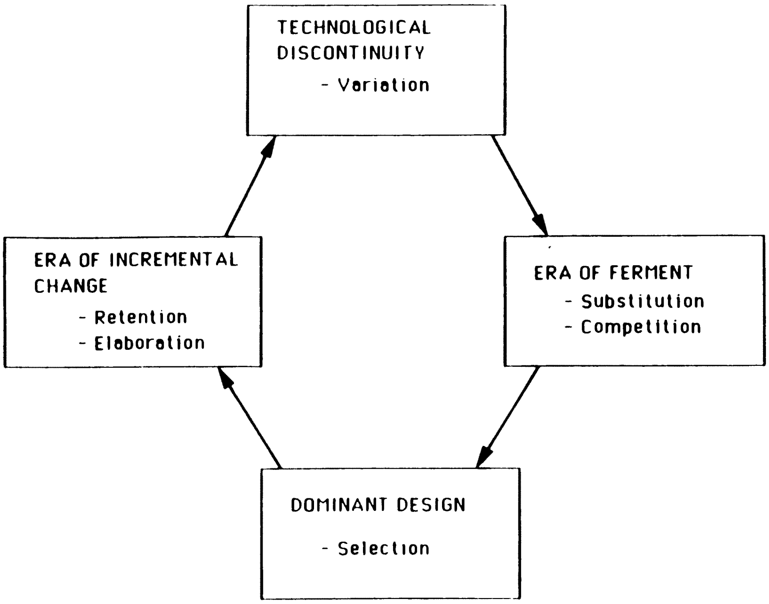

Figure 1. The technology cycle. Adapted from Anderson and Tushman (1990).

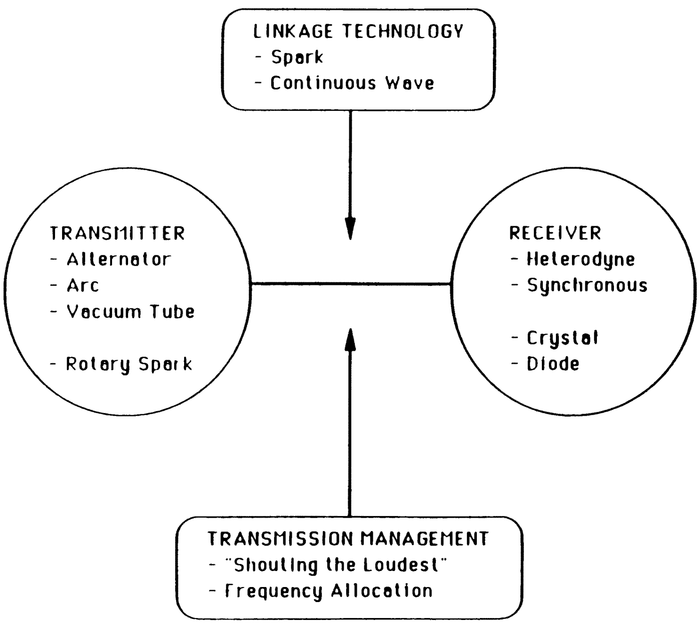

Figure 2. Technological evolution of radio systems. Adapted from Rosenkopf and Tushman (in press)

technological developments in other subsystems, is used by Tushman and Rosenkopf (1992), who view products as systems of components, linkages, and interfaces.[1]

Products vary in their levels of technological complexity. This range can be defined by the numbers and types of subsystems in the product, the level of interdependence between these subsystems, and the boundaries of the product. Nonassembled products, such as cement and glass, have no separable components, while simple assembled products, such as guns and skis, are constructed from components that are

[1] The reader is referred to Tushman and Rosenkopf (1992) for more extensive discussion of these concepts.

fit together in an assembly process. Closed assembled systems, such as automobiles and watches, require linkage technology between components for assembly, while open assembled systems, such as phone systems and electricity distribution systems, contain complicated interface technologies to connect their closed, assembled systems. Closed assembled systems are contained in some sort of casing, while open assembled systems do not have a clear cut boundary. Table 1 illustrates how drivers of technological progress, bases of design dominance, arbiters of dominant designs, and the influence of social, political and organizational dynamics become more complicated as technological complexity increases. We focus primarily on systemic technologies, because these more complex technologies are influenced much more heavily by social, organizational, and political processes (Tushman and Rosenkopf, 1992).

For complex systems, technological evolution often occurs through the interdependent evolution of subsystems. Figure 2 shows how radio systems are composed of multiple, interdependent components, each of which has its own technology cycle. For early radio systems, both transmitter and receiver technologies evolved from spark-gap to continuous wave components, while transmission management technology evolved from 'shouting the loudest' to frequency allocation. For most technologies, certain core subsystems spur complementary innovation in other peripheral subsystems (Hughes, 1983). With watch technology, for example, the transition from springs to batteries as the core technology of the energy component enabled the transition from mechanical escapements to quartz crystals in the oscillation component as well as the development of digital display faces.

The interest of this discussion from a strategic viewpoint is that interdependent systems offer distinct opportunities and constraints, depending upon the stage at which design dominance has emerged at each level of analysis. At the basic subsystem level, the emergence and replacement of dominant designs can be modeled with Anderson and Tushman's (1990) technology cycle, and technological merit is most important. As complexity increases, technological evolution may be considered as a collection of interlinked technology cycles: while a technology cycle may be identified for each subsystem, much of the force that spurs technological evolution of any particular subsystem is generated by the technological evolution of the remainder of the system.

Were dominant designs to emerge solely from a technological logic, in which the 'best' design becomes dominant on the basis of some optimization algorithm, the complexity of technology investments would be limited. The strategist under such a scenario would be well advised to invest resources primarily to capture technological superiority at the component level, when the elements of such superiority are relatively unambiguous. For products and systems with any degree of complexity, however, sociopolitical processes are crucial in the evolution of product classes. Thus, we see that for complex products, satisficing replaces optimizing in the closing on industry standards (Tushman and Rosenkopf, 1992; David, 1987; Noble, 1984). Since it is the rare technology which clearly dominates across all possible dimensions of merit, a process of compromise and accommodation between suppliers, vendors, customers, and government becomes important in adjudicating among feasible options (e.g., Constant, 1989).

Achievement of a dominant designs can thus be seen to be driven by the strategic decisions made by organizations interacting with other organizations and with practitioner communities which shape the understanding of dimensions of merit and which cause industry standards to emerge (e.g., Aitken, 1985; Noble, 1984; Frost and Egri, 1990).

Two factors trigger subsequent market segmentation following the establishment of a dominant design. First, the technology underlying the dominant design diffuses to the rest of the industry, bringing all surviving players on a rough par with one another as far as the new technology is concerned. Second, a number of forces start to reshape the attributes demanded by the market, creating new market segments or shifting the concentrations of old segments. There are several such forces:

— Technological change, which creates new design options;
— Market change, in which new needs emerge and new attributes become important, (such as increases in demand from airline passengers for greater comfort on long hauls, which

Table 1. The role of technological complexity

Technological complexity	Driver of technological progress	Basis of design dominance	Arbiter of dominant design	Influence of social, political, and organizational dynamics
Non-assembled and simple-assembled products	– Subprocess replacement or elimination – Materials substitution – Product substitution	Technical superiority of easily measured dimensions of merit	Single or focused practitioner community	Minimal
Closed-assembled systems	– Subsystem substitution or dominant design – Core subsystem evolution – Linkage technology	Competition among alternative designs with diverse dimensions of merit	Heterogeneous professional and organizational communities	High
Open-assembled systems	– Core subsystem substitution or dominant design – Linkage or interface technology	Competition among alternative subsystem designs with diverse dimensions of merit	Multiple and diverse organizational, professional, and governmental communities	Pervasive

Adapted from Tushman and Rosenkopf (1992).

ushered in the current dominant design based on wide-bodied planes);
- Regulatory change, which may impose a demand for new design characteristics (such as the requirement for minimum gasoline consumption for automobiles, which ushered in the current dominant designs employing engineered plastics in autos).
- Social change, in which pressures from society create demand for new designs (such as the current pressures on refrigerator manufacturers to radically redesign their product to be more environmentally friendly).

Under pressure of these forces, the market fragments into new segments, and the industry enters into a period of incremental change as variations of dominant designs jockey for market share (e.g., Sanderson and Uzumeri, 1990; Meyer and Utterback, 1992).

Strategically driven dominant designs—the problem of the strategist

The above discussion of dominant design has been intended to review what is known about process of industry evolution and to suggest that development of technology strategy takes place within this context. A difficulty with this conception of technological evolution is that the dominant design which is so central to identifying the current stage of technological evolution can only be identified *ex post*, and at an industry level.

From the point of view of the firm, and in particular the strategist in the firm, a more pressing issue is 'How do I create a dominant design in the industry for *my* firm?' The firm that can capture and appropriate returns from possession of the dominant design and its subsequent generations is guaranteed strategic supremacy in its industry, as Sony did in creating an entirely new product-class with the introduction of the Walkman (Sanderson and Uzumeri, 1990).

We have already described key processes in technological evolution as the introduction of new variations, the selection of some to remain in the body of technological offerings, and the diffusion of such offerings throughout the industry. From the perspective of the firm, rather than of an industry, one can begin to distinguish the underlying mechanisms through which these processes occur. Thus, market, regulatory, technological and social changes encourage firms to come to market with variations on the current dominant design. These variations from the industry perspective taken by most previous technology-evolution research are regarded as random. From a strategic point of view, however, a different question can be formulated. This is, 'How do firms go about deliberately shaping the odds of having their variation on dominant design selected as the industry standard?'

In order to pursue this question, it would be useful to develop a framework for thinking about the drivers of dominant design in complex, interdependent systems. This requires a more specific definition of dominant design, which both captures the industry level *ex post* construct but also allows the strategist *ex ante*, and at the firm level, to think through the linkage between the firm's technology strategy and the way it wishes to attack its markets. Such a framework is the focus of the next section.

TECHNOLOGY STRATEGY AND THE PRODUCT/PROCESS DESIGN SPACE

It is widely acknowledged that the success of a technological innovation (which may be thought of as the capture of design dominance) depends heavily on the extent to which market structure and market needs are understood (von Hippel, 1988; Maidique and Zirger, 1985; Cooper, 1979; Ayal and Raban, 1990; Crawford, 1991). Despite this recognition, we have yet to develop a widely accepted theoretical framework for the linkage between market structure and technological deployment decisions. Let us now introduce market composition considerations to our emerging model of product-class evolution.

Every product-class design may be conceived of as being confined within a 'design envelope' whose edges are defined by the current limits of technology. Designs are constrained by a multiplicity of technology barriers, in much the same way as a linear program solution is held within a multidimensional envelope of constraints. This multidimensional problem is depicted two-dimensionally in Figure 3—a highly oversimplified example of the design space for aircraft engines.

In aircraft engine design, two of the key

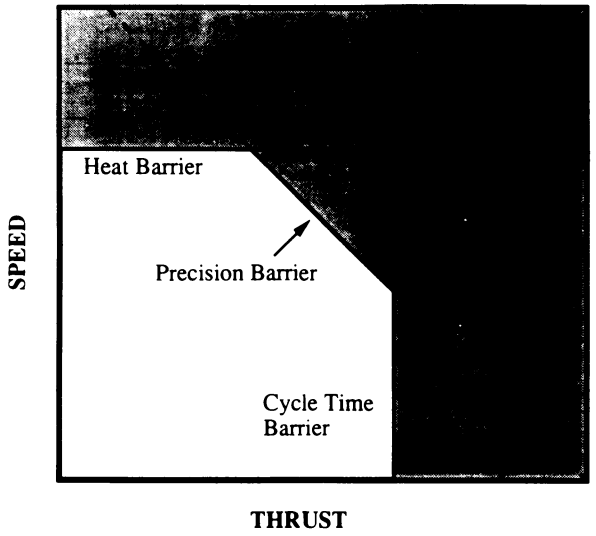

Figure 3. Constraints in the technology envelope for aircraft engine industry.

attributes desired are speed and thrust. The problem is that both these attributes are constrained by current technological limits. For instance, current materials technology precludes operating at greater than certain temperatures (heat barrier), or operating more than some limited number of cycles before failure (cycle time barrier), while current machine tool technology precludes machining at less than certain tolerances (precision barrier). These are but three of a host of barriers that prevent current design from maximizing all desirable attributes. The reality that managers face is that every product or service is locked within a complex multidimensional design envelope similar to that of Figure 3.

Thus, designs of products and their associated processes for production or delivery are confined within a 'technology envelope' which places limits on the deliverable attributes of a product or service given technological barriers faced by the industry. In the case of a particular firm, it may have advanced further on some barriers than others, so that different firms are each compelled to confine their designs within their particular firm level envelope. Thus, the supply of possible designs at firm level is determined by technology envelopes that are idiosyncratic to the individual firm.

From the point of view of the individual firm, given limited resources, it is impossible to maximize all the desirable attributes of any product offering. Technological barriers (what can be done with technology that exists and whose deployment is understood) as well as limits imposed by intended end use (design for durability or for speed, for example) constrain the universe of possible options and force designers to make trade-offs among these attributes.

Thus, the technological stategies of firms can be categorized in terms of choices regarding the allocation of resources to changing the limitations of the current design envelope. For instance, in the case illustrated by Figure 3, the firm may choose among investing to raise the heat barrier, increasing the cycle time before failure or developing more precise machining capability. What becomes interesting from a strategic point of view is that informed decisions simply cannot be made without taking into account the structure of the market.

DOMINANT DESIGN AND THE 'LUMPINESS' OF LIMITED POPULATION MARKETS

The framework proposed here for understanding the composition of markets is based on initial work by Shintaku (1990). Let us describe it by using a simple hypothetical example. In purchasing a motor vehicle, customers make trade-offs between attributes like speed and payload, depending on the price charged for it. In virtually all real markets, uneven concentrations of customers clustered around different attribute preferences create disparate subpopulations who each make their own trade-offs in product attribute space. These unevenly concentrated groups of customers comprise what we shall here term lumps or 'market knolls.'[2]

To illustrate, consider three groups of users in a hypothetical industry in which competitors are distributing light industrial products. Such an industry would typically purchase fleet vehicles for three major functions: service, sales and delivery. The service force seeks to rapidly meet customer service demands by minimizing transit time, as well as transport sufficient quantities of

[2] In the marketing literature these have been called niches — we make a distinction between niche and knoll below.

spares to deal with customer needs on the spot without return trips to the warehouse to restock. For the service force, therefore, both vehicle speed and payload are relatively important. In contrast, the delivery function seeks above all to minimize time spent reloading, while speed en route is less essential, although still desirable. Finally, the sales force seeks speed, to make the maximum number of calls in a given time frame, while needing to transport only as much product as is required for demonstration.

At a given price level, each group of users would have its own isoprice line, illustrated in Figure 4, which suggests that at the given price, the sales force would buy any design to the north and east of line A, the service force any line to the north and east of line B, and the delivery force any design northeast of line C.

Standard marketing treatments would divide such a market into niches—different vehicle models can be designed for each of the submarkets, and knoll players may decide to do this, each capturing 'access' to their particular knoll by designing a product at a price that puts them at points X, Y, and Z each northeast of the relevant preference contour. In the light of the potential for very rapid and substantial changes in technology, however, firms that exclusively focus on developing niche products that serve only one of the three knolls for service, sales and delivery do so at some peril. Technology

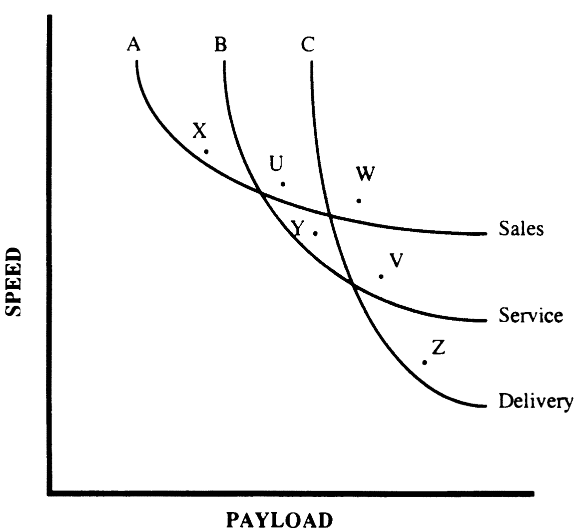

Figure 4. Isoprice lines for different users within a given market

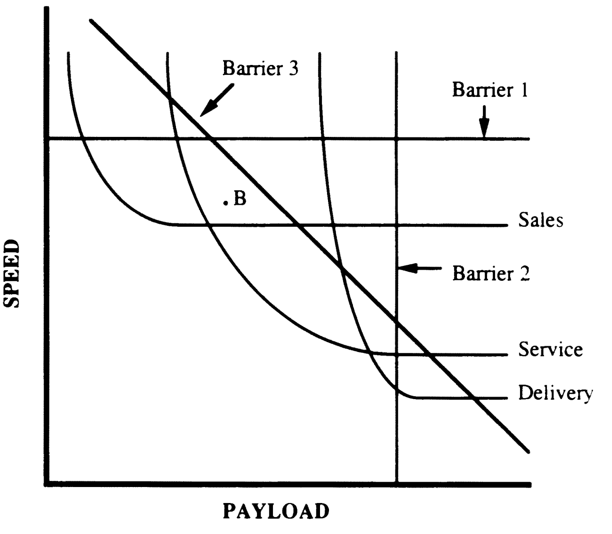

Figure 5. Combined effects of market 'lumps' and technology barriers

could be deployed to design products at points U, V or even W in which case each of the niche players will find their products obsoleted on their niche attributes, while at the same time the new entrant reaps the benefits of a larger market size than any of the niche players whose designs have been made obsolete.

As new designs advance north and east in an attribute space, the number of subpopulations that are attracted by that design increases. This means that there can emerge a design that captures all the market knolls lying to the south and west of the design. This highlights the specific conditions that determine the viability of a niche, as well as its fragility. *It is only for as long as technology barriers confine designs within specific market knolls, that these knolls can be thought of as niches. Since technology advances can create a design that lies to the north and east of whole groups of niches, niches are strictly tactical in the long run.*

As we shall show below, there are at least eight very different ways in which aggressive competitors can capitalize on the structure of market knolls to gain dominance over niche players. The firm that chooses to ignore the lumpiness of the market and develops its business strategy and its subsequent technology strategy based on niches does so at great peril—for whenever a new design breaks through one or another barrier on the technology envelope, all designs offered by existing niche players to the south and west of that design are made obsolete.

Obviously, in an ideal situation, every producer seeks to place products in the north-east quadrant of the design space, thus ensuring its appeal to the widest number of customers. The constraint in so doing is the technology envelope which may entirely cut off the most densely populated quadrant of the design space. This is illustrated in Figure 5, in which a typical design envelope is overlaid on the market opportunities in the design space.

To further illustrate how this approach can illuminate technology decisions, let us posit design B which we have inserted into Figure 5. Design B, which is a relatively high speed, medium payload design, has a market opportunity comprising both service and sales people. Delivery people have no use whatsoever for design B, therefore this market is entirely closed to that design. In our illustrative example, a firm that is currently producing design B can increase its market by increasing its payload, but to retain the 'sales' portion of its current market, it cannot much reduce its speed. The key challenge for the makers of design B then is to shift technology barrier 3 to the east, thus opening the delivery vehicle market to that design.[3] There is no point in investing to shift technology barriers 1 or 2, since neither will result in improved market opportunities for design B. In our hypothetical example, then, the critical technological barrier is barrier 3. To the extent that the producer can crack the barrier, a new market will open for their offering.[4]

By imposing these technological constraints upon our hypothetical lumpy market, the investment choices to be made as part of a technology strategy become clearer. To begin with, there is a large area in the design space which, while technologically feasible, will not result in combinations of attributes that anyone will buy. Second, as we have already specified, the 'marketable' portion of the design space is not smoothly distributed, but lumpy, with the consequence that relatively small shifts in design can result in large differences in market opportunity. Finally, the most tempting combination of market segments may be entirely out of reach of current technology.[5]

This discussion now allows us to introduce a revised definition of dominant design that captures the strategic problem of attempting to develop such a design *ex ante* and at firm level. A dominant design in any market knoll is *that design that lies the most northeast in that knoll's product attribute space*.

The challenge for exectuve teams wishing to shape technology strategy can now also be rather precisely defined. *Executive teams must put in place the processes that will drive technology development in the appropriate directions, so that the firm can navigate from its current design to a future design that gives the maximum increase in market access per unit of development cost.*

Their challenge is to help establish key dimensions of merit both by managing environmental relations and by managing intraorganizational dynamics to produce a system that dominates in the targeted product space. The more complex the product, the more complex the intra- and extraorganizational strategic and managerial challenges (Tushman and Rosenkopf, 1992).

Refining the concept of dominant design in the way we have done allows us to make two significant theoretical advances. First, we can begin to develop a more precise understanding of the factors that lead one particular design to dominate another. Second, we can begin to think through the strategic implications of managing technological investments to capture dominant design (Dosi, 1988; Abler, 1986). Although previous work has established the pattern of technological progress, strategy theory has yet to develop a framework that permits managers to do very much with this insight. The remainder of this paper offers such an approach.

[3] It is important to remember that the technology barrier could well be a process barrier, such as ability to machine at certain tolerances or ability to process information electronically at a certain speed.

[4] It is important to note that the creation of the design is not a sufficient condition for capturing the market opportunity, it merely provides access to it. However, *lack* of the design *denies* access to the market opportunity

[5] It is important to note that the creation of the design is not a sufficient condition for capturing the market opportunity, it merely provides access to it. However, *lack* of the design *denies* access to the market opportunity.

HOW EXECUTIVE TEAMS MIGHT SHAPE TECHNOLOGICAL EVOLUTION

The above discussion provides us with a framework for considering a central strategic question. This is whether and where the top executive team can play a role in shaping the successful evolution of technology at the firm level. In looking at how executive teams might shape the evolution of dominant design, we shall use the ecological framework, just as we did in considering evolution at the industry level (see Burgelman, 1991; Basalla, 1988; Van de Ven and Garud, in press). Thus, technological, market and social/regulatory factors encourage individual firms to generate and go to market with *variations* on the current dominant design. The extent to which variations on existing designs are purchased by the market can be considered the extent to which they have survived *selection* pressures. Finally, the extent to which designs selected by the market diffuse to more than one firm can be seen as an indicator of *retention* of the new design in the population of offerings (e.g., Sanderson and Uzumeri, 1990).

We have already noted that technological change is in part a result of the behavior of firms in shifting technology or design envelopes across a demand structure comprising lumpy, changing markets.

The strategic problem of concern here is not so much the explanation of technological evolution as the attempt by individual firms to obtain rent from their investments in technology (Bowman, 1974). Unlike population-level theories, which assume random mutations as the key driving force, strategy theory suggests that purposive, task-responsive organizations actively seek to effect change in products and markets.[6] Thus, the difference between a conventional population ecology treatment and the one pursued here is that we posit a myopically purposeful firm that is self-aware and consciously attempts to shape the processes of variation, selection and retention.

Thus, executive teams could shape technology development by the way in which they intervene in three subprocesses, these being the generation of variations of design, the shaping of the odds of selection of that design by the market, and the delaying of the diffusion of a selected design to competitors.

Executive teams and design variations

We call the selection of type of variation in design the firm should pursue a 'variation strategy.' As we show in Table 2, this choice is made in terms of two basic dimensions: strategic path selected and strategic outcome sought.

Strategic path: The first way in which to pursue dominant designs lies in selection of the choice of one of two basic strategic paths: technology 'push' or market 'appeal.' With a technology push path, the firm attempts to deploy technology to extend its design envelope in search of designs that deliver improvements on existing attributes. With a market appeal path, the firm attempts to deploy technology to offer additional attributes to the market. The objective in either case is to use investments in technology to move the firm's offerings northeast in the design space.

Strategic outcomes: Next, depending on the ambitiousness of the firm and its appetite for scope of change, there are four very different outcomes it can pursue to attempt to move into more attractive parts of the design space, depicted in Table 2:

- *dominate only an existing knoll*—this is a single niche strategy, in which the firm seeks to create a design that dominates competitors in a single knoll. This is depicted in Figure 6 for a technology push path (since the addition of a new attribute opens another dimension on the diagram, it is not possible to depict market appeal paths on two dimensional diagrams. However, the same principle applies as for a technology push path, only in a multidimensional framework).
- *invade adjoining knolls from a current base*—this is a multi-niche strategy, in which the firm uses an existing niche as a base from which to launch a dominant design in an adjoining knoll. This is depicted in Figure 7 for a technology push path.
- *create a design that dominates several knolls, thereby destroying several former*

[6] The perspective on firms taken in this article is that they are 'myopically purposeful' organizations, seeking to achieve their goals under conditions of uncertainty, given bounded rationality (Cyert and March, 1963; Levitt and March, 1988).

Table 2. Design variation strategies in search for dominant design

	Strategic outcome			
	Evolutionary			Revolutionary
Strategic path	Sub-outcome 1: dominate existing knoll	Sub-outcome 2: invade adjoining knoll	Sub-outcome 3: dominate adjoining knolls	Dominate industry
Technology push: Deploy technology to extend the firm's design envelope	Firm elects a niche strategy—competes in an existing knoll by moving to dominate competitors in that knoll	Firm elects to pursue a multiple niche strategy by invading adjoining knolls and then using its original knoll as a platform for competing in the invaded knolls	Firm elects to dominate several knolls, thus eliminating several former niches	Firm creates a new design which establishes a new technology envelope for the industry: No competitors can match, even by pooling their technologies
	Example: Successive generations of smaller, lighter tape recorders, camcorders etc.	*Example*: Entry of high quality Japanese autos like Lexus LS400, using global platform of lower priced autos	*Example*: Hewlett Packard's introduction of low cost laser jet printers obsoletes dot matrix and daisy wheel impact printers	*Example*: Replacement of typewriters by word processors, Japanese use of process skills to offer same auto attributes at vastly lower cost
Market appeal: Deploy technology to expand the number of attributes in the firm's offering	Firm elects a niche strategy—adds one or more attributes with appeal to the existing knoll	Firm elects to pursue a multiple niche strategy by adding attributes that appeal to adjoining knolls and uses the old knoll as a platform for competing in the invaded knoll	Firm elects to dominate several knolls by adding one or more attributes with appeal to all the target knolls	Firm introduces new attributes which no competitors can match even by pooling their technologies
	Example: Addition of chilled water dispenser on door of refrigerator	*Example*: Combining conventional, convection and microwave ovens in one cooking space	*Example*: Merrill Lynch cash management accounts create one-stop banking, capturing $120 billion in various forms of former deposits	*Example*: Use of electronic technology by Canon to allow autofocusing of their 35 millimeter cameras. Thereafter no high quality camera could be sold without this feature

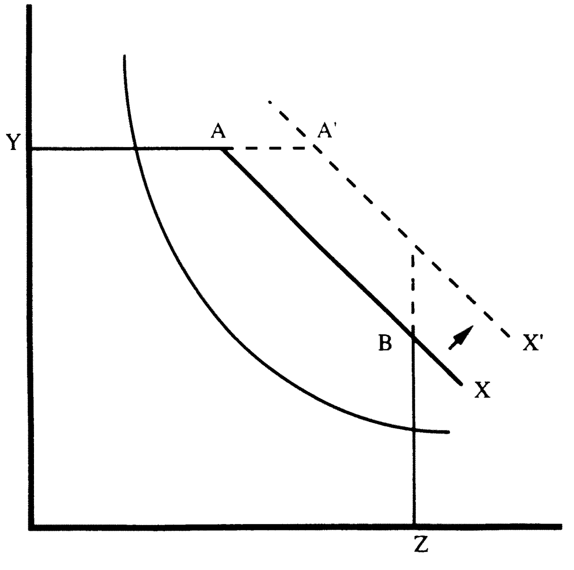

Figure 6. Single niche strategy. Firm A with model A is competing against firm B with model B. Design envelope of both firms is determined by barriers X, Y, Z. Firm A moves barrier X to X′, creating model A′ which dominates B and thus obsoletes B

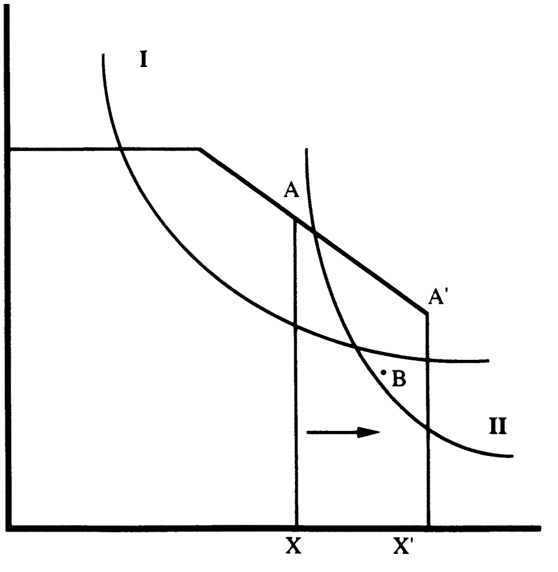

Figure 8. Multi-niche dominance strategy. Firm A is competing in niche I with model A, and firm B in niche II with model B. Firm A moves barrier X to X′, creating design A′ which dominates both earlier model A and B and destroys both niches

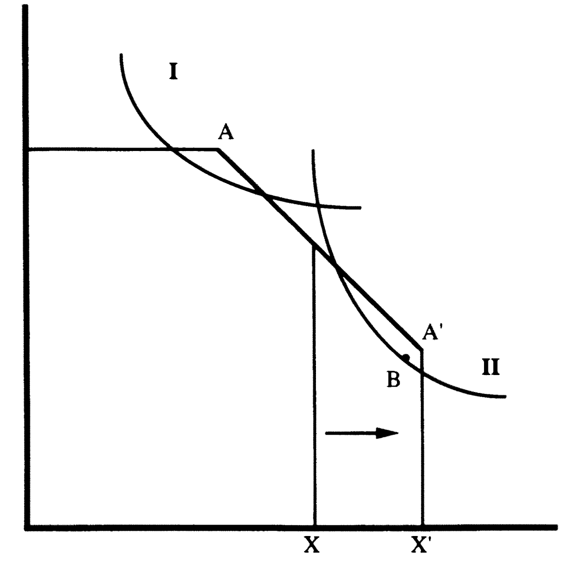

Figure 7. Niche invasion strategy. Firm A has a design envelope that confines it to design A, serving niche I, firm B is similarly confined to design B in niche II. Firm A then moves its barrier X to X′, allowing a new design A'. Firm A can now compete directly against Model B in niche II with A′, using model A in niche I as a platform

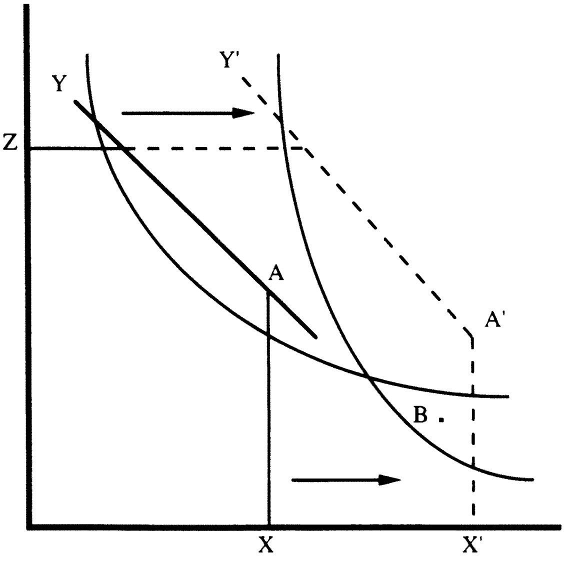

Figure 9. Revolutionary strategy. Firms A and B are competing in their respective niches with models A and B. Firm A quantum jumps barriers Y to Y′ and X to X′, creating a revolutionary design A′, which wipes out the earlier niches by establishing a new design envelope for the industry

niches, depicted in Figure 8 for a technology push path.

- *create a design that creates a new technology envelope for the entire industry*, thus obsoleting the capacity of all competitors to match, even if they pool their capabilities, depicted in Figure 9 for a technology push path.

Combining the stategic path dimension with the four strategic outcomes sought yields the array of eight fundamental variation strategies depicted in Table 2.

Research has not yet conclusively demonstrated that any particular variation strategy is superior—in fact, firms have succeeded in all eight categories, as shown by the examples in Table 2, as well as by using combinations of these variation strategies.

Dominant design can thus be pursued via eight different variation strategies. Let us now turn to the question of how the behavior of executive teams might affect the firm's approach to the generation of variations.

Executive team behaviors and choice of variation strategies

One of the fundamental roles of the executive team is to mediate the internal competition for the firm's limited resources, and create mechanisms for the allocation of these resources (Bower, 1970; Hambrick, Cannella, and Albert, 1989). We argue that the fundamental driver of the selection of a variation strategy lies in the ways in which the executive team mediates internal competition.

Two kinds of competition within the firm are relevant here. The first is internal competition for resources (financial and otherwise) for specific activities. This might be thought of as interproject or idea competition. By the way they mediate interproject competition, executive teams define the scope of design variations sought by the firm (Hambrick and Mason, 1984). The second is competition among individuals for resources to support personal goals. By the ways in which executive teams mediate competition to support individual goals they shape the intensity with which design variations are sought. Table 4 highlights the various ways in which executive team behavior might impact both scope and intensity of design variation, but given limitations on length we address only behaviors that can shape the scope of technology strategy—which we now address in detail.

Consider interproject competition. Given limited resources, no firm can pursue all attractive ideas, so the executive team is asked to select among competing technology project opportunities. Over time, explicitly or implicitly, their choices set the scope of what projects are deemed legitimate by the subordinates. It is important to stress that scope-setting processes often are not the outcome of conscious decisions or rational strategies. What is significant is that no matter what the articulated or conscious intent of the executive team, it is their behavior that will drive the organization to proceed along a predictable trajectory in the pursuit of new technological designs.

Once scope is set, this decision not only determines the probability that a particular variation strategy will be pursued, but also fundamentally imprints the subsequent fate of those designs that emerge from the technology development process. We show below that the scope setting represents the principal process through which the executive team, wittingly or unwittingly, influences the probability that the organization's design variation strategy will fall into one or another cell in the typology in Table 2. As we will argue below, this fundamental imprinting will also irrevocably shape how and where executive teams can influence the processes of design selection and design diffusion. If the scope set by the senior team is inconsistent with the routines, incentives and systems in place in the firm, the resulting mismatch tends to disrupt implementation of the strategy.

The most profound effect on choice of a variation strategy stems from the 'mindset' that the executive team brings to bear in deciding on which technology proposals to support. This mindset has two dimensions—breadth and orientation, and Table 3 depicts how the executive team mindset can shape the variation strategy choices made by subordinates.

First is whether the executive team tends to see technology or marketing as the prime 'driver' of the business. Firms like du Pont and AT&T have traditionally emphasized technology, while firms like P&G and MCI have a marketing orientation. Executive team orientation will significantly shape the probability that the vari-

Table 3. Implications of executive team orientation for technology strategy thrust

Executive team orientation	Niche	Competence platform	Relatedness	'Thousand flowers'
Increases odds of	Single niche designs	Adjoining knoll invasion	Multiknoll dominance	Revolutionary
Market knoll/design envelope prerequisites for technology push path	Ability to extend the firm's design envelope to dominate competitor's design envelopes in an existing knoll	Ability to extend the firm's design envelope into adjoining knolls	Ability to extend design envelop into a position which dominates several (now obsoleted) earlier niches	Ability to deploy technology to create a new technology envelope for the entire industry, thus obsoleting all earlier niches and designs
Market knoll/design envelope prerequisites for market appeal path	Ability to add attributes which create a design envelope that dominates the competitors' envelopes in that knoll	Ability to add attributes which create a design envelope that extends into adjoining knolls	Ability to add attributes which create a design envelope that dominates several (now obsoleted) earlier niches	Ability to add attributes that create a new technology envelope for the entire industry, thus obsoleting all earlier niches and designs

ation strategies selected by the firm will be technology push or market appeal. The most interesting contrast is between that of Sony, who will not go forward with a technology project without first getting evidence that the product will sell, and a major pharmaceutical firm, which instructs its technologists to emphasize publication-quality research and volume of prestige articles.

The next scope-setting issue is breadth of scope—how 'far from the knitting' the firm should stray. In essence the choices made by the executive team in the face of competing technology proposals delimits the 'ballpark' in which the developers of technology are expected to play. These ballparking decisions have enormous consequences on the probability that particular variation strategies in Table 3 will be pursued:

— *niche mindset*: Some executive teams have a very focussed, niche-oriented mindset and insist on serving only that niche. As a result, people in the firm will tend to focus technology development on the single niche outcome in Table 3. An example would be Mercedes Benz.
— *competence extension mindset*: Somewhat broader is an executive team that insists on pursuing only projects and technologies that draw off an existing competence base, but push the firm hard to seek opportunities to deploy that competence. This mindset increases the chances that the firm will begin to explore technology projects that invade adjoining niches, using current competences to enter adjoining segments. Examples would be the steady movement of Japanese auto firms into an increasing number of automobile and van markets.
— *relatedness mindset*: Even broader is an executive team that encourages a broad-ranging pursuit of both new products and markets, but with the admonition that there be at least some relatedness between the firm's current product, market or technology and the opportunity being pursued. The broader the 'license' granted to stray from the knitting, the more likely that the technology strategy options to dominate several knolls will be chosen by the firm's technologists. An example of such a mindset would be the movement of GE plastics division into a variety of industrial markets—automobiles, first in the U.S., then in Europe and Japan, personal computer frames, building materials and so on.
— *'thousand flowers' mindset*: The extreme case, advocated by authors such as Kanter (1988), in which the firm is encouraged to seek wide-ranging and revolutionary technologies, both for existing and new markets. This mindset dramatically increases the chances that revolutionary variations will be pursued. Bell Labs is a prototypical case.

Executive team's scope and the probability of design success

Depending on the way in which the executive team emphasizes and allocates resources to projects they will wittingly or unwittingly set scope and thus 'drive' the likelihood that their subordinates will tend to focus on the cells in Table 2, *whether or not it makes sense in market knoll terms to pursue that cell.* The point we wish to make here is that the mindset of the executive team, and the resultant scope that they subsequently set can not only determine what types of variations will be generated but can also indelibly imprint the probability of success of those design variations that do emerge from the strategy.

This is because for a specific variation strategy to succeed, there are specific prerequisites that must be in place when one overlays the firm's current design envelope onto the structure of market knolls. Table 3 specifies these prerequisites for each of the eight variation strategies we have identified. So, to the extent that the executive team fails to take into account the firm's current design envelope and how it maps onto the structure of the market knolls, there is a danger that the scope that is set can inexorably drive technology development into a 'barren ground' of market knolls, where the energy and investment in designs are never recovered, because the technology development cost of the model exceeds the revenues that derive from limited demand for the design in the target knolls.

This concludes the discussion of the ways in which executive team behaviors can shape the design variation process. Note that the focus has been on the scope of design variation, rather than how team behavior drives the intensity, or fervor, with which variations in design are sought. Given the limitations on length, this is beyond the scope of this article.

Executive team behavior and selection of dominant designs

The discussion so far has touched upon how firms go about generating variations on dominant design. All this activity, however, is meaningless for the firm unless it is able to help designs overcome selection processes, through which variations gain sufficient endorsement to stay in the product/market class. Once a variation has been produced by the firm, the extent to which this variation will be selected by the market is a function of a number of important factors. Importantly, because complex products have multiple dimensions of merit, no one bundle of technologies will dominate in a product class. Further, since new products must overcome market resistance such as switching cost problems, or credibility problems, the challenge is for organizations to shape the odds that their design will be adopted in a product class.

As an example, consider the competition between INTEL's Complex Instruction Set Computing (CISC) chip and several other manufacturers' Reduced Instruction Set (RISC) chip. The most significant barrier to adoption of the RISC design is that software designed for the Intel chip will not work. Despite a twofold jump in computing speed made possible by the RISC technology, an insufficient number of computer buyers are willing to leave their existing software investments (and associated investments in training, customization and learning) behind to adopt the new technology. This further emphasizes the point that superior technological performance is often insufficient to capture dominant design. Technological prowess must be linked with the ability to manage extra- and intraorganizational relations which are driven by four key forces that shape selection.

Forces that shape selection of dominant design

Infrastructure and coevolution requirements

The probability and rate at which the technological innovation becomes a dominant design is a function of the industry infrastructure capacity to match the needs of the design. With radical innovation there is often the need for coevolution of supply, distribution, service, and customer capabilities. The more complex the product is, the more likely it is that coevolution requirements will inhibit the selection of the dominant design, particularly if whole supply and customer segments have been assembled to fit with architectures that are invalidated by the dominant design variation. Associated with coevolution is the need in many cases to negotiate agreement among parties with vested interest in the date at which the design should be delivered to the market (David and Bunn, 1988; Teece, 1986).

The classic example of coevolutionary factors inhibiting a technology from becoming adopted as the dominant design is the case of Sony Corporation's failed Betamax Videotape offering. The producers of the VHS format offering licensed its technology to many manufacturers, thus causing a rapid coevolution of VHS-support systems. Thus, customers could find recent movie releases in video stores, the stores themselves stocked the format, and so on. Sony has since adopted an entirely different approach with its pursuit of 8mm camcorder technology. Sony freely licenses its camcorder innovations to others, with the result that its offerings of this format tape are rapidly emerging as industry standard dominant designs (Rosenbloom and Cusumano, 1987).

Need for and evolution of standards

Particularly with revolutionary change, the degree to which the dominant design will be accepted is a function of how closely new industry standards can be shaped to 'fit' the design. An example of this issue is the encouragement by computer firms of user associations in the PC area to help shape convergence on standards.

Industry clout

The pace at which dominant design is implemented can be slowed or accelerated depending on the amount of power and influence the originator and its competitors have with key stakeholders such as distributors, customers, regulators and suppliers in the industry. The classic example is IBM's attack on Apple in 1981. Once it became clear that there was a major business market for PCs, IBM entered with a product whose components were standard ones supplied by outside vendors—there were no major technology advances. IBM captured a dominant design which basically drew on IBM's name, its installed base of business customers, huge marketing capability, and reputation for service.

Need for internal consensus

Where managers must manage external relations to shape the probabilities that their design dominates, intraorganizational factors also affect the selection of a dominant design. Often times the ability to create, penetrate and grow a dominant design is inhibited by internal disagreement regarding the appropriateness of the design, and the budgeting and resource allocation processes associated with the launch of the design. Such internal dissensus will be associated with products that are late to the market with inferior performance characteristics (e.g., Souder, 1987; Stalk and Hout, 1990). For example a development of a $100 million radical new product, using laser welding for Trac-2 razors, was held up for months at Gillette while the European and U.S. groups sorted out marketing and product design differences.

A question which arises is what role the executive team might play in selection of the design offering to the market. Recall that scope-setting will have put the firm into a trajectory that either emphasizes revolutionary or evolutionary designs. Given this trajectory, the real issue here is what the executive team might do to support the trajectory that has been set, or, at minimum ensure that their behaviors do not conflict with what path has been set. We suggest that this leads us to two conclusions: first, to the extent that the executive team recognizes factors which influence selection and consciously intervene on behalf of the firm, they might be able to significantly enhance the probabilities of selection. Second, the opportunities to shape the odds of acceptance differ dramatically depending upon whether the design variation strategy is evolutionary or revolutionary. The differences are discussed below and highlighted in Table 3.

Executive team behaviors and selection of evolutionary designs

Evolutionary designs will tend to become dominant when they appeal to more customers than existing design, either within the current niche occupied by the firm's offerings, within adjoining niches, or by collapsing niches and taking them all, under circumstances in which no vastly superior technology has emerged. Therefore, actions by the executive team in such evolutionary situations that are generally oriented toward maintaining the current configuration of market knolls and firm offerings, in a sense preserving and reinforcing current positions, will enhance the chances of success of the new designs.

Probability of selection of evolutionary designs might thus be increased to the extent that the executive team monitors and rewards behaviors in the firm, or among customers and distributors that do the following:

— builds switching costs that favor extensions of existing accepted offerings,
— capitalizes on existing infrastructure,
— reinforces existing standards that favor the innovation,
— uses the clout of the firm to negotiate cooperation from transaction partners, where the firm has significant clout.

Executive team behavior and selection of revolutionary designs

Revolutionary designs will tend to be selected when a firm can reconfigure the entire niche structure of the market, either by meeting all known needs or by creating entirely new technology envelopes incorporating new needs.

Thus, probability of selection of a revolutionary design can be increased to the extent that the executive team monitors and rewards behaviors in the firm, and among suppliers, customers, distributors and other stakeholders that do the following:

— forge market acceptance among customers and distributors;
— anticipate and attend to need for new infrastructure or impetus for rapid development of new infrastructure, including negotiating coevolutionary requirements;

— negotiations that favor new technology over existing technology among stakeholders including negotiating new standards that favor the revolutionary technology and negotiating legitimacy with relevant parts of the environment;
— significantly influence transaction partners to support the emerging new design.

Since the firm in this case is attempting to shape entirely new configurations of offerings and knolls, establishing the new rather than preserving the old, the unique, almost 'ambassadorial' role of executive teams can be brought to bear upon removing selection obstacles to the progress of a new technology.

In shaping product class standards, executive teams can thus personally intervene to mobilize the full set of community actors, linkages and power distributions (Rosenkopf and Tushman, in press; Van de Ven and Garud, in press). Critical actors shaping industry standards include governmental agencies, professional associations, user groups, industry associations, as well as suppliers and customers. The more revolutionary the dominant design, the more community structure, relations and norms must change. Given the inherent inertia in communities of organizations (e.g., Glassmeier, 1991), the more radical the technological change, the more the executive team can play an external role in shaping and building a new industry infrastructure (e.g., Van de Ven and Garud, in press).

Having identified the role that executive teams might play in the selection process, let us now turn to the issue of retention, or the processes to inhibit the diffusion of dominant design to the competitors.

Executive teams and barriers to diffusion

The following statement frames the entire discussion of the role that executive teams may play in delaying diffusion: *The seeds of insulation from diffusion are sown in fundamental decisions that can be made by the executive team during the design stage of the venture.*

It is a fundamental frustration of strategic management that outcomes of truly strategic decisions are often the result of relatively irreversible decisions made long before. So too with investments in technological development. The key problem is that to reap the rewards of such investments, firms must be able to prevent others from copying or matching that which gives a particular design dominance. Often it is unclear what elements of a given design render it difficult to transfer. Unlike the choice of variation, which can be thought of as a series of strategic choices, we will argue that protection of technology from diffusion can interestingly be seen to be determined first by *tactical decisions made as a given design variation unfolds*. We shall argue that the key issue for delaying diffusion is that no matter what the design variation strategy chosen at a strategic level, it is the execution of this approach at a tactical level that yields inappropriability.

To elaborate, we now identify key factors that inhibit technological diffusion by making it difficult for a competitor to match the firm's offering with rapidity.

Organizational deliverables

The more a particular technology development is related to the ongoing businesses, the more the firm can depend on its inside routines to produce outputs that other firms cannot, thus protecting the development from appropriation. An example is American Airline's SABRE reservation system which employs unique computer and telecommunication routines to generate a constant stream of new offerings to the business class market.

Competitors find it difficult to match these deliverables quickly, even though they may be well-understood. To the extent that a firm can continue to outpace its competitors in developing its deliverables, it will be able to sustain inimitability.

The key tactical choice here concerns how closely the executive team can 'shepherd' the development of new design variations that are linked to unique, ongoing routines of the firm.

The probability that this will happen is significantly influenced by the ballparking decisions made by the executive team, who 'bake in' the extent to which future developments are protectable via existing routines by the narrowness of the scope that is set—the closer the ballpark is defined to the existing business, the more the protection, *but only to the extent that the executive team's decisions create linkages* *between the new technology effort and the firm's unique, existing deliverables.*

The way in which the executive team organizes project groups and allocates skills to them will dramatically affect linkages to existing, unique deliverables. The principles of boundary-spanning, multidisciplinarity, extensive horizontal communications, parallel rather than sequential processing and information redundancy in designing project teams have received particular emphasis in the literature as being essential to the integration of an innovation and the parent firm (Ancona and Caldwell, 1988; Bingham and Quigley, 1989; Rothwell and Whiston, 1990; Kanter, 1988; Gross, 1989; Perry, 1990; Aoki, 1990; Dougherty, 1990; Lorenz, 1986).

Specialized assets

Specialized assets, as a source of imitative insulation, are related to, but distinct from deliverables. Whereas deliverables have to do with internal routines possessed by the firm that allow it to render inimitable outputs, specialized assets have to do with unique input factors accessible to the firm. Specialized assets offer two quite different advantages from organizational deliverables. First, to the extent that the input asset is scarce or (at best) available only to the firm, (for example, ownership of a favorable location) competitors will not be able to duplicate the firm's offering without the asset. This includes both physical assets and 'invisible' assets, such as a great reputation. Second, to the extent that the input assets that make a given technology work are 'tacit' or unknown, imitative protection is enhanced (see Nelson and Winter, 1982, for a discussion of tacit routines in organizations).

The most important executive management decision that establishes inappropriability on the basis of specialized assets appears to be in selecting and allocating resources to 'core' technologies. By concentrating on core technologies, firms build specialized asset stocks of the very best people, the most extensive know-how, and the finest technology-specific assets (Leonard-Barton, 1991; Barney, 1991).

The amount of focus on core technology can also be seen to be important when subtechnologies need to be developed in parallel. As Itami (1987) recounts, when Matsushita developed its 8mm video camera, it had to simultaneously develop the tape, tape deck, recording heads, playback heads, parts, and assembly process. The firm selected the development of the tape as the driving subtechnology, building from its skill at vacuum metal deposition. Thereafter, the other technologies were forced to keep pace with the development of the tape, a process that encourages the development of specialized assets.

Coevolutionary contracting

The skill of executive teams in predicting the path of technological development can also lead to opportunities for protection from appropriation if they are able to anticipate coevolutionary requirements and preemptively contract with coevolutionary partners. For example Johnson and Johnson were able to move aggressively and garner the lion's share of productive capacity of tamper-proof packaging for their Tylenol product after the Tylenol poisoning tragedy—this was key to the salvation of Tylenol and its preservation of market position.

Cospecialized assets

Even greater difficulty for competitors seeking to appropriate a dominant design occurs when the firm employs cospecialized assets, namely assets that it possesses for other productive purposes, and which competitors therefore simply do not possess, but which can now be deployed to enhance the product offering.

The need for cospecialized assets is illustrated by the case of Toray. Toray elected to make a crippling financial commitment to license nylon spinning, dyeing and finishing technology from Du Pont despite the fact that they had developed a different, but equally efficient, technology for the production of nylon polymer (Itami, 1987). The reason is that Toray had failed to develop these processing technologies and without them, the ability to produce polymer was of little benefit.

Forging product-class prerogative

The next factor that provides the offerings of a firm with inappropriability is the extent to which distributors, regulators, suppliers and customers can be persuaded not to accept alternatives to the firm's dominant design. The earlier in the evolution of a technology the firm enters a particular product class, the more easily one can expect it to be able to garner this kind of influence. Thus, the aggressiveness with which a firm commercializes emerging technologies (the earlier it enters the market) should be positively related to the acquisition of market clout (e.g., Sanderson and Uzumeri, 1990). Rapidity and aggressiveness of commercialization allow a firm to develop market power along several dimensions. First, it contributes to superior understanding of the relationships between technology barriers and the construction of market preferences. By rapidly exposing technology to the marketplace, firms learn about both the nature of the barriers to their technology envelopes and the construction of consumer attribute trade-offs in the design space, which in turn yields the ability to fend off competitive offerings with a less developed understanding.

One approach to early entry can be seen in the case of Sanyo, which is bringing its solar cell technology to market before it has achieved commercially viable high efficiency. Instead of waiting to perfect a commercial-scale solar cell for large applications, the company puts its cells in watches and calculators where efficiency was less important (Itami, 1987). This enables Sanyo to continue to develop the technology with the benefit of information about regulators, suppliers, and customers which would have been impossible to obtain without some degree of experience. At the same time, the company can refine both the product and the process for commercial solar cells (contributing also to inappropriability on the basis of organizational deliverables and cospecialized assets). Competitors entering the market later will find it extremely difficult to duplicate Sanyo's offering.

The newer the technology, the more critical rapid commercialization becomes. In the case of very new technologies, shifts in the marketplace can eliminate the market for a firm's output before it is even introduced. The less aggressive the firm is in commercialization, the more likely it is that something else will come along to take the firm by surprise. For example, by the time Polaroid's instant video cameras were brought to market, the first electronic camcorders were being produced. Customers, it turned out, were far more favorably disposed to instant movies, which were erasable as well as longer and cheaper than Polaroid's high-quality, shorter, one-shot offering. Since Polaroid's product had not yet established a market, the new technology simply preempted it (Block, 1989).

Influencing evolution of formal standards

The fourth factor that makes a firm's offerings difficult to replicate is control over the social and regulatory standards governing the entry of competitors' technologies. The behavior of the executive team in establishing favorable standards is seldom considered jointly with the formulation and execution of strategies. Consider, however, the enormous investment of attention, firm resources and talent that corporations apply to public relations, to politics, to lobbying, to advertising, and to control over channels of favorable opinion.

In a pluralist society, such as the United States, formal regulatory standard-setting (such as the requirements for approval of a new drug) can be seen as a complex negotiation process in which the interests of many parties are accommodated. A key component of this negotiation is well-documented in the political science literature. This is the 'iron triangle' in which regulators, lawmakers (in particular, Congressional committees) and industry specialists develop a finely tuned network of relationships, through which standards are negotiated in a complex, largely tacit series of long-term interactions. The strategic issue is that access to a 'triangle' affords executive teams the ability to influence standards, while exclusion from a triangle makes influencing standards far more difficult.

Actions by executive teams and protection from diffusion

As in the case of selection, if we consider the cases of evolutionary and revolutionary design variations separately, it becomes clear that a different alignment of factors is associated with diffusion for the two strategies.

Protecting evolutionary designs from diffusion

As Table 4 shows, in the case of evolutionary strategies, protection can occur to the extent that the executive team puts in place monitoring

Table 4. Executive team influences on dominant design

Variation	Selection	Retention: Prevention of diffusion
Process driving scope	*Processes driving selection*	*Processes delaying diffusion*
Scope setting	*Evolutionary strategies*	*Evolutionary strategies*
– Search for opportunities	– Building switching costs	– Exploiting organization deliverables
– Screening	– Drawing off and reinforcing existing infrastructure	– Using specialized assets
– Evaluation	– Reinforcing existing standards	– Using cospecialized assets
– Progress reviews	– Using clout with transaction partners	*Revolutionary strategies*
Processes driving intensity	– Building technology links	– Coevolutionary contracting
Climate setting	*Revolutionary strategies*	– Asserting product-class prerogative
– Expectation setting	– Forging market acceptance	– Influencing formal standards
– Personal demonstration of support	– Negotiating coevolution	
– Disproportionate resource allocation	– Demonstrating commitment	
– Staffing and restaffing	– Negotiating standards	
– Managing disappointment and discontinuation	– Negotiated environment	
– Internal pathclearing	– Exploiting clout	
– Moderating internal conflict		
– Granting dispensation from policy		

and reward systems that assure that the new design:

— exploits current or creates new organization deliverables,
— utilizes current or creates new specialized assets,
— makes use of current or creates new cospecialized assets.

In other words, if the initial scope emerging from decisions of the executive team drives the design variation strategy towards evolutionary, then to the extent that the monitoring, control and reward systems are set up to encourage aggressive exploitation and extension of existing unique routines and rent-producing assets, the degree of competitive insulation of any resultant design that emerges will be increased.

Protecting revolutionary designs from diffusion

On the other hand revolutionary strategies can make little use of existing capabilities. Here protection is enhanced to the extent that the monitoring, control and reward structures encourage subordinates to enhance inimitability

— by active coevolutionary contracting,
— by forging and asserting product-class prerogatives,
— by aggressively influencing the creation of new industry standards that favor the emerging revolutionary design.

Further, the above strategies can considerably be enhanced by the degree to which members of the executive team devote personal time and attention to make sure that these externally oriented tactics are followed, particularly to the extent that they bring credibility to the negotiation by personal involvement.

This concludes the discussion of tactics that delay diffusion. We now turn to the conclusion of the paper, in which we propose a possible research agenda which flows from the above discussion.

CONCLUSION

In the introduction to this article we identified two major streams of literature in the strategy field that make a contribution to our understanding of the challenges of strategic decision making.

These are industrial organization and the resource based view. We further suggested that supplementing this research with a stream of literature focused upon the evolution of product classes (as pioneered by the work of Tushman and others) offers richer insight into the playing field upon which firms compete on the basis of technology. This paper has sought to integrate these three streams of literature, and to advance theory along the following lines. First, we have offered a definition of dominant design which allows it to be assessed *ex ante*, at the firm level and with greater precision than is possible at other levels of analysis. Second, we have extended ideas of resource-based theory in order to outline, from an individual firm perspective, how technology strategy can yield firm-specific design dominance. Finally, we have specified mechanisms through which the executive team of a firm can intervene in overall technological evolution in order to achieve dominant design for a firm's offerings. Such interventions are targeted toward allowing the firm to reap profits from the creation of technological assets which have significant value to the market and which are difficult for competitors to appropriate.

Let us now consider elements of a research agenda which might flow from the further development of these ideas.

The framework developed in this article has attempted to create close linkages between design attributes, market demand characteristics and technological capabilities of competing firms. A number of intriguing research questions emerge from this linkage.

To begin, we face the issue of whether and in what way the concept of market knolls can be systematically applied to empirical strategy research, and whether this yields substantially different conclusions than that which would be derived from extant theory. We argue that strategy researchers interested in technology ought to incorporate key market preference and population variables in future work. In thinking about entry strategies, for example, the stage of product evolution, and the durability and richness of market knolls are variables which are seldom explicitly addressed. Consider, for example, the concepts of environmental hostility and benignness or munificence (Covin and Slevin, 1989; Sahlman and Stevenson, 1985). Introducing the concepts of knolls of varying degrees of attractiveness and richness allows a far more detailed picture of the competitive field for a given product to be developed. Further, the concept of knolls can be used to explain the seemingly contradictory findings of many of these studies, in which firms entering hostile or sparse markets can empirically be seen to enjoy performance superior to that of firms entering markets which appear to be far richer. Thus, we might begin to understand how combinations of product attributes and the mastery of the executive team at achieving design dominance in a concentrated, but rich, knoll in an otherwise sparse marketplace can yield excess returns, even in situations in which common sense would suggest such returns should be unusual.

A second application of the idea of knolls can be seen in its ability to allow strategists to begin to distinguish among bundles of attributes on the basis of the extent to which investment in an attribute offers access to new market opportunity spaces or populations. Conversely, strategic mistakes can be better understood. A case with classic dimensions is that of a bank which invested millions in reducing waiting times at branches, only to find that customers in knolls served neither noticed nor cared, and that no new knolls became accessible on the basis of this investment.

To make progress of this kind, of course, it will be necessary to develop analytical methodologies to map the structure of market knolls in product attribute space and then overlay the multiple technology barriers of individual firms competing in that space. This would require considerable extension of work being done in the area of response surface measurement.

While recognizing that profits are intimately linked with the firm's particular set of idiosyncratic assets, a deficiency in the current literature using the resource based view is that it fails to address the issue of how these idiosyncratic assets evolve, and how the success of such evolution is related to the structure of the market spaces occupied by competing firms. Thus the resource based view of the firm largely takes strategic assets like dominant design products as a given, rather than something which can be strategically developed. Future research in the resource based arena could benefit by looking more closely at the dynamics by which inappropriable asset stocks like dominant designs are created, and how firms can select technology investments that increase the yield of dominant designs. This would suggest the following type of question: Which technology strategies yield dominant designs, and under what circumstances? The above discussion highlighted a number of technology strategies which can be pursued by firms electing to compete in a specific market space, namely single niche, niche invasion, niche dominance, or revolutionary. In addition to these outcomes, firms may also select between technology push or market appeal paths. At this point in time, evidence suggests that firms can be successful using one or more of these technology strategies. The question, therefore is to identify the circumstances under which alternative technology strategies are likely to be successful. There is a significant gap in the literature with respect to being able to identify the contingent conditions under which one strategy is superior to others. Here, too, we expect that the answer to this question is a function of the occupation of knolls by various competitors and technological capabilities of these competitors.

When it comes to the literature based on industrial organization, as also with the product class evolution literature, the shortcoming is that the question of consciously managing technological regimes is one which is simply not addressed. The theory developed here suggests that top management can influence the evolution of dominant design, and can do so in such a way that the firm gains a competitive advantage. However, more research is needed to explore this contention.

Further, to what extent do executive teams consciously attempt to intervene in the firm's technology strategy at all? It would be useful to get a better understanding of the circumstances under which the senior management of the company actively involves itself in the shaping of the technology strategy of the firm and its attempts to create a dominant design. In some firms, a strictly hands off approach has been followed. Whereas in others, the top management team plays a more active role. When top managers elect to intervene in the technological playing field, it is important to begin to understand whether, when and where these types of interventions matter.

A second set of questions relates to the strategic setting of scope. We can thus consider: How does scope setting influence design variation? How does scope setting occur? Is this done consciously or unwittingly? If it is consciously done, does it matter? We have suggested above that the actions and decisions of top management sets the scope for the firm's design variations. We need to begin to understand the circumstances under which scope setting is consciously made or unconsciously results from past patterns of top management decision behavior, and whether this fundamentally limits firms in the activities they may successfully undertake.

A third set of questions concerns itself with senior team behavior and managerial leadership. One might then ask, how do executive teams shape the processes of design selection and design diffusion? We have indicated in the discussion above, those places where executive team behaviors can either directly or indirectly shape the probability of selection of a particular design in the market or delay the diffusion of a successful design among competitors. Questions which arise from this discussion concern the circumstances in which the executive teams consciously decides to do such shaping and the conditions under which such conscious decisions make a difference. It would be useful, for example, to understand more clearly the linkages between the executive teams' ways of monitoring, controlling and rewarding behavior and the success of the firm in having its members design offerings which become dominant.

The forces which shape selection are also potentially rich areas for future work. At this point, relatively little is known about the strategic implications of infrastructure and coevolution requirements, evolution of standards, use of industry clout, and building of internal consensus. Similarly, we know relatively little about the linkages between the executive teams' ways of monitoring, controlling and rewarding behavior and the success of the firm in delaying the diffusion of its design offerings and whether and when the success lies in focusing on tactics that 'bake in' inappropriability, such as organization deliverables, specialized assets, coevolutionary contracting, cospecialized assets and product class prerogative.

In conclusion, we have argued that the destiny of the firm is intimately linked to the evolution of product class in the industry and shown that product-class evolution is driven by the variation, selection and retention of dominant designs in the context of lumpy markets. We have suggested that business strategy decisions simply cannot be undertaken without an intimate understanding of the relation between the firm's technology trajectory and the opportunity space created by lumpiness of the market. Finally, we have highlighted the key places where choices made, and processes put in place, by executive teams significantly influence the ability of the firm to generate design variations, enhance their probability of selection and delay the rate at which the successful designs are appropriated by competition. We believe that coupling the technology literature to the strategic, organization and marketing literatures further clarifies the role of executive teams in shaping both organization and product class evolution. We further believe that this integration and focus on eras of ferment as areas of strategic opportunity opens up fruitful areas for future research.

ACKNOWLEDGEMENTS

We would like to thank the Sol C. Snider Entrepreneurial Center for partial support of the project.

REFERENCES

Abler, R. A. (September 1986). 'The value-added of design', *Business Marketing*, pp. 96–103.

Aitken, H. (1985). *The Continuous Wave*. Princeton University Press, Princeton, NJ.

Ancona, D. G. and D. F. Caldwell. (1988). 'Beyond task and maintenance: Defining external functions in groups', *Group and Organization Studies,* **13**(4), pp. 468–493.

Anderson, P. and L. Tushman. (1990). 'Technological discontinuities and dominant designs: A cyclical model of technological change', *Administrative Science Quarterly,* **35**(4), pp. 604–633.

Aoki, M. (1990). 'Toward an economic model of the Japanese firm', *Journal of Economic Literature,* **28**(1), pp. 1–27.

Ayal, I. and J. Raban. (1990). 'Developing hi-tech industrial products for world markets', *IEEE Transactions on Engineering Management,* **37**(3), pp. 177–184.

Barney, J. B. (1991). 'Firm resources and sustained competitive advantage', *Journal of Management,* **17**(1) pp. 99–120.

Basalla, G. (1988). *The Evolution of Technology*. Cambridge University Press, Cambridge.

Bingham, F. G. and C. J. Quigley. (1989). 'Venture team application to new product development', *Journal of Business and Industrial Marketing,* **4**(1), pp. 49–59.

Block, Z. (March/April 1989). 'Damage control for new corporate ventures', *Journal of Business Strategy*, pp. 22–28.

Bower, J. L. (1970). *Managing the Resource Allocation Process: A Study of Corporate Planning and Investment*, Harvard University Press, Boston, MA.

Bowman, E. H. (1974). 'Epistemology, corporate strategy and academe', *Sloan Management Review,* **15**, pp. 35–50.

Burgelman, R. A. (1991). 'Intraorganizational ecology of strategy making and organizational adaptation: Theory and field research', *Organizational Science,* **2**(3), pp. 239–262.

Campbell, D. I. (1969). 'Variation and selective retention in socio-cultural evolution', *General Systems,* **14**, pp. 69–85.

Constant, E. (1987). 'The social locus of technological practice: Community, system or organization'. In W. Bijker, I. Hughes, and T. Punch (eds), *The Social Construction of Technological Systems*, Cambridge University Press, Cambridge, MA, pp. 223–242.

Constant, E. (1989). 'Cause or consequence: Science, technology and regulatory change', *Journal of Business History*, pp. 426–455.

Cooper, R. G. (1979). 'The dimensions of industrial new product success and failure', *Journal of Marketing,* **43**, pp. 93–103.

Covin, J. G. and D. P. Slevin. (1989). 'Strategic management of small firms in hostile and benign environments. *Strategic Management Journal,* **10**(1), pp. 75–87.

Crawford, C. (1991). 'The dual-drive concept of product innovation', *Business Horizons,* **34**(3), pp. 32–38.

Cyert, R. M. and J. G. March (1963). *A Behavioral Theory of the Firm*, Prentice Hall, Englewood Cliffs, NJ.

David, P. (1987). 'Some new standards for the economics of standardization in the information age'. In P. Dasgupta and P. Stoneman (eds), *Economic Policy and Technological Performance*, Cambridge University Press, Cambridge, pp. 603–642.

David, P. A. and J. A. Bunn. (1988). 'The economics of gateway technologies and network evolution: Lessons from electricity supply history', *Information Economics and Policy,* **3**(2), pp. 165–202.

Dosi, G. (1988). 'Sources, procedures and microeconomic effects of innovation', *Journal of Economic Literature,* **26**(3), pp. 1120–1171.

Dougherty, D. (November 1990). 'Interpretive barriers to successful product innovation in large firms', Working paper, The Sol C. Snider Entrepreneurial Center, The Wharton School, University of Pennsylvania.

Frost, P. J. and C. P. Egri. (1990). 'Influence of political action on innovation: Part 1', *Leadership and Organization Development Journal,* **11**(1), pp. 17–25.

Glassmeier, A. (1991). 'Technological discontinuities and flexible production networks: The case of Switzerland and the world watch industry', *Research Policy,* **20**, pp. 469–485.

Gross, N. (June 1989). 'A wave of ideas, drop by drop', *Business Week*, No. 3110, pp. 22–30.

Hambrick, D. C. and P. A. Mason. (1984). 'Upper echelons: The organization as a reflection of its top managers', *Academy of Management Review,* **9**, pp. 193–206.

Hambrick, D. C., A. Cannella, and A. Albert, Jr. (November 1989). 'Strategy implementation as substance and selling', *Academy of Management Executive,* **3**(4), pp. 278–285.

Hughes, I. (1983). *Networks of Power*, The Johns Hopkins University Press, Baltimore, MD.

Itami, H. (1987). *Mobilizing Invisible Assets*, Harvard University Press, Cambridge, MA.

Jenkins, R. (1975). *Images and Enterprise*, The Johns Hopkins University Press, Baltimore, MD.

Kanter, R. M. (1988). 'When a thousand flowers bloom: Structural, collective and social conditions for innovation in organization', *Research in Organizational Behavior,* **10**, JAI Press, Greenwich, CT, pp. 159–211.

Leonard-Barton, D. (May 3–4, 1991). 'Corporate culture and the dual nature of core capabilities in new product development'. Paper prepared for the Conference on the Evolution of Firm Capabilities, Reginald H. Jones Center for Corporate Strategy, Management, and Organization, Wharton School, University of Pennsylvania.

Levitt, B. and J. G. March. (1988). 'Organizational learning', *Annual Review of Sociology,* **14**, pp. 319–440.

Lorenz, C. (1986). *The Design Dimension*, Basil Blackwell, New York.

Maidique, M. A. and B. J. Zirger. (1985). 'The new product learning cycle', *Research Policy,* **14**, pp. 299–313.

Nelson, R. R. and S. J. Winter. (1982). *An Evolutionary Theory of Economic Change*, Belknap/Harvard Univ. Press, Cambridge, MA.

Noble, D. F. (1984). *Forces of Production*, Alfred A. Knopf, New York.

Penrose, E. T. (1959). *The Theory of the Growth of the Firm*. M. E. Sharpe, White Plains, NY.

Perry, T. S. (1990). 'Teamwork plus technology cuts development time', *IEEE Spectrum*. **27**(10), pp. 61–67.

Porter, M. (1980). *Competitive Strategy*, Free Press, New York.

Porter, M. (1985). *Competitive Advantage*, Free Press, New York.

Rosenbloom, R. S. and M. A. Cusumano. (Summer 1987). 'Technological pioneering and competitive advantage: The birth of the VCR industry', *California Management Review,* **29**(4), pp. 51–76.

Rosenkopf, L. and M. Tushman (in press). 'On the co-evolution of technology and organization'. In J. Baum and J. Singh (eds.), *Evolutionary Dynamics of Organization*. Oxford University Press, Oxford.

Rothwell, R. and T. G. Whiston. (1990). 'Design, innovation and corporate integration', *R&D Management,* **20**(3), pp. 193–201.

Sahlman, W. and H. Stevenson. (1985). 'Capital market myopia', *Journal of Business Venturing,* **1**(1), pp. 7–30.

Sanderson, S. W. and V. Uzumeri. (1990). 'Buying advanced manufacturing technology', *Manufacturing Engineering,* **105**(2), pp. 11–15.

Shintaku, J. (January 1990). 'Technological innovation and product evolution: Theoretical model and its applications', *Gakushuin Economic Papers,* **26**(3), pp. 53–67.

Souder, W. E. (May/June 1987). 'Stimulating and managing ideas', *Research Management,* **30**(3), pp. 13–17.

Stalk, G. Jr. and T. M. Hout. (March/April 1990). 'Competing against time', *Research-Technology Management,* **33**(2), pp. 19–24.

Teece, D. J. (December 1986). 'Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy', *Research Policy,* **15**(6), pp. 285–305.

Teece, D. J., G. Pisano and A. Shuen. (Revised November 1991). 'Dynamic capabilities and strategic management', Working Paper, University of California at Berkeley.

Tushman, M. and L. Rosenkopf. (1992). 'Organizational determinants of technological change: Toward a sociology of technological evolution', *Research in Organizational Behavior*, JAI Press, Greenwich, CT, pp. 311–347.

Van de Ven, A. H. and R. Garud (in press). 'The co-evolution of technical and institutional events in the development of an innovation'. In J. Baum and J. Singh (eds.), *Evolutionary Dynamics of Organization*. Oxford University Press, Oxford.

von Hippel, E. (1988). *The Sources of Innovation*. Oxford University Press, New York, 1988.

Wernerfelt, B. (1984). 'A resource-based view of the firm', *Strategic Management Journal,* **5**, pp. 171–180.