How does a company's innovation—and its response to innovative ideas—change as the company grows and matures? Are there circumstances in which a pattern generally associated with successful innovation is in fact

A SPECTRUM OF INNOVATORS

Past studies of innovation imply that any innovating unit sees most of its innovations as new products. But that observation masks an essential difference: what constitutes a product innovation by a small, technology-based unit is often the process equipment adopted by a large unit to improve its high-volume production of a standard product. We argue that these two units—the small, entrepreneurial organization and the larger unit producing standard products in high volume—are at opposite ends of a spectrum, in a sense forming boundary conditions in the evolution of a unit and in the character of its innovation of product and process technologies.

Such incremental innovation typically results in an increasingly specialized system in which economies of scale in production and the development of mass markets are extremely important. The productive unit loses its flexibility, becoming increasingly dependent on high-volume production to cover its fixed costs and increasingly vulnerable to changed demand and technica obsolescence.

Major new products do not seem to be consistent wit this pattern of incremental change. New products whic require reorientation of corporate goals or production fa cilities tend to originate outside organizations devoted t a "specific" production system; or, if originated withir to be rejected by them.

One distinctive pattern of technological innovation is evident in the case of established, high-volume products such as incandescent light bulbs, paper, steel, standard chemicals, and internal-combustion engines, for examples.

The markets for such goods are well defined; the product characteristics are well understood and often standardized; unit profit margins are typically low; production technology is efficient, equipment intensive and specialized to a particular product; and competition is primarily on the basis of price. Change is costly in such highly integrated systems because an alteration in any one attribute or process has ramifications for many others.

In this environment innovation is typically incremental in nature, and it has a gradual, cumulative effect on productivity. For example, Samuel Hollander has shown that more than half of the reduction in the cost of producing rayon in plants of E. I. du Pont de Nemours and Company has been the result of gradual process improvements which could not be identified as formal projects or changes. A similar study by John Enos shows that accumulating incremental developments in petroleum refining processes resulted in productivity gains which often eclipsed the gain from the original innovation. Incremental innovations, such as the use of larger railroad cars and unit trains, have resulted in dramatic reductions in the cost of moving large quantities of materials by rail.

In all these examples, major systems innovations have been followed by countless minor product and systems improvements, and the latter account for more than half of the total ultimate economic gain due to their much greater number. While cost reduction seems to have been the major incentive for most of these innovations, major advances in performance have also resulted from such small engineering and production adjustments.

to be rejected by them.

A more fluid pattern of product change is associated with the identification of an emerging need or a new way to meet an existing need; it is an entrepreneurial act. Many studies suggest that such new product innovations share common traits. They occur in disproportionate numbers in companies and units located in or near affluent markets with strong science-based universities or other research institutions and entrepreneurially oriented financial institutions. Their competitive advantage over predecessor products is based on superior functional performance rather than lower initial cost, and so these radical innovations tend to offer higher unit profit margins.

When a major product innovation first appears, performance criteria are typically vague and little understood. Because they have a more intimate understanding of performance requirements, users may play a major role in suggesting the ultimate form of the innovation as well as the need. For example, Kenneth Knight shows that three-quarters of the computer models which emerged between 1944 and 1950, usually those produced as one or two of a kind, were developed by users.

It is reasonable that the diversity and uncertainty of performance requirements for new products give an advantage in their innovation to small, adaptable organizations with flexible technical approaches and good external communications, and historical evidence supports that hypothesis. For example, John Tilton argues that new enterprises led in the application of semiconductor technology, often transferring into practice technology from more established firms and laboratories. He argues that economies of scale have not been of prime importance because products have changed so rapidly that production technology designed for a particular product is rapidly made obsolete. And R. O. Schlaifer and S. D. Heron have argued that a diverse and responsive group of enterprises struggling against established units to enter the industry contributed greatly to the early advances in jet aircraft engines.

A TRANSITION FROM RADICAL TO EVOLUTIONARY INNOVATION

These two patterns of innovation may be taken to represent extreme types—in one case involving incremental change to a rigid, efficient production system specifically designed to produce a standardized product, and in the other case involving radical innovation with product characteristics in flux. In fact, they are not rigid, independent categories. Several examples will make it clear that organizations currently considered in the "specific" category—where incremental innovation is now motivated by cost reduction—were at their origin small, "fluid" units intent on new product innovation.

John Tilton's study of developments in the semiconductor industry from 1950 through 1968 indicates that the rate of major innovation has decreased and that the type of innovation shifted. Eight of the 13 product innovations he considers to have been most important during that period occurred within the first 7 years, while the industry was making less than 5 percent of its total 18-year sales. Two types of enterprise can be identified in this early period of the new industry—established units that came into semiconductors from vested positions in vacuum tube markets and new entries such as Fairchild Semiconductor, IBM, and Texas Instruments, Inc. The established units responded to competition from the newcomers by emphasizing process innovations. Mean- ... strength through prod- which had been a flexible, new entrant in the industry two decades earlier and had contributed no major process innovations prior to 1968, was planning a single machine that would produce 4 percent of world requirements for its integrated-circuit unit.

Like the transistor in the electronics industry, the DC-3 stands out as a major change in the aircraft and airlines industries. Almarin Phillips has shown that the DC-3 was in fact a cumulation of prior innovations. It was not the largest, or fastest, or longest-range aircraft; it was the most economical large, fast plane able to fly long distances. All the features which made this design so completely successful had been introduced and proven in prior aircraft. And the DC-3 was essentially the first commercial product of an entering firm (the C-1 and DC-2 were produced by Douglas only in small numbers).

Just as the transistor put the electronics industry on a new plateau, so the DC-3 changed the character of innovation in the aircraft industry for the next 15 years. No major innovations were introduced into commercial aircraft design from 1936 until new jet-powered aircraft appeared in the 1950s. Instead, there were simply many refinements to the DC-3 concept—stretching the design and adding appointments; and during the period of these incremental changes, airline operating cost per passenger-mile dropped an additional 50 percent.

The electric light bulb also has a history of a long series of evolutionary improvements which started with a few major innovations and ended in a highly standardized commoditylike product. By 1909, the initial tungsten filament and vacuum bulb innovations were in place; from then until 1955 there came a series of incremental changes—better metal alloys for the filament, the use ... exhausting the bulb, coiling the that period occurred within the first 7 years, while the industry was making less than 5 percent of its total 18-year sales. Two types of enterprise can be identified in this early period of the new industry—established units that came into semiconductors from vested positions in vacuum tube markets and new entries such as Fairchild Semiconductor, IBM, and Texas Instruments, Inc. The established units responded to competition from the newcomers by emphasizing process innovations. Meanwhile, the latter sought entry and strength through product innovation. The three very successful new entrants just listed were responsible for half of the major product innovations and only one of the nine process innovations which Dr. Tilton identified in that 18-year period, while three principal established units (divisions of General Electric, Philco, and RCA) made only one-quarter of the product innovations but three of the nine major process innovations in the same period. In this case, process innovation did not prove to be an effective competitive stance; by 1966, the three established units together held only 18 percent of the market while the three new units held 42 percent. Since 1968, however, the basis of competition in the industry has changed; as costs and productivity have become more important, the rate of major product innovation has decreased, and effective process innovation has become an important factor in competitive success. For example, by 1973 Texas Instruments,

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Product and process evolved in a similar fashi the automobile industry. During a four-year perio fore Henry Ford produced the renowned Model company developed, produced, and sold five di engines, ranging from two to six cylinders. Thes made in a factory that was flexibly organized mu job shop, relying on trade craftsmen working with general-purpose machine tools not nearly so advanced as the best then available. Each engine tested a new concept. Out of this experience came a dominant design—the Model T; and within 15 years, 2 million engines of this single basic design were being produced each year (about 15 million all told) in a facility then recognized as the most efficient and highly integrated in the world. During that 15-year period, there were incremental—but no fundamental—innovations in the Ford product.

In yet another case, Robert Buzzell and Robert Nourse, tracing innovations in processed foods, show that new products such as soluble coffees, frozen vegetables, dry pet foods, cold breakfast cereals, canned foods, and precooked rice came first from individuals and small organizations where research was in progress or which relied heavily upon information from users. As each product won acceptance, its productive unit increased in size and concentrated its innovation on improving manufacturing, marketing, and distribution methods which extended rather than replaced the basic technologies. The major source of the latter ideas is now each firm's own research and development organization.

The shift from radical to evolutionary product innovation is a common thread in these examples. It is related to the development of a dominant product design, and it is accompanied by heightened price competition and increased emphasis on process innovation. Small-scale units that are flexible and highly reliant on manual labor and craft skills utilizing general-purpose equipment develop into units that rely on automated, equipment-intensive, high-volume processes. We conclude that changes in innovative pattern, production process, and scale and kind of production capacity all occur together in a consistent, predictable way.

MANAGING TECHNOLOGICAL INNOVATION

If it is true that the nature and goals of an industrial unit's innovations change as that unit matures from pioneering to large-scale producer, what does this imply for the management of technology?

We believe that some significant managerial concepts emerge from our analysis—or model, if you will—of the characteristics of innovation as production processes and primary competitive issues differ. As a unit moves toward large-scale production, the goals of its innovations change from ill-defined and uncertain targets to well-articulated design objectives. In the early stages, there is a proliferation of product performance requirements and design criteria which frequently cannot be stated quantitatively, and their relative importance or ranking may be quite unstable. It is precisely under such conditions, where performance requirements are ambiguous, that users are most likely to produce an innovation and where manufacturers are least likely to do so. One way of viewing regulatory constraints such as those governing auto emissions or safety is that they add new performance dimensions to be resolved by the engineer—and so may lead to more innovative design improvements. They are also likely to open market opportunities for innovative change of the kind characteristic of fluid enterprises in areas such as instrumentation, components, process equipment, and so on.

The stimulus for innovation changes as a unit matures. In the initial fluid stage, market needs are ill-defined and can be stated only with broad uncertainty, and the relevant technologies are as yet little explored. So there are two sources of ambiguity about the relevance of any particular program of research and development—target uncertainty and technical uncertainty. Confronted units that are flexible and highly reliant on manual labor and craft skills utilizing general-purpose equipment develop into units that rely on automated, equipment-intensive, high-volume processes. We conclude that changes in innovative pattern, production process, and scale and kind of production capacity all occur together in a consistent, predictable way.

Though many observers emphasize new product innovation, process and incremental innovations may have equal or even greater commercial importance. A high rate of productivity improvement is associated with process improvement in every case we have studied. The cost of incandescent light bulbs, for example, has fallen more than 80 percent since their introduction. Airline operating costs were cut by half through the development and improvement of the DC-3. Semiconductor prices have been falling by 20 to 30 percent with each doubling of cumulative production. The introduction of the Model T Ford resulted in a price reduction from $3,000 to less than $1,000 (in 1958 dollars). Similar dramatic reductions have been achieved in the costs of computer core memory and television picture tubes.

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As the enterprise develops, however, uncertainty about markets and appropriate targets is reduced, and larger research and development investments are justified. At some point before the increasing specialization of the unit makes the cost of implementing technological innovations prohibitively high and before increasing cost competition erodes profit with which to fund large indirect expenses, the benefits of research and development efforts would reach a maximum. Technological opportunities for improvements and additions to existing product lines will then be clear, and a strong commitment to research and development will be characteristic of productive units in the middle stages of development. Such firms will be seen as "science based" because they invest heavily in formal research and engineering departments, with emphasis on process innovation and product differentiation through functional improvements.

Although data on research and development expenditures are not readily available on the basis of productive units, divisions, or lines of business, an informal review of the activities of corporations with large investments in research and development shows that they tend to support business lines that fall neither near the fluid nor the specific conditions but are in the technologically active middle range. Such productive units tend to be large, to be integrated, and to have a large share of their markets.

A small, fluid entrepreneurial unit requires general-purpose process equipment which, typically, is purchased. As it develops, such a unit is expected to originate some process-equipment innovations for its own use; and when it is fully matured, its entire processes are likely to be designed as integrated systems specific to particular products. Since the mature firm is now fully specialized, all its major process innovations are likely to originate outside the unit.

But note that the supplier companies will now see themselves as making product—not process—innovations. From a different perspective, George Stigler finds stages of development—similar to those we describe—in firms that supply production-process equipment. They differ in the market structure they face, in the specialization of their production processes, and in the responsibilities they must accept in innovating to satisfy their needs for process technology and materials.

information processing. The level at which technological change takes place helps to determine the extent to which organizational dislocations take place. Each of these hypotheses helps to explain the firm's impetus to divide into homogeneous productive units as its products and process technology evolve.

The hypothesized changes in control and coordination imply that the structure of the organization will also change as it matures, becoming more formal and having a greater number of levels of authority. The evidence is strong that such structural change is a characteristic of many enterprises and of units within them.

FOSTERING INNOVATION BY UNDERSTANDING TRANSITION

Assuming the validity of this model for the development of the innovative capacities of a productive unit, how can it be applied to further our capacity for new products and to improve our productivity?

We predict that units in different stages of evolution will respond to differing stimuli and undertake different types of innovation. This idea can readily be extended to the question of barriers to innovation and probably to patterns of success and failure in innovation for units in different situations. The unmet conditions for transition can be viewed as specific barriers which must be overcome if transition is to take place.

We would expect new, fluid units to view as barriers any factors that impede product standardization or market aggregation, while firms in the opposite category tend to rank uncertainty over government regulation likely to be designed as integrated systems specific to particular products. Since the mature firm is now fully specialized, all its major process innovations are likely to originate outside the unit.

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The organization's methods of coordination and control change with the increasing standardization of its products and production processes. As task uncertainty confronts a productive unit early in its development, the unit must emphasize its capacity to process information by investing in vertical and lateral information systems and in liaison and project groups. Later, these may be extended to the creation of formal planning groups, organizational manifestations of movement from a product-oriented to a transitional state; controls for regulating process functions and management controls such as job procedures, job descriptions, and systems analyses are also extended to become a more pervasive feature of the production network.

As a productive unit achieves standardized products and confronts only incremental change, one would expect it to deal with complexity by reducing the need for

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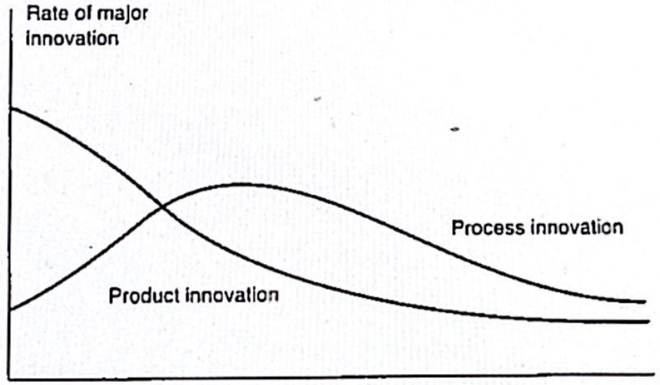
We believe the most useful insights provided b model apply to production processes in which featu the products can be varied. The most interesting ap tions are to situations where product innovation is petitively important and difficult to manage; the helps to identify the full range of other issues with the firm is simultaneously confronted in a per growth and change. (See Exhibit 1.)

CONSISTENCY OF MANAGEMENT ACTION

Many examples of unsuccessful innovations pc common explanation of failure: certain conditic essary to support a sought-after technical advar

EXHIBIT 1 The Changing Character of Innovation and Its Changing Role in Corporate Advance

Seeking to understand the variables that determine successful strategies for innovation, the authors focus on three stages in the evolution of a successful enterprise: its period of flexibility, in which the enterprise seeks to capitalize on its advantages where they offer greatest advantages; its intermediate years, in which major products are used more widely; and its full maturity, when prosperity is assured by leadership in several principal products and technologies.



	Fluid pattern	Transitional pattern	Specific pattern
Competitive emphasis on	Functional product performance	Product variation	Cost reduction
Innovation stimulated by	Information on users, needs and users, technical inputs	Opportunities created by expanding internal technical capability	Pressure to reduce cost and improve quality
Predominant type of innovation	Frequent major changes in products	Major process changes required by rising volume	Incremental for product and process, with cumulative improvement in productivity and quality
Product line	Diverse, often including custom designs	Includes at least one product design stable enough to have significant production volume	Mostly undifferentiated standard products
Production processes	Flexible and inefficient; major changes easily accommodated	Becoming more rigid, with changes occurring in major steps	Efficient, capital-intensive, and rigid; cost of change high
Equipment	General-purpose, requiring highly skilled labor	Some subprocesses automated, creating "islands of automation"	Special-purpose, mostly automatic with labor tasks mainly monitoring and control
Materials	Inputs limited to generally available materials	Specialized materials perhaps demanded from some suppliers	Specialized materials demanded; if not available, vertical integration extensive

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Materials	Inputs limited to generally available materials	Specialized materials perhaps demanded from some suppliers	Specialized materials demanded; if not available, vertical integration extensive
Plant	Small-scale, located near user or source of technology	General-purpose with specialized sections	Large-scale, highly specific to particular products
Organizational control is	Informal and entrepreneurial	Through liaison relationships, project and task groups	Through emphasis on structure, goals, and rules

not present. In such cases, our model may be helpful because it describes conditions that normally support advances at each stage of development; accordingly, if we can compare existing conditions with those prescribed by the model, we may discover how to increase innovative success. For example, we may ask of the model such questions as these about different, apparently independent, managerial actions:

- Can a firm increase the variety and diversity of its product line while simultaneously realizing the highest possible level of efficiency?
- Is a high rate of product innovation consistent with an effort to substantially reduce costs through extensive backward integration?
- Is government policy to maintain diversified markets for technologically active industries consistent with