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A GENERAL MODEL: INNOVATION AND PROCESS CHANGE IN A PRODUCTIVE UNIT

Intriguing regularities in the course of technological progress appear throughout the history of the automobile industry. A definite pattern is evident in the sequence of events that accompanied developments like the closed steel body or the automatic transmission, from their initial introduction through design improvements and the beginning of mass production to standardization and, finally, their wide adoption throughout the industry. From the common elements of product and process development in this pattern we can construct a general model of technological change that may be applicable to the automobile industry and perhaps to other similar industries as well.[1] Such a general model helps to explain the underlying forces that stimulate and shape technological progress.

DIFFERENT INNOVATION PATTERNS

The unit of analysis for this model is particularly important, for it captures both product and process characteristics in one entity—the productive unit. The productive unit consists of both a manufacturing unit and the product line produced. The types and sources of material inputs, the scale of operation, production-process equipment, necessary work-force skills, methods of organization and supervision, all help to characterize important production-process traits. The degree of product standardization or the rates of change, product-line diversity, and product design complexity provide useful product-line descriptors. A productive unit would typically be an operating unit of a firm that is located in one geographic area under the management of one senior executive. An engine plant and the

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line of engines it produces is one productive unit. An assembly plant and the particular car it produces is another.

Current knowledge about technological change is fragmented because there are few, if any, paradigms whereby insights about one product or industry can be applied in another. For example, much may be known about the management of technological change in rocket engines, but the application of this knowledge in another setting, such as the scientific instruments industry, is conjectural. This chapter presents a model of innovation and change that may be broadly applied and that interprets disassociated findings as parts of a common pattern.

One Pattern of Innovation

One pattern of technological innovation can be seen in the important changes that occur in established high-volume product lines, such as incandescent light bulbs, rolled steel, refined gasoline, and auto engines. Such products constitute the mainstream of current economic activity in industrialized nations. The kind of innovation that takes place in these industries is of particular interest because its impact is large and immediate.

The markets for such goods are well defined, the product characteristics are specific and often standardized, and competition is primarily on the basis of *price*. Per-unit profit margins are typically low. The production technology is efficient, equipment-intensive, and specialized to a particular product. In many respects, the product is defined by the process rather than the process by the product. The nature of technological change is greatly influenced by the characteristics of the process technology, as the development of Ford's small car, the 92A, illustrated. Change is costly because in such an integrated system product and process innovations become linked so that an alteration in any single feature has ramifications in many others.

In this environment, innovation is typically inncremental in nature and has a cumulative effect on cost and productivity. For example, Samuel Hollander has shown that more than half of Du Pont's reduction in the cost of producing rayon was the result of process improvements that could not be identified as formal changes.[2] John L. Enos's data show that less-striking developments in petroleum-cracking processes resulted in productivity gains that were often more significant in toto than the gain from the original process choice.[3] Kenneth E. Knight shows that new computer systems or major systems changes have contributed greater individual gains than minor product or systems improvements, but these minor changes accounted for more than half of the ultimate gain because they were so numerous.[4] Incremental innovations, such as the use of larger railroad cars and unit trains, have resulted in drastically reduced costs in moving large quantities of materials by rail, as reported by William Hogan.[5] While cost reduction seems to be the major focus of innovation in this pattern, both

Knight's study of computers and Rodrick W. Clarke's study of rocket engines[6] note that major advances in performance result from the sum of numerous small engineering and production innovations.

Typically, this pattern results in a situation where economies of scale in production and the development of mass markets become extremely important. Such productive units are usually divisions of large firms and are located to reduce factor costs of materials, labor, or transportation.[7] The firm is vulnerable to changed demand, technical obsolescence, and the need to maintain production volume to cover fixed costs.

A Second Pattern of Innovation

While minor product variations can be accommodated within the first pattern as described above, major changes in the firm constitute a distinct second pattern. Richard Normann contends that product variations may easily originate within the large, highly structured firm, but that new products that require reorientation tend to originate outside this type of firm.[8] If they originate within, they tend to be rejected. Radical product change involves identification of an emerging need or a new way to meet an existing need.[9] Here innovation is an entrepreneurial act, involving the introduction of a new product and often the formation of a new firm established to exploit the innovation. This case is like the automobile industry in its early years.

A variety of studies suggest that many new products in different industries share common traits. Innovations occur in disproportionate numbers in geographic regions characterized by proximity to affluent markets, strong science-based universities (or other research and development institutions), and entrepreneurially oriented financial institutions.[10] Innovative products typically compete with predecessor products on the basis of their own superior functional *performance* rather than lower initial cost, that is, they are performance-maximizing rather than cost-minimizing innovations, and they command correspondingly higher profit margins.[11]

When a major product innovation first appears, performance criteria are typically vague and poorly understood. Users may play a major role in suggesting the ultimate form of the innovation as well as the need for it, perhaps because they have a more intimate understanding of performance requirements. For example, Knight states that 76 percent of the computer models that emerged in the period 1944–50 were developed by users and were usually produced as one or two of a kind.[12] The corresponding figures for 1951–53 are 44 percent, followed by 20 percent in 1954–56, 16 percent in 1957–59, and dropping to 5 percent for 1960–62. A more recent study by Eric von Hippel of four scientific instruments shows that the prototype for the basic instrument was developed first by a user in each case.[13] As development continued, manufacturers took a greater part in initiating variations, including eight of forty-three major improvements and fourteen of forty-six minor improvements.

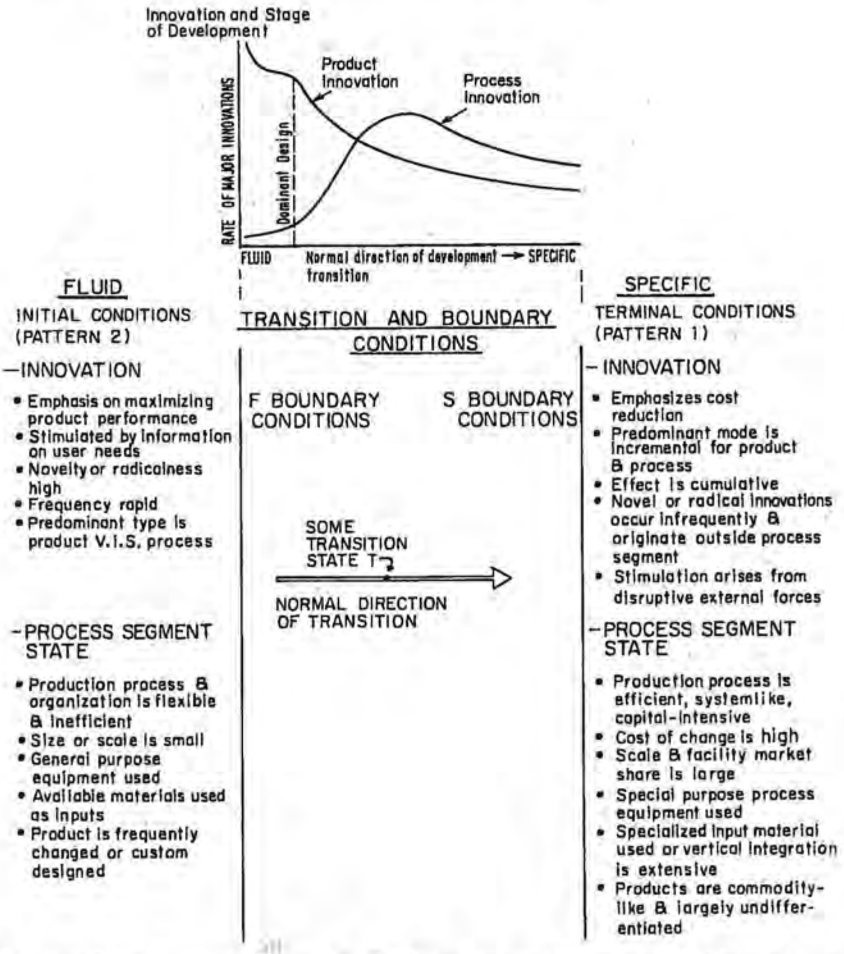
In this second pattern of innovation, the diversity and uncertainty of performance dimensions for major new products might be expected to require a more flexible organization and technical approach and a greater degree of external communication than in the first pattern. Robert A. Schlaifer and S. D. Heron have argued that a diverse and responsive group of firms struggling against established companies to enter the industry contributed greatly to the early advances in jet aircraft engines.[14] The first jet engine represented a relatively small performance advance over the piston engine, but once initial operating experience was gained, a series of advances led to rapid improvement. New enterprises also led the advances in application of semiconductor technology, according to John E. Tilton, often transferring into practice information from other firms and laboratories.[15] Tilton argues that economies of scale have not been of prime importance because the rate of product change makes production technology designed for a particular product rapidly obsolete.

Connecting the Two Patterns

In the first case, the product is standardized, change is incremental, production systems are rigid (*specific*) but efficient, information about needed product features is relatively visible, and the economic impact of any improvement is large and immediate. In the second case, product design is subject to radical change, product characteristics are in flux, the emphasis of product innovation is on improved functional performance rather than cost reduction, production systems are flexible (*fluid*) but inefficient, and even major innovation has little immediate economic impact. These patterns are not independent of one another, however. It is apparent in the automobile industry and several other industries that products currently represented by the *specific* pattern were much more like the *fluid* one at the time of their origin. This is represented in the lower part of Figure 4.1, where characteristics of the *fluid* (*F*) state are given in the left column, those of the *specific* (*S*) state to the right, and the path of *transition* (*T*) by the arrow.

As will be evident in the examples of transition considered below, several different productive units appear to have followed the same path of change. The predominant mode of innovation shifts from radical product innovation to incremental innovation, and process innovation increases in relative importance to product innovation. This is represented at the top of Figure 4.1. Sources of innovation, types of stimuli for innovation, production-process characteristics, productivity rates, product-performance characteristics, and organizational content all change as the productive unit

FIGURE 4.1. Transition, Boundary Conditions, and Innovation



FLUID

INITIAL CONDITIONS (PATTERN 2)

—INNOVATION

- Emphasis on maximizing product performance
- Stimulated by information on user needs
- Novelty or radicalness high
- Frequency rapid
- Predominant type is product V.I.S. process

-PROCESS SEGMENT STATE

- Production process & organization is flexible & inefficient
- Size or scale is small
- General purpose equipment used
- Available materials used as inputs
- Product is frequently changed or custom designed

SPECIFIC

TERMINAL CONDITIONS (PATTERN 1)

- INNOVATION

- Emphasizes cost reduction
- Predominant mode is incremental for product & process
- Effect is cumulative
- Novel or radical innovations occur infrequently & originate outside process segment
- Stimulation arises from disruptive external forces

-PROCESS SEGMENT STATE

- Production process is efficient, systemlike, capital-intensive
- Cost of change is high
- Scale & facility market share is large
- Special purpose process equipment used
- Specialized input material used or vertical integration is extensive
- Products are commodity-like & largely undifferentiated

in *transition* evolves from the *fluid* to the *specific* state. Neither extreme pattern by itself represents an attractive stable state for a firm.

LESSONS AND EXAMPLES OF TRANSITION

Tilton's study of technological and economic developments in the semiconductor industry from 1950 through 1968 indicates both that the rate of major innovation has decreased and that the type of innovation has shifted with the development of the industry. Eight of the thirteen product innovations he classed as most important occurred within the first seven years, before 5 percent of the industry's total sales for the period had occurred.[16] Established firms, those that entered the industry early from a prior vested position in vacuum tube markets, met subsequent competition from new entrants like Fairchild, IBM, and Texas Instruments by emphasizing production considerations and process innovations. The newcomers sought entry through product innovation. As a consequence, these three very successful new firms were responsible for 46 percent of the major product innovations and only 11 percent of the process innovations that Tilton considered up to 1968. Conversely, three comparably established firms, General Electric, Philco, and RCA, made only 25 percent of the product innovations but 33 percent of process innovations in the same time period.[17] Such an emphasis on process innovation did not prove to be an effective competitive stance so early in the development of the industry, for by 1966 the three "established" receiving-tube firms held only 18 percent of the market collectively, while the three new firms held 42 percent. This changing mode of competition has had a pronounced effect on the development of the industry. As costs and productivity have become more important, the rate of major product innovation has decreased, and process innovation has increased in competitive importance. This pattern is similar to that of the automobile industry.

In the aircraft industry the development of the DC-3 stands out as a major turning point both in the type of product innovation that took place and in the market structure of the aircraft and airlines industries. Almarin Phillips's study of aircraft technology and economics points out that the DC-3 was a cumulation of prior innovations.[18] It was not the largest or the fastest or the least expensive airplane to operate, but it was the most economical large, fast plane. The features that made this design so competitively successful were introduced and proved in prior aircraft, such as the Ford Trimotor, the Boeing 241, the Douglas DC-1, the DC-2, and the Lockheed L-10.

Reacting to requests from the airlines about needed operating improvements, Douglas designed the DC-3 and flew it first in 1936.[19] Around eleven thousand were subsequently produced, and of these some thousand were still in use in 1966. Phillips observes that the DC-3 was so successful that, aside from the turbine-powered transports in Britain, no major innovations were introduced into commercial aircraft design until the new jetliners appeared in the 1950s. Instead, many refinements were made, such as stretching the design, adding appointments, and so forth, with the result that the airline operating costs per passenger dropped 50 percent.[20] However, production methods in airframe manufacturing were not correspondingly advanced as in the capital-intensive industrial sectors, even though the product was standardized. Without this constraint, product designs returned to a more fluid state after World War II and have remained fluid ever since.

The electric light bulb in its present form also came about through a long series of evolutionary improvements, starting with a few major innovations and ending in a highly standardized, commoditylike product. From 1909 to 1955, after the initial tungsten-filament and vacuum-bulb innovations, a series of incremental changes were made, including better metal alloys for the filament, the use of "getters" to assist in exhausting the bulb, and the coiling of filaments. In association with these changes, the price of a 60-watt bulb decreased (with no inflation adjustment) from $1.60 to $.20 per unit, the lumens output increased by 175 percent, and the amount of direct labor content was reduced more than a factor of 10, from 3 to 0.18 minutes per bulb. Over the same period, the production process evolved from a flexible job-shop configuration,* involving more than eleven separate operations and a heavy reliance on the skills of manual labor, to a process that was virtually embodied in a single machine.[21]

One common thread in these examples is the shift from a pattern of radical product innovation to one of evolutionary product innovation. This shift is related to the development of a dominant product design and is accompanied by heightened price competition and an increase in process innovation. Tilton's work on semiconductors, as discussed earlier, suggests that this shift may have come about because of competitive action and reaction in the industry. Newly entering firms emphasized product innovations as a basis for gaining initial market positions, and existing firms reacted to retain their market positions through cost-reducing process innovations. Process considerations cannot long be ignored by new firms, however, in an industry where prices have been reduced continually for more than a decade. For example, by 1973, Texas Instruments, originally a major new firm in the semiconductor industry, had shifted much attention to process innovation and planned to develop a single machine that would produce 4 percent of world market requirements for integrated circuits.[22] It had contributed to none of the major process innovations in Tilton's sample prior to 1968.

In yet another case, Robert D. Buzzell and Robert E. Nourse trace innovations in processed foods.[23] Their data show that new food technologies such as soluble coffees, frozen vegetables, dry pet foods, cold breakfast cereals, canned foods, and precooked rice came very early and from individuals and small organizations that were experimental practitioners or otherwise relied heavily upon information from users. As the industry has developed, the firms have increased in size, and marketing, production, and distribution methods have been greatly improved, but on

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* The term "job shop" refers to a particular type of production process. General-purpose equipment is used, and it is usually organized so that common types of equipment that require similar worker skills are grouped together. A wide variety of different products can be produced by routing the work pieces back and forth among different equipment groups. Such a system is flexible, but has high inventory levels and slack resources.

the basis of new products that extended rather than replaced the earlier basic technologies. The predominant source of ideas for this type of new product innovation is no longer the experimental practitioner. As Buzzell and Nourse show, some 60 percent of the ideas for new products now come from the larger firms' own research and development organizations and almost none from users. The transformation has been very significant, affecting type of innovation, source of information, size, method of operation, and the use of formal research and development. Not all firms in this industry are large, however. There is evidence that new firms still find modes of entry for innovative products through market niches generated by consumer enthusiasm for health foods or for natural or convenience food products. Frozen orange juice concentrate provides one such example,[24] and packaged yoghurt another.[25]

ASPECTS OF REGULARITY IN TRANSITION

Each aspect of change is significant and important in its own right. When viewed collectively, however, the individual aspects become part of a larger and regular pattern of transition. These regularities encompass the role of a dominant product design, the characteristics of the product line, the changing nature of innovation, improvement in direct labor productivity, changes in the production process, performance criteria, the stimulus for innovation, and the organization's means of coordination and control.

A Dominant Design

The superior designs of products like the DC-3 and the Model T Ford[26] seem to mark turning points in the development of their respective productive units. These designs were synthesized from individual technological innovations that had been introduced independently in prior products. The important economic effects of a dominant design afford a degree of enforced product standardization, so that production economies can be sought, and provide a bench mark for functional performance competition, so that effective competition can take place on the basis of cost as well as product performance. Product design milestones are also apparent in other product lines where evidence is available on patterns of development over time. Sealed refrigeration units for home refrigerators and freezers, the development of an effective can-sealing technology in the food-canning industry,[27] and, in the locomotive industry and railroads, Charles Kettering's[28] standardized diesel locomotive can be considered dominant product designs.

Product-Line Diversity

Changes in product-line diversity also accompany transition. Initially, the product tends to be made to customer order or to exact specifications, and in this sense the product line is diverse. Frequent model change is forced by major innovations that rapidly make existing products obsolete. As was the case in the early years of the automobile and aircraft industries and later in the computer industry, there were initially many radically different product versions. The impact of a dominant design decreases the diversity in product line, and the subsequent advances in production processes cause even further decreases.

The Type of Innovation

Before a dominant design is achieved, product innovation is manifest in the introduction of radically different products. Subsequently, however, innovations act to improve an existing design and are necessarily more incremental but also more cumulative in effect. As a product becomes standardized, production volume rises, and cost becomes an increasingly important basis of competition. These concurrent changes stimulate process innovation through reduction in product variation, increased competitive pressures, and rising demand for greater output. As shown at the top of Figure 4.1, the predominant type of innovation will shift from major to incremental and will result in an overall decrease in major innovation. The rate and importance of process innovation will also increase relative to product innovation. These trends are illustrated by the changing mix of innovation in the semiconductor industry (as discussed above), and in the competitive interaction between Ford and General Motors in the early years of the automobile industry.[29] An analysis of the relative mix of product and process innovations among 330 innovations from 77 firms in the railroad equipment, computer, and housing supply industries also supports these hypotheses.[30]

Productivity Improvements

As mentioned earlier, unit costs of incandescent light bulbs have fallen more than 80 percent since their introduction; airline operating costs were decreased 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. Transition in the auto industry began with the introduction of the Model T Ford, which resulted in a price reduction from $8,000 to less than $1,000 (in 1958 dollars). Similar dramatic reductions have been observed in the unit costs of computer core memory and television picture tubes.[31] A linear percentage cost reduction with doubling of cumulative production of a product has been commonly represented as a learning or experience curve.[32] Although the causes of this phenomenon are not well understood, there is evidence that the occurrence of the learning curve is related to the transition of a productive unit, in that it depends on a standardized product design, a reduction in market uncertainty, predictability in organization and work-force incentives, and advances in production-process technology.[33]

Production-Process Changes

In the early fluid state, the production process is inchoate, the duration of labor tasks is long, there is reliance on skilled labor often organized along trade-craft lines. Flows of work in process are erratic, inventories are high, and general-purpose equipment is utilized. In general, the organization of the production process is like a job shop: there is slack, and capabilities are flexible even though they are not "efficient" in the same sense as mass-production facilities. With transition, the division of labor is increased, the work force is deskilled, and its tasks increasingly become those of the operative.

In the midrange between the fluid and specific states, some specialized process equipment begins to be purchased or is originally developed through mechanical analogy to manual tasks as process innovation and "islands of automation" begin to form in the process flow. In the extreme specific state, the process is mechanically integrated to form a near-continuous flow, is designed and purchased as a system that has well-defined capacity limits, is highly automated, and is designed so that product and process change become synonymous. In important instances these advances have so altered capabilities that product change has become very costly[34] and has decreased the productive unit's ability to respond to external forces for change.[35]

Changes in Product-Design Criteria

The performance criteria for product and process design (the bases of competition) change from ill-defined and uncertain targets for innovation to well-articulated design objectives. In the fluid state there is a proliferation of product-design criteria or performance dimensions.[36] These frequently cannot be stated quantitatively, and the relative importance or ranking of the various dimensions may be quite unstable.[37] Clarke has shown that manufacturers are likely to produce an innovation where the performance requirements are clearly specified, but that users are likely to introduce the innovation where performance requirements are ambiguous.[38] The facts that performance requirements are uncertain in the fluid state and that users are the likely sources of innovation under these conditions fit nicely with Knight's and von Hippel's findings, as discussed earlier, that users are the source of major product innovations. One way of viewing regulatory constraints such as those governing auto emissions or safety is that they add new performance dimensions to the set faced by the engineer and may lead to designs that give better performance on a larger number of dimensions.[39] The criteria for design are clearer for productive units approaching the specific state, but the highly developed structure in this state may reduce the productive unit's capability to exploit new opportunities for change.

Shifting Roles of R&D and Market Needs

The predominant stimulus for innovation varies as the productive unit evolves from the fluid toward the specific state. Innovations are first stimulated by market needs, but later by technological opportunities. The studies of innovation in computers, foods, scientific instruments, and rocket-engine technology show that initially the user is highly involved in originating major innovations. Then, as the productive unit develops, formal (R&D) organizations contribute increasingly to innovation. For example, Buzzell and Nourse observe that in recent times the main source of stimuli for food companies' new products has been the firms' own R&D programs.[40] The automobile firms did not establish formal R&D organizations until mass markets were developed, even though at an earlier time bicycle firms had research laboratories. While true that this change in the relevance of formal R&D to product innovation might be explained by an economywide shift toward a greater reliance on R&D as a source of innovation, other results show that more complex factors are at play. Peter R. Richardson's recent study of innovation and R&D activities in the Canadian mining industry explores the relationships among the development of the firm, sources of innovation, and R&D expenditures directly.[41] Using cross-sectional data on contemporary firms, he found that firms with larger total sales volume, or market share in mining operations, also placed greater reliance on formal R&D activities as a source of innovation. He observes that the extent of the firm's reliance on R&D changes because the nature and extent of uncertainty change.

The present model helps to explain how transition would increase the prominence of R&D as a stimulus for innovation. In the initial fluid stage, market needs are ill-defined and can be stated only with broad uncertainty. So there is uncertainty about the relevance of the outcomes that might be achieved through R&D (the targets of R&D activity), even if investments of R&D resources were made to bring about such outcomes. This has been called "target uncertainty,"[42] and its influence on decision making in R&D projects is very different from that of technical uncertainty. The expected value from any R&D investment is reduced by the combined effects of target uncertainty and technical uncertainty. The decision maker has little incentive to invest in risky R&D efforts as long as target uncertainty is high.

As the productive unit develops, however, uncertainty about markets and appropriate targets for R&D is reduced. Therefore, R&D projects bearing the same level of technical risk are made increasingly more attractive, and larger R&D investments are justified. At some point before the mounting consequences of transition make the cost of implementing technological innovation prohibitively high, and before increasing cost competition erodes margins below levels that can support large indirect-expense categories, it would be anticipated that the benefits of large R&D efforts would reach a maximum. Although R&D expenditure data are not readily available on a productive-unit basis, the apparent characteristics of the main business lines of corporations with high R&D rates provide support for this explanation. These corporations tend to sustain main business lines that fall neither near the fluid nor the specific boundary conditions, but are represented by the technologically active middle range. Jesse W. Markham observes that corporations with high R&D spending rates tend to be large, to be integrated, and to have a large relative market share.[43]

Organization and Control

Coordination and control over the productive unit also vary with the changes in product and production process within the firm. Jay Galbraith amply illustrates the impact of an abrupt innovative change on a large, established air-frame manufacturer.[44] It changed the ability of the organization to coordinate its activities successfully through the usual means of goal setting, hierarchy, and rules. In a situation that may be interpreted as a reversal in the normal direction of transition, he shows that as task uncertainty increases, the organization must increase its capacity to process information through increased investment in vertical information systems, creation of lateral relations, liaison and project groups, and so on. James M. Utterback and Elmer H. Burack have hypothesized that changing coordination requirements extend to the creation of formal technology forecasting and planning groups, which would be organizational manifestations of normal directions of movement from a fluid to a transitional state.[45] Burack adopted a unit of analysis very similar to the present productive unit in a study of highly automated production systems.[46] His analysis shows that as these production systems evolve toward the specific state, the controls that are necessary for both the regulation of process functions and management also change. Job procedures, job descriptions, and systems analyses are extended to become more pervasive features of the production network.

These results suggest ways in which the firm would modify its organization as well as its means of coordination and control as the productive units it manages develop. As products become more stable and standardized, altered only by incremental change, one would expect firms to deal with complexity by reducing the need for information processing through the use of buffers, slack resources, and the creation of selfcontained and homogeneous units and tasks.[47] A reduction in the rate at which technological change takes place increases the available time for principal organization groups to anticipate and adjust to the changes.[48] Each of these considerations helps to explain the firm's impetus to divide into homogeneous productive units as its product and process technology evolve.

The changes in control and coordination that are hypothesized to accompany the unit's transition imply that the structure of the organization will also change, becoming more formal, having a greater number of levels of authority, and a greater division into units that are internally homogeneous. Several studies of firms have shown that organization structure varies with changing process technology, and also that this variation is accompanied by a specialization in subordinate units and different rates of product change and innovation as anticipated in the present hypotheses.[49] For firms that are very large[50] or rapidly growing,[51] the relationships between the characteristics of the productive unit and the total firm appear to be less important. This factor would be consistent with an observation that larger firms tend to support multiple productive units in different stages of development. To summarize, the available evidence confirms that as firms move toward more rigid process technology, standard products, and higher levels of efficiency,[52] corresponding changes in means of control and coordination and organization structure can be expected.[53]

A SYNTHESIS

The model of development in a productive unit is shown in Table 4.1. Each aspect of change has been identified independently in the preceding section, and now they are related as joint variables that change together. Table 4.1 presents the major regularities, the joint relationships, and the normal direction of transition in summary form. The fluid and specific boundaries appear at the top and bottom of the table respectively. Within the table are listed the milestone events that represent common stages of transition, as manifested in innovation, product-line characteristics, production process, organizational control, and kind of capacity. The structure of the table embodies some principal ideas found in our model: that there is a normal rate and direction in technological progress, that progress in one aspect is dependent on that in others, and that a certain degree of evenness in progression among many different elements is essential to the advance of any one. The hypothesized relationships among many variables are at once consistent with the general and detailed findings of many previous studies of innovation. They conflict with some others, but they are helpful in explaining many of the dilemmas raised in earlier studies.

The Shift in Origin of Process Innovation

The distinction made between product and process innovation and the relationships between the two are also central to the present argument. A productive unit in the fluid state uses general-purpose process equipment, which is by definition purchased. In the transitional state the firm is expected to originate some process-equipment innovations for its own use. In the specific state, entire processes are designed as technologically integrated systems that are specific to particular products and developed and produced by specialized equipment-supplier firms. Therefore, in the specific state, major process innovations are expected to originate outside the firm. However, most process-equipment innovations are expected to come from supplier companies in all stages. Viewed from the perspective of a given firm, most innovations are therefore product innovations. In the aggregate, many of these new products are process equipment for use by other firms.

This is consistent with George J. Stigler's work on *The Organization of Industry*.[54] He points to the generality of the notion of phases in industrial development: from young to maturing to declining. From this perspective, he considers how subsidiary firms that supply production-process equipment will develop with evolving phases. This would lead to a shift in the originating source of process innovations from the user segment in early stages of development to the supplier firms in later stages. Firms in various phases of development are also seen to differ in the market structure they face, in the division of labor and equipment specialization of production processes, and in the responsibilities the firm must accept in innovating to satisfy its own needs for process technology and material inputs.[55] Although Stigler's work does not focus on characteristics of innovation, the nature of evolutionary change that he identifies is much the same as the characteristics of transition discussed above, even though derived from very different data sources.

Connections with Prior Research

J. R. Bright examines the conditions that enable application of process automation in several different processes involving complex manufacturing and assembly tasks. He suggests the importance of a parallel progression among several factors, as shown in Table 4.1: predictability in product and input material characteristics, regular process flows in production, well-specified and routine labor tasks, and a sequence of cumulative incremental product and process innovations. All of these joint enabling conditions were present in several different industries in which an evolutionary sequence of development toward a high level of automation was observed.[56]

Edward Harvey applied a framework, compatible with the present

TABLE 4.1. Summary of Hypothesized Relationships between Innovation and the Evolving Structure of the Productive Segment

	Innovation	*Product Line*	*Production Process*	*Organizational Control*	*Kind of Capacity*
			Fluid Boundary		
	Frequent and novel product innovation market stimulated.	High product-line diversity produced to customer order.	Flexible, but inefficient. Uses general-purpose equipment and skilled labor.	Loosely organized. Entrepreneurially based.	Small scale, located near technology source or user. Low level of backward vertical integration.
	Cumulative product innovations usually incorporated in periodic changes to model line. and Increase in process innovations—internally generated.	At least one model sold as produced in substantial volumes. Dominant design achieved.	Increasingly rationalized process configuration with line-flow orientation, relying on short-duration tasks and operative skills of the work force.	Control achieved through creation of vertical information systems, lateral relations, liaison and project groups.	Centralized, general-purpose capacity where scale increases are achieved by breaking bottlenecks.
	and Technology-stimulated innovation.	Highly standardized product with few major options.	"Islands" of specialized and automated equipment introduced in some parts of process.	Control achieved by means of goal setting, hierarchy, and rules as the frequency of change decreases.	Facilities located to achieve low factor-input costs, to minimize disruption, and facilitate distribution.
Normal Direction of Transition	Cost-stimulated incremental innovation predominates. Novel changes involve simultaneous product and process adaptations and are infrequently introduced.	Commoditylike product specified by technical parameters.	Integrated production process designed as a "system." Labor tasks predominantly those of systems monitoring.	Bureaucratic, vertically integrated, and hierarchically organized with functional emphasis.	Large-scale facilities specialized to particular technologies, capacity increases achieved only by designing new facilities.
			Specific Boundary		

one, for forty-three essentially single-product firms in the food, chemical, and plastics industries, as well as in the machinery and electronic equipment industries.[57] His results show a progression among four characteristics of each firm: bureaucratization of organization, rate of product change, product-line diversity, and the "specificity" of the process technology, a measure indicating the degree to which the production process exhibits strong line-flow qualities. In a related line of inquiry, D. J. Hickson examined joint relationships among size, organizational structure, the extent of the production-process line-flow quality, and the input of technology for an even larger and more diverse group of British firms, including service organizations.[58] Here again, results show strong consistency among these characteristics, even though the industries are very different. Focusing on health care delivery, Charles Perrow explains the necessary conditions for transition in terms of concomitant and parallel progress in process technology. Standardization of product (service task), scale, and organizational structure are similar to this model.[59]

Taken collectively, this evidence suggests that the present concepts of boundary conditions and transition apply to a variety of productive units. A good description of a common path of development is promised for products in the industrial sector that involve complex manufacture and assembly, but there is also the suggestion that the model need not be so limited.

WHERE THE MODEL APPLIES

Where does this model of the development of productive units apply? Where does it not apply? What would be contrributed if it were known to be valid? How much is really known about the hypothesized characteristic? And, of these unknowns, which questions would it be most useful to answer first?

Applicable Products and Processes

The model applies most directly to a productive unit in which multiple inputs are combined and transformed through a complex production process that yields a highly valued product whose characteristics may be varied. The key phrases here are "productive unit," "complex production process," and "product whose characteristics may be varied."

Some confusion about application may exist because the terms "firm" and "productive unit" have sometimes been used interchangeably. Also, results from the present model are sometimes coincidental with findings that have been obtained from other units of analysis, such as firms, industries, or innovations. It is important, however, to recognize that my model pertains uniquely to the productive unit and not to the other classes of definition.

The model provides the most useful insights for complex production processes in instances where the features of the product can be varied. In cases where the product of a productive unit is definitionally standardized (for example, sulphuric acid, nylon, or copper), the prospect of radical product innovation is definitionally limited, if not practically impossible. Without the prospects of interaction between product innovation and process development, the evolution toward mass production can be much more rapid, and it will be constrained by other factors. While some important aspects of the model would still seem to apply in such instances,[60] they are special cases that are not addressed directly. The more interesting applications are to situations where product innovation is competitively important, difficult to manage, and needs to be viewed in the context of the full range of other implications that are identified through application of the model.

There is some evidence, as noted in the previous section, that applicability need not be limited to industrial products per se, but may extend to services where there is a complex process for producing or delivering a highly valued, standardized service. This seems to be the case with the evolution of communication services like the telephone system, and the initial stages of development might apply to certain health care services. In the latter case some intriguing parallels are apparent where well-defined procedures and delivery technologies are evident, as with some acute surgery units and in primary care with multiphasic screening.[61]

Exceptions in Application

The notion of evolutionary transition is a characteristic of the model that may be particularly troublesome. In some cases transition may not have occurred or may have occurred very rapidly, either because the productive unit initially began at a high state of development, or because development has simply failed to come about.

The pattern of very rapid progress appears to occur with some chemical products and other continuous-flow processes where advanced, elaborate, and large-scale process equipment is used to make a new product virtually from the initial product introduction. This exception extends beyond the pure continuous-process industries to certain products with low unit values, like cigarettes, and simple plastic and metal products, where the available process technology defines the mode of operation and may have made the product feasible in the first place.

APPLICATIONS AND EXTENSIONS IN THE AUTOMOBILE INDUSTRY

There are important questions about the model that need to be answered. All of the evidence considered shows that the normal direction of transition is toward a more rigid process structure, more homoegeneous products, increased substitution of equipment for labor, and so on. Is change evolutionary, or does it come in steps and stages? What are the forces that constrain abrupt change and cause progress to come about through a steady and cumulative progression? Is it possible that a lateral move offering both flexibility and efficiency may be realized through advances in process-equipment technology, or is transition always in one direction? That reversals do occur is indicated by studies of firms' workflow structure and organization both before and after major changes, in the design and production of new commercial aircraft[62] and in the early major model changes in the automobile industry.[63] More needs to be known about these questions and the conditions that lead to these observed outcomes.

The automobile industry offers visible evidence of a large increase in product-line variety and diversity since the mid-1950s, accompanied by continued process automation. The emphasis on frequent style change has continued throughout the period, in apparent contradiction to the model. Our first question, then, is whether the present model has any practical significance in this situation, where there is visible evidence of contrary trends. To find the answer, we will analyze the development of the engine and engine plant at Ford as a unique productive unit. The separate aspects of product-line change, process-equipment development, the characteristics of task and direct labor, and patterns of vertical integration will be considered over an extended period of time to clarify the forces that pace technological change. We will look at whether the anticipated evenness and direction of development in each aspect are present as anticipated, and whether the concept of a productive unit has operational relevance and can be measured and defined in units that have practical significance. In Chapter 6, we will use the same approach to analyze the development of Ford assembly plants, as a contrasting case in which development has not advanced as far.

included in productive units, and individual plants are more specialized to particular products.

Looking to the future of this productive unit in the new energy environment, the trends will increasingly be shaped by government regulation, the rising price of fuels, and the action of management in guiding innovation to meet this challenge. The real question is whether the car will become a commodity. Against the present pressures, management in a stagnant industry would probably not be able to avoid this extreme. The major automobile producers have historically responded rigorously to market-related change, however, and given this fact, a more likely forecast is that the recent trend toward the specific state will be reversed.

The concept of a productive unit does not provide answers to these important questions. It does, however, provide a framework wherein many implications surrounding the issue can be related one with another. In this sense it helps to identify consistent patterns of management action in response to the issues.