7 SOME IMPLICATIONS

The precursory but tentative ideas about innovation and process change that stimulated this inquiry fit well with the account of actual events in the automobile industry. Initial ideas about subtle links between innovation, product-line characteristics, production capabilities, and management organization, as presented in Chapter 4, are nicely borne out by the historical course of change in engine and assembly plants. The analysis of actual events does more than support the initial hypotheses, however; it offers a rich source for practical interpretation.

THE MODEL REVISITED

From the more detailed data given in Chapters 5 and 6 the ideas in Chapter 4 can be enriched and recast to reflect the development of both automotive units. At this higher level of abstraction some details of the historical analysis can be grasped more clearly.

Table 7.1 recasts and summarizes the model in a form similar in format and intent to Table 4.1. In contrast to the more limited number of aspects considered in the earlier table, seven are included in Table 7.1 over the full course of evolutionary transition from the fluid to the specific boundaries. The body of the table contains events for each of the seven aspects, and Exhibit 7.1 abstracts the sequence of transition.

EXHIBIT 7.1. The Productive Unit: Direction and Key Events in Transition

A. *Product Characteristics*

Direction. Overall, there is progress toward a "dominant design"—a broadening of appeal beyond a narrow market niche. Initially, a productive unit accommodates substantial product variety, and each product is specialized in the sense that it has limited breadth and duration in market appeal. It is virtually produced to customer order. Evolutionary progression ultimately leads to a high-volume, functionally standardized product.

Events. The transition is marked by a series of steps. The first step is the

TABLE 7.1. Productive Unit Characteristics

	A *Product Characteristics (Main Line)*	*B* *Mode of Product and Process Change*	*C* *Process Configuration*	*D* *Task and Labor Characteristics*	*E* *Process Equipment*	*F* *Sourcing of Inputs*	*G* *Capacity*
Central tendency in development	From: Custom product, specialized for appeal to specialized markets To: Standard product with appeal to aggregate markets.	From: Fluid change To: Incremental improvement.	From: Flexibility and independence among included operations To: continuous machine-paced line flow.	From: High trade craft skill and manual tasks To: Operative skills To: System overseer and maintenance skills.	From: General-purpose equipment To: Specialized integrated systems.	From: Components and materials available through common supply channels To: Devoted channels, back to raw material sources.	From: Small scale; assembly with ill-defined output limits To: Well-defined processes that are specialized to particular products.
Fluid *I.*	Produced to customer order and specification.	Frequent major and novel product change. Prior models made obsolete.	Job Shop: Adaptable, fluid flow configuration	Craftsman or artisan skills required.	General-purpose equipment predominates.	Commonly available grades, through normal distribution channels.	Capacity limits ill-defined. Scale is small, many components purchased.

2.	At least one model "sold as produced" in substantial quantities (with or without options).	Major but cumulative changes made to successive product models across product line.	Progressive flow configuration around particular product(s).	Semiskilled workers; long task durations, training on job important.	Some specially designed machines for key tasks.	Override of common distribution channels and pricing policies.	General-purpose plant of moderate scale. Capacity increased by paralleling similar plants.
3.	Dominant product design (one type design gains major market share, forcing competitive reaction).	Incremental changes introduced during production, with periodic major model redesign across product line to increase functional product performance.	Line-flow configuration with separate production process for each standard product.	Operative skills and short task duration (minimum skills and training).	Frequent use of machines that perform multiple operations at one station.	Commands especially designed input materials and components and product development services by suppliers.	General-purpose plant organized and controlled by product/market categories. Includes production of most components. Capacity increased by investments to break bottlenecks.
4.	Highly standardized product. Options for different market segments formed as peripheral variations	Long periods between major model changes. Refinements emphasized. Changes no longer made across all models in line but are introduced selectively by model.	Closely balanced, commonly paced tasks organized and controlled by component.	Mixed skills and tasks. Some operatives and others monitoring.	Integration of special machines at some stations to form islands of automation	Substantially devoted input sources either through backward integration or other forms of close supplier control.	Capacity organized by process types. Separation of dissimilar or uncommon production processes from segment.
Specific 5.	Functionally standardized product(s).	Incremental product change implemented through process improvement, emphasizing greater product consistency and standardization.	Technologically controlled continuous or near-continuous flow.	Predominant tasks are equipment monitoring and intervention when equipment fails. Predominant skills are process maintenance.	Extensively integrated and direct linked process designed and procured as system.	Extensive integration into raw materials.	Large-scale plant specialized to particular process function, capacity well defined, increased only by designing new facilities.

development of a model that has sufficiently broad appeal to be produced in long runs and promoted and sold as a standard rather than a made-to-order product. The second and decisive step is the achievement of a dominant product design, one that attracts significant market share and forces imitative competitive design reaction. This induces product standardization throughout the industry. Finally, the dominant design is exploited to achieve a highly standardized product that is changed only incrementally from year to year, with emphasis on cost in competition.

B. *Product and Process*

Direction. The nature of change evolves from frequent, fluid, and novel product change toward conditions of stability.

Events. Early in the life of a unit, important functional improvements cannot be postponed. Then, as produced-to-order models are developed, improvements are incorporated in a more organized manner. The period between new model introductions is short, however; new models introduce major functional improvements; and in a competitive environment they cannot be withheld too long without serious loss of market position. The changes are introduced across the entire product line, imparting a simultaneity to the timing of model change. A dominant design, once achieved, decreases the urgency of product modification, and the character of model change shifts to become more that of design refinement and cost reduction than of major functional improvement. Then, with successive refinement, the interval between major design changes lengthens, although the frequency of incremental change may increase. The impact of change is localized as each component is separately standardized and produced.

C. *Process Configuration*

Direction. As a productive unit develops from initial conditions to those of the later stages, the configuration of the production process is altered from one that affords a high degree of independence among included operations and tasks to one with a high degree of integration and balance among these operations. Characteristics of the process configuration in the beginning stage of development are similar to those of a "job shop." That is, subordinate operations include diverse technologies that are loosely organized and independent of one another so that they can be flexibly applied to produce a wide variety of products under conditions of change. As a consequence, the flow of work is erratic, output rates are unpredictable, much management attention is required, and inventory levels are high; but change is readily accommodated at minimum cost.

Events. By successive redefinitions the flow of work in process and the subordinate operations are redefined and rearranged to achieve an intermittent line-flow movement. That is, changes are made so that operations are performed as the work moves forward, without retracing, typically in batches that are processed intermittently. With further development the flow becomes more continuous. Intermittent processing of batches gives way to continuous product flow with mechanical pacing keyed to final product output. Control comes to be based on rate-flow adjustments. With subsequent development, subordinate operations are redesigned to provide tight balance among included operatives. Heterogeneous and disruptive technologies are eliminated from the process flow as necessary to achieve continuity. Inventories are introduced where needed to buffer the outputs. Finally, the flow configuration is mechanically linked to form a single continuous line-flow system that is managed on a rate-flow control basis, affording few options in the product output.

D. *Task and Labor Characteristics*

Direction. Task characteristics and the skills sought in the work force shift with development, so that there is less skilled-labor input in direct work tasks and more skilled-labor input to process overseer functions.

Events. The transition from the initial to the later stage of development involves an evolutionary progression. Tasks are first reduced in duration and content, so that only semiskilled workers are required, and then are redefined even further, until they require only the manual dexterity of the operative. As tasks are broken down into smaller and smaller elements, better specified, organized, and made more predictable, they become more susceptible to automation. Islands of automation are created as a sequence of related tasks are mechanized, first by analogy to manual methods and then by reengineering the methods to make them more appropriate to automation. Ultimately, then, as these islands are linked, the predominant task of the work force becomes that of the systems overseer.

E. *Process Equipment*

Direction. As the productive unit develops, the type of equipment changes from general-purpose, independent equipment to equipment that is designed, integrated, and purchased as a system.

Events. In the beginning stage, when the economic future is uncertain, general-purpose process equipment is used. A type of equipment is used that can be procured from conventional suppliers. Only in cases where technical feasibility of production requires special-purpose equipment is it specially developed. Then, as confidence and market acceptance of the product grow and the demand for output increases, special equipment is designed to overcome particular bottlenecks. Because the process is new, because a large supplier industry does not exist, and because requirements are uncertain, special-purpose equipment is likely to be developed by the organization itself. With increasing demand for output, growing economic success, greater stability in product design, more predictable process flows and task definitions, there is a corresponding increase in the development of special-purpose machines. Islands of automation in the process grow through an increase in the number of multiple operations that are performed at one work station. Subsequently, advanced development takes place through the linkage of adjacent stations into common units of equipment. As integration proceeds, machines become more reliable and complete, so as to support unattended operation. It finally becomes possible to join major elements of the process into a common large system that operates as a single machine. At this stage, equipment is purchased and integrated as a specially developed system from special suppliers. By linking equipment in this manner, however, it becomes highly specialized to a particular product design.

The effect is to link product and process so that both are costly to change, but highly efficient.

F. *Sources of Material Inputs*

Direction. As a productive unit develops, change takes place in the types of material input that are utilized and in the sources for these inputs. Initially, materials are used that are commonly available through traditional supply sources. In highly developed stages the materials are special, and supply sources are wholly devoted.

Events. Initially, when product design, market needs, and process configuration are all uncertain and in flux, the type and sources of inputs vary widely, precluding the major commitments in time, equipment, and money that would be required to obtain the ultimately most appropriate and efficient types of inputs. With development, suppliers seek to compete through innovation in materials and services. Successful innovation forges tighter, more specialized linkages and dependencies between the unit and its suppliers, with implications for further cost reduction and improved efficiency. To seek economic returns and ensure predictability of inputs, control over supply sources is achieved through backward vertical integration by new facility construction, merger, acquisition, or long-term contract.

G. *Capacity*

Direction. The aggregate characteristics of a productive unit's capacity change with transition. Initially, the capacity is centralized, it includes heterogeneous technologies, and capacity limits are ill-defined since the process itself is unstructured. In a highly developed state, capacity is very specific, it includes homogeneous technologies, and it is provided by a decentralized and independent facility.

Events. Through horizontal and backward integration, the scope of included operations is first rounded out to encompass those operations that affect the basis of competition. At first this increases the heterogeneity of included process technologies and imparts a general purpose as opposed to a specialized quality to capacity. Capacity limits remain ill-defined, and increases in capacity are achieved by paralleling existing general-purpose segments. As development advances, subprocesses take definite form. To increase capacity, bottlenecks are eliminated in particular processes. With still further development, individual units and subprocesses are organized and managed independently. Heterogeneous technologies are separated, and the processes become specialized to particular components. Finally, in a highly developed state, capacity is explicit, composed of tightly balanced homogeneous operations and organized in units synonymous with product components (engine plants, rolling mills for sheet steel, body-building lines, and so forth). Increases in capacity are achieved by designing entirely new plants.

The events are ordered in Table 7.1 so that milestones included in a given row are judged to be at a comparable stage of development. At any given time, however, it would not be expected that the characteristics of an actual productive unit would be evenly aligned across a row. Development is expected to be somewhat uneven in specific detail at specific times but to proceed overall with a definite degree of evenness.

DYNAMICS OF TRANSITION

Although a certain degree of evenness among the major elements of the productive unit is evident over the long run, the timing of progress is ragged, and it varies considerably among the different elements. For example, the product line can be highly standardized as a matter of market conditions and management policy, corresponding to an advanced stage in column A of the table. Until equipment is advanced to a comparable stage, however, the evenness of progression will be out of balance. A product-line policy that embraces standardization will facilitate equipment advances, but until such advances are realized and until parallel advances in other elements are also realized, the overall productive unit cannot be considered to be at the same stage as the one element, product line. The full economic benefits of this higher stage will not be realized until, among other things, labor tasks are altered to achieve the gains in efficiency that are possible through higher division of labor; more efficient equipment is used; and backward integration lowers input costs. At the same time, until these other developments come about, there will not be an accompanying loss in flexibility. Consequently, a reversion back to an earlier stage in product-line policy will be relatively cost-free. In other words, the productive unit will still be flexible in response to product innovation.

This means that product-line characteristics may move through a cycle of development and revert back to an earlier stage with comparative ease. In contrast, the development of equipment and changes in labor or management task characteristics tend to be cumulative in nature and persistent in effect. Once these aspects are advanced, reversals occur less frequently and carry higher costs.

Reverse Transition—An Illustration

These concepts of uneven development—transition and reversal—are illustrated in Figure 7.1.

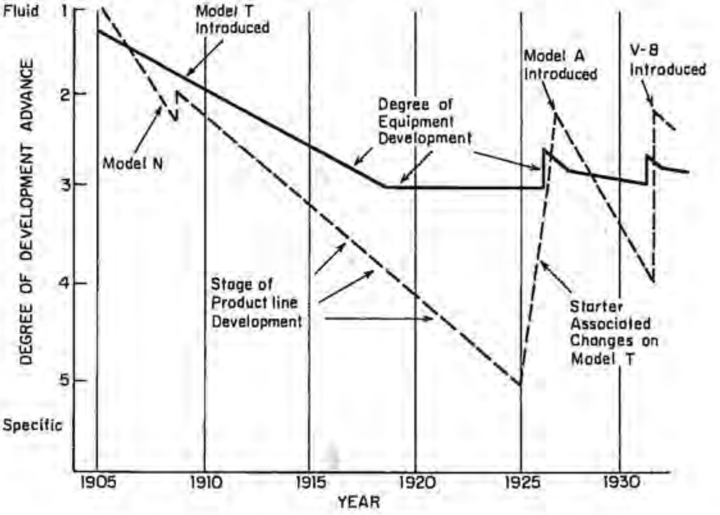
This figure uses changes in product-line and equipment characteristics in the early years of Ford's engine plant to illustrate different relationships among the various elements that affect progress. The scale of development on the left can be identified with the five successive steps that are shown respectively for product-line and equipment development in Table 7.1. Note, however, that the use of these stages causes the scale to be inverted, with the most advanced stage near the origin. Years are indicated along the bottom. The shape of the two curves depicts trends described by the data and historical accounts of development in Chapter 5.

This figure contrasts the relatively volatile quality of product-line changes with the steady cumulative advance in equipment characteristics. Although equipment trends are shown to lag behind product-line changes, they act like a ratchet to limit or constrain a complete return in product-line conditions to the early fluid state. Equipment development acts like a steadily rising lower limit that presses the productive unit's overall development. Practically, this represents the pervasive impact of equipment advances on the cost structure, the way labor can be used, minimum economies of scale, and equipment flexibility itself, as well as the associated effects on the organization and management.

Innovative product change, as represented by the introduction of engines for the models T, A, and V-8, is shown to reverse temporarily the trend in equipment development only if the stage of equipment development had advanced beyond the lower limit of variation in the stage of product-line development. For example, even though the Model N engine was being produced, the introduction of the Model T did not cause a reversal; yet the other two engines did at a later time. (We noted these same interactions in prior chapters for equipment-development trends in the assembly plant and the engine plant.)

It would be expected that developments in productive units of other industries have differed significantly from those in the automobile engine plant in respect to convergence between the states of equipment and product-line advancement. For example, although the product characteristics of the DC-3 were rather standardized,[1] there is no indication that

FIGURE 7.1. Interactions in Ford Engine Development: Product Line and Equipment Developments in Transition



process equipment evolved as extensively as in automobile engines. Neither did equipment developments in automotive assembly plants keep pace with the opportunities posed by the product standardization of the early car models.

Conceptually, the convergence of the two curves to a common advanced stage of development represents the linking of major product innovation with process innovation. When both aspects reach an advanced stage, product and process innovation become highly interdependent.

PRODUCTIVITY CHANGE BY STAGE OF DEVELOPMENT

Productivity improvement comes about when a product unit undergoes transition to a more advanced stage. This important relationship warrants careful consideration.

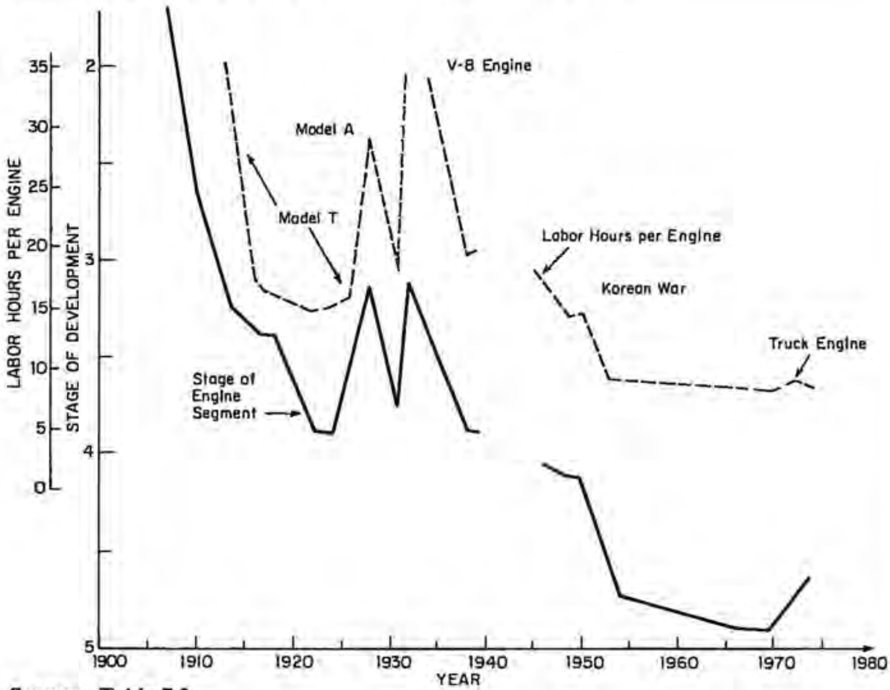
A profile of the productive unit's course of development in aggregate, as illustrated in Figure 7.1 for product-line and equipment characteristics, can be extended to illustrate the tie between productivity, innovation, and the overall stage of development. The average stage of all seven aspects in Table 7.1 may be used to gauge each productive unit's overall degree of development at different times. The profiles of aggregate development obtained in this way can be used to see how changes in stage of development are related to changes in both technological innovation and labor productivity.

Figures 7.2 and 7.3 each relate productivity and stage of development through two curves: one curve is the development of engine plants and assembly plants; the other curve presents data showing the labor hours per product that were actually used by the respective productive units in various years.* As in Figure 7.1, above, the stage of development uses an inverted scale, so that the origin represents an advanced stage. The profiles are derived from published data, and better information is available about the earlier years than about the years since World War II.† The stage changes are more sharply defined in the earlier period because of this and because conditions have stabilized in later years. Tables 7.4 and 7.5, at the end of this chapter, indicate the events or circumstances in various periods that underlie the assessments. The data on labor hours are summarized in Tables 7.6 and 7.7. It should be noted that total nonsalaried labor hours

* Note that the labor hours are those of all nonsalaried employees, approximated from other sources. Direct labor hours per engine are now only a fraction of one hour, although total hours are seven to nine hours per engine.

† Although financial data were not disclosed until Ford became a publicly held company in the 1950s, there are numerous personal accounts, books, articles, and so on, about prewar conditions. The Ford archives contain little material from the postwar period.

FIGURE 7.2. Stage of Development and Labor Hours per Engine



SOURCE: Table 7.3.

are reported rather than just direct labor hours. Direct labor hours would be much lower for engine plants.

Transition and Productivity Improvement in Engine Plants

The curve at the bottom of Figure 7.2, the profile of development stages, suggests there were two periods of rapid development: the initial years of the Model T era and the immediate postwar period that led up to the integration of engine plants with transfer lines. Between these periods, conditions were on a plateau in the sense that Ford was reacting defensively to product advances by other manufacturers. A strong relationship between the labor hours per engine and the assessed stage of the engine segment is evident in the figure. Although there might be some disagreement about the exact stage rankings, there should be little contention about the overall shape of the profile, and it is from the overall fit between the two curves that the major conclusions arise.

The *change* in the stage of development ties closely to labor productivity gains. The periods of major improvement in labor productivity occur with large and rapid advances in the stage of development. Such rapid advances took place in two periods when engines were relatively standardized and demand was strong. The first period was the production build-up phase of the Model T and the second was market expansion following World War II.‡ When the postwar expansion took place, the same basic V-8 engine had been in production since 1932.

Evidently the direction of transition reversed during the 1930s and with it the trend in labor productivity. During the periods of rapid change, labor inputs increase or remain high. This is evident as both a short-run disruptive spike and a longer-run trend. The introductions of the Model A and V-8 engines provide two conspicuous illustrations of the short-run effect. Massive increases in labor inputs per engine were required when they were introduced. More significantly, however, the base line of the trend shows that the labor content per engine increased from about 1924 until the end of the prewar period. The upward sloping base line is not surprising, for many design changes were made to improve the engine throughout this entire period. Design changes increased the number of required operations and the overall complexity of the product. The upward trend began with the addition of the starter while the Model T engine was in production.* Before the starter was introduced, the curve showing labor hours per engine reached its lowest level, in the early 1920s, and climbed steadily upward from there. This period can legitimately be interpreted as a reversal in the normal direction of a productive unit's development.

Since 1955, however, the overall trend in labor content per unit seems to be smoother, and rates are still decreasing, but progress is no longer rapid. The structure of this productive unit has apparently already reached a highly advanced state, and there is little opportunity for further progression. These trends support the concept that productivity changes are associated with structural changes in the productive unit.

Different Sources of Productivity-Improvement. Productivity improvement during the two periods of rapid increase came from different sources. In the first period, during the Model T build-up, productivity improvement came about smoothly in association with total production volume growth. These are the relationships of an experience curve or learning curve, and they are dynamic in the sense that productivity improvements depend directly on innovations that take advantage of volume growth. As identified in Chapter 3, many of the important innovations in engine plants during

‡ Some of the apparent improvement is explained by the changes in the scope of operations that are included. Changes in scope generally correspond with the concentration index changes given in Chapter 5. Based on an analysis of detailed cost data for the Model T, it is concluded that the effect of these structural changes on labor content was less than proportional. Decreases in scope probably account for less than 10 percent of the overall reduction in labor content. The types of operations that were separated from the engine segment include foundry and iron making. Although these weigh heavily in the concentration index, they do not contribute nearly so heavily to labor content as do engine assembly, testing, and machining (in earlier years).

* The effect of adding the starter was of considerable consequence in the design of many engine components. Cost data on Model T engine components show a ripple effect of cost increase in many components after the starter was first added.

this period originated in the automobile firms themselves, and they involved changes in process organization.

The second period of rapid improvement in productivity came about through the mode of designing and purchasing an entirely new integrated plant. In this case the mode of productivity improvement could be called static, for a given level of improvement was obtained by purchasing a plant of a given capability.

The two modes are entirely different insofar as both internal management and the entry of new firms in the industry are concerned. In the latter case, a competitive level of productivity could be purchased by a new firm at time of entry through capital expenditures. In the first case, however, a competitive position requires innovation, and this in turn requires volume growth, so entry by a new firm would be more difficult. Such difficulty of entry seems highly consistent with two modern industries, computers and semiconductors. In these industries a strong experience-curve pattern of productivity improvement, like the early automobile pattern, has been apparent. The successful entrants have been small firms that evolved into larger companies rather than large established firms that gained entry through head-on competition in established product lines.[2]

The modes of productivity improvement depend upon the stage of development. Concepts like the experience curve and learning curve are only parts of a larger framework that must be considered in discussing productivity issues.

Productivity Comparisons for Assembly Plants

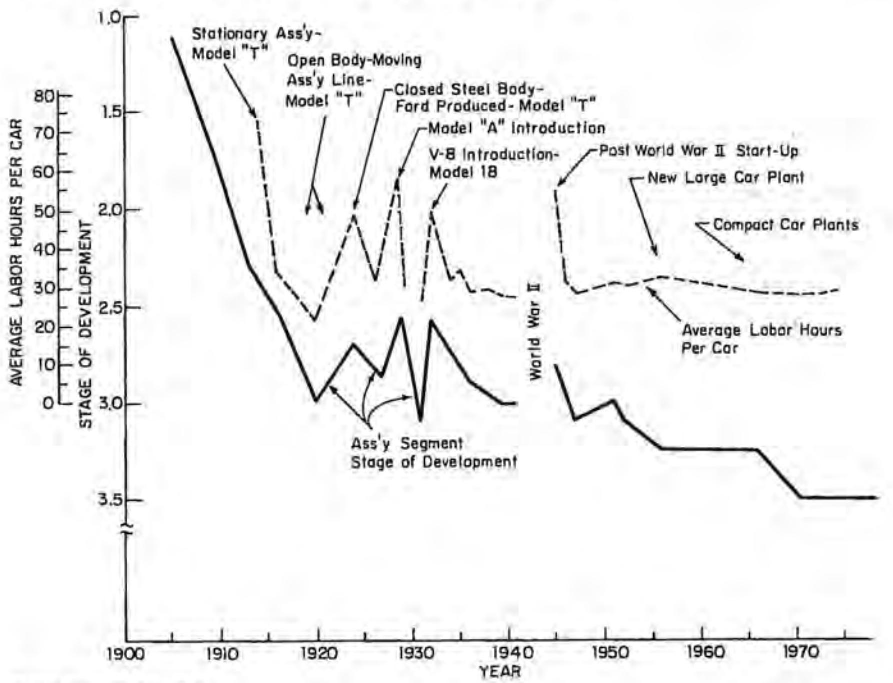
A close relationship is also evident between labor-hour rates per car and the profile of development for assembly plants. The profile of development in Figure 7.3 is consistent with the notion that assembly plants are less developed than engine plants, although one might be misled in a visual comparison of the two figures because the scales are different.

The major changes that followed the introduction of closed steel bodies, the Model A, and the V-8 produced peak cost increases, as was the case in engines. During the postwar period, major short-term peaks that might have followed new model introductions are not evident. This partly results from data limitations but, more generally, in recent years, new model change in assembly has been better planned. Greater reliance has been placed on modular component lines, as discussed in Chapters 5 and 6, so that new model introduction is more smoothly handled.

The remarkable evenness in labor content per vehicle since the 1920s stands out as a major feature of this graph. It understates real productivity improvements, however, because many body operations that were once performed centrally, outside of the assembly plant, are now performed in the plant, and, of course, the car has grown in complexity.

The overall picture is consistent with the model and the discussion in

FIGURE 7.3. Stage of Development and Labor Hours per Car



SOURCES: Table 7.4.

Chapter 6. The assembly plant is a productive unit that has remained relatively flexible, and consequently the labor content per vehicle has remained constant and has not developed like that in the engine plant. It is somewhat surprising, however, that rates of labor input have not varied a little more during the last decade, as would be anticipated from the changed stage of development as discussed in Chapter 6. Of course, the data extend only through 1974. It may also be that all of the necessary enabling conditions for a stage change (product standardization and design stability) are not yet present, so that the full consequences of recent changes have yet to be realized.

INNOVATION AND THE AGGREGATE STAGE OF DEVELOPMENT

In Chapter 4 the hypothesis was presented that patterns of innovation would change with stage of development in type, frequency, and locus of innovation. In respect to type and frequency, it is expected that major product innovations will be more frequent initially, relative to process innovation, but that process innovations will increase in relative importance as development advances. In respect to the locus of process innovation, process-equipment innovations are initially expected from the using firm, in this case the major automotive producers. For more advanced stages, innovative equipment is expected to be purchased as major process systems from special producers. Stated alternatively, the originating source of important process innovations is expected to shift from within to outside the firm.

Types of Innovation

The cases, as analyzed in Chapter 3, generally confirm these ideas about innovation. The anticipated changes in type of innovation are better analyzed, however, from data on one firm, here the Ford Motor Company.

Two simple sources of data provide direct evidence about the questions: "Ford Firsts" for the initial period and patents for later periods. Neither covers the entire period alone, for patent data are inadequate before 1920. The types of advances that are reported in "Ford Firsts" appear to change over the years. In later years they reflect largely sales-oriented product changes,* while in earlier periods very substantative technological innovations of all types were reported.

Table 7.2 lists all "Ford Firsts" that relate to the two productive units of interest from 1901 to 1915. These represent innovations of four types: overall chassis design (product changes), process innovations in assembly, engine-design innovations, and innovations in engine manufacturing.

The frequency of product and process innovations in this table changed over time, as we might expect. The first innovations pertained exclusively to product designs, for both engines and chassis. They constitute major conceptual changes in the organization and relationship of major car components. By 1906, however, process innovations began to appear, and the nature of product innovations began to shift, reflecting technological improvements in existing components or the addition of new ones. By the time the Model T was in production, 1908, the relative frequency of innovation had shifted, as expected, in favor of process innovations. These data nicely illustrate the ideas about changes in the type of innovation.

The Locus of Process Innovation

Patents are not necessarily equivalent to innovations, but data on patent applications can be expected to indicate how technical activity is

* It is surprising that a search of both company names and principal employees revealed few Ford patent applications for these early years. The type of advances Ford documents also change in a curious way. For the early years company chronologies of important events or "Ford Firsts" make frequent reference to notable technological achievements. In recent years, however, even significant contributions recognized industry-wide are omitted in favor of less significant sales-oriented firsts. For example, the major postwar contributions in cast cam and crankshafts, thin-wall cast-iron engines, and electrocoating are not listed.

TABLE 7.2. Ford Firsts to 1915

	Chassis and Assembly		*Engine and Transmission*
P 1901	Left-hand steering	P 1903	Adjustable spark advance
P 1904	Mount engine longitudinally	P 1906	Unitary engine and transmission
P 1904	Torque-tube drive	P 1907	Separate removable cylinder head
P 1904	Bevel-gear drive	P 1907	Magneto for ignition
M 1906	Wiring harness	M 1907	Simultaneous machining operations on cast parts
M 1907	Electric resistance welding	P 1907	Vanadium steel crankshaft
M 1908	Moving assembly line tried	P&M 1908	One-piece cast vanadium-steel crankshaft
P 1908	Left-hand steering on production model	P&M 1908	Planetary transmission and single-casting 4-cylinder block
P 1909	Steel running boards	M 1913	Moving assembly lines on motor, axle, and magneto
M 1911	Industry's first branch assembly plant (Kansas City, Mo.)		
M 1914	Endless chain-power-driven final assembly line for chassis		

SOURCE: Ford Motor Company Chronology of Important Events, Ford Archives, Henry Ford Museum, Greenfield Village, Dearborn, Mich.

NOTE: P = Product-design innovation; M = Manufacturing or process innovation.

directed within a company. On average, more patents would be anticipated in areas of greater technical activity and vice versa.

To use patent statistics in this way in analyzing activities at Ford, a few periods were selected for consideration. Ford patents pertinent to the engine plant as a productive unit were classified from their description as product, process, or other. For the assembly plant, however, no attempt was made to define the broad class that would represent product patents for the car as a whole. Instead, only process patents were classified. The necessary inferences can be made without data on product innovation for assembly.

Table 7.3 shows results in the form of percentage changes among

TABLE 7.3. Ford Patents by Application

	Engine Patents		*Assembly Patents*		*All Ford*	*All Process Patents as a Percent of all Ford Patents*
Period	*Product and Design*	*Process*	*Product*	*Process*	*Product and Process*	
1926–36	15	9	—	13	195	23.7
1946–52	6	2	—	4	162	26.7
1957–62	30	0	—	6	433	8.7
1970 and 1972	14	0	—	26	323	17.8

product and process patents for four different periods. All Ford patents were classified in this way. As a control, the percentage of process patents to total patents is also shown.

The concept that the originating source of innovation will shift outside the firm as the productive unit matures is supported by the patent statistics. The engine plant reached an advanced stage of development around 1952, as previously shown. Table 7.3 indicates there were only two process patents in the period ending in 1952, and afterward there are none. These data complement the case data in Appendix 1 and Chapter 3, which show that engine lines were purchased after 1950 and strongly confirm the ideas about originating sources of innovation at Ford.

A shift has come about in all Ford productive units. Patents that pertain to the assembly plant are still frequent, and some of these correspond to major process innovations that Ford originated for this unit. Since the 1950s, Ford has originated innovations in the electrocoating process for reducing corrosion of car bodies, welding, and others (see Chapter 3). Throughout the corporation the percent of process patents to all patents increased in the period of revitalization at Ford following World War II. The late 1950s and early 1960s reflect a slump. Then, since 1970, an increased rate is apparent. Because significant product innovations are linked to process innovations, as discussed in Chapter 3 and later in this chapter, this percentage may reflect an overall tendency toward maturity and then renewal in the industry. To the extent that this is such an indicator, an increase in the rate of significant innovation has occurred since the 1960s. In any event, the overall direction of technical activity in the company has not turned away from efforts that would lead to process patents. A fact that supports our hypothesis is that process patents in assembly seem to have led the corporatewide trend in numbers of patents, indicating a more fluid response to industrywide innovative stimuli, the engine plant has not followed the trend. The engine plant is a special case, which is nicely explained by its advanced stage of development.

The shift in originating sources does not mean that Ford stopped contributing to innovation in engine-manufacturing processes altogether. Contributions in concept and in process organization and method have apparently been made and implemented through purchasing policy. The Cleveland engine plant is an example, for this plant itself is considered an innovation.* In this plant Ford established the concepts, organization, and equipment specifications and absorbed most of the risk of the equipment producer. Process equipment in this plant was designed and purchased as a system and not by individual equipment units.

* The extensive integration of engine plants with transfer lines was identified in Chapter 3 as one of the major industrywide process innovations in engines in the 1945 to 1954 period. Ford's Cleveland engine plant is identified as the first plant to be so integrated.

Our model would predict that Ford will again originate an increasing percentage of process innovations for engine manufacturing if the recent emphasis on fuel economy causes this productive unit to reverse its historical direction of transition. Recent work at Ford on the Stirling and the Dual Displacement engines leads me to believe that such a change is promised. Whether it actually occurs, however, remains a question for future research.

Other Evidence on Shifts in Innovation. The shift in type and locus of innovation with stage of development is not just an idiosyncrasy of Ford. The importance of stage of development in the shift is borne out by differences between U.S. and European automobile firms and by innovative patterns in other industries.

Along with Ford, other U.S. producers turned to the machine-tool industry for innovative process equipment for engine plants after World War II, as observed above, but this was not the case with European automobile firms. European manufacturers, whose engine plants were not developed to such an advanced stage as U.S. plants, retained their capability for internal innovation.[3] This is consistent with the idea that the locus of innovation depends upon the stage of development, and not just the passage of time.

The change in type of major innovation, from product to process, as illustrated for Ford in Table 7.2, has also been studied for firms in other industries. James Utterback and I analyzed patterns of product and process innovations for seventy-seven firms in four different industrial sectors: railroad-equipment suppliers, computer firms, computer-components producers, and housing-contractor suppliers.[4] Among these firms, their stage of development seems to explain significant differences in their innovative potential, much as observed in engine and assembly plants at Ford.

The change in the locus of process innovation is much more than a matter of idle curiosity. George Stigler's work on the birth of industries[5] predicts that process-equipment sources will develop external to the firm, as has been observed. But the explanation he proposes is not successful in accounting for the differences between engine plants and assembly plants in the United States some fifty years after the automobile's birth, nor between those in Europe and in the United States.

IMPLICATIONS FOR MANAGEMENT IN THE AUTOMOBILE INDUSTRY

The automobile producer manages a portfolio of different productive units whose products are the components of the final product—the car. The present general model specifies the set of trade-offs that affect each productive unit, but individual units cannot be managed independently;

rather, the entire portfolio must be considered as a whole in order to realize both short-run and long-run competitive advantages.

For individual productive units, we have seen that conditions for innovation and efficiency are strongly linked, but in an inverse manner. The conditions that support a high level of efficiency are entirely different from those that support a high rate of innovation. Decisions that determine equipment development, product-line standardization, labor-force characteristics, and vertical integration simultaneously influence capabilities for innovation and productivity improvement.

Many variables are involved, but the present findings suggest that the path of progress can be changed and directed to achieve desired objectives. The objectives must be set, however, taking account of all the productive units in the portfolio.

Corporate Perspective

From a competitive standpoint, the mix in stage of development among the included productive units is absolutely critical. If all productive units were at an early, fluid stage, then costs would be prohibitively high for the customer. If, on the other hand, all units were highly advanced, then costs would be low but innovation would be eliminated as a competitive variable. This is what happened with the Model T: all productive units were allowed to advance together. The consequences were a great reduction in price, but the loss of capability for change.

A better balance in stages of development among productive units would have all the productive units highly developed except one. The one would embody a competitively important feature, it would be in the early stages, and it would be in transition.

Such a controlled rate of innovation in deference to cost is essential with a high-priced consumer good like the car. Unlike an industrial product, such as a computer, the allowable price cannot increase with the real value of the product. At some price, not far above the present market price for cars, most of the market would be lost, no matter how excellent the product.

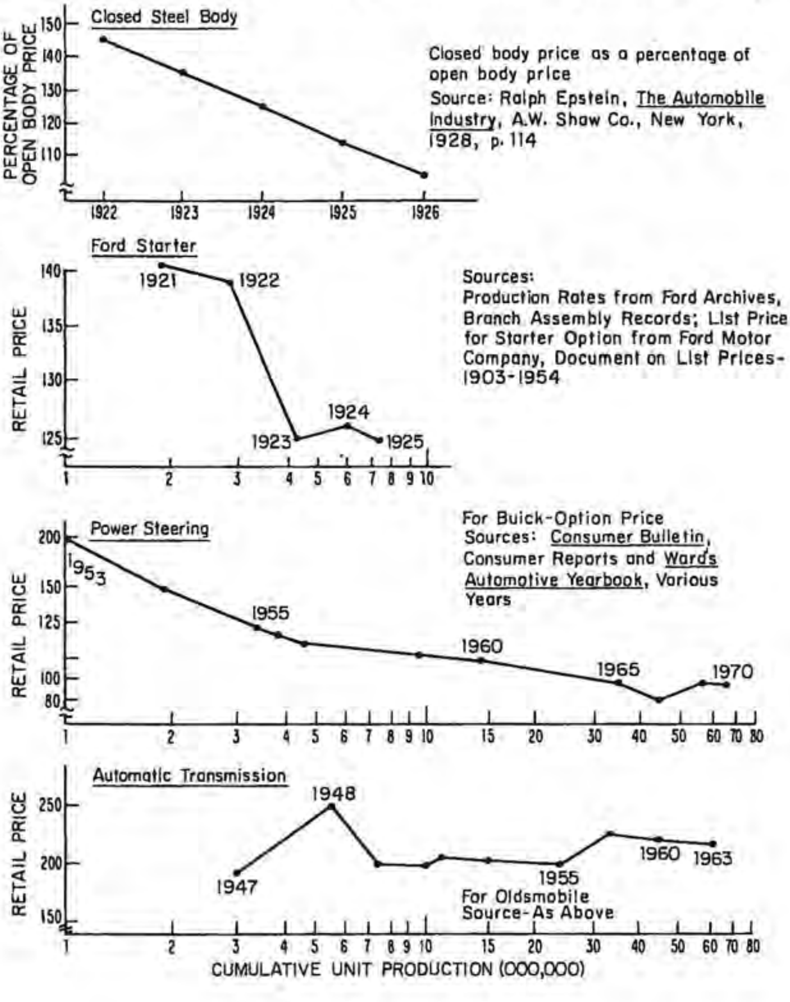
Cost control is the first requirement in managing the set of units. The essential trade-off between innovation and cost is illustrated by historical data for four productive units of the automobile. Figure 7.4 displays trends in price and volume* for the closed steel body, the Ford starter, power steering, and automatic transmission. These curves show that, as anticipated, prices generally decrease with advancing volume and diffusion following a learning-curve formula. (The diffusion data for these innovations

* Power-steering and automatic-transmission graphs are based on industrywide volume and, as might be anticipated, price trends are more shallow than the Ford-starter graph, which uses exact Ford-starter volume.

were given in Chapter 3.) The automatic-transmission graph is the exception, and it is here that the present concepts about a productive unit deviate from the traditional wisdom about the learning curve (or experience curve). The learning curve predicts an absolute decrease in cost with cumulative volume. The present general model anticipates cost reductions only when product designs are stable and product innovation is incremental. The case on automatic transmissions indicates that designs were fluid for a long period, so prices rose and declined. As Figure 7.4 shows, a trend toward reduced prices did, in fact, not begin until the late 1950s.† These

† Ford automatic-transmission trends after 1963 are not given because of difficulty in following the quoted price of this feature. Changes in the base price of the car to include this as an option package obscure prices.

FIGURE 7.4. Price-Volume Trends for Selected Features (1958 Dollar Value)



data are quite consistent with the observed changes in engine labor content during the 1930s, as previously shown in Figure 7.2.

Taken collectively, these curves reinforce the ideas discussed above about managing technology at the corporate level for a costly and complex consumer product. Strategy can be viewed in terms of managing a portfolio of productive units that are continuously changing. Innovation to create new features is essential, but the cost must be controlled to keep the total price of the product within reach of the consumer. Once the feature is perfected, costs are reduced, the technology is packed down, the diffusion is rapid, and all competitive advantage is lost. Another innovation is needed, or the basis of competition will shift to cost competition, and profit margins will be lost.

As this process continues over time, the final product comes to be made up of intermediate components from highly developed productive units. Such growth complicates the problem of cost control under conditions of change. The cost spikes in Figures 7.2 and 7.3 show that costs revert to earlier high levels when major change is introduced. Careful studies of the learning curve have shown that previous cost-reduction gains can be lost when innovative change occurs.[6] There is a reset, as it were, and cost returns to higher levels when the volume-growth progression is disrupted.

These relationships explain why it is important to localize the impact of change through the use of independent standardized component lines. Because of these considerations, the cost of change can be expected to increase as productive units become more numerous and mature.

Major product innovations for the car as a whole (as discussed in Chapter 3) were less frequent in the last decade. Recently, however, the rate of innovation has increased, although most innovations have not yet diffused. Safety, pollution, and fuel economy have added new constraints. Fuel economy now seems to be desired by the U.S. public, but this in itself is another form of an efficiency emphasis.

The long-term trends have greatly increased the cost of further change, and the effect of many regulations has raised the cost even higher. Only large firms are viable under present conditions. If firms were smaller, the rate of change would be even slower or prices would be higher. Large firms are needed to run highly advanced technologies to meet our society's desire for product innovation.

All the changes discussed might seem to imply that the automobile has matured as a product, but this is not the case. In the first place, the automobile is not the relevant unit of analysis: the productive unit is a better focus. As long as new productive units are being added, or as long as existing ones are resisting extreme states of development, the car has not matured. There is every indication that new technologies are now being introduced, notably in electronics and engine controls.

Second, maturity must be defined in relation to the market's preferences. If the product line matches market needs, the product would be mature. This is not the case presently in automobiles. Recent regulations and the consumer's interest in fuel economy have changed the competitive environment. After years of progress in perfecting the U.S.-produced automobile for the established market environment, the environment has suddenly changed. There are now new targets for innovation. Until the product again fully satisfies both market and regulatory requirements, the industry will not mature. And with ever more stringent regulation and uncertain energy supplies there is certainly no match between future needs and the product. There is now reason to believe that the direction of evolution has reversed in several important productive units. This suggests that severe government action can be used to manage technology in industry. It does not guarantee, however, that all of the consequences will be positive.

CONCEPTUAL IMPLICATIONS

The ideas underlying the model have been illustrated by the changing characteristics of automobile engine and assembly plants. Product and process innovation are not isolated events; they are linked together and to the characteristics of the productive unit where they occur. The mainstream of technological progress occurs through evolutionary changes in the major characteristics of a productive unit, changes that are difficult to reverse and that normally move from the Fluid toward the Specific condition.

This model applies two ways, to the productive unit that creates an industrial good and to the productive unit that may adopt it either as process equipment or as a new component for its product. It is important to recognize that a product innovation in one productive unit may be viewed alternatively as a process innovation for the adopting unit.[7] The characteristics of both the creator and the adoptor require serious consideration if technological innovation is to be better understood. By representing the different types of innovation that such related productive units can accommodate in their respective stages of development, the present model offers a new way of examining the potential for innovation between supplier and adoptor.

Prior research findings about variations in innovative behavior in different settings and firms and from different disciplinary perspectives are not unrelated or independent phenomena. They may be reinterpreted as factors in this larger picture of technological progress.

Conditions for Innovation within the Firm

The management of innovation within the productive unit and the firm goes far beyond the problems of creating an environment that is favorable to radical innovation. Because radical innovations are interesting of themselves, they may have received undue attention, perhaps obscuring management requirements for technological progress in other forms. Special, but different, conditions are required for steady cumulative progress in high-volume established products and production processes: to reduce costs, improve productivity, perfect product features, and assure quality. These capabilities are found in a productive unit's more advanced stage of development. They are much different from those needed to achieve a high rate of major product innovation—characteristics akin to the fluid stage. Both types of capabilities are needed in our economy. Effectiveness in either form of technological progress involves balanced and matched characteristics, or capabilities, of different types. Consequently, there is a real danger that if both types of innovative capability are sought in one productive unit, effectiveness will not be realized in either. The conditions in a productive unit need to be internally consistent or matched with one another at different stages of development.

These ideas fit nicely with findings from earlier studies that have examined particulars of innovative behavior and technological progress, like organizational characteristics, or degree of concentration and capital intensity, or labor and automation relationships. They contrast, however, with recommendations that are sometimes drawn from the very same studies. The notion that the effective capability for innovation can be practically altered through the arbitrary introduction of innovative traits in any single characteristic, like a changed organizational structure, does not fit the observed requirements for balance. This would be equivalent to changing any one column in Table 7.1 without varying the other necessary characteristics.

The implication is that a given productive unit cannot respond well to all types of demands. It cannot be both highly efficient and support a high rate of innovation. Of course, a given firm can manage a portfolio of productive units, theoretically at different stages of development. Even for management at this level, however, there are problems, and the ideas of match and balance may extend in some degree to corporate management.

There is some evidence that corporations are limited in their ability effectively to manage several productive units (or business lines) that are in widely different stages of development. Very little systematic research has been done in this area but, as a practical matter, firms that are effective at one stage are seldom successful at the same time with productive units at an opposite extreme. Corporations such as the major automobile firms, petroleum refiners, or steel producers, that stand out as the most competitively successful in making mass-produced, standardized products are not frequent sources of radical new products. Conversely, successful "high-technology" organizations often experience difficulty competing success-fully in high-volume commercial markets. This model of balanced and matched capabilities helps to represent the different environments which managers in firms face at different stages of development.

Evenness of Progression

As a productive unit progresses from the fluid toward more advanced stages, its respective characteristics are modified through evolutionary and parallel development. There is a certain degree of evenness in this progression, and the movement is difficult to reverse. Explained in terms of Table 7.1, this can be seen as a parallel movement down the columns.

Transition from stage to stage is related to the experience or learning-curve phenomenon, in which spectacular rates of productivity improvement have been observed in products like the Model T Ford, rayon, incandescent light bulbs, and, more recently, pocket calculators. While the productivity improvement that accompanies this transition is vital to national progress, it is achieved with attendant losses. Productivity gains are realized through an associated change in stage of development with ramifications for innovative capability. While evidence from the present study suggests that productive units sometimes regain (or revert to) their earlier stage of development, the problems that arise are difficult to manage. They often depend on major changes in the environment that are beyond the control of managers in an individual firm. The strategic problems of managing productive units hinge on the issues of trading the possible gains in productivity against possible losses in innovative capability.

External Stimuli for Innovation

The nature of technological innovation takes on much different characteristics as the productive unit progresses from Fluid to Specific on the spectrum of development. There is no one best way to encourage technological innovation through external action or government policy, for the appropriate types of stimuli, the coupling between scientific advance and innovation, and the barriers to innovation all vary depending upon stage of development. The concept of innovation as a linear process, in which scientific advance stimulates innovation and ultimately broad commercialization, can mislead the selection of policies that would be most appropriate to encourage innovation in every stage.

Several factors change with the stage of development in addition to the particular types of innovation (product versus process and incremental versus major as discussed above). The locus of process innovation (where innovation originates) tends to move outside the firm that uses the process, and the role of scientific and engineering advances as a stimulating factor also changes (see below).

Fluid State Stimuli. Radical innovations underlying the creation of successful new businesses are seen to occur as an entrepreneurial act, corresponding to the fluid stage of development. The impetus is typically provided by individuals and organizations that are either users of the new product or have intimate insight about latent market needs. New Technologies or scientific advances are used as available to satisfy these new insights about user needs. Evidence from a variety of different viewpoints suggests that such innovations do not frequently occur through a process wherein advanced technologies seek out new needs, but instead a new understanding about needs draws in the best available technology. This is consistent with evidence that shows that radical innovations initially arise from without established large firms and industries. Advanced technologies may lie fallow until market conditions are correct and the necessary stimuli are present to nurture this type of innovation. It is true that advanced technological capabilities must be available to support major new technology-based products. This condition is far different, however, from that implied by the traditional linear model of innovation, which implicitly suggests that greater inputs of R&D offer an output of greater economic benefit. At this stage of development, actions to encourage the development of new market niches for high-performance products, and incentives to stimulate entrepreneurial action in desired areas of technological innovation, seem to offer better prospects for rapid progress.

Shifting Locus of Process Innovation. As a productive unit evolves from early Fluid condition toward a more advanced stage of development, the originating source of major process innovation shifts outside the unit. With automotive engines, for example, the present study shows that the major automobile firms were once the originators of major process innovations. The machine-tool industry has now become the major source of advanced process technology. Such a shift in locus is apparent in other industries like computers, where the rate of transition in development is rapid and capital equipment supplier firms have increased their contribution to major process innovation.

In terms of process innovation, it is significant that productive units that might be classed as "mature" or less innovative, such as coarse weaving mills in textiles or shoe producers or oil refineries, are the very same industries that look almost exclusively to other firms, their capital goods suppliers, for advances in manufacturing-process equipment. Those productive units that might be classed as innovative, like jet engine manufacturers, semiconductors manufacturers, and even Japanese automotive engine producers, contribute directly in process as well as product innovations.

These changes that occur in the evolution of an industry cause the linkage between scientific advance and ultimate economic application to shift and change in a corresponding way. For mature productive units the potential for innovation will depend heavily on technological progress by capital equipment suppliers, while this linkage will typically be less important nearer the Fluid stage. These types of dependencies are particularly evident in textile weaving and shoe manufacturing, where the characteristics of a few equipment producers have played a large role in innovation and productivity, or the lack of it, throughout the industry.

Science and Innovation

Several indicators suggest that the most direct link between science and innovation occurs for productive units in the midranges of transition, in the technologically active stage of development. At this stage the economics appear most favorable, and empirical evidence suggests that investment in R&D is indeed at a peak.

The economic justification would seem to be most favorable in such cases for three reasons. First, the markets are still volatile though already aggregated. Second, for this reason and because adequate profit margins can still be realized, the economic benefits from applying the results from a relevant R&D breakthrough are large and relatively sure. Finally, the cost of change will not have risen to the prohibitive levels that are likely to attain in the specific stage.

Data are not available to pinpoint actual R&D investment by productive unit, but evidence from several sources suggests that the largest investments in R&D are made by successful firms whose main lines of business depend on productive units in these middle ranges. According to a recent National Science Foundation survey, a handful of companies, twenty in all, spend more than half of all their funds for R&D within industry.

From his review of economic research on innovation, concentration, and R&D investment, Jesse Markham describes these firms that make high rates of R&D investment. The characteristics of such firms also suggest the nature of their major business lines, or productive units: "Data are beginning to suggest that large vertically integrated companies with relatively large market shares have a greater incentive to invest in R&D than other firms have." He goes on to cite specific research findings that show that "R&D spending is negatively associated with profits for companies having small 'relative market shares.' "[8]

Too much attention may have been given to radical innovation as a mechanism for exploiting the fruits of R&D investment. The mainstream of our economy and the United States position in crucial international markets require competitive success in high-volume established products. It is here that our scientific and engineering capability may have its greatest advantage. This would also seem to be the lesson from the Japanese experience. They have succeeded in applying technology to improve major products in established industries like automobiles, cameras, consumer electronics, and steel. Perhaps national R&D investments should seek their major benefits in existing major productive units. This concept is likely to be controversial, for it is contrary to other recommendations calling for more R&D investment to encourage innovation in new industries.[9]

For productive units that have evolved to a highly advanced, or Specific, state of development, advanced technology still fills an important role. Here innovation is more incremental in nature, however, and it is often stimulated by competitive pressure on prices and the need for greater efficiency and quality standardization in the product and manufacturing process. Changes in the environment, shortages of materials, and the threat of government regulation provide the greatest stimuli for major innovation in productive units at this stage of development. Stated another way, in this case government regulations or changes in the competitive environment that act to fragment mass markets and create niches for new products may encourage innovative product designs. Such disruptions are not achieved without attendant cost, however, and can be expected to cause dislocations and to raise costs as economies of scale are lost and the conditions supporting efficiency are disrupted.

The model predicts that productive units at different stages of development will respond to differing stimuli and undertake different types of innovation. This idea extends to the question of barriers to innovation and probable patterns of success and failure in innovation for units in different situations. For productive units in an early stage of development, factors that impede product standardization, or market aggregation, or lack of capital are barriers to innovation. Conversely, for those nearer the specific state, disruptive factors like uncertainty over government regulation or labor demands are the most important barriers to the normal direction of technological progress. At the same time, these same factors that reverse the normal direction of technological progress may evoke more radical innovation, although with attendant productivity consequences.

In sum, then, the effects of alternative government policies and management action will vary, depending on the productive unit's stage of development. Actions that encourage standardization or market aggregation may increase the rate of technological progress in one case, while actions that disrupt markets may be associated with another type of progress in other circumstances.

FINAL QUESTIONS

The ideas presented in this study outline a framework for evaluating the cluster of conditions that support technological change. The descriptive model will not represent every case or, perhaps, even most cases. Only future investigation will show which situations do or do not fit the model. It does fit some important cases, however, and by highlighting regularities that are important in these cases it can help to focus attention on exceptions in other situations. It may be more important to understand why a regular pattern of progress is not realized than to seek a universal explanation.

A model or framework of this type can be helpful if it can clarify consistencies or inconsistencies among policies in widely different areas that must be coordinated as a condition for progress. Answers to four different questions raised in chapter 1 help to illustrate the variety of issues that are encompassed by the model:

(1) Can a firm decide to increase the variety and diversity of a product line while it simultaneously realizes the highest possible levels of efficiency?

(2) Is a policy that envisions a high rate of product innovation consistent with one that seeks to reduce costs substantially through extensive backward integration?

(3) Is government policy action that would enforce a low level of market concentration in technologically active industries consistent with a policy that envisions a high rate of effective product innovation?

(4) Would a firm's action to restructure its work environment for employees so that tasks would be more challenging, require greater skill, be less repetitive, and embody greater content be compatible with a policy that proposed to eliminate undesirable direct labor tasks through extensive process automation?

"No" is the answer prompted by the model to each of these questions. On the basis of current hypotheses, each question suggests a pair of actions that are mutually inconsistent in respect to either forward or reverse transition.

The model clarifies the ramifications that follow from actions that accompany a regular pattern of technological development. It is not assumed that progression toward a more advanced state of development is always beneficial or inevitable. To the contrary, it may be argued that management can and should control both forward and reverse transition. If a typical path of transition can be described, then better judgments can be made about the advantages and disadvantages of reaching a new stage of development.

Neither extreme state, Fluid or Specific, would be attractive to the firm or to the economy as a whole. In the Fluid state, the future is uncertain, productivity is low, and any particular unit is apt to experience economic and personal failure for those involved. In the other extreme, Specific condition, continued transition may first be slowed and then halted in the economic stagnation or even death of a productive unit. This may take the form of a geographic migration of production to less-developed areas or countries, where the factor prices of production are low enough to support continued economic vitality. Or it may take the form of absorption and restructuring of product and process, as was the case with the demise of the gaslight companies at the turn of the century. Or it may be a case of attrition, as with the slow death of telegraph services, provided initially from a dominant position by Western Union, following its strategic decision in the early 1900s to limit its communication interests to nonvoice media.

A sustained policy of product innovation and of constantly reconceptualizing market needs and opportunities can provide the mechanism for avoiding these extremes. In planning such a policy, the present framework seeks to make the unfavorable as well as the favorable implications of continued technological advance more obvious.

TABLE 7.4. Events Highlighting Stages of Development of the Engine Plant

			*Factor**	*Stage* Change to*
1905	Program to improve manufacturing process undertaken. Concept of progressive flow in process configuration placed in application.		C	2
1905–7	Horizontal and vertical integration into primary engine parts manufacture to round out manufacturing capacity—pressed parts, machining operations, etc.		G	2
1907	Systematic purchasing policies introduced to reduce cost of inputs and stimulate suppliers to develop new components (vanadium steel innovation, forward planning of requirements, and competitive bidding).		F	2
1908	Tasks largely deskilled, but division of labor not extensive.		D	2
1910	With move to Highland Park plant and large expansion in facilities:			
	Program initiated to support development of efficient special-purpose machine		E	2
	tools	(by 1913)	E	3
	Started further backward integration into engine parts, foundry operations, forging, etc.	(by 1915)	F	4
	Start of program to put broad-based manufacturing capability in place in one facility with a variety of relevant process technologies	(by 1915)	G	3
1911–13	Most tasks redesigned to reduce division of labor; begin use of moving conveyors and progressive assembly in engines.		D	3
1913–14	By 1914, extensive use made of conveyors, gravity feeds, or moving assembly and other methods of line-flow management in process organization.		C	3
	Following settlement of Seldon patent suit (which struck down claim on broad concept of internal-combustion		A	4

TABLE 7.4. (Continued)

		Factor*	Stage* Change to
	auto), uncertainty over commitment to Model T design was reduced and market was pursued.	B	3
1914	Renewed emphasis placed on cost and price reductions through standardization in all components. By 1916 prices in some cars reduced by 41 percent over late 1913 prices, but functional and cost-reducing changes	A	4
	still being made.	B	3
1917–18	Refinements continue but increasingly on incremental basis (for example, cooling-system improvements).	A	5
1920–24	Period of extreme standardization, very high volume, and little change (2 million cars a year produced,	A	5
	higher than any rate at Ford until 1950s).	B	5
1920–24	Tightly balanced, near-continuous line-flow configuration in manufacturing and assembly; lathe beds cut	C	3½
	short so they would fit in line.	D	3
	Extensive backward integration into iron mining, blast furnace operation, etc.	F	5
1925–26	Competitive advances caused obsolescence in engine design and major loss of market share and volume (overheating of engine, vibration, manual starting, planetary transmission rather than shift, etc.). At-	A	3
	tempts still made to continue policy of product standardization through cost reduction and minor change.	B	4
1927–28	Complete shutdown and new crash start-up with experimental development of new Model A power train, new engine, transmission, carburetor, etc., but still on basis of prior 4-cylinder engine concept. Initial	A	3
	period of introduction and start-up (1927–28) marked by design improvement.	B	3
	New components and materials used, replacing some sources (aluminum pistons).	F	4
	Most prior specialized machine tools scrapped.	E	2½
1929	New process equipment developed and purchased.	E	3
1930–31	With wide market acceptance of Model A, overtaking Chevrolet, policy of product standardization, allow-	A	4
	ing only minor change, resumed.	B	4
	Further backward integration undertaken.	F	5
1932	Experimental development and introduction of V-8 engine; first low-cost, single-cylinder block-casting engine in industry; extensive disruption.	A	3
1932	Improvements continued to be introduced during mid-1930s.	B	3
	Much prior process equipment rendered obsolete by new design; new equipment developed.	E	2½
	New materials and components required.	F	4
1934–39	Refinements and improvements to engine continue to be made but basic design remains standard for twenty years (cast-iron crank and camshafts added	A	4
	and variation in CID made).	B	4
1945–46	Major investments made in developing new process equipment; introduction of multiple-transfer machines begun.	E	4

TABLE 7.4. (Continued)

		Factor*	Stage* Change to
	Backward integration into materials—steel manufacturing, rolling mills, casting facilities, etc.	F	5
	Major disruption in materials sources due to World War II shutdown and postwar material and component scarcities.	F	2
	V-8 and IL6 engines are dominant types.	A	4
	Move toward new product division organization started, ultimately giving product divisions their own production facilities.	B	3
1947–48	Engine plant and engine foundry placed under management separate from other manufacturing units.	G	4
	Backward integration position reestablished.	F	5
1952–53	Cleveland engine plant placed in operation, representing major advance in extensive integration of process through introduction of transfer machines and automation, separation of engine and foundry capacity into separate, decentralized facilities managed as a separate plant, focused to a particular engine.	E G C	5 5 5
	Predominant characteristic of labor task changed to process overseeing and system maintenance.	D	5
1954–59	Horsepower war starting, causing increase in size of engine.	A B	4 4
1961–67	Decrease in frequency of model change and end of horsepower race causes greater standardization in engines.	B A	4 5
1968–70	Management of engine plant separated from that of foundries because management problems differ.	G	5
	Environmental controls increase rate of design change in engines.	B	4
1971–72	Small 4-cylinder engine introduced into line, and environmental requirements raise uncertainty about dominance of existing engine design.	A B	4 4

* The factor refers to the column heading and the stage refers to the row in Table 7.1.

TABLE 7.5. Events Highlighting Stages of Development of the Assembly Plant

		Factor	Stage Change to
1907	Systematic purchasing policies introduced.	F	2
1905–7	Horizontal and vertical integration into production of chassis parts, rounding out capacity.	G	2
1905–6	Move toward progressive manufacturing initiated with successful standard model—Model N.	C A B	2 2 2
1910	Backward integration into some material (foundry, wood, etc.) started with move to new Highland Park facility, some suppliers absorbed.	F	3

TABLE 7.5. (Continued)

		Factor	Stage Change to
1910–11	One dominant chassis design adopted (Model T), bodies still varied; 20 percent market-share increase.	A	2½
1910–18	Periodic incremental improvements introduced in chassis; bodies changed frequently.	B	2½
1912–14	Division of labor increased in assembly.	D	3
1914–15	Moving assembly-line innovation for final assembly.	C	3
	Assembly operations begin to be decentralized in regional assembly plants.	G	3
1918	Extensive decentralization of assembly into regional assembly plants achieved.	G	4
1920	Period of high standardization in chassis production begins. Bodies continue to vary.	A B	3½ 3½
1924–25	Chassis configuration made obsolete by market trend to closed body. Chassis changes and new closed body line tried experimentally, then adopted; 15 percent market-share loss.	A	2
1925–26	Change in body still frequent, but chassis standardized.	B	2½
1925	Body production incorporated in assembly plants; stationary body framing mixed with moving final assembly in same assembly plants.	C	2½
1925	Extensive backward integration into bodies and materials achieved (wood for frames, fabric weaving, glass manufacturing, body parts, etc.).	F	5
1926–28	Model T design rendered obsolete by market trend, market position lost to GM. Experimental development of new model undertaken (Model A) and introduced; 30 percent market-share loss.	A	2
1927–28	One-half of bodies purchased, many other prior chains of vertical integration rendered inappropriate as inputs to new model.	F	3
1929–31	With market success of Model A, prior policies of standardization resumed. Backward integration in bodies and other components reestablished.	A B F	4 4 4
1932–33	Model A rendered obsolete by market trends and entirely new model experimentally developed; new bodies' chassis and V-8 engine; 15 percent market-share loss.	A B	2 2
	Model change made some prior sources arrangements inappropriate.	F	3
1932	Introduction of some special-purpose process equipment begun.	E	1½
1933	Start of competitive annual-model-change era by Ford.	A	3
	Car bodies evolved rapidly through changes made during remaining years of decade. (Appendix 2).	B	2
1936	Further backward integration achieved in steel and other materials and components.	F	4
1939–41	Successful streamlined body designs are in place (Appendix 2).	B	3
1941–46	Shut down during World War II; supply sources unreliable following war.	F	2
1945–57	Backlogged demand after World War II encourages product standardization; period of increasing market share.	A B	3½ 3

TABLE 7.5. (Continued)

		Factor	*Stage Change to*
1947	Normal sources and backward integration reestablished following World War II.	F	4
1950–60	Move toward organization and management of assembly capacity by type of product line (Ford-Mercury) rather than functionally by type of body. Returned to functional, centralized control after 1960s (Appendix 2).	G	3½
1955	Beginning of trend introducing special automated process equipment in assembly plants (welding presses, multiple nut runners, etc., integrated into line-flow process).	E	2½
		C	3
1958–60	Frequent model change—short-duration models (Mercury, Edsel changes); 2 percent market-share loss.	A	3
		B	2
1960	Successful, compact unit-construction car introduced. Rate of model change reduced.	A	3
		B	3
1965	Start of sharp trend toward specialization of assembly plant to particular car, for example, Mustang.	G	4
1967	Beginning of trend toward slowed model change, extensive use of common body/chassis designs spanning several market segments, and long-lived small-car models.	A	3½
		B	3½
1970	Integration of machines at some stations to form transfer lines.	E	4

TABLE 7.6. Labor Content Data for Engine Plants

Year	*Labor Hours per Engine*	*Model*		*Data Sources**
1913	35	Model T		a
1914	23.1	Model T		a
1916	17.3	Model T		a
1917	16.5	Model T		a
1918	16.3	Model T		a
1922	14.3	Model T		a
1924	14.9	Model T		a
1926	16.0	Late Model T		b
1928	29.0	New Model A		b
1931	18.0	Late Model A	Extrapolated from direct time study data, engine assembly, wage rates, and accounting data, giving direct labor for chassis components.	b
1932	19.5	Model B, IL-4		b
1932	59	Model 18, V-8		b
1938	19.5	V-8		b
1939	20	V-8		b
1949	14.2	V-8 car and truck		c&d
1950	15.1	V-8 car and truck		c&d
1953	9.0	V-8 car and truck		d
1966	8.5	V-8 truck (old plant)		d
1970	8	V-8 car and truck (high-volume plant)		d
1972	10	V-8 truck engine (low volume)		d

TABLE 7.6. (Continued)

Year	*Labor Hours per Engine*	*Model*	*Data Sources**
1972	8.2 overall	For plant engine mix (9.4 large V-8, 6.7 hrs. IL-4)	e
1974	9.5	Large V-8 engines (low volume)	d

NOTES:

Data through 1939 include labor costs of manual transmission, which represents approximately 20 percent of the labor hours given above, based on 1924 records.

From 1953, labor content excludes direct foundry labor included in earlier stattistics. It is estimated that this introduces no more than a 5 percent difference.

Data are approximations of direct and indirect labor hours. Pre-World War II data are based on accounting records; post-World War II figures are based on total employees per plant.

* DATA SOURCES:

a. Model T Cost Books, Ford Archives, Henry Ford Museum, Greenfield Village, Dearborn, Michigan.

b. Cost Studies Accession 250, Ford Archives.

c. Allan Nevins, and Frank Hill, *Ford: Decline and Rebirth* (New York: Charles Scribners, 1963), pp. 345–76.

d. Ford Motor Company, *Facts and Figures*, respective years. The necessary assumptions as to number of shifts covered in stated employment rates, from 1 to 3, were based on estimates of output rates for engines produced.

e. D. N. Williams, "NEP Evaluation Speeds Pinto Engine Naturalization," *Iron Age*, January 20, 1972, p. 27.

TABLE 7.7. Labor Content Data for Assembly Plants

	Assembly Plant Labor Hours/Car			
Year	*Including Body Assembly and Finishing*	*With Preassembled and Painted Bodies*	*Vehicle Type and Plant Location*	*Data Sources*
1914	73		Model T before moving assembly line (N.J. Branch)[e]	d
1916	38	17	With moving assembly line (Mass. and Tenn. Branch)[e]	a
1917		16	Open car (Mass. Branch)	a
1920	21	14	In plant finish, closed car versus finished open car (Mass. Branch)	a
1924 (Sept.)	47		New Tudor closed body, introducing standard assembly plant body (assembly and painting) (Ave. of Branches)	b
1926	34		Closed Tudor bodies, Late Model T (Ave.)	b
1926	33		Mix of bodies, Late Model T (N.J.)	d
1928	66		Closed Tudor body, New Model A (Ave.)	b

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7.7. (Continued)

Assembly Plant Labor Hours/Car			
Including Body Assembly and Finishing	*With Preassembled and Painted Bodies*	*Vehicle Type and Plant Location*	*Data Sources*
29		Closed Tudor body, Model A (Ave.)	b
26		Mix of bodies, Late Model A (N.J.)	d
47		Mixed Ford bodies, New model —body, frame and engine (Ave.)	b
37		Mixed Ford bodies V-8 (Ave.)	b
38		Mixed Ford bodies V-8 (Ave.)	b
27.8		Mixed Ford bodies V-8 (Ave.)	b
28–29.5		Mixed Ford bodies, comparative data for 60-hp Delux Ford (Ave.)	b
28		Mixed Ford bodies (Ave.)	b
27.5–28.8		Mixed Ford bodies (Ave.)	b
60		100 hp, Super Delux Tudor Sedan (Ave.)	b
31		Average for four locations	b
28.8		Data average for four locations	b
33		Station wagon (Michigan)	d
32		Station wagon (Michigan)	d
34–37		Large Mercury car, San Jose assembly plant (proposal) (Calif.)	d
28		Compact car, UBC 7 body (Michigan)	d & c
26		Compact car, UBC 7 body (Michigan)	d & c
27		Compact Car, UBC 7 body (Michigan)	d & c
29		Compact car, new body introduction, UBC 10 (Michigan)	d & c

ıTA SOURCES:
Accounting Data, Ford Archives.
Cost Study, Ford Archives.
Ford Facts and Figures, respective years.
Employment and Operating Rates Data, Ford Archives Assembly Plant Rec-

Location of Assembly Plant N.J.: Edgewater, N.J.; Mass.: Cambridge or ille, Mass.; Michigan: Dearborn (Central Ford Facility); Illinois: Chicago; Memphis; Calif.: San Jose, Calif.; Ave: Average of several locations.