2 TECHNOLOGICAL CHANGE IN THE U.S. AUTOMOBILE INDUSTRY: A HISTORICAL OVERVIEW

The United States automobile industry was born in Springfield, Massachusetts, in 1896, when J. Frank Duryea made thirteen cars from the same plans. This was the first time in the United States that two cars were made from the same design and the first time that cars were produced for sale.[1]

During the next ten years, developments were typical of an emerging industry. A great diversity of products appeared on the market. Each automobile was produced in very limited quantities, often to consumer order, and each model was rapidly made obsolete by succeeding models. Most models were built by entrepreneur-tinkers in their own back yards or in local machine shops, using equipment that was rudimentary, even at that time. At the turn of the century, the Stanley brothers designed and built their own steam-driven automobile and drove it to the top of Pikes Peak; electric, gasoline, and steam cars were built in many eastern and midwestern cities; and Henry Ford, who had already built one car in his spare time, was beginning to build a second.[2] By 1909, there were sixty-nine manufacturing firms in the industry, each committed to its own design. But technological change was rapid, and only half of these firms survived for even seven years.[3]

Today there is little real diversity among the various U.S. automobile designs. The 350 models of U.S. manufacturers offer options in respect to size, price, horsepower, and fuel economy, but in basic design features they are all very similar. Today, basic design changes very slowly, and the changes that do occur no longer spring from competition among technological entrepreneurs in the industry. The most important impetus for radical change now comes from pressures outside the industry—the Arab oil crisis, Environmental Protection Agency action, competition from foreign car manufacturers. Major components of the automobile are manufactured in highly specialized and automated production plants; the scale and capabilities of these facilities are now critically important in determining the types of changes that can be made in the product.

Innovation has given way to standardization as a competitive tool;

product diversity has given way to economies of scale; and external pressure on the industry has replaced entrepreneurial action as the major stimulant of technological change. The number of firms has decreased from around seventy to four, and the economic role of the industry has changed from producing an irrelevant luxury for the upper class to providing a vital source of national employment and transportation.

THE PERSPECTIVE

That these changes have come about is a matter of general public knowledge. There is broad agreement that the rate of major innovation has slowed, but there is no consensus about how serious a problem this is or what the causes are.

Explanations tend to reflect the particular viewpoint of the authority at hand. Ralph Nader claimed in his testimony before Congress that the slow rate of real innovation was due to lack of competition in the industry.[4] A U.S. Department of Commerce report claimed that the relatively low rate of innovation among firms in the automobile and steel industries was due to lack of "management ability." The study says: "We find the major barrier is one of attitude and environment. It is a problem of education—not of antitrust, taxation or capital availability."[5] The late Senator Philip A. Hart of Michigan attributed most of the problem to concentration among the firms in an industry: "New technology should be taking us in another direction—toward deconcentration, [and] greater efficiency in smaller units. But its natural thrust has been distorted—new technology has been used to rationalize the very theory it has proved to be a lie—that bigness is inevitable in a technology-oriented economy."[6] Senator Hart's statement nicely focuses the question: What is the "natural" direction of technological change and what causes it?

PRODUCT ADVANCES

Emerging consumer needs, not new technological capabilities, triggered the rapid development of the U.S. automobile industry at the turn of the century. A practical steam-powered car could have been produced twenty years earlier.[7] Allan Nevins observes that the industry was born from the consumer's desire for a light personal transportation vehicle, a desire stimulated by the bicycle boom of the 1890s. Hitherto, the motor-powered vehicle had been envisioned as a product for the commercial transportation industry, not the consumer. The firms that had the technology to produce steam engines were oriented toward railroads, shipping, and industrial application.[8]

Men with experience in the bicycle industry were the first to see the possibilities of the automobile as a means of personal transportation. Their technological orientation led them to improve the automobile's performance through lightweight designs, high-strength materials, and low-friction ball bearings rather than increased motor power. This orientation toward a lightweight vehicle suited to personal transportation was important in shaping the development of the U.S. automobile industry. It helps to explain why new firms were more successful in this new industry than the established transportation-equipment manufacturers of the nineteenth century.

The Fundamental Engine Choice

Competition among electric, steam, and gasoline engines at the turn of the century started the long sequence of market-determined design decisions that set the characteristics of the present-day U.S. automobile. The choice of an engine was the pinnacle in a hierarchy of design choices that established constraints for other choices in components. The choice has only recently been reversed.

The internal-combustion gasoline engine was initially a poor third choice among the three alternatives, but it developed rapidly. Before 1900 both steam and electric cars were more successful and reliable. Steam cars won the local and national races, and many electric cars were produced for consumer as well as commercial uses. In 1900 a gasoline-powered car defeated electric and steam cars for the first time in a free-for-all race at Washington Park racetrack in Chicago and, after this, improvements and market acceptance came rapidly.[9] Races played major roles in stimulating advanced designs, as experimental proving grounds, and as advertising. When Barney Oldfield won his first major automobile race in the 999, its builder, Henry Ford, received broad recognition that was helpful in founding the Ford Motor Company.[10]

The dominance of the gasoline engine was largely established by 1902, when the Olds Motor Works (predecessor of Oldsmobile) produced and sold twenty-five hundred small two-cylinder cars. By designing a light car, introducing mass production, and pricing the car at only $650, a 30 percent share of the U.S. market was gained, and for the first time competition was focused on one large market segment.[11] The Olds Motor Works was recognized as the world's first company to mass produce cars, and its success in the low-priced end of the market foreshadowed the competitive pattern the industry would follow for the next quarter of a century.

In rapid succession, the engine and "power-train" features of today's car were perfected and introduced.* Buick relocated the engine in the front

* The power train includes the engine, transmission, clutch, drive-shaft differential, and axle. The term refers to the mechanical components that generate power and transmit it to the driving wheels.

of the car in 1903; the now-familiar four-position transmission, with positions in the shape of an H, was patented by Packard in 1904,[12] and the Ford Motor Company introduced a series of models from A to R that advanced progressively toward a moderately priced four-cylinder car. The earlier photographs showing six of these models, in Plate 1, help convey the rapid rate of change in this period.

In steps and stages Ford made the engine and the rest of the power train to the wheels more reliable, cheaper to produce, and easier to maintain. Initially, the block and head for each of the engine's cylinders were cast together as one unit. Ford redesigned the block and cylinder as two separate parts that could be cast and machined with fewer difficulties. The engine was mounted longitudinally with the car, as is current practice, instead of transversely, or across the car. The earlier bicyclelike chain coupling between the engine and transmission and the wheels was replaced with a direct drive shaft to the rear wheels using the "torque-tube" principle; and the steering wheel was located on the left-hand side of the car.[13] By 1907 many of the features that distinguish the overall characteristics of today's car were in use, but they were not all used on the same car, and there was no clear indication of the best combinations.

The Fundamental Chassis Design

The Model T, which Ford introduced in 1908 at a price less than $1,000, was a spectacular success. It established the essentials of a dominant design at a higher level of component aggregation—the chassis.† The Model T chassis embodied an innovative synthesis of the industry's major advances up to that point, plus a few Ford innovations. Ford used a high-strength vanadium steel alloy in critical chassis components to reduce the overall weight by as much as one-half that of comparable cars. In past cars, the engine was often rigidly secured to the frame, and frequently even the cylinder blocks were twisted in half by the enormous strain that resulted when the car hit a rut or hole. Instead of strengthening the frame, the Model T introduced a three-point motor suspension that isolated the engine from the twisting forces that the frame absorbed. The ignition was powered by a magnet, so the traditional dry-cell batteries were no longer needed. Other new features included tough, flexible construction, high road clearances, and other mechanical dimensions suited to the rough roads and the essentially rural market the car was designed to serve.

For eighteen years the design of the Model T chassis was not significantly changed. During this period the industry's production of passenger

† The chassis is the whole car, except for the body. The chassis includes the frame, engine, transmission, brakes, wheels, radiator, and other mechanical components except the passenger enclosure (body) and its appointments.

EVOLUTION OF CARS IN MASS PRODUCTION

Comparing the 1908 and 1926 Model Ts shows that the design changed significantly in response to Henry Ford's policy of product standardization. Among the changes were the substitution of electric for acetylene lights, the use of a steel body instead of a wooden one, and the introduction of demountable wheels to facilitate tire repair. In addition, the 1926 version included an electric starter and a bumper. But with improvements also came efficiency-oriented losses; the magnificent brass radiator, brass fittings, and leather upholstery of 1908 had given way to austerity by 1926.

As a comparison of Ford cars manufactured between 1931 and 1942 will show, this was probably the period of the most rapid evolution in body styling. The car became more streamlined, headlights were absorbed into the fenders, and running boards were systematically eliminated in a series of changes that took place over ten years.

THE IMPRINT OF PREDECESSOR INDUSTRIES

Plate 1 shows the confluence of both the carriage and bicycle technologies in the early models. The footboard, seating, steering, and brake configuration in Ford's first car reflected the conventions of horse-drawn vehicles. The wire wheels and tires, however, showed the imprint of the bicycle industry. These features persisted in the Model C but evolved toward a unique automotive design in subsequent models.

THE RAPID PACE OF EARLY PRODUCT DESIGN

The rapid pace of design improvement in the early models can be discerned by comparing the step-by-step changes within the series of models A, C, and R, which were produced for the lower-price segment of the market. Notice that with progressive designs the engine was moved forward. In the Model A, power was applied to the rear wheels by a chain that was connected to a gasoline engine under the driver's seat. (The chain can be detected through the rear-wheel spokes, Plate 1b.) The Model C shows a clever styling response to a rapid shift in market preference for a front-mounted engine. The body was cut off at the footboardlike front end and replaced with a simulated engine housing. The engine's actual location remained under the driver's seat. Concurrently, the chassis was lowered, running boards appeared, and fenders began to take form over the wheels. In the later Model R the engine was front-mounted, behind the radiator, and the chain was replaced by the now traditional drive shaft. The pictures indicate that right-hand steering was used through Model R; not until production of the Model T did left-hand steering become firmly established.

EARLY MODEL DESIGNATIONS

The model numbers are indicative of the change and variety in the automobile industry's infancy. The Ford Motor Company was incorporated in 1903, and its first car model was designated the Model A, although Henry Ford had apparently first designed and built the car before incorporation. Numerous models were designed, built, and introduced over the next five years, addressing different markets, with model designations A through T. Only seven of these early models are shown here. All previous models were discontinued once the Model T proved to be successful. When the production of Model Ts was finally halted in 1926, after a phenomenal production record, Ford decided to retire the old model designation series and begin anew. So in 1927, twenty-five years after Ford had produced the first Model A, a second car also bore this model designation. Shortly after a second-generation Model B was introduced in 1932 alphabetic model designations were discontinued in advertising Ford cars; the policy of annual model changes had been adopted.

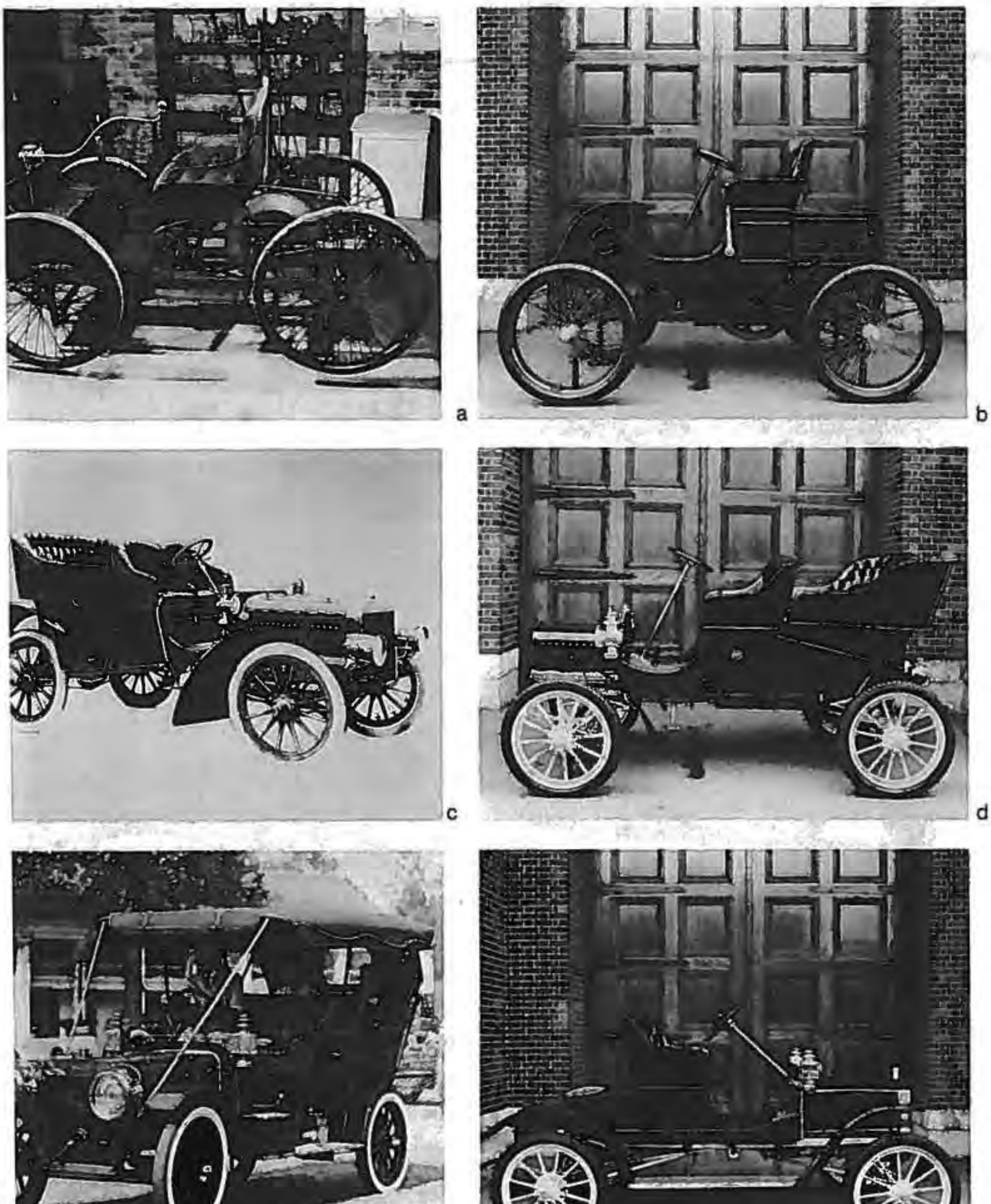


PLATE 1. *a*, Henry Ford's first car, 1896—a hobbyist's creation; *b*, Ford Model A, 1901–1903—Ford Motor Company's first car, list price $800; *c*, Ford Model B, 1904–1905—Touring Car body, list price $2000; *d*, Ford Model C, 1904—Touring Car body, list price $1000; *e*, Ford Model K, 1906–1907—Touring Car body, list price $2800; *f*, Ford Model R, 1906–1908—Runabout body, list price $750. (Photographs courtesy of the Ford Motor Company.)

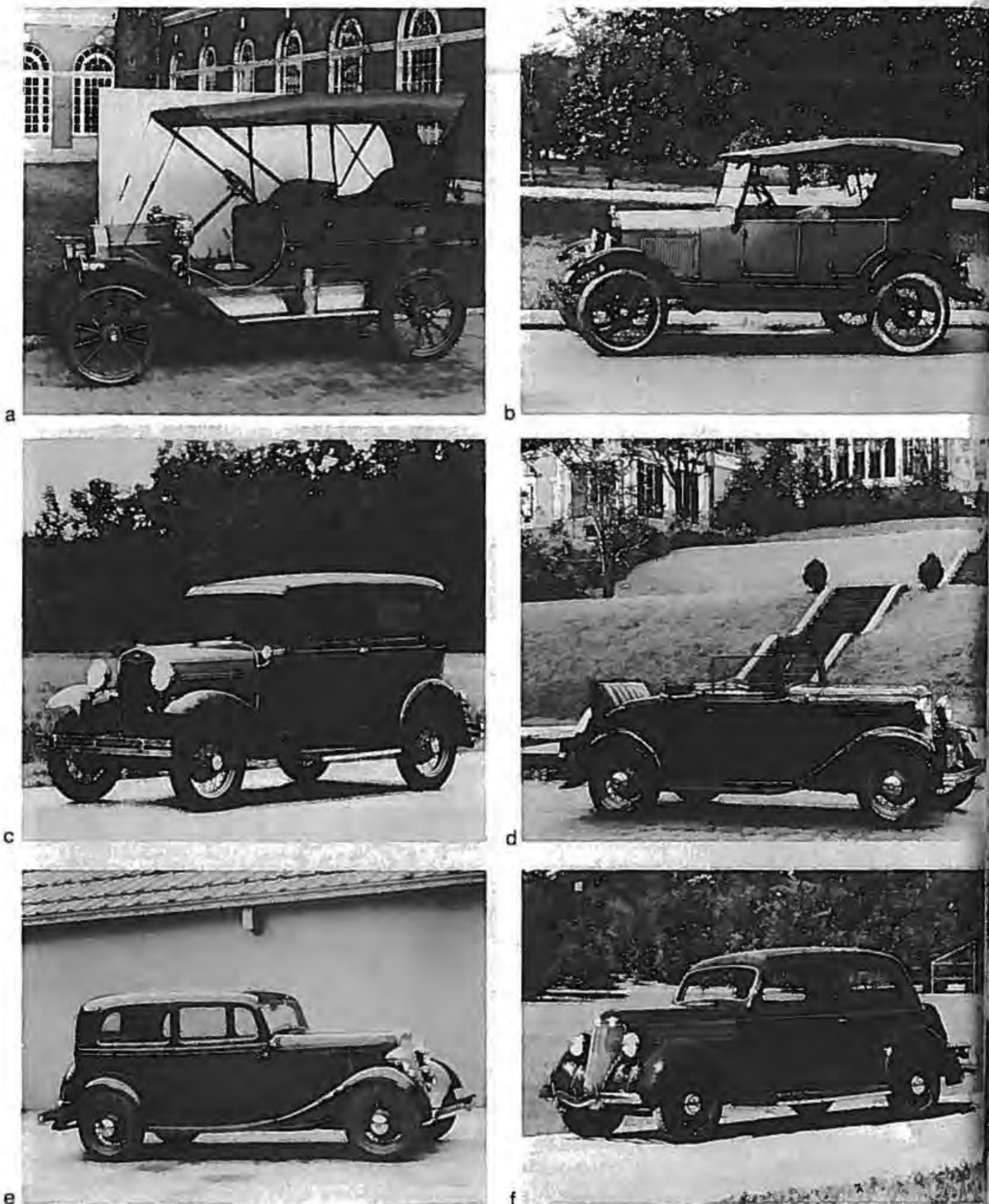


PLATE 2. *a*, Early Ford Model T, 1908–1909—Touring Car body, list price $850; *b*, Ford Model T, 1926, the last production year—Steel Touring Car body, list price $380; *c*, Ford Model A, 1927–1931—Tudor Sedan body, list price $500; *d*, Ford V-8, 1932—Sport Coupe with rumble seat, list price $535; *e*, Ford, 1933—Tudor sedan, list price $550; *f*, Ford, 1936—Tudor Sedan, list price $565. (Photographs courtesy of the Ford Motor Company.)

PLATE 3. *a*, Ford Coupe, 1938—list price $685; *b*, Ford Fordor Sedan, 1939—list price $765; *c*, Ford Fordor Sedan, 1941—list price $775; *d*, Ford Coupe, 1942—basic model produced after World War II and until 1949; *e*, Ford Fordor Sedan, 1949—the new postwar model; *f*, Ford Granada, 1978. (Photographs courtesy of the Ford Motor Company.)

TABLE 2.1. Passenger Car Sales in Selected Years from U.S. Plants

1899	2,500	1910	181,000	1921	1,468,067	1932	1,103,557
1900	4,192	1911	199,319	1922	2,274,185	1935	3,273,874
1901	7,000	1912	356,000	1923	3,624,717	1940	8,717,385
1902	9,000	1913	461,500	1924	3,184,881	1945	69,532
1903	11,235	1914	548,139	1925	3,735,171	1950	6,665,863
1904	22,130	1915	895,930	1926	3,692,317	1955	7,920,186
1905	24,250	1916	1,525,578	1927	2,936,533	1960	6,674,796
1906	33,200	1917	1,745,792	1928	3,775,417	1965	9,305,561
1907	43,000	1918	943,436	1929	4,455,178	1970	6,546,817
1908	63,500	1919	1,651,625	1930	2,787,456	1975	7,050,120
1909	123,900	1920	1,905,560	1931	1,948,164		

SOURCES: Automobile Manufacturers Association, *Automobiles of America* and *Automotive Industries*, Annual Statistical Issue, respective years.

cars increased nearly sixtyfold, from 63,500 cars annually to 3,700,000, as shown in Table 2.1. Ford maintained about a 50 percent market share through 1924.

Ford's strategy caused an inverse product-adoption pattern in the United States that is unparalleled in any other high-cost consumer product. The wave of product adoption moved from remote areas toward the city. The mass market first developed in small towns, rural settings, and farms.[14] Above all else, Model T buyers needed basic transportation. This and the fact that there were initially no competitors in the low-priced market segment explains why Ford was able to dominate the U.S. market for so long with one unchanged model.

Through its success, the Model T had the effect of establishing many design features. These features include the water-cooled front engine with drive shaft and rear-wheel drive, left-hand steering, independent chassis and body construction (the body is manufactured separately and installed on the chassis), front and rear bumpers, and the essential driver controls of today's car.

Closed Steel Bodies

The very concept of the automobile was changed for the consumer by an early technological advance in body design. The introduction of closed steel bodies during the 1920s raised a whole new set of criteria for automotive design—passenger comfort, room, heating and ventilation, and quietness of ride.

As late as 1920 about 85 percent of the U.S. passenger vehicle bodies were constructed of wood. They were open; that is, they did not have solid sides and tops for the passenger compartment.[15] A closed wooden body was not widely used because it was expensive and did not stand up well on rough roads. Open bodies had been available in many varied styles, and in most cases the bodies were not produced by the company that manufactured the chassis. Ford, for example, produced few of its bodies before 1925.

In 1921, Hudson offered its Essex with an enclosed steel (that is, steel-clad wood) coach body for $1,245. The significance of this price is shown by comparison with the traditionally designed closed Hudson body, which alone cost about $1,100.[16] The closed steel body was very successful, and by 1926 over 70 percent of passenger cars were of closed construction. The premium price charged for closed bodies over open ones dropped from about 50 percent in 1922 to 5 percent in 1926. This conversion to closed steel construction was largely achieved in six years.

The closed steel body greatly increased investments by the manufacturers, for it required expensive sheet metal-forming equipment. Many firms were forced out of the industry, and by 1925 only forty-nine U.S. passenger-car manufacturers remained. There was a corresponding reduction in the body options available to the customer.

The early closed steel body resembled a rectangular rolling box, but it introduced the basic concepts of today's car. It established sheet steel as the basic construction material and the problem of effective passenger and luggage space containment as a major competitive criterion in automobile design.

Streamlined bodies evolved through incremental changes in the earlier steel bodies. The Chrysler air-flow design and the Studebaker Land Cruiser were pioneering designs that started the trend. Studebaker innovated in replacing wooden structural members. Sections of sheet-metal body components were formed to provide reinforcement so that the body shell and its reinforcing members were integral. The streamlined body and the ability to mass produce deeply contoured sheet-metal parts developed hand in hand. The last body part replaced by sheet steel was the fabric insert in the center of the top. It was not until the steel industry developed wide widths in rolled sheet steel that a one-piece steel turret top was introduced to eliminate this insert. Fisher Body of General Motors was the first to introduce the turret top in late 1934.[17] By 1940 virtually all major designs had streamlined bodies, fenders and running boards had been absorbed into the bodies, and headlights were recessed into fenders. Many of these changes are illustrated by the year-to-year differences in Ford models during these years as shown earlier in Plates 1 and 2.

The Universal Automobile Design

The new post–World War II models were introduced by all major U.S. manufacturers around 1948. They were innovative in the sense that they offered better-designed bodies and optimized the overall design of the automobiles to serve emerging postwar demands. The major innovation was the automatic transmission, which General Motors first introduced in mass production just before World War II.

This era was a plateau. The necessary technology for the major components of the car had been established during the prewar years and, for the first time, the market's attention was not predominantly drawn to rapid change in any one particular area. It is true that the automatic transmission and high-compression engines were still "in the wings," so to speak, since they had not yet diffused broadly. In general terms, however, the overall design was most important competitively. On this plateau, Nash, Packard, Hudson, Kaiser, Studebaker, Crosley, and Willys lost market share and were ultimately forced to merge or drop out. The major manufacturers excelled. Chrysler, Ford, and General Motors captured most of the market, and, in a functional sense, the designs of their major lines represented a virtually universal car for the U.S. market. They all produced six-cylinder and V-8 engines that offered ample reserves of power. All models offered durability and comparable mileage, and they were reasonably comfortable, quiet, and well heated or ventilated. Designs for different market segments were dissimilar only in degree.

The major model change introduced in postwar cars was the last one to move designs in the same direction. For the first fifty years of automobile production, through 1950, there was a sense of common direction. At any time, rapid advances in one component, such as the body or engine, provided a focus for technological competition. The resulting advances created a standardized design. The process of standardization followed a hierarchy: first came the propulsion choice, then the overall chassis configuration, and then major components were advanced. Finally, once technological change in the components subsided, the overall design of the automobile was optimized. This trend ended in the 1960s.

The horsepower race started in the middle 1950s, and the trend toward larger size continued into the 1960s. These two trends differed from earlier advances, however, for they did not have the same functional utility in the market. Later, size as well as horsepower increases were canceled by other product changes.

Diverging Design Changes

Large, general-purpose road cruisers continued to dominate the major U.S. automobile markets in the 1960s, but an underlying increase in diversity became evident. General Motors' 1960 model Corvair was radical for the U.S. market and even more so for General Motors. Its aluminum, rear, air-cooled engine, the "unitized" method of body construction, the suspension, and the fact that it did not include an integral heating system were a departure from many conventions of the market leader. Front-wheel drive was introduced in the Oldsmobile in 1966. Ford and General Motors began to diverge from the long tradition of separate frame and body construction. Unitized body construction* was introduced in some cars in the line, but not all, beginning in the late 1950s. Unitized construction saved weight. It found its major application in small cars and had the effect of increasing diversity in automobile designs. The Ford Pinto and General Motors Vega, introduced around 1970, departed extensively from conventional body designs in their size and power; number of body parts was reduced by 30 percent. The variety of engines increased greatly during the 1960s and 1970s, and by 1976 many different engines—such as V-6, overhead cam valve 4-cylinder, and slant 6—complemented the pure lines of V-8 and six-cylinder engines that had propelled cars for the preceding two decades.

The industry also demonstrated an ability to achieve technological progress in performance through incremental change. For example, under recent competitive pressures for higher fuel economies in American-made cars, mile-per-gallon ratings for some models have doubled without increasing the rate of major new model introductions.

The Logic of Design Trends

The preceding summary provides one interpretation of the trends that accompanied major changes in the principal components of U.S.-produced cars. For much of its history, the U.S. automobile evolved through a hierarchy of standardization to a highly standardized design, almost as if there were a natural logic to standardization. In the extreme state of standardization, change occurs only through adaptation and substitution of minor components.

The recent reversal in standardization has produced changes in the same manner but in backward order. For example, the response to the initial foreign-import surge of the late 1950s was generally to scale down existing designs. The Corvair would seem to be an exception, but in perspective it was not, for it finally was discontinued and did not have a lasting effect on General Motors' line of cars. Pollution regulations were first met with add-on components and modifications of existing components. Similarly, initial gains in fuel economies were realized by changes in components and not in basic design. As problems with imports and environmental regulations have persisted and have been compounded by higher fuel prices, however, the chain of ramifications has extended further up the design hierarchy to affect the basic configuration of the car. Separate frames and bodies in smaller cars have been replaced with a rationalized design combining the two in unitized construction. Body designs have been changed to reduce the number of parts. Changes that strike at more basic relationships among components are reportedly planned for post-1976

* With unit body construction the frame and body are the same unit. In effect there is no separate frame, and the body provides structural support.

model cars. These include more space-efficient transverse-mounted engines, new drive configurations to obtain more passenger space with less weight, and even more radical departures in basic designs for some cars.

It would seem that long-term trends in design and product-line development do exist, and these may be related to what is sometimes called the maturity of an industry. It would also seem that these trends may reverse themselves in changed competitive environments.

THE DEVELOPMENT OF MASS PRODUCTION

As a measure of productivity, home building and car manufacturing can be compared. Automobile manufacturers in the 1910s used roughly the same number of employee labor hours per car that a home builder uses in constructing a modest dwelling today. An early study provides data on two typical but anonymous firms in 1912. In one company that produced small cars, 1,260 man-hours were required per vehicle;[18] another firm that built a larger car used 4,664 man-hours per vehicle. Today the number of direct labor hours per car would be around 50 for a company whose material and component purchases amount to 60 percent of the car's price to dealers. If all company employees were included, the rate would be around 100 hours per car. The important role of production advances in this transformation is inescapable, but, as will be seen, these changes have also had side effects.

Early Formative Events

By most popular accounts, the early production innovations began with the moving assembly line that Henry Ford introduced in 1914. In my view, this famous innovation is not actually the proper starting point, for it is neither the most important of the process innovations that Henry Ford introduced nor the essential formative innovation in the mass production of automobiles. Some of the industry's basic contributions in mass production preceded the moving assembly line by more than a decade.

High-volume, low-cost production of automobiles rests on two basic concepts: precision-made interchangeable parts and mass production. Both of these concepts were widely applied in the bicycle industry before 1900, and the early producers of automobiles were familiar with them. Of the early firms, Cadillac was recognized for its expertise in precision-machined, interchangeable parts, and, as noted earlier, the Olds Motor Works was mass producing cars in 1901, before the Ford Motor Company was founded.

The automobile producers contributed innovations in production planning and control. The concept of interchangeable parts and the precision-machining capability needed to implement it were already in hand, but early manufacturing practices left the craftsman virtually in control of production. No one knew how to manage the total production of such a complex product. The early manufacturers had to develop new concepts to manage the massive quality-control problems, inventories, large work forces, and equipment investments involved in manufacturing something composed of tens of thousands of complex and costly parts. The problems and risks were somewhat similar to those that a mass-production home-building contractor would face today, except that house designs are not subject to rapid design obsolescence. Effective concepts for dealing with the problems of automobile manufacture came quickly. Today many of these seem obvious, but at the time they were highly imaginative and innovative.

A disaster first led firms in the industry to organize their manufacturing for large-scale mass production. A fire in the Olds Motor Works in late 1901, when mass production was just beginning, destroyed the Olds shops. Consequently, a final assembly operation was organized for the first time, and parts were subcontracted out to suppliers.[19] Historians of this era claim that this change established the idea that final assembly of parts could be set up and managed as a separate operation. More generally, it demonstrated, perhaps for the first time anywhere, that a major production process could be organized as a series of separate specialized plants.

A second important step in production organization was taken in October 1910, when Henry Ford established the first decentralized branch assembly plant in Kansas City, Missouri, to carry out the final assembly of cars.[20] This may well have been the first time in any U.S. industry that a company established specialized plants in different geographic areas as units of a common manufacturing process.

The implications of these two steps were significant. They segregated production along lines that gave opportunities for extensive mechanization and recognized the need to accommodate technological change and labor utilization rates. The component-manufacturing operations, centralized near Detroit, afforded opportunities for economies of scale through mechanization, specialization, and other process advances. The assembly operations that required many workers and a close matching of product output rates to regional sales rates were located close to the regional markets they would serve. Taken jointly, these moves recognized and probably encouraged the development of economies of scale in component manufacturing, while they minimized the employment impact in any one region. These choices in the aggregate structure of the manufacturing process were a major innovation for the automobile industry, and they provided a model for other manufacturing industries.

Moving Assembly

The moving final assembly line and other process innovations, for which Henry Ford has been credited, developed rapidly after the groundwork had been laid. Between 1911 and 1913 the specialization of labor at Ford was greatly increased, and by 1912 the moving assembly concept, without mechanized lines, was successfully applied in the manufacture of engines, radiators, and electrical parts. Finally, the famous mechanized line for the final assembly of the chassis was adopted in early 1914. H. L. Arnold and F. L. Faurote's early study of Ford production shows that with the introduction of the moving assembly line the number of labor hours required in the final assembly process for a chassis decreased by an 8 to 1 factor: from 12 hours and 28 minutes in September 1913 to 1 hour and 33 minutes in March 1914.[21]

The moving assembly line was important as one of a number of changes introduced in automobile manufacturing, but it may not be as important as these numbers suggest. The 8 to 1 improvement factor as developed by Arnold and Faurote has always been cited to demonstrate the importance of this innovation. Although the facts were carefully developed by these two independent, nationally recognized engineers and authors of the era, the improvements seem now not to be solely attributable to the moving assembly line. Ford made a second important change while the moving assembly line was being installed. In January 1914, Ford set a national precedent by introducing the eight-hour workday and by doubling wages to $5 per day. According to historians, the work environment changed overnight. Whereas previously the labor turnover rate had approached 60 percent per month, the change brought efficient tranquillity to Ford's operations.[22] Arnold and Faurote's analysis captured the benefits of this change as well as the moving assembly line innovation, since both occurred at the same time.

Thus the moving assembly line was certainly important in its own right, but its contribution may have been overstated. Productivity gains came from a series of changes, like those in length of the workday and in wages. These changes in scale, mechanization, work-force organization, process organization, and product standardization were dependent on one another, and it would seem that these trends may be reversing in the present market environment.

Mass-Produced Car Bodies

At the quarter-century point in the industry's history, the mid-1920s, techniques for mass producing car bodies were being rapidly developed, and the major automobile manufacturers frantically began their own steel body production. The mass production of bodies went hand in hand with the rapidly rising popularity of closed steel bodies, as discussed earlier, but it also depended upon advances in the widths and surface finish of rolled steel, the development of welding technology and, particularly, new paints and painting methods.

There were compelling reasons behind Henry Ford's original decision

TABLE 2.2. Cost Data for Three Model T Bodies, December 1913 (In dollars)

	Chassis Assembly				*Body Assembly*					
Model	*Material*	*Labor*	*Overhead*	*Subtotal*	*Material (Body Cost)*	*Labor*	*Overhead*	*Subtotal*	*Total*	*Retail Price*
Touring Car	122.23	17.034	22.65	161.92	62.55	0.362	0.48	63.00	225.32	550
Torpedo Car	122.23	17.034	22.65	161.92	43.97	0.323	0.43	44.72	206.64	590
Town Car	117.63	17.034	22.65	157.314	246.51	0.407	0.541	247.46	404.74	750

SOURCE: "Model T Cost Books," Ford Archives, Henry Ford Museum, Greenfield Village, Dearborn, Michigan.

NOTE: Chassis costs are the fully allocated total costs of producing the entire car up to and including chassis assembly. Body assembly labor is for the body only. Bodies were purchased already finished.

to offer the Model T in only a black finish. Colored finishes could not be economically mass produced on both the exposed metal chassis parts and wooden bodies. Wooden bodies could not be satisfactorily baked to dry and harden finishes. A satisfactory colored finish required sanding, rubbing, and polishing operations between repeated coat applications and long drying periods. By one estimate, 106 days were required to produce a colored body. Of this time, most was spent drying; 25 percent was spent in the paint shop where paint was applied in twenty-four successive operations.[23]

Du Pont introduced pyroxylin paint (DUCO) in 1923. This paint reduced painting time to three days. Steel bodies made baking feasible, and this further reduced production time.

Mass-production techniques could not be applied successfully as long as wooden construction materials were used. Table 2.2 shows how the cost in body construction varied by type of body. This table breaks down body and chassis costs of the Model T cars for three different bodies. All three were wooden bodies that Ford purchased already painted from suppliers. The purchase price to Ford is shown as a material cost in the "Body Assembly" side of the figure. Only the town car was a closed body.

Notice that at this time the closed body cost 150 percent more than the Model T chassis alone. Recall that the chassis included the full cost of producing all of the mechanics of the car. The closed body also cost almost five times more than the other bodies.

The mass-production technology for closed steel bodies had to be developed fresh, so to speak. It hinged on methods of sheet-metal forming with presses and welding technology. The primary production technology of the major firms before this time had been machining or metal removal and assembly, not sheet-metal forming. Moving-assembly techniques were ultimately to be developed in this area, too, but they were not of major importance until the late 1930s. Nevertheless, mass production came about, and by 1928 a closed steel body cost only 5 percent more than an open body.

Streamlined body designs became competitively important in the mid-1930s, as new ways to contour sheet steel body parts were developed. The large presses and dies for metal forming assumed a prominent role in mass production. This new technology increased the cost of model change and increased the sales volume that was needed to sustain a separate car model. Many firms, such as Graham-Paige and Reo, were forced out of production, even after the recovery from the depression had begun. Although failure to keep up with changing market trends was the market analyst's frequent explanation for many firms' misfortunes, the escalating cost of keeping abreast of body changes was an underlying cause.

Automation

The excitement of automation and systems analysis swept the automobile industry and the nation in the 1950s. The very term "automation" was developed and popularized in Detroit.[24] Transfer lines were coupled with automatic machine tools to create long machinery lines that could produce engine parts, such as the cylinder block, virtually without operator intervention. In body-parts manufacturing, automatic-feed mechanisms were coupled with high-speed stamping presses to increase productivity in sheet-metal forming. In many other areas where designs were relatively stable, such as radiator production, entire automated lines replaced manual operations. The assembly plant stood out as the one area that was largely untouched.

The influx of automation at this half-century point in the industry's history was acclaimed by the press as a revolution. The effect of these changes, however, was very similar to that of the moving assembly line. They were innovations in process organization and control, and they acted to make product and process design more interdependent rather than independent. With transfer lines, any significant change in engine design had to be accompanied by extensive retooling. As with stamping presses, these changes raised the cost of change.

Automated Assembly

The assembly plants stands out as the last major production area that has not been extensively mechanized and that still uses large amounts of direct labor. Since 1970 both General Motors and Ford have applied robots and in-line transfer concepts in some assembly plants. The more notable cases are the Lordstown, Ohio, plant for General Motors' Vega and Ford's Econoline plant at Lorain, Ohio. Volkswagen and other foreign small-car plants have probably gone even further toward mechanization in assembly. At the industry's seventy-five-year mark, extensive automated assembly seems the most likely potential area for change in mass production. A move to automated assembly also seems the logical sequel in the historical pattern of mass production. The assembly plant accounts for about half the direct labor that is now required to produce a car. The pressure on prices from foreign producers and rising wage rates make further assembly automation attractive.

Some Implications

The evolution of mass production has influenced much more than just the cost of the automobile. The industry could not have developed, of course, without the manufacturing advances that brought the cost of the car down within the economic means of the consumer. But while the course of development in mass production helped create the industry, it has also introduced a set of constraints. The moving assembly line, steel bodies, automation, and many other advances have made change and product innovation more expensive. Large-scale production processes in which the direct labor costs are low but indirect costs are high create strong economic forces to reduce real product variety.

Ford's program to develop a small car in the 1930s, the Model 92A, nicely illustrates the economic forces at play.

Ford's Small-Car Program—Model 92A

During the late 1920s and early 1930s, General Motors, with a broad product line, gained the lead in market share over Ford and by 1925 held approximately 40 percent of the market versus Ford's 25 percent and Chrysler's 22 percent. The high-volume Chevrolet (the lowest-priced GM car) emphasized product appointments and luxury over price, and it was particularly troublesome to Ford. The differential between the Chevrolet and Ford in 1926 is typical of product differentials in weight and size over many years:

	Price	*Weight*
1926 Chevrolet	$ 510	1,875-pound Touring
	645	2,130-pound Coach
1926 Ford	$ 310	1,607-pound Touring
	520	1,961-pound Sedan (Tudor)

Ford had been essentially a single-product company, and to compete with General Motors, Ford increased the size and price of its cars. By 1936, no major producer was selling to the low-price market that had been served by the Model T. Ford undertook the development of the 92A to supply this market. Eugene Farkas of Ford's engine development group engineered the project.

The car was to use the small, 136-cubic-inch displacement version of the V-8 engine, first introduced to the market in 1937, and a scaled-down version of the Ford frame and body. The project was a technical success but an economic failure. The reasons are discussed in Nevins's account of the project:

> Farkas engineered the model. He used the smaller V-8 engine, and the 92A, as the car was called, emerged narrower and shorter than the regular Ford, and 600 pounds lighter. The first completed model, as Farkas recalls, was a "sweet-running job." But difficulties arose. The small motor cost but $3.00 less to manufacture than the larger one. The remainder of the car was also cheaper only as it used less material, for practically all the essential elements were common to both the 92A and the V-8. Wibel calculated the possible savings in each case at a mere $36. Since the 92A would have to compete with year-old larger used cars, this was not enough . . . so by mid-April the project was abandoned, signifying that the company would not expand the range of its models downward.[25]

The implications of an integrated manufacturing process for product design changes are clearly illustrated by this example.

Several constraints placed by integrated production facilities on product design and market policy were evident. In the first place, most of the cost was apparently fixed and depended only on the number of units produced and not the specifics of model. Thus there was little incentive to produce a small car that might replace or "cannibalize" the sale of a larger car with a higher profit margin. In the second place, one would suspect that the 92A was a scaled-down version of a larger model because it could be produced in existing facilities. Otherwise, new duplicate facilities would have been required at a time when the company was operating well below capacity.

COMPETITION

Competition in the automobile industry has always been a conflict among giant firms. In terms of effective market power, there has not been a significant change in the degree of fragmentation, or division of the total market, in the industry since the early 1900s. The market-share comparison in Table 2.3 for eight major firms in 1923 and 1967 illustrates the point. The table shows unit sales and market shares and illustrates the use of the Herfindahl Index to indicate the "equivalent number of major firms." The number of equivalent firms in the industry is defined as follows:

$$\text{Equivalent Firms}^* = \frac{(\text{Sum of [Market Shares]})^2}{\text{Sum of [Market Share]}^2}$$

It can be roughly interpreted as the number of firms that would populate the industry if all had the same market share as the larger firms. For

* This measure is essentially the reciprocal of the so-called Herfindahl Index, which has been used by economists to define concentration of producers in a given market (see note with Figure 2.1, which follows).

purposes of comparison, the third column in the table presents a hypothetical example in which eight firms have equal market shares. For this case, then, there are eight equivalent firms. The equivalent number of firms is a single number that usefully indicates effective fragmentation. Although only four firms existed in 1967 compared to seventy in 1923, in both years about 70 percent of the market was controlled by only three firms. The number of equivalent firms, 3.4 for 1923 and 3.1 for 1967, offers a better indication of actual fragmentation than does the total number of firms.

Trends in industry fragmentation are shown in Figure 2.1, where the number of equivalent firms is shown as a graph and the actual number of firms for various years is given in parentheses at the bottom. The two initial sharp dips in equivalent firms coincide with the onset of mass production by the Olds Motor Works and the success of Ford's Model T. Since these very early events, the industry has been controlled by large firms, and trends have been stable and remarkably even.

Many small firms were forced out of the industry by the Great Depression but, surprisingly, this had only a minor effect on the number of equivalent firms. The major deflection in the trend was caused by the backlogged demand for cars and the surge of new firms that entered the market after World War II. Contrary to some popular notions, technological and market developments in the automobile industry have come about in a surprisingly consistent competitive environment as far as market fragmentation is concerned.

TABLE 2.3. Illustrative Market Share Statistics

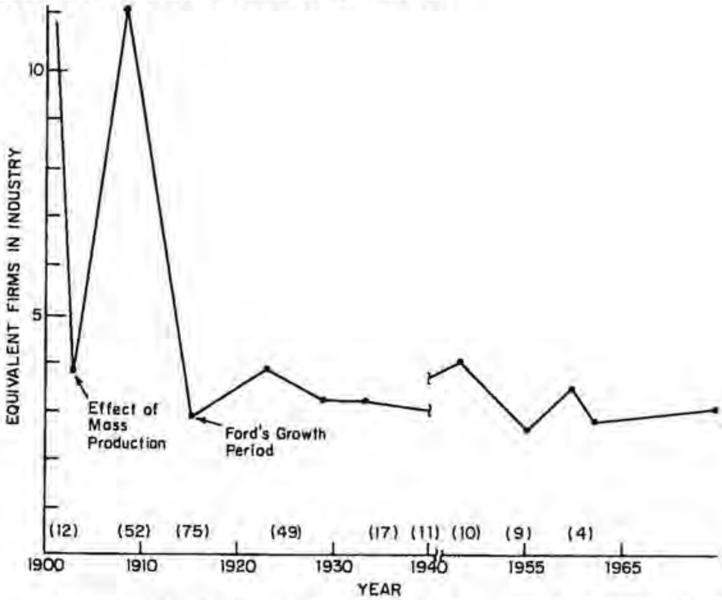
	1923		*1967*		*Hypothetical Example*	
	Unit Sales	*Market Share M (percent)*	*Unit Sales*	*Market Share M (percent)*	*Unit Sales*	*M (percent)*
Total cars sold in U.S.	3,625,000	100	8,361,900	100	8,000,000	100
General Motors	754,700	20.8	4,142,900	49.5	1,000,000	12.5
Ford	1,825,800	50.4	1,853,300	22.2	1,000,000	12.5
Chrysler (Maxwell)	69,000	1.9	1,342,500	16.0	1,000,000	12.5
American Motors			234,100	2.8	1,000,000	12.5
Studebaker	145,200	4.0	—	—	1,000,000	12.5
Hudson	88,200	2.4	—	—	1,000,000	12.5
Packard	18,900	0.5	—	—	1,000,000	12.5
Nash	75,000	2.1	—	—	1,000,000	12.5
Subtotal	2,976,800	82.1	7,572,800	90.5	8,000,000	100
Other	648,200	17.9	8,600	0.1		
Foreign	—	—	780,500	9.4		
Equivalent number of major firms $\frac{(\text{Sum of } [M/100])^2}{\text{Sum of } [M/100]^2}$	3.4		3.1		8.0	
Actual number of firms	70		4		—	

SOURCE: Same as Figure 2.1.
NOTE: Percentages may not total to 100 due to rounding error.

Initial Competitive Strategies

During the early years of the industry, it was not unusual for firms to rely heavily on technological innovation as their competitive edge. Cadillac's early success and reputation, for example, has been attributed to its precision machining capabilities, 1/10,000 of an inch or better. In 1904, Buick's chief asset was claimed to be its patented valve-in-head engine design.[20] Since 1915, when the mass automotive market emerged, firms have not been successful in gaining a lasting advantage through radical technological innovations. Counted among the casualties are the 1915 Haynes car with an electric gear shift, the Franklin with an air-cooled engine, and the Cord with front-wheel drive. The Model T was a turning point. It blended technological innovation with a very insightful production and marketing strategy.

FIGURE 2.1. Trends In Market Fragmentation



SOURCES: U.S. FTC, *Report of the Motor Vehicle Industry*; L. J. White, *The Automobile Industry since 1945* (Cambridge, Mass.: Harvard University Press, 1971), Appendix.

NOTE: The equivalent number of firms, as used here, is essentially the reciprocal of the Herfindahl Index. The reciprocal is used because it is more easily interpreted than the basic index. It provides a convenient measure of industry concentration when both the number of producers and inequalities of size affect real market power. F. M. Scherer, *Industrial Market Structure and Economic Performance* (Chicago: Rand McNally and Co., 1970), p. 51.

* Figures in parentheses are the actual number of U.S. firms manufacturing passenger cars.

Creating a Giant Industry

Henry Ford's enormous success with the Model T was not blind luck; his innovations were directed by a broad strategic plan. The essential outline of his strategy, or bragging as some called it then, is suggested by an advertisement Ford placed more than two years before the Model T was introduced: The "idea is to build a high grade, practical automobile that can be maintained as near $450 as it is possible to make it, thus raising the automobile out of the list of luxuries and bringing it to the point where the average American citizen may own and enjoy his own automobile—the question is not 'how much can we get for the car?' but 'how low can we sell it and make a small margin on each one?' "[27] Another account stated: "The Ford Company—was trying to make low-cost cars as reliable and as well supplied with good, cheap spare parts as a Singer Sewing Machine or the McCormick Reaper."[28]

The strategy was provocative, but the technology was not then at hand to carry it out. Ford's manufacturing capabilities were not as advanced as those of other firms in the industry. The vanadium steel on which the Model T's light, tough construction was claimed to depend had not yet been perfected, and automobiles that approximated this vision of performance cost around $2,800.

The impetus for implementing the strategy came from a technological innovation in steel making:

> In 1905 [Henry Ford] saw a French automobile wrecked in a smash-up. Looking after the wreck, he picked up a valve stem, very light and tough—it proved to be a French steel with vanadium alloy. Ford found that none could duplicate the metal—[he] found a small steel company in Canton, Ohio [and] offered to guarantee them against loss. The first heat was a failure—the second time the steel came through. Until then [Ford] had been forced to be satisfied with steel running between 60,000 and 70,000 pounds tensile strength. With vanadium steel, the strength went to 170,000 pounds.[29]

Charles Sorensen, who helped design the Model T and was later Ford's senior production executive, reported Henry Ford's reaction to test data on the new alloy: "Charlie," he said, "this means entirely new design requirements and we can get a better, lighter, and cheaper car as a result of it." Sorensen reports further: "The vanadium steel development, which without question furnished the real impetus for abandoning the sensational success of Model N for the evolution of the Model T and ultimate realization of Henry Ford's dream of a car for the masses—this demonstration of vanadium steel was the deciding point for him to begin the experimental work that resulted in Model T."[30]

So, on the basis of a new technological development, vanadium steel, new design goals were established, and the Model T was designed. This chassis was reported to be less expensive than that of any vehicle of comparable quality and only half as heavy. Ironically, vanadium steel turned out not to be well suited to automobiles. It proved brittle, many part failures were experienced, and after a few years in production all vanadium steel in the Model T was replaced with other available steels.[31]

Thus, in retrospect, it was not really the technological advance in vanadium steel that brought about the Model T. The moving factor was the expectation aroused by this advance. After this came the policy of product standardization and Ford's later innovations in process methods and decentralized assembly plants, with mass production and distribution to provide control of markets in an era of slow communications. To summarize, it was Ford's *strategy*—bringing together appropriate product design, production, distribution, and marketing—that stands out as the most important factor in competitive success.

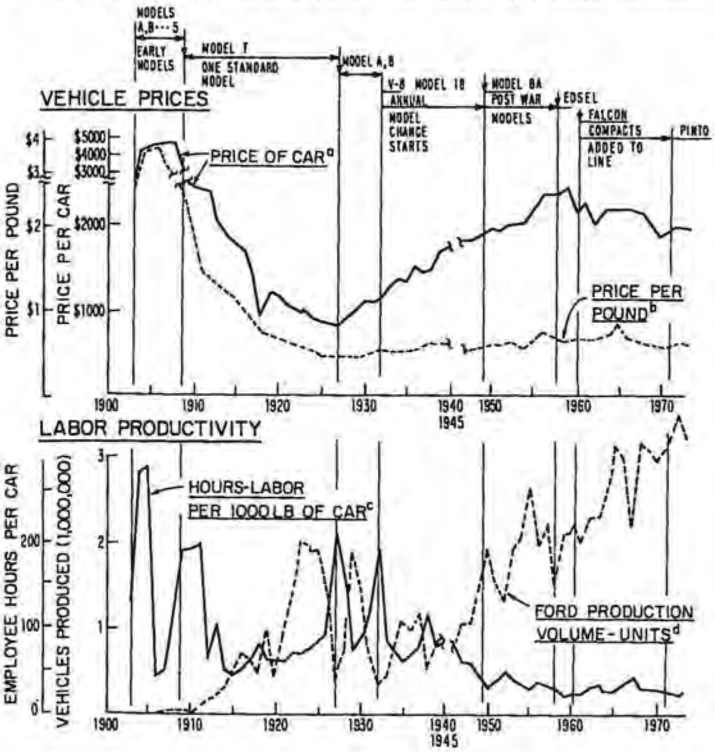
The expansion of market and production capacity and the pricing sequence that followed are shown in Figure 2.2. The graphs display four operating statistics of the Ford Motor Company. The graphs are extended to 1973 because they also provide a useful point of reference for interpreting interactions among alternative competitive strategies in later periods. The top two curves show changes in the median retail list price of the Ford line of cars, in 1958 dollars. The solid curve is the price of the car, and the dotted line is the price per pound of the car. Below the solid line is an index of labor utilization. It is an approximation of the number of employee hours that Ford used over the years per thousand pounds of car produced. The other graph is Ford's U.S. (North American after 1965) production in thousands of motor vehicles.

The dramatic price reduction and market expansion sequence that unfolded between 1908 and 1926 today would be called a "learning curve" or "experience curve." Very large gains in productivity were made, as suggested by the index of man-hours per thousand pounds of car produced. The full extent of labor productivity gains is masked by these graphs, however, for after 1912, Ford made unprecedented extensions in backward-integration* moves into iron and glass production, lumbering, and mining. In 1922–23 a peak production of two million Model T cars and trucks was achieved.

By early in 1920, the Model T was an aging design, however, and even though Ford added a starter and a closed steel body, there was no change in basic design. To retain market share Ford dropped the price to \$290 (or \$890 in terms of constant 1958 dollars), but General Motors still gained market share rapidly. Ford closed down completely in 1926 for

* Backward integration refers to a move by the producer, Ford, to manufacture parts or materials hitherto purchased, an expansion backward along supply channels, as it were. Forward integration would imply an expansion forward toward the market.

FIGURE 2.2. Operating Trends, Ford Motor Company: North American Operations



SOURCES: Corporate Reports; Ford Archives; *Automotive Industries* Statistical Issue, various years; and U.S. Bureau of Labor Statistics

[a] Retail price for median priced car in 1958 dollars

[b] Price per pound of car for curve (a)

[c] Ford employee hours (non salaried) per 1000 lbs of vehicles produced

[d] Unit production volume for North American operations—Ford

nine months to design and change over to a new model. General Motors, with a broad product line of cars, took over the leadership position in the industry.

In 1927, with unchanging strategy, Ford introduced its second-generation car for the low-price market, the new Model A. Although Ford briefly regained its prior market share, the old competitive strategy of low price, standardized design, and mass production did not work for long. After three years, Ford's market share dropped below 25 percent. In 1932, in the depths of the depression, the V-8 engine was introduced and product standardization was abandoned.

Alfred Sloan of General Motors criticized Ford's strategy as follows: "Mr. Ford had unusual vision, imagination and foresight—[his] basic conception of one car in one utility model at an ever lower price was what the market, especially the farm market, needed at the time. . . . [His] concept of the American market did not adequately fit the realities after 1923. Mr. Ford failed to realize that it was not necessary for new cars to meet the need for basic transportation. . . . Used cars at much lower prices dropped down to fill the demand. . . . The old master had failed to master change."[32]

Ford's strategy can be described as brilliant but static. A market need was identified; the product and the manufacturing, marketing, and distribution facilities to meet the need optimally were then developed and implemented. But Ford's strategy recognized neither the dynamics of market development nor the counteractions of competitors.

General Motors

General Motors' invulnerable competitive policies were carefully evolved from experience with both success and failure in the contest with Ford, according to Alfred Sloan:

> In 1921 . . . no conceivable amount of money, short of the United States Treasury could have sustained the losses required to take volume away from [Ford] at his own game. The strategy we devised was to take a bite from the top of his position—and in this way build up Chevrolet volume on a profitable base.
>
> Nevertheless—the K Model Chevrolet—was still too far from the Ford Model T in price for the gravitational pull we hoped to exert in Mr. Ford's area of the market. It was our intention to continue adding improvements and over a period of time to move down in price on the Model T as our position justified it.
>
> We first said that the corporation should produce a line of cars in each price area, from the lowest to one for the strictly high-grade quality-production car. . . . We proposed in general that General Motors should place its cars at the top of each price range and make them of such quality that they would attract sales from below that price. . . . This amounted to quality competition against cars above a given price tag and price competition against cars above that price tag. . . . The policy we said was valid if our cars were at least equal in design to the best of our competitors' grade, so that it was not necessary *to lead in design* or run the risk of untried experiment.
>
> The same idea held for production—it was not essential that for any particular car, production be more efficient than that of its best competitor—coordinated operation of our plants would result in great efficiency—the same could be said for engineering and other functions.[33]

Thus there were three essential elements in General Motors' strategy. (1) Product design was conceived as a dynamic process that would lead to an ultimate target through incremental change. Design was not a once-and-for-all optimization as it had been with Ford. This process later became the annual model-change policy of General Motors. (2) Market needs would be met through the product-line policy rather than independent designs.

(3) Radical product innovations were to be avoided. Sloan says it was "not necessary to . . . run the risk of untried experiment."

General Motors had learned to avoid the risk of radical innovation from its experiences from 1920 to 1923 with an experimental air-cooled engine it called the copper-cooled engine. The copper-cooled engine program was begun in 1919 by an independent company under Charles F. Kettering's direction. By acquiring this company and securing Kettering's full-time participation to develop the air-cooled engine, General Motors first instituted a formal research and development group within the corporation.

The copper-cooled engine program failed for a variety of reasons, both technical and organizational. There were many technical problems with the high-conductivity alloys used in its manufacture, and attempts to mass produce the engine failed. The central problem may have been that the engine was championed by top management and Kettering and was forced upon the Chevrolet and Oakland divisions over their resistance. All of the one hundred cars that went to retail customers were recalled by 1923. Lessons learned from the "engineering dream," as Sloan once described it, substantially influenced General Motors' policy regarding advanced development:

> We were . . . more committed to a particular engineering design than to the broad aims of the enterprise, and we were in the position of supporting a research position against the judgment of the division men who would, in the end, have to produce and sell the new cars. Meanwhile, obsolescence was overtaking our conventional water-cooled models. . . . The problem was one of conflict between the top management of the corporation and the producing organizations and of a parallel conflict between the top management of the corporation and divisional management. . . . It showed the need to make an effective distinction between divisional and corporate functions in engineering and also between advanced product engineering and long-range research.[34]

In describing the new policy that emerged, Sloan further stated: "Divisions . . . can [now] go ahead about their business in their own way as they have very big problems to work out to maintain their present positions for the future."[35]

These new policies in effect changed the method of introducing major new technological features. Instead of being pushed into application as they were developed, they came to be used only as desired, or pulled into application by operating executives. While the policy spawned by this technological failure helped to protect the operating divisions against the uncertainties of technological change, it also isolated mass-produced cars from the influence of advanced technology.

The broad competitive strategy that General Motors hammered out in specific decisions, like those following the failure of the copper-cooled engine, was to prove unbeatable. The company gained a dominant position in the U.S. market in the 1920s and has held it to the present. Under General Motors' market leadership, the automobile grew in size, price, and economic importance into the 1960s. The influence of General Motors' leadership may be seen in product-price trends at Ford (see Figure 2.2). The price and weight of the Ford line rose steadily from 1927 until 1960, as is evident from the difference between the trends in price per vehicle and price per pound of vehicle.

Apparently, productivity improvement was not neglected by General Motors, even though direct price competition was shunned. When new management took control at Ford after World War II, it found that the manufacturing cost of a Chevrolet was actually lower than that of a comparable Ford.[36] Even though Ford had spent millions in the thirties on new manufacturing facilities to integrate backward fully into iron and steel production as well as other areas, and even though Ford had sought direct price competition through lower retail price until 1946, General Motors had still achieved a cost advantage.

Little change in the essentials of General Motors' strategy has been apparent over the long period since the 1920s. Increased centralization among operating divisions, less difference in technological characteristics of various cars in the product line, and greater sharing of common components have tended to make the different car lines more like a single product. In general terms, however, the strategy seems to remain intact.

The Corvair program in the early 1960s is one exception; and, ironically, it parallels the copper-cooled engine in respect to organizational implications, technology, and ultimate outcome. According to industry sources, the Corvair was introduced to combat small imports at the insistence of top corporate management and over the opposition of Chevrolet's divisional management. The slow death the Corvair suffered in the market suggests that many of the problems encountered in the copper-cooled engine in transferring a radical technology to an operating division are generic to a strong, decentralized organizational structure.

Other Strategies

Other firms followed General Motors' lead and adopted a similar competitive structure. Several important variations emerged, however, in both Chrysler's and Ford's strategies.

The Chrysler Corporation seized a foothold in the market when Ford faltered in the Model T program and shut down for nine months. Chrysler offered four basic car lines in 1929: Chrysler, DeSoto, Dodge, and Plymouth. Unlike General Motors, however, production for all product lines was centralized, and Chrysler apparently did not integrate vertically backward as extensively as either General Motors or Ford.[37] Although only spotty data on vertical integration are available for the prewar period,

TABLE 2.4. Vertical Integration Comparisons

	Value Added/Sales		
Year	*GM*	*Ford*	*Chrysler*
1947	.470	.370	.288
1950	.515	.384	.306
1955	.500	.413	.353
1960	.486	.471	.319
1965	.522	.404	.373

SOURCE: Robert W. Crandall, "Vertical Integration in the U.S. Automobile Industry" (Ph.D. dissertation, Northwestern University, 1968), p. 82.

the relative positions of the three companies are suggested for the postwar period in Table 2.4. This table provides data on "value added/sales value" ratios for selected years. This ratio of "value added/sales value" can be interpreted as the fraction of the final product's economic value (price to buyer) that is made up of work done by the producer rather than purchased from suppliers.*

Because Chrysler produced fewer of its own components, it was less constrained in adopting advanced innovative components. Thus Chrysler could seek competitive advantages through flexibility in product engineering and in styling. Chrysler pioneered in high-compression engines in 1925, frame designs permitting a low center of gravity in the 1930s, and the experimental introduction of disc brakes in 1949, power steering in 1951, and the alternator† in 1960.

This strategy of design flexibility and shallow vertical integration proved very successful in the prewar period, when the rate of technological change in the product was rapid. As product designs stabilized after the war, however, other factors, like the strength of dealerships and customer service, became more important. Chrysler's market share followed a downward trend after World War II. Cost control was difficult during times of inflation, when cost increases could not be passed on to the consumer. This aspect was particularly troublesome after 1970. Inflation, government price control, and the consumer's loss of real purchasing power have squeezed margins and capital at the very time when resources have been

* The concept of "value added" is used to identify the economic contribution of different firms or producers that do work along the line in making a final product. For example, steel mills, rubber goods producers, electronics firms, etc., all contribute value to the car. The so-called "value added" by the final producer is usually computed by substracting the cost of purchased materials and components from the final sales price of the product. Thus the ratio of "value added/sales" can be roughly interpreted as the fraction of the final product's price that the company makes rather than buys from suppliers.

† The alternator replaced the traditional d.c. generator that was standard on all U.S. cars. The alternator produces a.c. current and then a.c. is converted to d.c. for recharging storage batteries. The alternator is much more efficient and leads to better electrical performance of the car. See case abstract on "Electronic Ignition" in Appendix 1.

needed to develop and introduce smaller, more efficient cars. A competitive strategy emphasizing flexibility in product design was well suited to prewar conditions. As with Ford's early policies, however, it would seem that the development of the industry changed the necessary conditions for success.

Under new management after World War II, Ford rapidly adopted a new strategy. Independent divisions, each having its own product lines and production facilities, were envisioned. Separate engine and assembly plants for Lincoln-Mercury and Ford divisions were introduced, but the market failure of the Edsel thwarted the planned development of three separate car divisions. After 1960 all North American production facilities were consolidated under a centralized functional organization; that is, many of the same production and engineering functions serve all product lines.[38]

In describing competitive policies, Lawrence J. White concludes that Ford has been a follower in styling, but a leader in seeking out market niches.[39] New models like the Mustang, Maverick, Pinto, and a combination car and truck called the Ranchero seem to confirm this characterization. Despite these successes, Ford has not been able to excel in head-on competition with General Motors across the full product line. Since 1960, Ford has maintained about a 25 percent market share.

The Foreign Invasion

Successful market penetration by small foreign imports has had important competitive consequences since 1958. The first invasion by imports began to build up in the late 1950s. A number of European producers introduced small cars, and the market share of imports rose from 1 percent in 1955 to 10 percent in 1959. The Big Three firms did not seem to take small imports seriously at first. The American car buyer had shown little interest in small cars ten years earlier, when the Henry J. and the Willys had been forced out of the market. Both Ford and General Motors had aborted the new small-car programs they undertook after World War II.

The Big Three's compact-sized cars, introduced for 1960, checked the first foreign invasion, and by 1962 the market share for all imports fell to less than 5 percent. The second import invasion was more serious. The smallest-sized cars of the Big Three were again increased in size after 1960. This is reflected in the short-term rise from 1961 to 1965 in Ford car prices (Figure 2.2). With Volkswagen in the lead, the market share of imports started back up in 1964, reaching 9 percent of the market by 1967. Despite the introduction of subcompacts like the Vega and Pinto in the early 1970s, the tide was not halted. During the oil embargo, foreign imports achieved a 16 percent market share, with Japanese cars leading the trend. And in some California markets, which historically have been leading indicators of national automobile sales, foreign cars gained 40 percent of the market.

The successes and failures of imports in penetrating the U.S. market reveal fundamental changes in competitive conditions. Sustained inroads into major U.S. markets have been made by the foreign imports like Volkswagen, Datsun, and Toyota, all of which developed strong dealerships. Foreign firms with less thorough dealer development, like Renault, have not been able to sustain initial successes.[40]

Successful foreign cars have offered a comparative advantage in a few objective, tangible performance characteristics the consumer can assess. Preferences in different market segments seem to have diverged more widely since 1973. Initial purchase price, full-tank driving range, fuel economy, and weight-efficient passenger-space capacity have risen in competitive importance within different market segments as forces of inflation, recession, the oil embargo, and increased gasoline prices have battered the car buyer. The common denominator seems to be an increased reliance on tangible criteria by the consumer in making purchasing decisions. The more uncertain and intangible advantages of novelty, status, styling, or even safety, which might be provided by Mazda's rotary engine, for example, or Volvo's claimed extra safety features, seem to have had uncertain appeal in most market segments.

The explanation for these changes in the market may be the sequence of events since 1958 that has sharpened and channeled the consumer's focus on objective criteria. Congress enacted legislation in 1958 that required the list price to be posted on all new cars, so that dealers could not obscure real price comparisons through complex deals. The reputation of the U.S. firms as a favorable factor in purchase decisions was undoubtedly altered in the minds of some consumers by the controversy over safety and pollution controls in the late 1960s. The posting of mileage ratings by the Environmental Safety Agency, the disruptions in gasoline supplies, doubled gasoline prices, and the loss of real consumer purchasing power in 1974 have raised the importance of price and fuel economy. In addition, the long-term increase in two- and three-car families has meant that the consumer can more frequently "segment his own needs" and buy at least one small, specialized car rather than rely on a single, large, general-purpose automobile.

Because of these changes, it is not surprising that more purchasers have recently favored the small, less costly, and fuel-efficient or space-efficient cars. Once adopted, however, it is unlikely that the consumer will now turn away from the use of objective criteria in purchasing, regardless of favorable changes in the economy. New competitive strategies are needed.

COMPETITIVE FACTORS IN EVOLUTION: AN ANALYSIS

The way the firm competes successfully has been slowly altered by the sequence of developments discussed above as automotive technology has been perfected and competing products have become similar in more respects. Recent government regulations have also limited the firms' freedom to change product features. Through these trends, the essential features of firms' competitive strategies seem to have been altered. Market volatility decreased after World War II, the introduction of major new models has tended to have less effect on market share, price competition seems to have changed in importance, and consumer service has become a more important aspect of dealership policy. Evidence of such change is particularly apparent in Ford's and General Motors' product-line pricing policies in the transitional decades of 1920 and 1930. Ford was initially able to gain a dominant position by following what today would be called an "experience curve" pricing strategy. Prices were aggressively reduced as volume increased and manufacturing costs were reduced. This worked well while primary demand expanded rapidly. As the industry developed, further product-line price reductions proved unsuccessful in competition with General Motors. This is but one example of several changes that together constitute a pervasive change in the basis of competition. Table 2.5 summarizes the changes in four competitive variables that arise from the history of the industry. The systematic nature of these changes can be explored more thoroughly through a statistical analysis of the competitive variables that actually influenced Ford's market share for over seventy years.

Competitive Variables

Three types of independent variables can be used in the analysis to represent the three top cells in Table 2.5: (1) the price differential between Ford's product line and that of its nearest competitor (Chevrolet in recent years); (2) a function representing the introduction of major new models by Ford; and (3) an index of Ford's product-line prices in respect to per capita disposable income. Statistical regressions can be used to determine how changes in these three variables are associated with changes in Ford's market share over time.

Price Differential. The price differential is the difference between the median price of cars in the Ford product line and the median price for the nearest competitor, for example, Chevrolet. The nearest competitor is considered to be a competing car line with the largest market share of passenger cars in the United States market (other than Ford). Data on car prices from 1905 to 1973 were obtained from the trade literature.

Major Model Introduction. The introduction of a major new model is represented by the number of years since the prior new model introduction (model age), as illustrated in Figure 2.3.

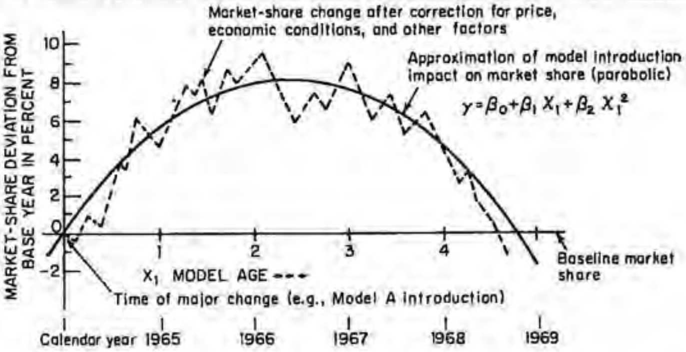
The assumption is that at the time of a successful major model change (the zero age of a new model in Figure 2.3), the firm will begin to add additional market share to its existing level. As knowledge of the new

TABLE 2.5. The Changing Mix of Competitive Factors

	Stage of Development	
Competitive Factor	*Early: (1905–48)*	*Late: (1949–73)*
Competitive Pricing (Competitive Differential)	*Secondary Competitive Factor* Variations in product performance among competitive products makes price comparisons difficult. Initial purchasers are also more likely to be affluent and to value performance over price.	*Primary Competitive Factor* As the technology is perfected, the degree of standardization among competing products increases and most offer minimum acceptable performance. Under these circumstances, price becomes a highly important factor in competition.
Model Change (Major Innovative Change)	*Primary Competitive Factor* The potential for product improvement is great, and technological progress is rapid. The market reacts in a volatile manner to new model introduction.	*Secondary Competitive Factor* The technology is refined, and most of the purchasers' needs are satisfied by earlier product models. The market reaction will be more uncertain and influenced by subjective or style consideration.
Relative Product-Line Pricing (In Respect to Consumer Disposable Income)	*Primary Competitive Factor* "Experience curve" product-line pricing is accompanied by reduction in "real" prices and increases in market share as new purchasers are drawn into the market. Stated alternatively, trading the product line down in price is expected to attract a larger market as primary demand is increased.	*Secondary Competitive Factor* Once the market is fully developed and the product is accepted by purchasers, the new entry, price-sensitive market segment, is not expected to be as large as in early stages of development.
Channels of Distribution (Dealerships)	*Primary Competitive Factor* The dealer's personal contact with customer and his own reputation is expected to be important for a new high-priced product.	*Primary Competitive Factor* Mass dealership channels, cost, and quality of service are expected to be most important with a more mature product.

model diffuses to consumers throughout the market, further gains will be realized. At some time, however, the success will be noted by competitive firms, and they will respond to counteract their loss of sales. As competitors take retaliatory action, perhaps through the introduction of their own new model, the growth will slowly decrease and eventually reverse. Com-

FIGURE 2.3. Market-Share Response from New Model Introduction: Fitted by Parabola



petitors will soon regain their original position, and market shares will be back to their original position.

This change in the initiating producer's market share can be represented as a parabola of a variable, model age, whose shape can be determined through regression. If χ_1 is model age, it would take the form of the equation shown in Figure 2.3. Thus, through the use of data on the timing of new model introduction,* two terms of a multiple regression equation can be used to approximate the effect of model change on market share.

Product-Line Price Index. The ratio of Ford's product-line price to per capital consumer disposable income is used as an index of product-line prices relative to consumer purchasing power. Change in this index is expected to reflect overall product-line pricing strategy, as explained in Table 2.5. A steadily decreasing trend in this index would correspond to an experience curve pricing policy. It does not concern competitive pricing behavior, however, since competitive price differentials are reflected only in the earlier term.

Results of the Analysis

The entire period from 1905 to 1973 (except the World War II years) is included in the analysis. To show the difference in competitive factors as the industry developed, these seven decades have been partitioned roughly in half. The break point chosen was 1948 since the pre–World War II models were continued in production through this year. The differences between the two periods reflect systematic changes in the competitive environment. Variables are considered significant only when they have a 95 percent or higher confidence level.

The results are presented in Table 2.6, and the regression coefficients

* The models or years in which major changes were introduced include the following. For the years up to 1932, the introduction of models N, T, and A represented major changes. The new chassis introduction for the V-8 engine in 1933 is another. For later periods the model years 1941, 1949, 1952, 1957, 1960, 1965, and 1971 are considered major change years.

TABLE 2.6. Statistical Analysis of Competitive Factors: Determinants of Ford's Share in the U.S. Passenger Car Market (dependent variable)

	Stage of Development	
Competitive Factor	*Early*	*Late*
Price differential	*Not Significant* −4.1* (70%)	*Significant* −13.5 (99%)
Major model change	*Significant*	*Not Significant*
Terms of parabola		
Model age	3.5 (99%)	− 0.3 (70%)
Model age squared	−0.1 (95%)	0.1 (90%)
Product-line price index (Relative to per capita consumer disposable income)	*Not Significant* −4.1 (90%)	*Not Significant* .9 (60%)
Dealership	Increase in number of Ford dealerships is associated with increasing market share.	Increase in the average size of Ford dealerships is associated with improved market share.
Other statistics of regression		
Constant	2.3	35.8
R square	.532	.50

NOTE: Variables offering confidence levels of 95 percent and above are considered significant.

* The partial coefficient of regression is with the confidence level in parentheses.

and their confidence levels are given for each period. The coefficients show how great a change in market share accompanies a change in the indicated variable. These data strongly suggest that the competitive environment has completely changed as the industry has developed. Major model changes were a predominant competitive factor initially, but their role greatly diminished after World War II. This may be seen in Table 2.6 by comparing the magnitude and confidence levels of the parabolic terms. To simplify comparisons, the difference in magnitude of the parabola for the early and late periods (from a related regression analysis that also includes dealerships) is illustrated in Figure 2.4. These parabolas can be interpreted as an "average effect" of model change, for the top curve represents the average for five major model introductions in prewar years and the bottom one represents six for the postwar period. Not only is the magnitude greater in the earlier period, but the certainty of a favorable competitive consequence is better. In other words, Ford could be more sure of gaining a competitive advantage by introducing a major new model in the earlier period.

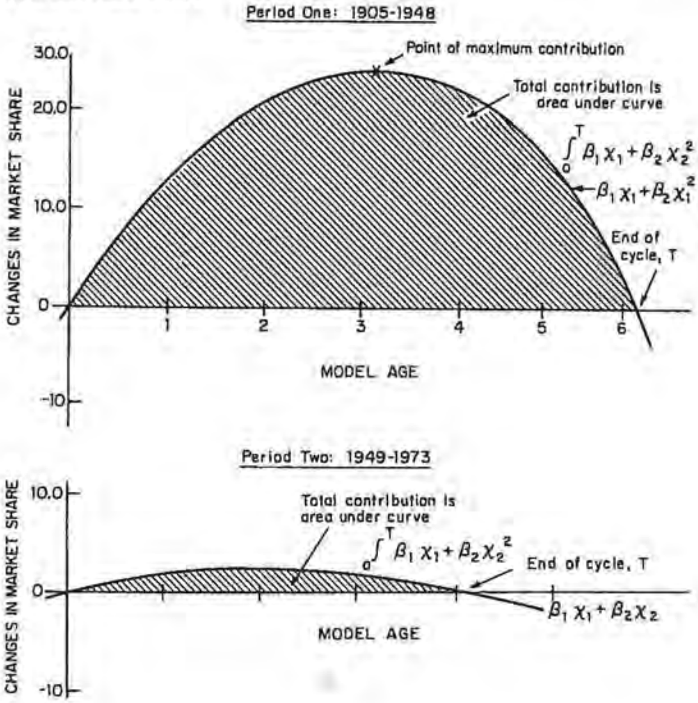
The importance of competitive pricing changes between the two periods. As expected, a decreasing price differential is associated with market-share gains in both periods, but the magnitude of effect is three times stronger in the postwar period and the uncertainty about effects is lower (99 percent confidence level versus 70 percent). In fact, price is the most important competitive variable in the postwar period. It is important to note, however, that these results do not pertain to conditions since 1973. Much different results might be expected in this more volatile market environment.

Changes in the coefficients of the price index confirm earlier observations about pricing strategy. Experience-curve product-line pricing proved more important during the initial phases of industry development and unimportant later. It would seem that such a strategy should be used with caution in the later stages of development.

The model for so simple a formulation is surprisingly powerful in representing the competitive environment. The fraction of total variance in market share explained by the variables is about 50 percent (R^2), and the results nicely support the prior conceptual model that preceded the statistical analysis.

Although not reported here, other more speculative but complex forms of the model have also been analyzed with similar results and an

FIGURE 2.4. Contribution of Model Changes to Ford Market Share (Versus Base Unit)



improved fraction of explained variance. When variables that pertain to channels of distribution are included, the results suggest that they are competitively very important in both periods. An increase in the *number* cf dealerships seems to be associated with improved market share in the prewar period (99 percent confidence level). For the postwar period the *size* of dealerships seems most important to Ford. These trends lend support to the concept that appropriate channels of distribution shift as the industry develops.

Further analysis concerning which variables might stimulate change, or be "causal" as it were, have not produced fruitful results. The timing of relative changes in numbers of dealerships was systematically shifted relative to other variables to see whether a successful model change preceded an increase in dealerships or vice versa. This analysis showed no evidence of such a "leading" or "lagging" relationship. In a preliminary way, this suggests that a successful competitive strategy may require close timing and coordination among its various components. These later analyses provide the basis for the parabolas in Figure 2.4.

Economics of Major Model Change

Huge profits are at stake in the changes that have come about in the industry. The parabolas shown in Figure 2.4 provide a way of approximating the economic returns that accrue from a major model change. The area under each parabola represents the additional units that were sold because the change was made. Although the units used in the figure are percentages of the U.S. automobile market, they can be used to roughly approximate dollar-equivalent value if the contribution over variable costs per car is known.

For the average 6.14-year period that a major model change influenced the market in the pre–World War II period, additional unit sales were captured equivalent to 100 percent of annual U.S. automobile sales in an average year.* The gain in market share was only 25 percent in a peak year, but over six years the cumulative addition, as determined by the area under the parabola, was 100 percent. The comparable market-share gain for the postwar period is less than 5 percent, a decrease of 20 to 1. Table 2.7 extends these market-share figures to make a rough approximation for the value of a major model change in the prewar and postwar periods.

The differences between the two periods are quite sizable, ranging from about $1.5 billion for the earlier period to $.25 billion after World War II. Since the value of a model change rose from nearly zero when the industry was formed at the turn of the century, these numbers can be used

* As indicated in Figure 2.4, the area is the integral of $\beta_{1}\chi_{1} + \beta_{2}\chi_{1}^{2}$ over the limit of 0 to T where T is the period of effect, is 100 percent of any one year's market share.

TABLE 2.7. Approximating the Value of a Major Model Change

	Prewar	*Postwar*
1. Annual U.S. car sales (cars in average year)	4,500,000	8,500,000
2. Additional market share captured by major model change (in units of percent annual market share)	100%	5%
3. Additional unit sales captured by major model change (item 1 × item 2)	4,500,000	425,000
4. Average price per car (in 1958 dollars)	$1,300	$2,100
5. Contribution per car to fixed cost, model change costs, and profit (assuming 25% contribution)	$ 325	$ 525
6. Value of new model introduction (item 3 × item 5)	$1,462,500,000	$275,625,000

to outline changes over time. This trend is illustrated by the upper curve in Figure 2.5.

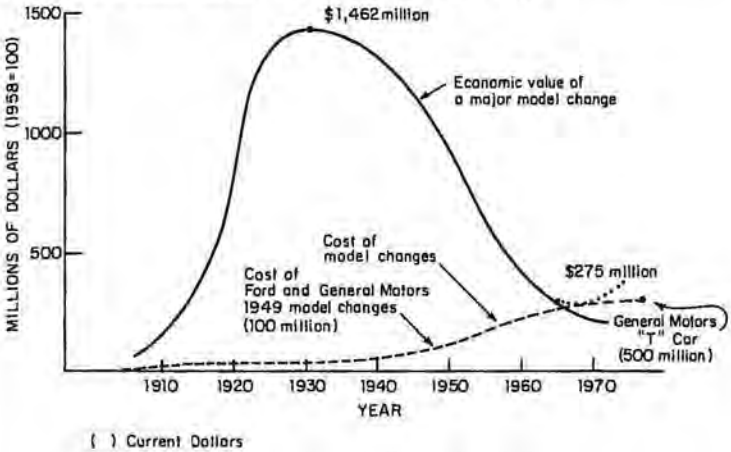
The Net Value of Model Changes

The full significance of the decline is not shown by the value of major model change alone. The net value of a model change, or the difference between the value and the cost of a model change, is more informative. This is suggested by the gap between the two curves in Figure 2.5. The curve for the cost of model changes is based on industry estimates of actual model change costs during the postwar period for both Ford and General Motors (adjusted to 1958 price levels). The costs of particular model changes apparently are similar for both companies.

The implications of the curves are clear. The net value of an average model change fell nearly to zero in the postwar period. This explains the reduced rate of model change observed below (see Chapters 4 and 5). It may also explain why incremental change is relatively more attractive. The convergence of the two curves is also consistent with the shift in competitive emphasis to price and dealerships. These relationships clearly illustrate the magnitude of changes that have accompanied industry developments. If the two curves were to cross so that the net value of a major model change were negative, as suggested for the period since 1973 in the figure, then the automobile would be virtually a commodity.

Most of the data on which the model-change analysis rests pertain to the pre-1970 period. There is ample evidence that the market does value new models in the post-1970 period. Lightweight cars with more fuel efficiency and interior space have apparently gained in market share—the market now seems to be demanding this type of automobile. In fact, the market seems dynamic, sensitive to differences, and able to express its preferences. This is a far cry from a commodity market. The cost of model change does not seem to be as volatile as the value of model change,

FIGURE 2.5. Value and Cost of a Major Model Change



NOTE: Amounts in parentheses indicate 1958 dollars.

however, and these costs continue to rise. In the face of a continuing shift in consumer preferences and a rising cost of change, the industry's market power may concentrate even further among producers.

This analysis focuses attention on forces that induce technological change in the product and process and on the cost of making these changes. Previous studies have often concluded that static economies of scale in production were the major barriers to entry into the industry. These data suggest that the cost of change and the market's demand for change may be competitively much more important.

CHOOSING A UNIT OF ANALYSIS

As we have seen, the automobile industry has been fundamentally changed by progress in improving productivity and serving mass markets. Product innovation has been replaced as a major competitive factor by customer service and product-line policy. The development of highly efficient technologies for mass production has increased costs and raised design constraints to the point of slowing product change. Technological progress is no longer introduced by radical product innovation, but comes about as the cumulative result of incremental change. Forces outside the industry, like government regulations, political action, and fuel prices, now provide the primary stimulant for change rather than entrepreneurial competition within the industry.

These changes in innovative capability have come about slowly and cannot be attributed to any one factor. Rather, they seem to be generally associated with the competitive strategy choices of major firms and the technological trends that accompany the extensive development of mass production.

A sense of consistency and direction has pervaded the course of long-term development in the automobile industry. For decades, the central tendency in design led toward a universal car for all market segments. As new features made the car perform better, more reliably, more simply, and with greater convenience, the basic distinctions between high- and low-priced cars disappeared. The peak of convergence toward a common design seems to have been reached in the early 1960s; from that point to the present, there is growing evidence of divergence in design. To take full advantage of inherent consistencies in production and product changes, a unit of analysis is needed that will support systematic study. But should the unit of analysis encompass the firm or the automobile or the manufacturing process or the industry?

Salient features in the historical pattern of product and process development provide a framework of technological change that seems to apply outside the automobile industry as well as within. The technological histories of mass production in incandescent light bulbs, electronic calculators, and television share intriguing similarities with the history of the automobile. Progress in defining a unit of analysis must be made, however, before we can develop a common framework for comparison.

Such a unit of analysis properly includes the characteristics of the product, the constraints of the production process, and certain aspects of the particular firm's competitive strategy. During the early stages of development, the product alone might seem to be a useful unit of analysis. In more advanced stages of development, however, the production process takes on increased importance and, in the extreme, the process principally determines the characteristics of the product. (As an illustration, both the Oldsmobile and Ford's Model T were initially well-defined and unique entities. Today, however, little is communicated about a car by saying it is an Oldsmobile. To say that it was produced in a General Motors assembly plant for midsized Buicks, Oldsmobiles, and Pontiacs [a "BOP" plant] is much more informative.)

A special unit of analysis is therefore needed to encompass both the product and the characteristics of the manufacturing unit that produced it. A "productive unit," as I have defined it in prior studies, meets these requirements for a unit of analysis.[41] A productive unit is defined as an integral production process that is located in one place under a common management to produce a particular product line. The unit's characteristics are determined by a variety of factors—whether mass production is involved, how the production process is organized, and the cost and type of equipment and work-force skills. In a specific case, such a unit might be an automobile assembly plant for a given type of car or an automobile engine plant for a particular type of engine or a stamping plant and the intended body type. In other industries, the equivalent unit might be a plant for pocket calculators or a cold rolling mill. The important feature of this definition is that both product and process characteristics are considered jointly. Together they best represent constraints and opportunities for change.

By using the productive unit as the basis for study, an important reality about the technological development of the automobile can be addressed. The automobile is not well represented by just one productive unit; rather, several are important, and they may all be at different stages of development.

The stage of development in the productive units of the major components of the automobile must be evaluated to determine the development of the automobile as a whole. For example, as discussed above, the technology for mass producing automobile engines at Ford had undergone ten to fifteen years of development by the time Ford undertook the mass production of closed steel bodies. Although the mass-production technology for bodies ultimately became highly developed, in 1925 it was still a rudimentary process that required much hand fitting and stationary assembly work. Similarly, the automatic transmission at the time of its introduction in the early 1940s had the characteristics of an innovative product and demanded process innovation.

The maturity of an industry is often equated to many different factors like the rate of innovation, profit margins, and standardization of product as well as the industry's age. If the maturity of the automobile as a whole depends upon the development of the major productive units, however, then the chronological age of the car as a product, per se, is not as important in determining its vitality as is the development of major productive units. Innovation in major productive units up through the 1950s kept the car as a whole from reaching an advanced stage of maturity (see Chapter 6). It remains to be seen whether impending innovations in electronics, fuel engines, and frame and body designs can counterbalance the tendencies toward maturity.

Recent trends offer encouragement that such change is possible and may now be under way. If this is the case, then much of the responsibility must rest with forces external to the industry that have encouraged change. Even though the major automobile firms may have resisted change initially, forces have stimulated a new direction of development that in the long run will be in the vital interest of the industry and the firms themselves.

The concept of the productive unit and the way it normally evolves and is shaped by innovation are central issues in this book. The way a productive unit develops and changes or resists change, and its relationship to the structure of the automobile industry and to the automobile as a final market product, all require more study. These ideas are developed and refined in subsequent chapters.