J PROD INNOV MANAG 2014;31(1):8–16

DOI: 10.1111/jpim.12076

The Long Tail of the Auto Industry Life Cycle

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This article explores how the industry life-cycle theory, proposed by Abernathy and Utterback, can be reinterpreted from the viewpoint of product architecture dynamics. The "long tail" of the automobile industry life cycle, observed during the past several decades, is explained by an evolutionary framework in which a product's architecture is treated as an endogenous variable affected by customers' functional requirements, environmental-technical constraints, and their changes. The present article explains how the existing industry life-cycle model effectively explains the early history of automotive product-process innovations, but that it fails to explain the "long tail" of the life cycle, and that an evolutionary approach of product architectures can be used to explain the architectural sequence and the long-term trend of the increase in nonradical innovations. That is, the industry life-cycle model certainly fits well with the actual pattern of product-process innovations at the early phase of the automobile's development, between the 1880s (invention) through the 1920s (the end of the Model T) and into the 1960s, when product differentiation continued without significant product/process innovations (e.g., the Big Three's annual model change). But the question remains how this model can explain the rest of the industry's history (1970s to 2010s), which is characterized by "rapid incremental innovations," or a "long tail of the life cycle," with its upward trend of technological advancement rather than the end of innovations or the beginning of another industry life cycle (i.e., "dematurity"). The evolutionary framework of product architecture predicts that the macro architecture of a given product category (e.g., passenger cars) will be relatively integral when the functional requirements that customers expect, the constraints imposed by society and the government, and the physical-technical limits inherent in the product are strong, and that it will be relatively modular when they are weaker. The dynamic architectural analysis starts from the Lancaster-type analysis of a set of function-price frontiers for a given product category (e.g., cars). Based on the design theories, it hypothesizes that the shape of function-price frontiers are different between integral models and modular models. It then hypothesizes that price-oriented customers tend to choose relatively modular products, whereas function-oriented customers choose relatively integral products more often than not, other things being equal. Thus, the macro architecture of a given product can be determined depending on whether each architecture's price-function frontier touches the price-function preference curves of its customers. As for the future architecture of the car, its macro architecture, determined by markets and environments, will remain relatively integral and complex as long as it continues to be a fast-moving heavy artifact in the public space, whereas its micro architecture, determined by engineers, will be somewhat mixed, as the engineers try to simplify and modularize the automobile design wherever the market and technology permit. The evolutionary framework of architectures also predicts that the architectural sequence inside the industry life cycle will differ by products (e.g., cars and computers) depending upon the dynamic patterns of technological advancement (e.g., shifts of the price-function frontier) and market-societal constraints (e.g., shifts of the price-function preference curve).

Automobile Innovation Is Driven by Innate Problems

What is the long-term future of the world automobile industry in the 21st century? Quantitatively, growth in the industry is a near certainty. In a decade or so, annual demand will reach 100 million units (it was roughly 70 million in 2010), the majority of which will be sold in emerging markets (which comprised roughly 50% in 2010). Another safe assumption is that the desire for personal mobility—the motivating rationale for owning this artifact called the car—will remain more or less universal, and that nothing is going to come along that is better than the car at satisfying that desire. Accordingly, there will soon be over a billion automobiles on the planet, making the world auto industry one of the largest in existence (with a value of more than $1 trillion).

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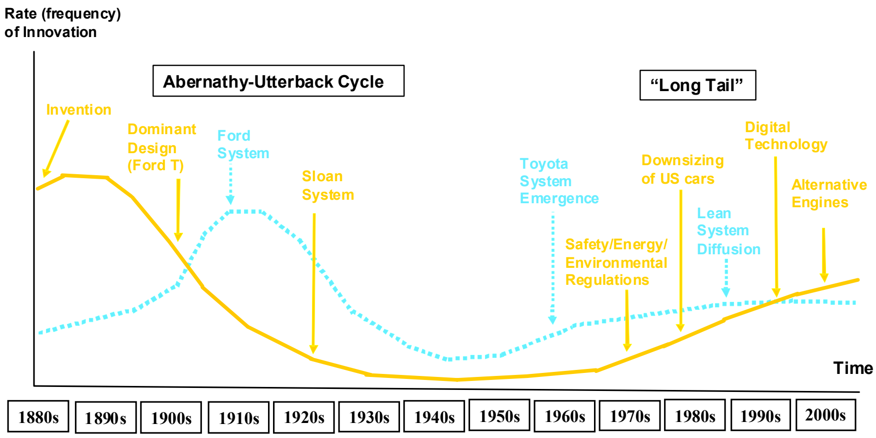

Figure 1. The Automobile Industry Life Cycle—A Hypothetical Pattern. Note: The author's subjective estimation based on Abernathy (1978), Cusumano (1985), Womack et al. (1990), Clark and Fujimoto (1991), Fujimoto (1999), and other sources

Unfortunately, the automobile also comes with a myriad of problems. After all, cars are heavy, fast-moving objects operated by individuals in the public space, and that reality will not change in the foreseeable future. This combination of mass, speed, and space is often deadly, with over a million people dying each year in traffic accidents worldwide. In addition, nearly 20% of the world's carbon-dioxide emissions come from the automobile sector. There are also noise and other issues. And although new technologies, social systems, and specific human efforts have alleviated these difficulties to some extent—particularly in advanced nations (Japan, for example, cut its traffic casualty rate nearly in half and improved the fuel efficiency of gasoline-powered cars by over 30% between 2000 and 2010)—they are far from satisfactory, and they are never enough. The innate problems of the car—its "original sins," if you will—together with drivers' ever-increasing expectations regarding functionality and charm, necessitate endless design improvements. The sins guarantee constant innovation.

But the patterns of industrial innovation for a massive product like the automobile are not the same as those for digital devices and software, for example, which are operated by essentially weightless logic and electrons. Bearing this physical reality in mind, the paper that follows will attempt to illustrate the past, present, and future dynamics of automobile innovation using certain analytical frameworks that can also be generally applied to other industries.

BIOGRAPHICAL SKETCH

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The Abernathy-Utterback Industrial Life Cycle

One of the most widely known frameworks depicting the dynamic pattern of industrial innovation is the Abernathy-Utterback model of the "industry life cycle" (Figure 1; Abernathy, 1978; Abernathy and Utterback, 1978). Also known as the product-process life-cycle model, it hypothesizes that an industry begins with the invention of a seminal, but functionally premature, model (e.g., the 1886 Daimler and Benz), followed by a wave of numerous innovations that improve product functionality while using mostly versatile workers and general purpose factories, machines, and materials that help to absorb the design fluctuations. The customers at this "fluid stage" tend to be fewer, richer, and product-function-oriented, rather than price-sensitive.

As the products become conceptually articulated and functionally sophisticated, a highly competitive model is eventually introduced into the market that crystallizes all past product innovations (e.g., the 1908 Ford model T). Also called the "dominant design," this standard-setting and concept-articulating model becomes a turning point for the industry as a whole. The focus of competition then begins to shift from functional maturation to price-cost reduction as the competing models become less differentiated by functional-structural designs. As the uncertainty regarding product design decreases, heavier investments in product-specific process technologies and equipment become economically justified, and a wave of process innovations follow (e.g., the so-called Ford system) while product innovations become less frequent.

At this "specific stage" of the industry life cycle, products and their processes are more standardized, and production equipment, materials, components, and work skills become more product specific. The focus of competition becomes economies of scale and developing effects that can decrease the unit production costs without altering the specific production factors. Productivity goes up, but both product and process innovations become stagnant—what Abernathy called the "productivity dilemma."

Overall, the product-process life-cycle model is graphically illustrated as two overlapping waves of innovation, in which a hilly curve representing the frequency of product innovations is followed by another hilly curve depicting process innovations, with the dominant design emerging between the two peaks.

As Abernathy (1978) described and analyzed in detail, the abovementioned industry life-cycle model fits the world automobile industry very well when it comes to the early phase between the 1880s (the invention of an automobile with an internal combustion engine) and the 1920s (the end of the Ford Model T)—and perhaps even into the 1960s in the case of the United States auto industry, in which product differentiation continued without significant product/process innovations (e.g., GM's policies of full line and annual model change).

But this model is not very good at explaining the rest of the industry's history. It seems strange to say that product and process innovations have been stagnant since the era of the Model T or the heyday of big American cars. The present paper offers an additional framework that explains the evolutionary patterns of the world auto industry.

The Long Tail of the Auto Industry Life Cycle

Let us take a brief look at what has happened to the global auto industry since the 1960s. The past 50 years can be characterized as a period of "rapid incremental innovations," according to Clark and Fujimoto (1991), who used that term to describe product development in the industry.

On the one hand, the product-process innovations have not changed the overall architecture or basic structure of the automobile. The technological changes have been evolutionary rather than revolutionary in nature in that they did not render previous products obsolete, but rather strengthened their functionalities and competitiveness. The innovations were not totally disruptive (Christensen, 1997; Tushman and Anderson, 1986).

Consequently, most of the major auto manufacturers have survived (unlike certain high-tech industries over the same period), although some have been technically bankrupted, and others have merged or allied with their competitors. The price of a standard car has not changed dramatically, unlike with certain digital products. There has also been no drastic reduction of parts and components.

On the other hand, technological developments in the global auto industry have indeed been very active since at least the 1970s. Major auto manufacturers in the United States, Europe, and Japan have spent between 3% and 5% of their sales revenue on R&D throughout this period. The cars of 1960 and those of 2010 may look alike in terms of fundamental architecture, exterior/interior shapes, and basic functionality, but the latter have improved dramatically in terms of functional performance, comfort, safety, and fuel efficiency, as well as their friendliness to passengers and the environment.

Such rapid functional improvement has been achieved through significant technological changes in the structural components of vehicles, the way those components are interconnected (i.e., architecture), and the massive introduction of electronic control systems (ECU), with tens of millions of lines of embedded software now standard in high-end models. This vast technological change is still ongoing as of 2012. Consequently, high-functional cars in advanced nations, with experienced/demanding users and strict environmental/safety regulations, are now overwhelmingly complex, and that causes many design–quality problems for major manufacturers (MacDuffie and Fujimoto, 2010).

At the same time, there has been, since the beginning of this century, explosive growth in the emerging auto markets (including China), where the customers, most of whom are first-time car owners, generally prefer much simpler and cheaper models than those in the advanced markets. This, however, has not resulted in a massive attack of disruptive or revolutionary technologies from the newcomers. The market for large automobiles in those markets is still dominated by the simplified models and technologies of existing multinational automakers, with the Chinese, Indian, and other local makers having earned only a small market share so far. The popular models that the multinationals produce for advanced markets are overengineered vis-à-vis the current emerging markets and do not sell well there.

On the side of process innovations and manufacturing capability building, progress has been far from stagnant. There have been many challenges since the era of the original Ford system of the 1920s, which was extremely efficient and fast, but inflexible and stiff. Some of the influential examples are flexible automation, including assembly automation (Shimokawa, Jürgens, and Fujimoto, 1995), the Volvo system, Total Quality Control, the Toyota system, the lean system (Cusumano, 1985; Fujimoto, 1999; Liker, 2003; Monden, 1983; Womack, Jones, and Roos, 1990), and integrative product development (Clark and Fujimoto, 1991; Cusumano and Nobeoka, 1998). In particular, the last three examples involved challenges that forced the Japanese auto firms to become flexible, fast, and efficient in the tough postwar competitive environment. Their aim was to alleviate the productivity dilemma at the end of the life cycle.

To sum up, the world automobile industry's evolution over the past 90 years can be characterized by the "long tail of the industry life cycle," with a somewhat upward trend of technological advancement, rather than by the simple end of one product-process life cycle and the beginning of another, which Abernathy, Clark, and Kantrow (1983) called "dematurity" (Figure 1).

Historically, many journalists and analysts have preferred catchy scenarios for the future. Some have argued, in the past 40 years at least, that the burden of huge R&D and capital investments would allow only about 10 major auto companies to survive, but that reality has never come to pass. Others supported "dematurity," or the disruptive technology hypothesis; when the U.S. market faced a rapid increase in gas prices after the second oil crisis, future R&D investments on various nontraditional vehicles (e.g., steam, gas turbine, electric, and others) attracted popular attentions, and some journalists advocated the "reinvention" of the automobile. But that never happened.

In the end, the most appropriate interpretation of the historical reality seems to be the long tail of the industry life cycle, with its rapid incremental innovations. The rest of this paper will sketch an evolutionary framework of the architecture-capability fit, striving to provide some additional explanation of what has happened in the industry to this point, and offering some predictions on what is likely to transpire in the future.

A Framework of Architecture-Capability Evolution

Let us explore the logic behind the long tail of the industry life cycle. As the details of this framework have been written about elsewhere (Fujimoto, 2007, 2012), only a skeleton sketch is offered below (Figure 2).

Design Information

Design activity refers to those efforts by a firm to coordinate an artifact's functional and structural elements (parameters) prior to its production. Design information represents the resulting pattern of interconnections regarding such design elements.

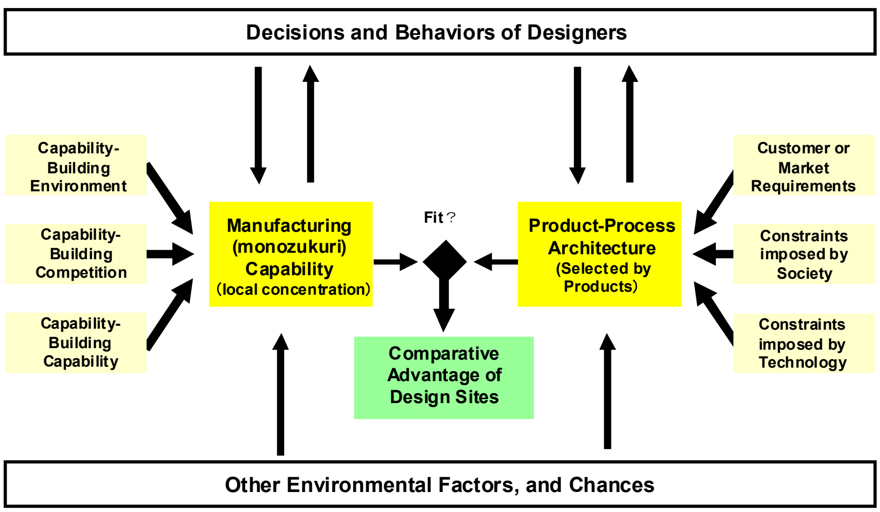

Figure 2. An Evolutionary Framework of Design-based Comparative Advantage—the Dynamic Capability-Architecture Fit. Source: Fujimoto (2007).

Manufacturing

In a broad sense, manufacturing is nothing more than the efforts by firms to create good flows of good design information for their customers.

Manufacturing Capability

Organizational capability in manufacturing refers to a firm's specific system of organizational routines for creating and processing value-carrying design information to customers more accurately (high quality), more efficiently (low cost), and more quickly (short lead time) than its competitors (Fujimoto, 1999, 2007; Nelson and Winter, 1982).

For example, Toyota's manufacturing system (the so-called lean manufacturing system) is an example of "coordinative capability," or a manufacturing site's organizational capability to realize a high level of alignment among its productive resources or design elements (Fujimoto, 1999; Monden, 1983; Womack et al., 1990).

Evolution of Capabilities

A certain type of manufacturing capability can evolve over time in a particular country that has a particular capability-building environment. For example, the United States—a nation of immigrants—has tended to emphasize "division-of-labor," or coordination-saving capability, wherein its firms make immediate use of incoming talent (e.g., standardization, modularization, specialization); whereas postwar Japan—a nation that experienced rapid economic growth and chronic labor shortages due to a lack of immigration influx—had no choice but to build coordinative capability with long-term employment and teamwork involving multi-skilled workers to deal with this challenge (Fujimoto, 1999, 2007). Thus, the present framework assumes that history matters when it comes to the evolution of manufacturing capability.

Product-Process Architecture

An artifact's architecture refers to the formal pattern of dividing and connecting its design information (Simon, 1969; Suh, 1990; Ulrich, 1995). Product architecture is that between its functional and structural design elements, while process architecture is that between its structural and process design elements.

There are two ideal types of architecture: "modular" architecture, with a simple one-to-one correspondence between the functional-structural-process elements and the standardized interfaces between them; and "integral" architecture, with a complex many-to-many correspondence between the elements and the customized interfaces (Baldwin and Clark, 2000; Ulrich, 1995). (Actual cases are always found somewhere between these two extremes on the architectural spectrum.)

Evolution of Architecture

The evolutionary framework treats a product's architecture as an endogenous (rather than exogenous) variable. That is, the overall architecture of a given product category (e.g., passenger cars) can be relatively modular or integral, depending upon the nature of the functional requirements that customers expect, the constraints imposed by society and the government, and the physical-technical limits inherent in the product. More specifically, a product's architecture tends toward "integral" when the abovementioned requirements are stricter, as the precise optimization of design elements is necessary to cope with the greater constraints.

By contrast, when constraints are less strict, a product's architecture tends toward "modular," as the efforts by engineers to simplify the functional–structural connections of its design elements can be more easily realized. Although the product's "micro-architecture" may be a complex composite of modular and integral areas and layers that the engineers can choose, the "macro-architecture" of the whole product (i.e., the tradable artifact) is affected by the market and society. Thus, there is no such thing as "intrinsic architecture" for any given product category.

Capability-Architecture Fit

By using the above typology of architectures and capabilities, and by applying the logic of comparative advantage in the trade theories to the locations of design activities, the author has proposed a framework of "design-based comparative advantage" (Fujimoto, 2007, 2012). This logic, based on the axiomatic design approach (Suh, 1990), regards product design as the coordination of an artifact's functional and structural parameters and predicts comparative advantage in design cost when a country's endowment of a certain type of manufacturing capability fits a certain industry's architectures and other design attributes. For example, coordination-intensive (i.e., integral) products are more likely to be developed economically in a coordination-rich country (i.e., a geographical area with a high endowment of coordinative organizational capabilities).

Predictions

Applying the abovementioned framework to the auto industry in the 21st century, it seems likely that, as long as environmental constraints and the functional requirements of customers continue, on average, to grow stricter, the automobile's macro-architecture will remain more or less integral, despite the worldwide efforts by engineers to modularize the micro-architecture of this complex artifact. Because unlike with many digital products, there are limits to what modularization can achieve as long as cars remain these "heavy objects that travel at high speed through public space." This implies that certain countries with a rich endowment of coordination-intensive capabilities (e.g., lean manufacturing or integrated product development) will continue to enjoy competitive advantages in this industry, particularly as the wage gap narrows between advanced and emerging nations.

However, the same framework also predicts that, to the extent that customer requirements and environmental constraints remain less strict in the emerging economies, automobiles there are, on average, likely to remain relatively modular and simple. Whether the two product groups converge or diverge in the future will depend upon whether or not the customer preferences and social constraints of the two regions become equally demanding.

The framework also predicts that the engine mix of automobiles will, in the first part of the current century, grow more diversified, rather than one particular type (e.g., gasoline combustion engines or electric motors) dominating the whole global market. To date, small differences in control regulations pertaining to nitrogen oxide (NOx) between the EU on one hand and United States/Japan on the other have translated into dramatic differences in the gasoline/diesel engine mix. Thus, depending upon the differences in requirements and constraints (e.g., the functional preference of customers, price-performance sensitivity, utilization ratio, route regularity, geographical concentration of trips, and other factors), the expectation is for a mix of advanced gasoline/diesel engines (e.g., downsizing of the turbocharger and direct injection [like VW]), altering compression ratios (like Mazda), parallel-type hybrid electric vehicles (e.g., Toyota Prius or Honda Insight), ordinary combustion engines, genuine electric vehicles (e.g., Tesla, Mitsubishi i-MiEV), fuel cell electric vehicles, series-type hybrids (range-extended EVs; e.g., General Motors' [GM] Volt), and low-specification electric vehicles (e.g., China's rural-purpose electric vehicles [EVs])—with these innovations developing in an order that moves from the integral to the modular end of the architectural spectrum (Fujimoto, 2011).

Integrating the Industry Life Cycle and Architectural Evolution

Architectural Sequence in the Industry Life Cycle

Let us now combine the abovementioned framework of capability-architecture evolution with the Abernathy-Utterback theory of the product-process life cycle. It is interesting here to compare the evolution of architectures between the automobile and the computer (Figure 3). As is known well, the industrial history of the automobile started with the "horseless carriage," a rather "crudely open-modular" product that employed a mixture of newly designed engines and existing/modified parts from horse carriages and bicycles (Abernathy, 1978; Hounshell, 1984).

The dominant design, Ford's Model T, was highly integral, with lots of newly designed, model-specific parts. Subsequently, GM's common parts policies under Alfred Sloan, Jr. made automobile architecture somewhat more "closed-modular." A typical new model car sold today in the advanced markets—with less than 10% generic parts, less than 50% firm-specific common parts, and over 50% model-specific parts—falls somewhere between the integral and closed-modular architectures.

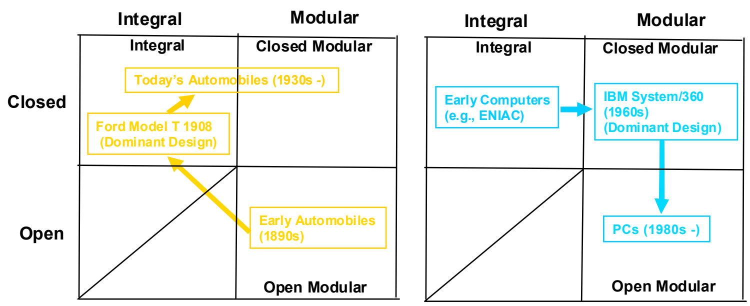

Figure 3. The Architectural Sequences of Automobile and Computer Industries

In the case of computers, however, the architectural sequence is very different. The first generation (e.g., ENIAC) was highly integral, with model-specific circuits. And the dominant design, IBM's System/360, can be seen as a closed-modular model, with an IBM-specific operating system (Baldwin and Clark, 1997; Freeman, 1982). But then along came personal computers, which are open-modular, with their industry-standard OS and CPU. Thus, the architectural sequence of the automobile, with functionally and structurally similar ancestors like carriages and bicycles, has been "open-modular ⇒ integral ⇒ closed-modular," whereas that of the computer, without such predecessors, has been "integral ⇒ closed-modular ⇒ open-modular."

Function–Price Frontiers and Customer Preferences

This sequence and the "long tail" can be explained using the logic of capability-architecture evolution. It is best to begin with a Lancaster-type analysis (Lancaster, 1966, 1979) of the function–price frontier for a given product category with functionally equivalent models (e.g., compact passenger cars). According to Lancaster's approach, customers with different preferences between a product's functionality and price will have indifference curves of different shapes—a price-oriented customer will have a relatively flat curve in the function-price space, while a function-oriented customer will be characterized by a steeper curve (Figure 4). It can also be assumed that, like Lancaster, a customer will choose the product that is located in the tangency point of its function-price frontier and his or her indifference curve.

Furthermore, based on the design and architectural theories, the function–price frontiers within a given category are different between integral models and modular models. The development of integral products incurs higher "fixed coordination costs" but offers higher functionality due to optimization; the coordination-saving modular products enjoy lower fixed coordination costs but offer lower functional performance because of their "mix-and-match" nature (Figure 4). The set of frontiers of different shapes can be seen as an overall envelope that contains all the different architectures.

Consequently, our framework predicts that price-oriented customers tend to choose relatively modular products, whereas function-oriented customers choose relatively integral products more often, other things being equal (e.g., production volume and specific technologies).

Explaining the Architectural Sequence

Figure 5, a graphic expression of customers' architectural choices, can help explain why the industry life cycles of different products experience different architectural sequences.

In the evolutionary setting, a product category's function–price frontiers, with product and process innovations, normally shift toward the lower right side. In the case of the automobile industry, the initial frontier of crudely modular products (A) is totally overwhelmed by the integral dominant design, the Model T (B), and subsequent process innovations (the Ford system) and volume expansions (C). The pace of innovation slowed down once, as Abernathy (1978) pointed out, but since

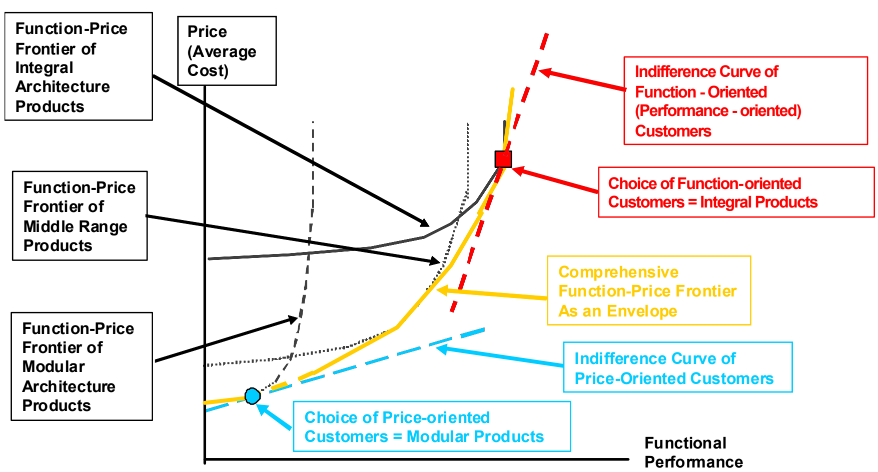

Figure 4. Diagram Cost–Performance Frontiers, Customer Preferences, and Choices of Architectures for a Given Product Category. Note: Modified from Fujimoto (2012).

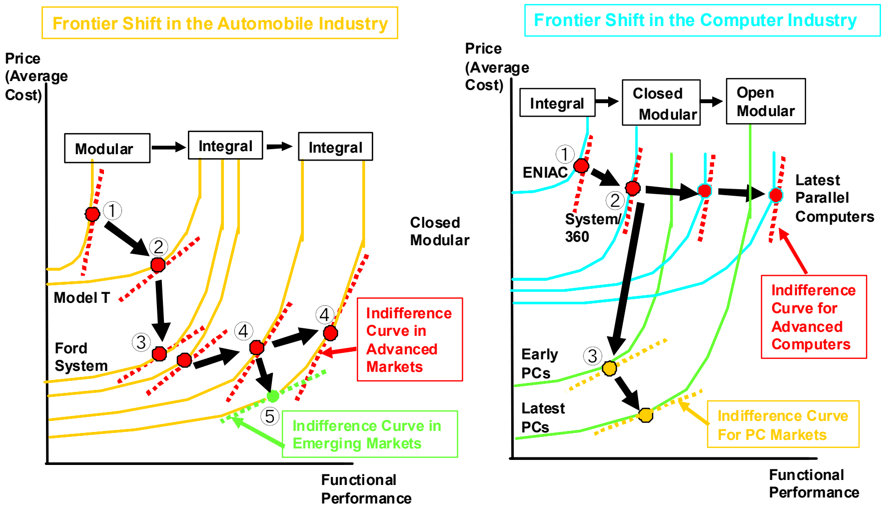

Figure 5. Shift of Price–Function Frontiers and Architectural Sequences in Industries Lifestyle

the 1970s, the pace of product–process innovations has been increasing, as global competition and environmental constraints have grown more intense (D). This pattern of shifting frontiers roughly illustrates the architectural sequence and the long tail in the automotive industrial life cycle.

It should be noted that the automotive market was dominated in the beginning by rich and function-oriented customers; that era was followed by the price-oriented masses made happy by Ford's Model T; and since the 1970s, the market has been dominated by increasing function–orientation due to energy-safety-environmental constraints and customer sophistication. Note also that, since the 2000s, the number of price-oriented customers in the emerging countries has rapidly expanded, and they tend to prefer simpler and relatively modular models (5).

Their demand for simpler models, however, has been fulfilled for the most part by simplified versions brought to market by existing auto manufacturers, rather than by disruptive technologies from new entrants (Christensen, 1997). Whether the integral segment in advanced markets and the modular segment in emerging ones will ultimately merge or remain separate will depend upon on how the average requirements and constraints of the two markets converge, and at what level.

Using Figure 5, the patterns of architectural sequence in the computer industry can be roughly described as (1) the emergence of seminal and integral computers ⇒ (2) the dominant design, with a closed-modular architecture (System/360) ⇒ (3) dramatic cost reduction thanks to open-modular architecture (PC). The difference between the two patterns can be explained in part by the simple physical fact that passenger cars are weighty, fast, and expensive consumer durables, while computers are operated by things that are basically weightless—electrons and digital logic.

Conclusion

This short essay sketches how the industry life-cycle model explains the early history of automotive product–process innovations but that it fails to explain the tail of the life cycle, and how an evolutionary approach involving capability-architecture can be used to explain the architectural sequence and the existence of the long tail of the automobile life cycle.

Over the past two decades, academic discussions on product innovations have been heavily concentrated in the area of digital products, and for good reason, considering the huge impact that digital technologies have had on the global economy. Over the same time period, however, there have been many incidents that remind us that we do, after all, live in the physical world, surrounded by a mixture of both the weighty and the weightless, digital and analog, by both real and virtual artifacts.

In order to effectively analyze and compare the industries of this century, including the future of automobiles, we must continue to carefully investigate the design attributes of our artifacts, including their architecture, and the organizational attributes of design–production sites, including their manufacturing capability.

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