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Architecture, Capability, and Competitiveness of Firms and Industries

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Abstract

This paper explores basic concepts of architectural strategy, or application of the concept of product-process architecture to strategic management and industrial policy-making, as well as the issue of measuring architecture. First, the paper discusses definitions and types of product architecture, including integral, modular, closed, and open types. It also points out hierarchical and continuous (spectrum) nature of product architecture, and discusses the issue of how to measure architecture. The paper then applies the concept of architecture to strategic management and industrial policy-making. The topics selected here include the fit between architecture and organizational capability, dual architectural strategy, architectural positioning strategy, and architectural portfolio strategy, and architecture-based industrial classification and policy.

1 Introduction

The main purpose of this paper is to explore application of the concept of product architecture to strategic management and industrial policy-making. By product architecture I mean the basic design policy to map a product's functions to its structural elements and to make interfaces between these structural elements. My prediction here is that a certain fit between the organizational capabilities of firms and the architectures of their products may affect firm competitiveness. In other words, product architecture may be a good indicator for predicting the industrial sectors where a firm (or a cluster of firms) will tend to demonstrate competitive advantage.

Economists have long tried to explain why country A (or firms in country A) enjoys international competitiveness in industry X, while it does not in industry Y. A standard answer of the trade theory, since the era of David Ricardo, has been that a certain fit between resource endowment in country A and relative resource-use intensity of industry X creates international competitiveness of country A in industry X. More recently, business academics have tried to explain why company A enjoys above-normal profit in industry X, but not in others. A tentative answer has been that distinctive organizational capability of company A makes it profitable in industry X, or that company A was smart enough to find an easy-to-make-profit sector such as industry X and to establish a unique position there ahead of its rivals. These arguments, however, have not paid much attention to detailed aspects of industry characteristics that might affect the competitiveness of firms.

Against this background, the present paper attempts to illustrate how the detailed aspects of industry characteristics, or product architecture, can serve as a basis for analyses of strategic management and industrial policies.

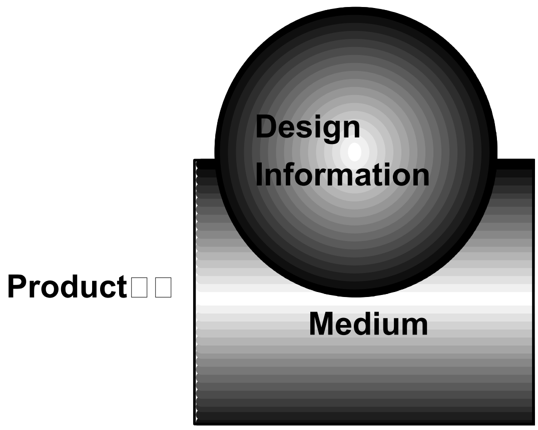
2 Architecture-based Analysis of Industry

2-1 Design-Information View of Industries: Basic Terminology

As a basis for the subsequent analysis of strategies and industrial policies, let's begin with a detailed characterization of product, production and product development for a given industry. My framework, based on insights from technology and operations management, may be regarded as a *design-information view of industries*.

This view of industry regards a *product* as design information that is embodied in a particular medium or material (**Figure 1**). Products are the primary outputs of manufacturing firms to the market. In the design-information view, the essential part of what manufacturing firms deliver to the customer is a bundle of design information or messages that each product carries, rather than the product itself as a physical object. In other words, product design information is value-carrying information from the customers' point of view.

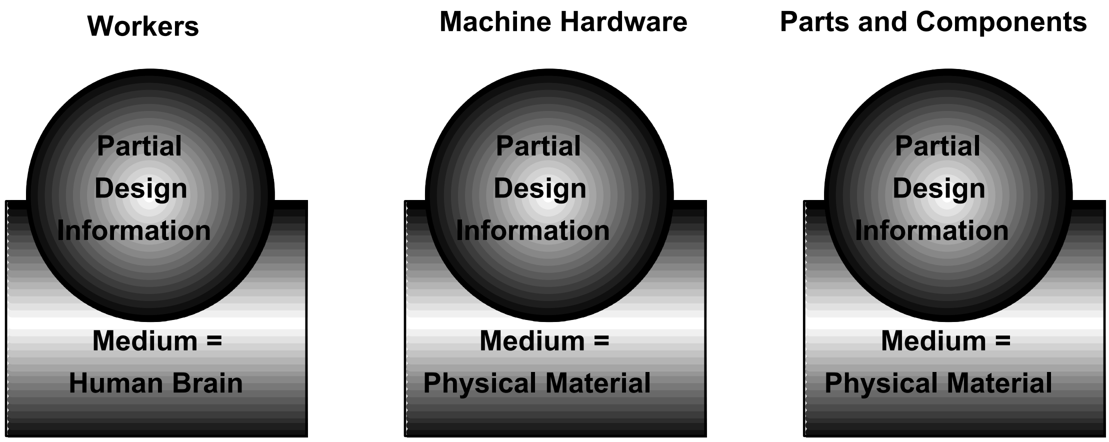
Figure 1 Product = Design Information + Medium



Product design information has at least two aspects: *product structure* and *product function*. Structural design information represents what a product is, or the shape (form) and materials of a product. Product structure information represents what a product does for its customers, or the performance of the product when users operate it. Such design information is normally created prior to the commercial production of physical products. Product functional design is usually created first and is then translated into structural design.

The *production process* is a system of productive resources on the shop floor and in the technical facilities of a firm. In the production process, the structural design information of a firm's products is embodied in workers, machine hardware, software, or other media. Thus, in the design-information view, productive resources are essentially information assets. *Material* purchased and *work-in-process* are also productive resources that embody partial design information. In this sense, the design-information view regards a firm as a set of productive resources (Penrose, 1968), which is nothing but design information deployed and stored in labor or capital stocks as media (**Figure 2**).

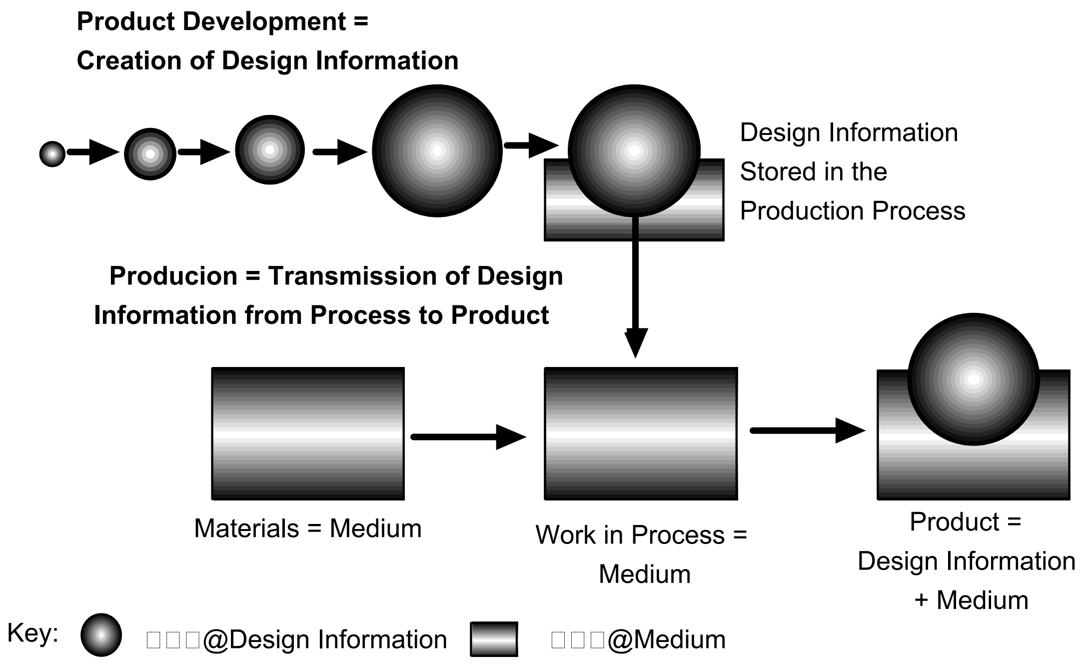
Figure 2 Productive Resource as Information Asset



A firm's main *activities* can also be regarded as the creation and transfer of value-carrying design information between its productive resources (**Figure 3**). *Product development* means the creation and verification of such design information. It is essentially a translation process from an analysis of the expected future consumption process and technological possibilities to product concept creation, product functional design, product structural design, and then to production process design. Each stage consists of repetitive problem solving cycles (Clark and Fujimoto, 1991; Thomke and Fujimoto, 2000) of design, prototyping (physical or virtual) and testing (physical or virtual).

Production on a commercial scale is nothing but the repetitive transfer of product design information from the production process to materials or work-in-process. At each station of the process, a fraction of the product design information that is stored in the workers, tools, equipment, manuals and so on, is transferred to material or work-in-process, which "absorbs" the information step by step and is transformed eventually into a product. In the field of production and operations management, the sequence of transformation by which the materials and work-in-process receive the information is often called the "process flow," while the transfer of the information that occurs at a given station is usually called an "operation."

Figure 3 Production and Development as Design Information Processing



Non-essential information and medium were omitted for graphical simplicity.

Sales is transmission of the design information embodied in the products from the firm to the customers. *Consumption* is another information creation process in which customers process the design information embodied in the products creating satisfaction or dissatisfaction in their minds. In this way, design information circulates like the cycle of water through an environmental system, from consumption to development, production, sales, and back to consumption.

Productive performance, such as productivity, lead times, yields and defect rates, essentially measures the efficiency, speed and accuracy of the transmission of design information across productive resources. Productivity is affected by the time during which design information is actually transferred from the production process to work-in-process as a fraction of the total operation time. The time when information is NOT transferred from the production process to work-in-process is called "waste" or "muda" at Toyota. It is "non-value-adding time." Thus, as Toyota Production System architects advocate, reducing the ratio of "non-information-transmission time" in the total operation time increases productivity, other things being equal. Likewise, reduction of the ratio of inventory time, or non-information-transmission time, as a fraction of total process flow lead time makes production lead times shorter. Finally, in-process defects are affected by the accuracy of the information transmission from the production process to the product. Overall, productive performance is measured either on the shop floor or by the firm in question.

Market performance, on the other hand, is essentially the ability of product design information embodied in the product to persuade, attract and satisfy customers. It is measured in the mind of each of the customers themselves.

In this way, the *design-information view of industries*, from an operational point of view, consistently sees a firm's products, processes, resources, and activities as design information assets and is concerned with their creation and transmission (Fujimoto, 1998, 1999). Although this view may be a minority view in the field of economics and business studies, it might provide additional insights to strategic and industrial policy analyses.

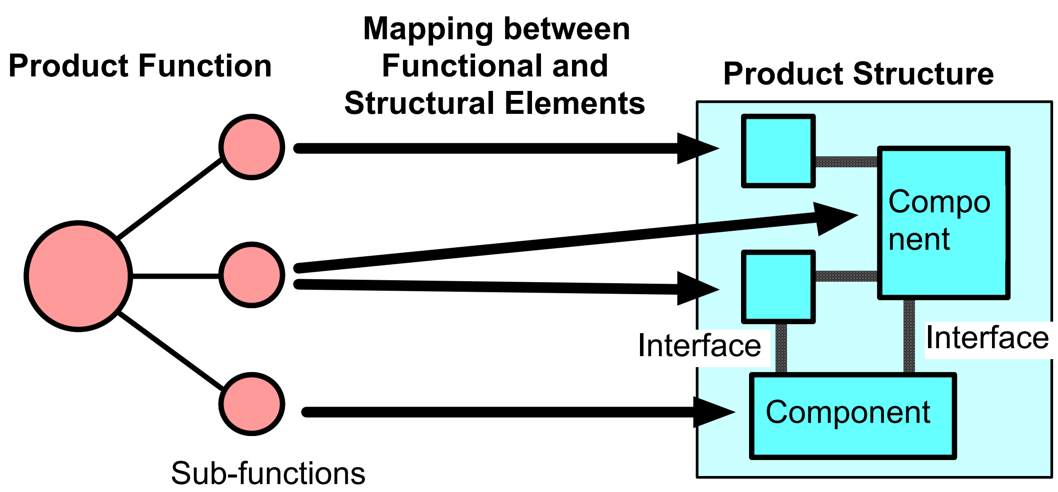
2-2 Architectural Thinking and Industrial Classification

Based on the above reinterpretation of industries based on the design-information view of productive activities, I propose an alternative industry classifications based on product-process design architecture. We start from the basic notion that, in the modern era, a vast majority of the products and services that firms supply are designed prior to production, and that the source of value to the customer is design information that the product embodies. This informational view of products and industries naturally leads us to the architectural approach to industrial classification.

Let's first define the *architecture* of a product and the process by which it is produced. Generally speaking, architecture is defined on a given artificial system (Simon, 1969), including a product, use system, production process, logistics network, telecommunication network, and so on. Whatever the object or system may be, architecture means a basic design approach to map a system's functions to its structures and to interconnect the elements of the system (Langlois and Roberstson, 1992; Ulrich, 1995).

Product architecture, in this sense, implies the basic way of thinking of engineers when they design functions and structures of a new product. When designers or engineers do basic design of a product, they first usually start from its total functional requirement, which is derived from the product's concept, and then decompose this requirement into a set of sub-functions, or functional elements. They then conceive of components that will belong to the product, or its structural elements, and map the functional elements mentioned above to the structural elements (**Figure 4**). At this point, they will find that, to the extent that the functional and/or structural elements are interdependent, the components need interfaces with other components, through which signals and energy flow for their mutual adjustment. After completing a basic design of this sort, the engineers can then move on to detail design of each component.

Figure 4 Product Architecture



Thus, product architecture is nothing but the engineers' basic way of thinking when they go through this basic design process. And, through past literature and my direct observations, we know at least three things by now.

First, the product architectures of two products that are regarded as similar by traditional industrial classification may actually be very different. For example, the way of thinking of motorcycle engineers is very different from that of bicycle engineers although they are both transportation machines. Likewise, architecture of package software for personal computers and that of video game software may be significantly different, although they are both "software" products. Another famous example is the basic architectural difference between mainframe computers and personal computers.

Second, the product architectures of two products that are very different from the traditional industrial classification point of view may, in fact, be strikingly similar. For example, the basic way of thinking by engineers' for bicycles and for personal computers appears to be similar, and likewise are the basic architectural patterns of passenger cars and video game software.

Third, when architectures are very different between two products, this architectural difference may affect the way of developing, producing and selling the products, as well as affecting management style, business models, strategies, competitiveness of firms, industrial structures, trade flows and global configuration of plant locations. For example, the industrial structure of Japanese motorcycle industry (oligopolistic) is very different from that of Japanese bicycle assembly industry (highly fragmented), but is rather close to the Japanese automobile industry.

These three observations lead us to infer that product architecture is an important aspect of strategic management and industrial policy-making. However, research in this field has not yet been fully developed. On the one hand, studies on *micro-architectures*, such as the application of architectural approaches to design approaches and project management, have been prevalent since the mid-1990s (Langlois and Robertson, 1992; Ulrich, 1995; Baldwin and Clark, 2000; etc.). Studies on *semi-macro architectures* at the level of strategic management and industrial economics may be relatively underdeveloped, though. To the extent that product architectures affect competitiveness of firms and clusters, as well as the structure and international configuration of industries, it may be worth exploring the potential application of architectural thinking at the semi-macro or macro level.

On the other hand, traditional theories of trade and international competitiveness have tended to focus on non-architectural aspects of products and industries. For example, from our architectural point of view the standard distinction between labor-intensive and capital intensive industries focuses on the media side of the information-medium pair (i.e., media composition of production processes between labor and capital.). Difference in product architecture on the design information side has generally been ignored.

The notion of a high-technology industry does capture the design information aspects of the industry in that it deals with the amount of technical information (knowledge) embodied in various elements of the products, but such a definition does not capture architectural difference between equally high-tech products. Similarly, the notion of a "high-value-added" sector has been very popular as a target for industrial policymaking, but it simply measures market value of design information aspect of the product relative to its media (material) aspect, regardless of its total product architecture. Thus, while the traditional industrial classification may still be valid for many aspects of economic-business analyses, certain applications of architectural thinking may provide us with additional insights, to the extent that architecture matters to the competitiveness and profitability of a firm or a cluster of firms.

2-3 Basic Types of Product-Process Architecture

Existing research has identified some basic types of product architectures: modular versus integral architectures, and open versus closed architectures (Ulrich, 1995; Fine, 1994; Baldwin and Clark, 2000; Fujimoto, 1999). These are more or less ideal types, and so we may not observe pure forms of such types in the real world. Nevertheless, this is a good starting point for empirical analyses in this field.

As mentioned before, product architecture primarily deals with the mapping between product functions and product structures. As both functions and structures of a product can be described as hierarchical systems, we can illustrate the product architecture of a given product as a correspondence between the functional and structural hierarchies (Clark, 1985; Goepfert and

Steinbrecher, 1999; Fujimoto, 1999; Takeishi and Fujimoto, 2001). Note that the architecture, or the mapping pattern, may differ significantly depending upon which layer of the hierarchy we choose as a basis for the mapping. Thus, an operational definition of types of architectures requires an unambiguous criterion as to which layer of the hierarchies we should choose for subsequent mapping.

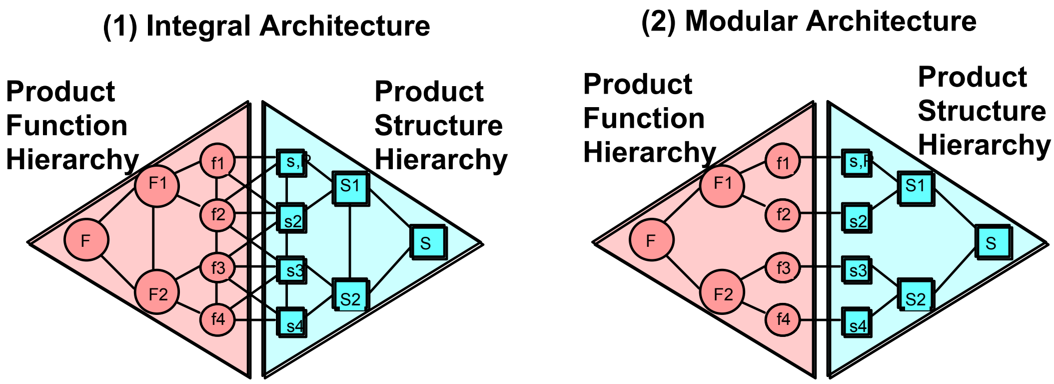
Product architecture may also be defined more broadly to include *process architecture*. Process architecture is related to the correspondence between functional and/or structural elements of a product and its production process factors. To the extent that a production process for a product can also be described as a hierarchy, we can also define process architectures as patterns of mapping between the product and process hierarchies. The concept of process architecture is important particularly in non-assembly type industries such as chemical, steel, and other process industries. In this paper, I will call the narrowly defined product architecture between functions and structures as "product architecture," and the broadly defined one including both product and process hierarchies as "*product-process architecture*."

We can now define basic types of product and process architectures according to the patterns of correspondence among functional, structural and process elements found at a given layer of each hierarchy. Let's stick to the narrow (function-structure) definition of the product architecture for now.

Modular architecture, in its pure form, represents a *one-to-one correspondence* between functional and structural elements. As a result, each structural element (i.e., component, module, subassembly) is functionally complete, while each function is contained in one structural element. The parameters for components or production processes can be designed and operated independently or quasi-independently (Simon, 1969) from each other with little interaction between them. Because of the limited level of interactions, the *interfaces* between such components can be simplified and standardized. "Mix and match" of structural elements can generate variety in the total system without sacrificing functionality. In other words, many common components can be shared between many different variations of the total system.

Integral architecture, on the other hand, refers to cases in which there is a many-to-many (or at least one-to-many) correspondence between the functional and structural elements of the product. Take the example of three functional elements (handling, ride, fuel efficiency) and three structural elements (body, chassis, power-train) of an automobile. Engineers know that the characteristics of the product's handling is determined by a subtle orchestration of body, chassis and power-train designs, and likewise in the cases of ride and fuel efficiency. This is why an automobile is usually classified as having "integral architecture." Each component is functionally incomplete and interdependent with other components functionally and/or structurally. Designs of the components tend to be specific to each variation of the total system. For each product, components have to be optimized with the other component designs by mutual adjustment. Mix and match is difficult, and so is the use of many common components without sacrificing functionality and the integrity of the total product (**Figure 5**).

Figure 5 Integral and Modular Architecture



Legends: F = Product Function as a Whole, S = Product Structure as a Whole, F1, F2=Sub-functions of the Product , f1 - f4 = Sub-sub-functions of the Product S1, S2 = Large Modules, s1 - s4 = Small Modules ------------ = connection

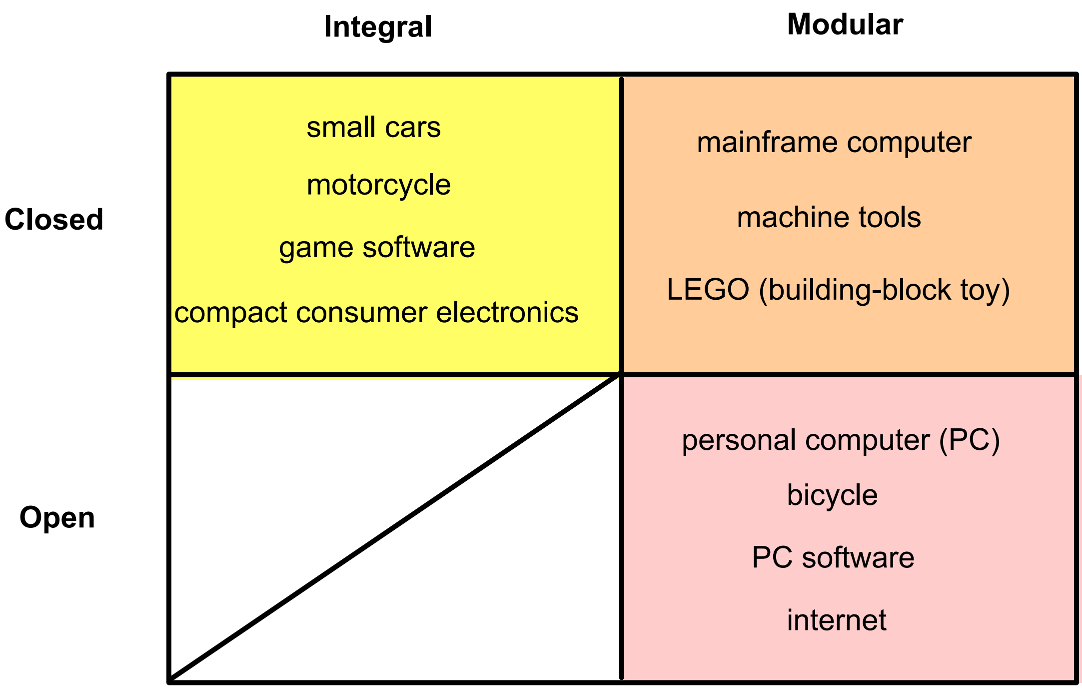
* In order to simplify the diagram, the connection between F and S, and the same between F1, F2, S1 and S2 are omitted.

Open architecture is a type of modular architecture, in which "mix and match" of component designs is technically and commercially feasible not only within a firm but also across firms. An open architecture system normally requires standard interfaces between components at the industry level, such as common connector shapes (e.g., USB port) and common transmission protocols (e.g., TCP/IP), across the component suppliers. Personal computer systems, the internet, low-end bicycles, and stereo-audio sets are examples of open-architecture systems or products.

Closed architecture, on the other hand, is the case where mix and match of independently designed components is possible only within a firm, as the interface designs are common only within a firm, if not within a product. Detailed design of components may be subcontracted to outside suppliers (e.g., black box parts practices in the car industry; Clark and Fujimoto, 1991), but the basic design of the total system is contained within one company. Closed architecture products may be either modular or integral.

By combining these two pairs of basic architectures, we can identify three basic types of product architectures: (1) Open-modular, (2) Closed-modular, (3) Closed-integral (**Figure 6**). The *open-modular* type is, by definition, identical to "open architecture" mentioned above. The *closed-modular* type includes such products as mainframe computers (after the legendary IBM 360; Baldwin and Clark, 2000) and Lego (a highly modular building-block toy in which all pieces are provided by a Danish company, Lego). Mix and match of common components is possible, but only within a company's design regime. *Closed-integral* type is, by definition, identical to "integral architecture" mentioned above.

Figure 6 Basic Types of Product Architecture



We have so far defined architecture of a product, but we can make a similar classification based on the relations between product characteristics and process characteristics – a *process architecture*. Suppose that a production process for a given product can be decomposed into elements (e.g., workstations in an assembly line, or machines in a machining line). Since the main function of a production line is to realize product structure and product function, we can define process architecture as a basic pattern of mapping between process elements and a product's structural or functional elements. We can make a distinction between "modular" and "integral" types of process architecture, just as in the case of product architecture.

Modular process architecture is the case where the design parameters of each process element can be determined independently from other process elements, so that mutual adjustment of process operations is not necessary across the workstations. *Integral process architecture*, by contrast, means that the design parameters of the process elements are interdependent, so that mutual adjustments of process operations across the workstations are essential for making functional products.

Product architecture, in a narrow sense, is defined based on the functional and structural elements of a product. In a broad sense, however, product architecture may include process architecture, and thus is defined based upon the triangular relationship between product function, product structure, and production process.

2-4 Measuring Modularity/Integrality of Architecture

Note, again, that these architectural types are only ideal types (in Max Weber's sense). Each of the real-world examples is likely to be found somewhere along the integral-modular spectrum and open-closed spectrum. In this sense, empirical analyses of product architecture eventually require an *operational definition of architectures* along the modular-integral axis and/or open-closed axis, as opposed to a simple classification based on researchers' "gut feelings," on which much of existing research depends. Candidates for use in operational definitions of "modularity" include at least the following.

One possible indicator of "architectural integrality" is the number of correspondences (x) between functional elements (n) and structural elements (m), as described in **Figure 7**. Since the theoretical maximum of the number of correspondences is "n□m," the degree of "integrality" may be operationally defined as "x/(n □ m)." Alternatively, we may count the number of interdependent relations (y) as a fraction of the theoretically possible number of interdependent relations between structural elements (m), or "y/(m□m)" (this indicates the degree to which the Baldwin-Clark's matrix(Bakdwin and Clark, 2000), or lower right area of **Figure 7**, is filled with "y"s).

Figure 7 Product Function-Structure Matrix (example)

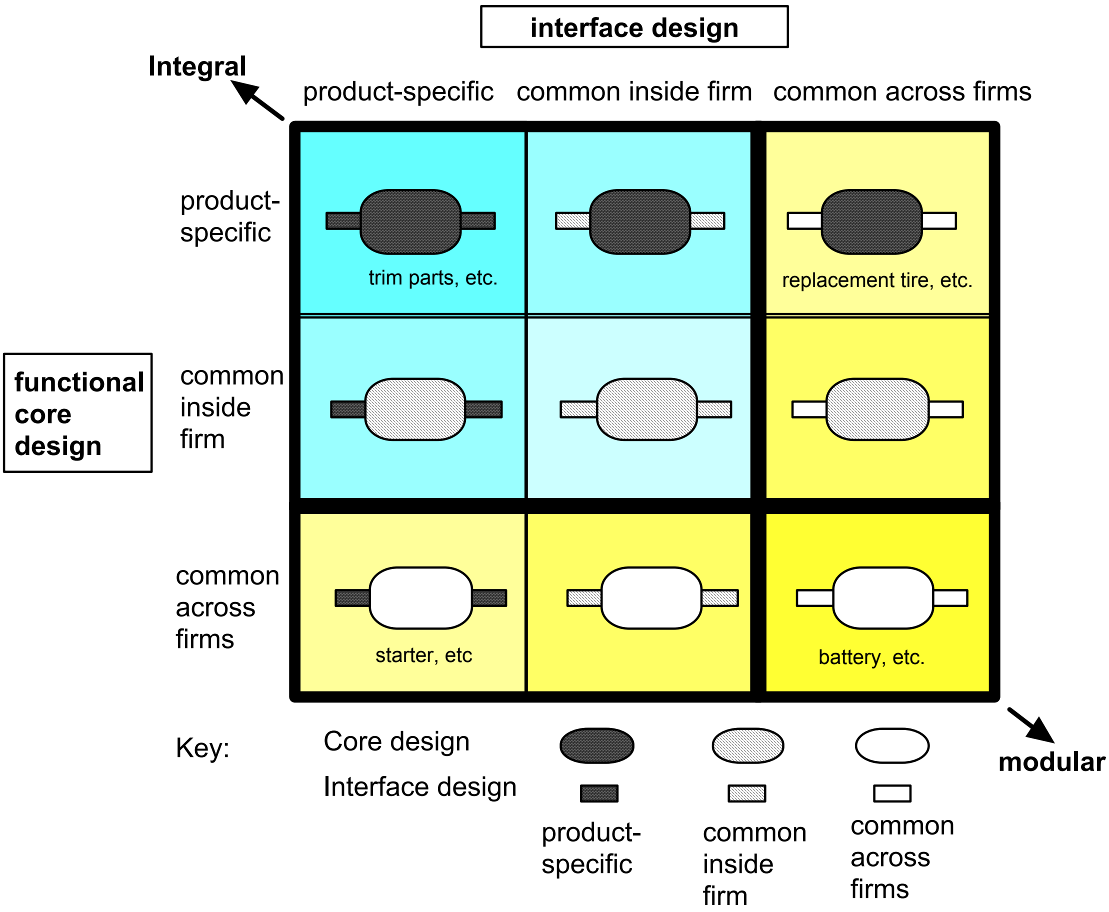
		productf unction				products tructure					
		f1	f2	....	fn	s1	s2	s3	s4	....	sm
productf unction	f1		z			x	x	x			
	f2	z						x			
	....								x		
	fn									x	x
products tructure	s1	x					y	y			
	s2	x				y		y			
	s3	x	x			y	y				
	s4			x							
	....				x						y
	sm				x					y	

Note: The relationship between elements is assumed to be non-directional.

Key: x = relation between functional and structural elements
y= relation between structural elements
z = relation between functional elements

Another possibility is to count the number of common interfaces and/or common components as a fraction of total number of interfaces/components. Generally speaking, we predict that the more modular the product architecture, the higher the percentage of *common interfaces* within and across firms. Likewise, the more open the product architecture, the higher the percentage of *industry-standard interfaces* that are common across competing firms. We also predict that the percentage of common components across a product's variation is a good indicator of the modularity of the product, assuming that common interfaces tend to make their components common (**Figure 8**).

Figure 8 Classification of Parts by Core/Interface Commonality



In reality, however, measuring architecture is not easy. For example, it is difficult to determine the level of hierarchical decomposition in a non-ad-hoc way. The degree of modularity of a car may differ when it is decomposed into 1000 functional parts, as opposed to 100 sub-systems or 10,000 piece parts. Also, when we judge if a given interface is common across products, the definition of "connectivity" between two components may not be the same between digital electronic products and mechanical products. In the former case, connectivity can be defined unambiguously, but in the latter case, it cannot be determined in a clear-cut way whether two mechanical parts can be linked. Furthermore, measuring architectures of monolithic products such as chemicals and basic materials is even more tricky than with fabricated-assembled products.

Despite these practical difficulties, measurement of architectural modularity/integrality and openness/closed-ness is essential for our future empirical analyses of architectures. Starting from measurement within one company, we need to broaden our efforts to measure architectures within each industry, and eventually across industries.

2-5 Market and Technology Affect Architectural Choices

There is one important principle of product-process-architecture, which we tend to forget – the market ultimately selects architecture. In other words, a product's architecture is developed and selected through the interplay of firms' design choices, technological possibilities, and customers' tastes in the market. Certainly, it is technologically easier to realize modular architecture in digital-electronic products than in mechanical products or chemicals, other things being equal.

However, this does not mean technological determinism, or the unilateral tendency, for all products to become modular ultimately. Generally speaking, generating variations of an integral product tends to be more expensive than generating variations of a modular product because the former relies on part designs that are specific to each variation. On the other hand, when customers expect a very high level of product performance, sophistication or integrity, it is easier for an integral product to achieve this goal than a modular product. This is because the optimal design for a modular product is limited by constraints imposed by the use of common interfaces and components. When market expectation for a product's performance dramatically increases for some reason, an integral product has a better chance to meet this goal because optimal design of its components is possible (Ulrich, 1995; Reinertsen, 1997; Fujimoto, 2000).

As a result, as Fine (1998) predicts, the architecture of the products accepted in the market may swing between the modular/open and integral/closed poles, as opposed to a unilateral movement toward modularity. To be sure, the 1990s, under revolutionary innovations in information technologies, witnessed a disproportionate expansion of digital products in our economy worldwide. In this sense, the 1990s was "the decade of modularity." However, this does not mean technological determinism. Given the trends of technological innovation, it is always the market that ultimately selects the architecture of a given product. When market needs emphasize variety and change, selection pressures toward modular products increase. When the market expectations swing to product sophistication, product integrity and high performance, the selection mechanism will also swing toward integral architecture products.

3 Capability, Architecture and Competitiveness

3-1 Organizational Capability

Let's turn to the other key concept – *organizational capability*. Resource-based or capability theories of the firm have attracted much attention among business academics and practitioners in recent years. They illustrate a business firm as a collection of firm-specific resources, organizational routines, capabilities and competencies, which may explain inter-firm differences in competitiveness and profitability, as well as inter-temporal dynamics (i.e., evolution) of business enterprise systems[1].

The concept of organizational capability has the following features. First, organizational capability is unique to a specific firm or group of firms. Whereas the standard economic theory assumes "representative" firms all with identical organizational capability for simplicity of analysis, the capability view of the firm starts from the natural question of why company A looks different from company B.

Second, organizational capability is an attribute of organization rather than individuals. It is more than a simple sum of individual talents. It is a system of *organizational routines*, or repetitive patterns of activities, that are retained despite turnover of organizational members.

Third, the organizational capability of each individual firm affects inter-firm differences in competitiveness and profitability in the long run. It

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[1]For the concepts of resources, organizational routines, capabilities and competence, see, for example, Penrose (1959), Nelson and Winter (1982), Chandler (1990, 1992) , Praharad and Hamel (1990), Grant (1991),Leonard-Barton (1992), Teece, Pisano and Shuen(1992), and Teece, Rumelt, Dosi and Winter (1994). For evolutionary aspects of the firm and its strategies and technologies, see, also, Dosi (1982), Nonaka (1985), Mintzberg (1987), and Fujimoto (1999).

influences, if not determines, the long-term survival rate of competing firms.

Fourth, the organizational capability of a best-practice firm is difficult, if not impossible, for other firms to imitate. Therefore, inter-firm differences in competitiveness and profitability stemming from organizational capability tend to be sustainable for a relatively long time.

Fifth, organizational capability tends to be cumulatively built up by a firm, rather than established all at once by one big investment or acquisition. The process of capability building is not always based on a deliberate planning process. It may well be described as emergent (Minzberg and Waters, 1985) or evolutionary (Fujimoto, 1998, 1999).

The organizational capability of a firm may be found evenly throughout the entire organization of the firm, but it may be unevenly distributed in a certain layer or function of the firm's organization. A firm's organizational capability as a source of its profitability may be disproportionately found in its manufacturing functions such as factories, technical centers and purchasing organizations. We may call it *manufacturing capability* (i.e., organizational capability in manufacturing). Toyota's half-century stream of profitable years is often attributed to its manufacturing capability, including that of the Toyota Production System (Monden, 1983, 1993; Womack et al., 1990; Fujimoto, 1998, 1999). A firm's organizational capability may also be disproportionately found in its headquarters, which formulates strategic planning. We may call it *strategic capability*. General Electric's remarkable stream of profitable years is often attributed to its capability of strategic formulation, which dates back to the 1950s, 60s and 70s, even prior to the era of Jack Welch.

Since our focus in this paper is primarily the operational and design aspects of industrial activities, let's examine the manufacturing capability of a best-practice firm in this field – Toyota Motor Corporation[2].

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2 Assuming that both competitive performance and organizational capabilities change over time, we have to distinguish at least three levels of firms' capability: (1) *routinized manufacturing capability*, which affects the level of competitive performance of repetitive manufacturing activities, (2) *routinized learning capability*, which affect the pace of repetitive performance improvements, and (3) *evolutionary learning capability*, which is related to accumulation of the above capabilities themselves (Fujimoto, 1999).While

3-2 Toyota Manufacturing System as Organizational Capability

Whereas the resource-capability view of the firm in strategic management has been powerful in explaining why firms are different from each other, a potential problem in much of the past literature on this approach is the danger of tautology. Whereas many of the early works of the "resource-based view" focused on theoretical explanation of inter-firm profit differences, relatively few of these works paid attention to empirical investigation of the specific details of such resources or capabilities. Consequently, they tended to end up saying "difference in capability explains difference in profit, and the existence of the capability difference is inferred from the profit difference" – a typical tautology. In other words, organizational capability tended to be theoretically assumed rather than empirically measured.

Since my interest in this paper is rather empirical and operational, my approach here is to get into the details of the specific content of the manufacturing capability itself, and thereby avoid a tautology. For this purpose, I go back to the design-information view of manufacturing activities, in which I reinterpret a firm's production and development activities as creation and transmission of design information throughout a system of productive resources.

As space is limited, let's focus on the production side of the manufacturing capability for now. From the design-information point of view, the production capability of the effective Japanese automakers, such as Toyota, can be summarized as *dense and accurate information transmission between flexible (information-redundant) productive resources*. The density of information transmission from the production process to the materials leads to high productivity and short throughput time at the same time, while accurate information transmission from the product design to the product is also achieved.

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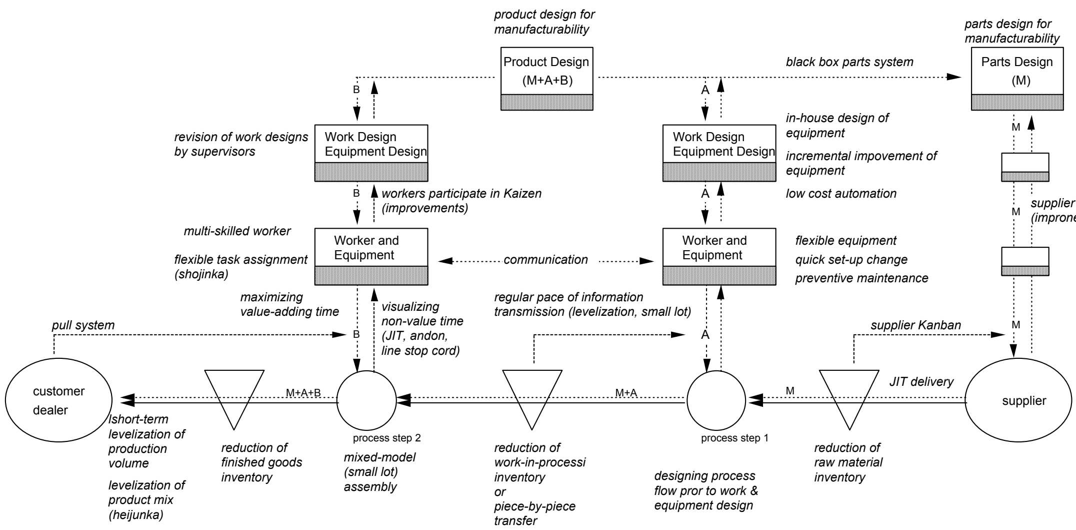
(2) and (3)both can be regarded as dynamic capabilities, they are different in that the latter is a non-routine meta-capability (i.e., capability of capability building). This paper, however, focuses on (1), or the static aspect of manufacturing capability.

Higher Productivity and Shorter Throughput Time (**Figure 9**): The Toyota-style production system focuses on reduction of the amount of time when information transmission is <u>not</u> happening (i.e., non-transmission time) on both the sender and receiver side. Let us take an example of a labor-intensive process, where trained workers are the senders and works-in-process are the receivers of the value-carrying information. The system aims at low levels of non-value-adding time on the worker side (e.g., waiting time) on the one hand, and non-value-receiving time on the work-in-process side (e.g., inventory) on the other hand. Elimination of unnecessary non-transmission time is particularly emphasized. In essence, what the Toyota production system defines as "muda" is unnecessary non-transmission time, which includes inventory, over-production, transportation and defects on the information receiver side, and waiting and unnecessary motions on the sender side.

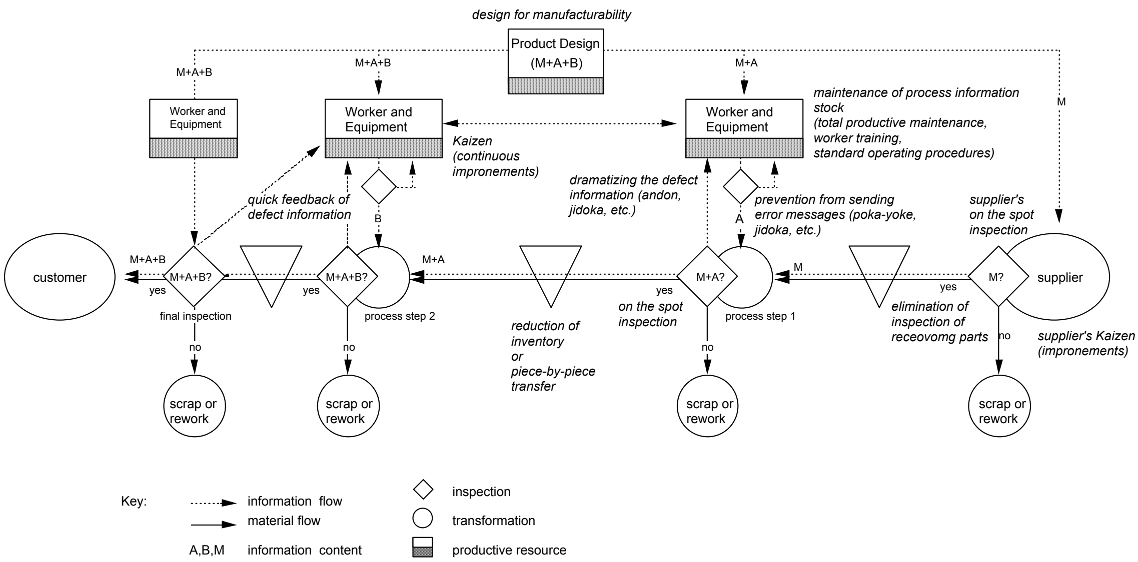
Figure 9 Organizational Capability Regarding Productuvity and Throughput Time (Toyota)



Thus, the ideal system for Toyota-style production resembles a network in which design information continues to be transmitted and received between the nodes without much intermission (See Fujimoto, 1999, for details). In order to approach to the lean situation, some principles of information handling are applied to the system: an "information receiver first" rule (i.e., production process improvements before operation improvements); an emphasis on reducing non-transmission time (i.e., "muda"); maintaining information redundancy (i.e., process flexibility); regularity of information transmission (even cycle times and "levelization" of workload).

Higher Manufacturing Quality (**Figure 10**)**:** The Toyota System also emphasizes accurate information transmission from the production process to the materials. First, the system is designed so that the information sources (e.g., workers and equipment) do not make transmission errors in the first place. This notion of "do the right transfer the first time" (tsukurikomi) contrasts with traditional quality control system that emphasizes optimal deign of inspection on the information receiver side. When the transmission errors do happen, effective automakers try to make quick feedback cycles of defect information. On-the-spot inspection, reduction of cycle inventory and piece-by-piece transfer of work-in-process reduce lead time between problem finding and problem solving.

Figure 10 Organizational Capability Regarding Manufacturing Quality (Toyota)



Overall, the Toyota-style manufacturing capability can be described as an *integrative organizational capability*, or a firm's ability to orchestrate a complex network of design information flows between productive resources. As is discussed later on, such a capability is an effective weapon particularly in an industry whose products and production process are highly complex and integral. Thus, it seems natural to find a company with a highly integrative capability like Toyota outperforming others in a highly integrative product, like a passenger car.

The simple observation that Toyota's manufacturing capability has emerged in the automobile industry and not in the personal computer industry naturally leads us to the following prediction – the fit between a firm's capability and its product's architecture may affect the competitiveness of that firm.

3-3 Prediction on Architecture-Capability Fit

So far I have applied the design-information perspective to both the product and organization sides for an alternative approach to industrial analysis. On the product side, I emphasized architecture, or basic schema for product and process designs. Basic classifications of architectures, the integral, open, and closed types, were defined. This framework regarded the automobile as a typical product with closed-integral architecture.

On the organizational side, I reinterpreted manufacturing capability as a system of routines for creating and transmitting design information. As an example, the Toyota-style manufacturing capability was described as an integrative organizational capability of dense and accurate transmission of design information.

Based on these frameworks and observations, I have the following predictions as to the "fit" between modularity/integrality of product-process architectures and organizational capabilities for handling design information in manufacturing.

- A product and/or a production process with *closed-integral architecture* calls for a relatively high level of integration-coordination efforts in product development and production activities. A firm with a high level of *integrative manufacturing capability* (e.g., Toyota) tends to enjoy competitive advantages in productive performance, such as productivity, lead times and quality in manufacturing.
- A product and/or a production process with *open-modular architecture* calls

for a relatively low level of integration-coordination efforts in product development and production activities. A firm with a high level of *technological capability* in specific components, processes or functional fields tends to enjoy competitive advantages in productive performance.

- Also, in the case of an *open-modular architecture* product, a firm with a high level of *strategic capability* tends to enjoy a higher level of profits, because its ability to create profitable business plans by combining existing product-process elements tends to bring about higher profits in a more direct way. In the case of closed-integral products, a lack of integrative manufacturing capability may become a bottleneck that could hamper profit making from potentially effective business plans.

Although these are very rough-cut predictions about the competitiveness and profitability of certain types of firms for certain types of products, the above framework, based on the design-information perspective, may be a meaningful first step toward an alternative approach to industrial and strategic management analysis.

3-4 Postwar Japanese Firms and Integrative Capability

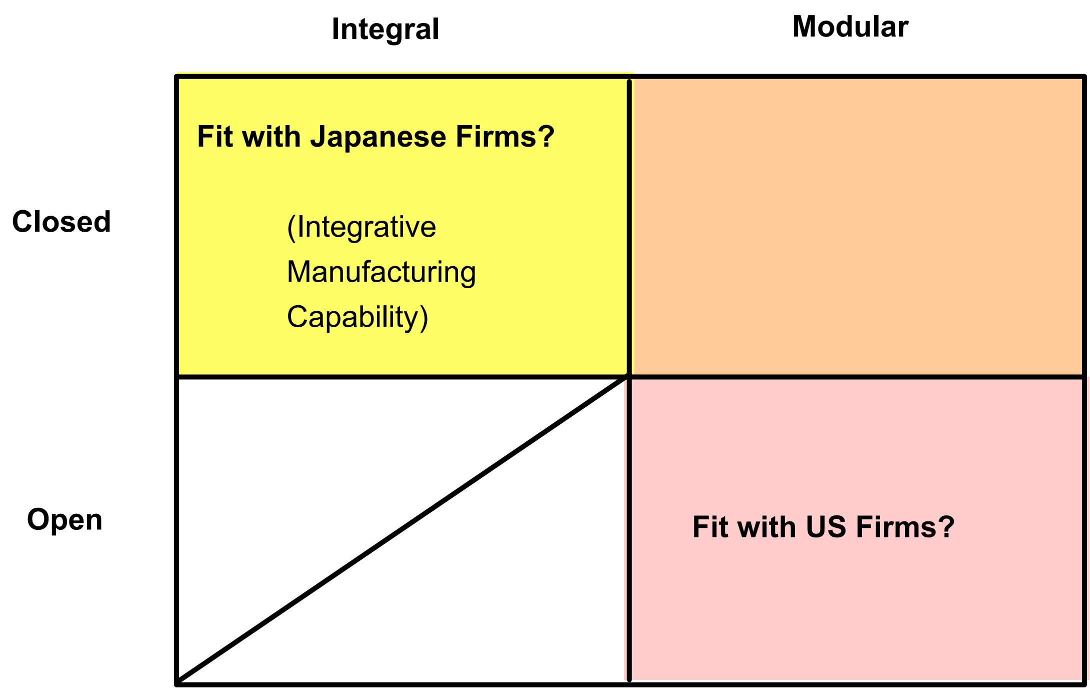
Let me now apply the above framework to comparative industrial analysis at the national level. I add one more prediction as to the country-specific nature of organizational capability. In principle, organizational capability is, by definition, unique to each individual firm or business organization. However, a group of firms in the same country or region, facing similar environmental constraints, national-regional institutions, demand patterns or other forces specific to a particular geographical area may develop similar types of organizational capabilities (Porter, 1990; Clark and Fujimoto, 1991; Nelson, 1993; Aoki, 2001).

As a result, the geographical distribution of a certain type of organizational capability (e.g., the Toyota-style integrative manufacturing capability) may be distributed unevenly among firms from different countries or regions.

And this may be one of the reasons why industry X of country A is more competitive (measured by trade surplus) than industry Y in country A or industry X of country B. In the design-information view of industry, the architectural characteristics of an industry may be as important as its intensity of resource utilization as a predictor of its international competitiveness.

Let's apply this prediction to the situation in the post-War industries in selected countries. My general and impressionistic observation for industrial performance during the second half of the 20th Century is as follows (**Figure 11**).

Figure 11 Basic Types of Product Architecture



- *Japanese firms* tended to be more competitive in products with *integral-closed architecture*. Their organizational capabilities of integration and communication within and across the firms, developed in the second half of the century, tended to fit these types of products. The *integrative organizational capability* of post-War Japanese firms seem to have been formed as a rational response to the high-growth era during the late 20th Century. That is, when labor, material, and financial resources were chronically scarce, it was economically rational to go for a system of long-term employment and long-term transactions with suppliers. As a result, integrative organizational capability was naturally formed in many of the Japanese firms sharing these similar constraints.

- By contrast, *U.S. firms* tended to be more competitive in products with *modular-open architecture*. Their capabilities of specialization and systematization, stemming from Taylorism, Fordism, and even from American System of Manufacture in the 19th Century, tended to fit these types of products. This tendency may also be remotely related to the fact that American economy had to make the most use of immigrants and other resources coming from abroad quickly. Minimizing the efforts to integrate the incoming resources meant standardizing the process, product and organizational interfaces.

- Europe is difficult to characterize because of its variety, but some of the European firms may be characterized as being competitive in *closed-integral products*. The source of their competitiveness, unlike the typical Japanese firm, may be that of integrity in marketing, design and brand, rather than operations. Behind this European advantages may be stable and sophisticated patterns of demand and supplier base sin this region.

To the extent that this rough cut analysis is valid, a careful architectural strategy would be necessary for any company competing internationally to appropriate profits out of its capability mix. Quite simply, for the firm in question to make the most of its strength in it would need to pursue a business that features the product architecture at which it is good (e.g., integral architecture products). In a business that features the product architecture at which the firm is not good (e.g., open architecture products), by contrast, the same firm may need to learn intensively from best practice rivals, make strategic alliance with them, or buy them if necessary, in order to make up for its architectural weakness. Thus, the firm would need to pursuit a "*dual architecture strategy*." Or the firm may choose simply to refrain from such areas and focus on the architecture at which it is good.

3-5 Case: Dual Architectural Strategy of U.S. Auto Firms

A remarkable example of the effective "dual architecture strategy" is the U.S. automakers in the 1990s. It is important to note here that the U.S. Big Three firms were historically producers of truck-architecture products with body-on-frame structure, as opposed to typical European and Japanese small cars with unit-body structure. Quite consistent with the above hypothesis, the truck architecture, with body and frame functionally separable, was more a modular one than the unit body small cars, which tended toward integral architecture.

From Ford Model T to GM's annual model change strategy and to the high profit strategy of large American cars like Cadillac in the 1970s, U.S. auto firms were relying almost entirely on truck architecture products until the early 1980s, when the second oil crisis had finally forced them to shift to smaller cars with unit body structure – the architecture at which the U.S. firms were not good.

To buy time to allow for the major architectural change from modular (truck) to integral (small car) architecture, the U.S. auto industry pursued import restrictions of Japanese cars with integral architecture in 1981. They also started intensive learning of Japanese integrative management technologies, such as the Toyota Production Systems, in order to catch up with their Japanese rivals in the integrative small car segment.

This was not all, however. The U.S. automakers, since the mid-1980s, started to re-introduce various truck architecture products at which they were traditionally good: minivans, pick-up trucks, and truck-based sports utility vehicles (SUVs). Over half of the huge U.S. market of the late 1990s chose this type of vehicle, and the market grew rapidly. Thanks to the effective product and marketing strategies of the U.S. firms, strategic mistakes of Japanese firms virtually ignoring the American truck-based segments, 25% tariff protection, the U.S. economic boom of the 1990s, and so on, the market of truck-based vehicles turned out to be a quite lucrative segment. It enjoyed a high growth rate and profit per vehicle – over double the level of that of sedan-type cars.

This dual architecture strategy, which was quite effective until the end of the 1990s, is the main reason why U.S. automakers enjoyed much higher profitability than their Japanese counterparts in the late 1990s. Although the U.S. firms' capability building efforts and catch up in the integrative architecture products (small cars) was also remarkable, it cannot explain the profit turn-around vis-à-vis the Japanese automakers, because the operational advantages of the Japanese firms still remains as of 2001.

The Japanese automakers, on the other hand, continued to de-emphasize the North American truck-based markets and focused instead on the small passenger car segment, a market of integral architecture products. In other words, the Japanese automakers were sticking to a single architecture strategy. Thanks to their integrative capability, Toyota and Honda could sell their best selling products (Camry and Accord) in the U.S. passenger car market and made decent profits, but U.S. makers were able easily to outperform the Japanese firms in profit performance. Again, the profit difference came from the smart architectural strategy of the U.S. firms, rather than their catch-up vis-à-vis the Japanese manufacturing performance.

The Lesson to the Japanese Firms

There is an important lesson from the above story of the U.S. truck-based market in the 1990s. What many Japanese manufacturing firms with integrative capability can learn from the U.S. auto industry is the dual architectural strategy, although the direction will be totally reversed. In the integrative business where product architecture matches the firm's existing capability, try to expand it by emphasizing the benefits of integrative products to the customers (e.g., performance advantages of optimally designed products). In the open-modular business where better performers are likely to exist outside Japan, do benchmarking studies, find target best-practice companies to learn from, pursue alliances wherever appropriate, or exit from the business if the obstacles are too big for the firm. In short, the dual strategy is an application of the very basic principle of strategic management: expand business wherever the firm is strong; find complementary resources or learn from the best practice wherever the firm is weak. What the Japanese firms have to do first may be to go back to the basics of strategic management.

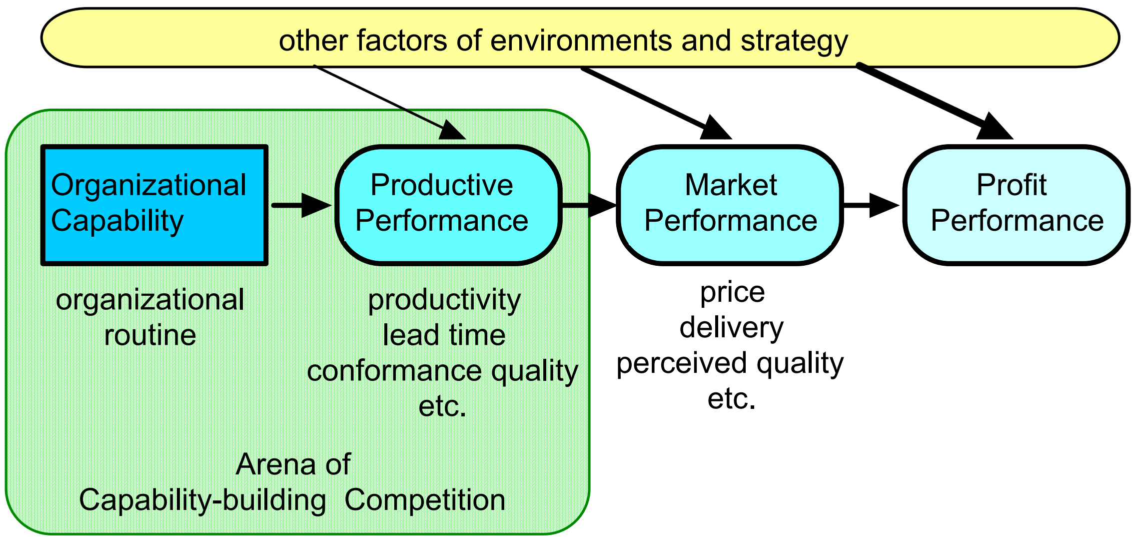
In many of the markets where product architecture is integral and customers appreciate product integrity, many Japanese manufacturers still enjoy competitive advantages in manufacturing performance. Although most of the rapidly growing sectors in the IT/internet era consist of digital products with open architecture, integral architecture products still occupy a large portion of today's economy. In this type of industry, what Japanese firms should do is not to abandon their integrative business to rush into the open-modular business, but to keep and expand the integrative business while at the same time strengthen their capability for open-modular business.

4 Architectural Strategy and Profitability

4-1 From Competitiveness to Profitability

I have so far hypothesized that the fit between types of product-process architectures and types of organizational capabilities affect the level of competitiveness of a firm. A high level of competitiveness, however, does not necessarily mean a high level of profitability. **Figure 12** illustrates a framework that explains the multi-layer relations between capability, competitiveness, and profitability. In this framework, I distinguish between two levels of competitive performance of a firm's products or services: productive performance and market performance.

Figure 12 Capability, Competitiveness, and Profitability



Productive performance represents levels of efficiency, speed and accuracy of productive and developmental activities, and includes productivity, lead time, the turn-over ratio of work-in-process inventory, and in-process defect rate. As mentioned earlier in this paper, such performance can be reinterpreted as efficiency and accuracy of design-information-processing between productive resources (Fujimoto, 1999). As such, the logical connection between manufacturing capability (i.e., an organization's ability to create and transmit design information between its productive resources) and productive performance is quite direct (Monden, 1983, 1993; Shoenberger, 1982; Womack et al., 1990; Fujimoto, 1999).

Market performance is the level of attractiveness and satisfaction that a product generates in the mind of target customers, as well as the factors that directly affect the generation of this level, including price, delivery time, and perceived product quality. It is clear that productive performance (e.g., productivity and defect rate) of a given product influences its market performance (e.g., price and perceived quality), but other factors, such as wage rate and a firm's capability in brand management and marketing, can also influence the level of market performance.

Finally, the level of *profit performance* (e.g., return on sales, return on assets, return on equity) of a company is affected by its productive and market performance. It is also influenced by environmental factors such as exchange rates, business cycles, and a company's strategic choices.

A firm that already has a good combination of manufacturing capability and product-process architecture is likely to enjoy a certain level of advantage in productive performance, but it also needs to pursue a corresponding level of market performance and profitability. In other words, it needs to balance the level of the four elements in **Figure 12**: manufacturing capability, productive performance, market performance, and profit performance. This balance is not easy to achieve, though.

4.2 The Case of the World Auto Industry -- Three Profit Strategies –

Take the example of the automobile industry in the 1990s. A passenger car is a typical integral architecture product, in which the integrative manufacturing capability of the average Japanese automakers brought about their international competitive advantage in productive performance throughout the 1980s and 1990s (Womack, et al., 1990; Fujimoto, 1999).

However, the Japanese advantage in productive performance was not translated directly into market performance and profitability. Due partly to unfavorable exchange rates, recession, and a mistake in strategic positioning in the North American market (i.e., ignoring the profitable truck market segment), the average Japanese return on equity was significantly lower than the U.S. Big Three during the late 1990s. The Japanese automakers also seldom made substantial profit in their European business because of the unfavorable exchange rate of their production base (UK pound) and their weak brand identity in the European market.

Although I omit the details of the story, none of the major automakers worldwide achieved balanced leadership in all four aspects of capability and performance in the 1990s. The Japanese continued to outperform their Western rivals in manufacturing capability for "lean production" (Womack, et al., 1990), and productive performance, but their track record in market performance and profit performance was never impressive during the same period.

In retrospect, there have been at least three ways for automakers to make profits: process, product, and strategy. During the 1990s, roughly speaking, companies from the three regions had different sources of profits. None of them were strong in all the three domains. The Japanese continued to rely on their process (or operational) capabilities in both production and development, partly because they were not good at the other two areas. The Europeans relied on the power of their product, or brand identity, partly because they were not good at the other two areas. The U.S. firms relied on their spectacular strategic success by focusing on the North American truck market, partly because they were not good at the other two areas.

Of the three sources of the profits, strategy is the most unstable. It can give you huge profit within a short period, but the profit may go away quickly as well. The profit from product may last longer; the profit from process may last even longer, although the profit was not spectacular in this case.

In a sense, the problem of the U.S. firms might have been that their strategic success in the truck business was so spectacular that they tended to de-emphasize the other two paths -- process-based and product-based competitiveness. When you have an alternative way of making profits, you may not be so interested in profit making through capability-building competition.

At the beginning of the 21st Century, the question is whether we will be able to find any auto firms that are strong in all three -- strategy, product, and process. No one company, at this point, has reached this position.

In this sense, the Japanese manufacturing firms in an integral architecture business should not underestimate the potential and actual competence of their own factories and technical centers. The real bottleneck is likely to be with headquarters that are unable to formulate grand strategies for appropriating profits from their manufacturing capabilities. In many cases, what they have to overcome is the twist between productive performance and profit performance, which stems from the capability gap between stronger factories and weaker headquarters vis-a-vis their Western rivals.

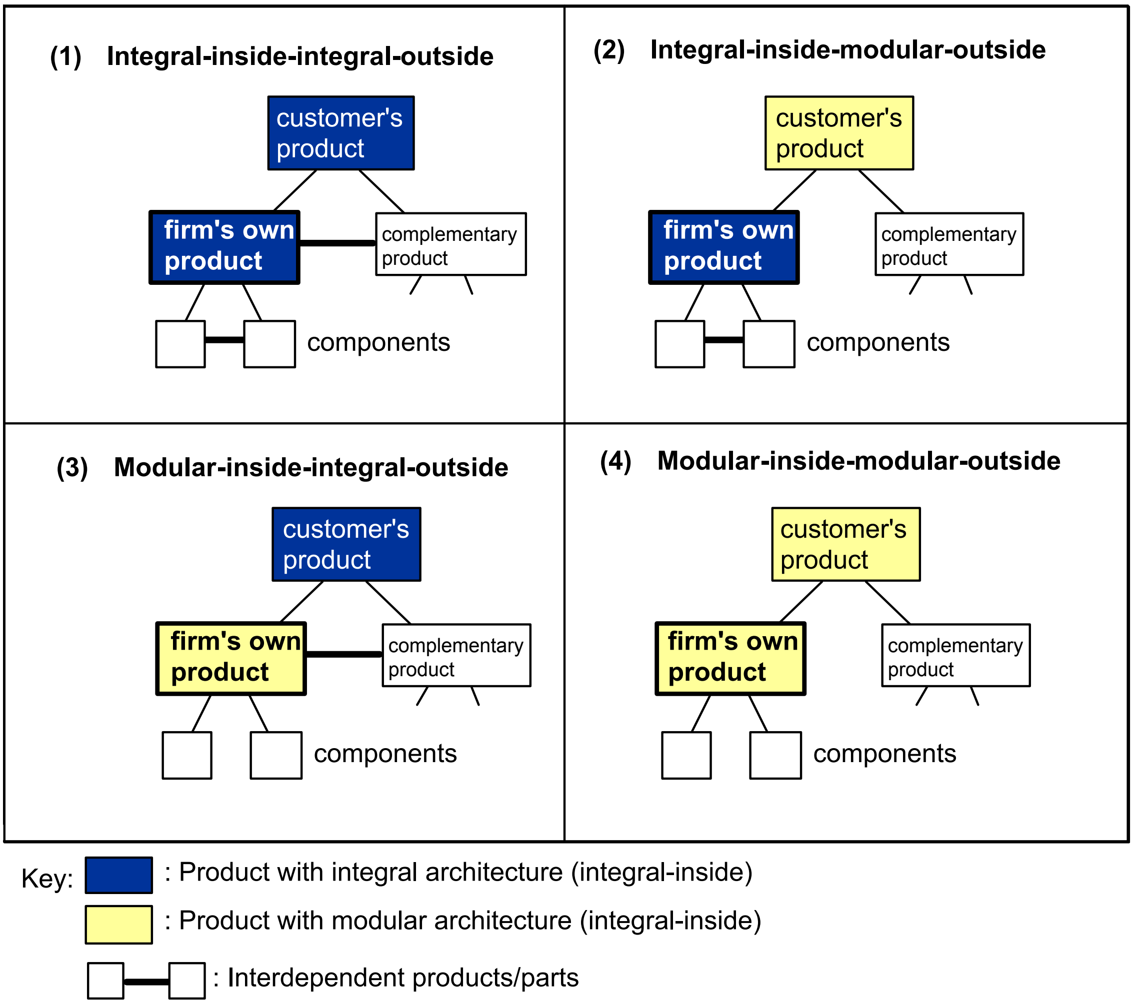
4-3 Architectural Positioning Strategies

As the above-mentioned case of the automobile industry indicates, superb productive performance, which certain Japanese firms with integrative manufacturing capability and integrative product-process architecture tended to enjoy, does not guarantee superb profit performance. There are, of course, many factors that may affect a firm's profitability, given its manufacturing capability and environmental conditions. As mentioned before, for marketing specialists, effective brand management is one such intermediary linking productive competitiveness and profit. Scholars in strategic management, on the other hand, have recognized market-positioning strategy (Porter, 1980) as a significant source of above-average profits. While the market positioning school of strategic management focuses on structures of the market, industry and competition it has not focused on another potential predictor of a firm's profitability – its products' technological characteristics.

In this context, the design-information view of firms and industries proposes an additional framework, *architectural positioning strategy*, which may partially explain why firms of an identical productive performance may end up with different profit performance.

A simple 2 x 2 version of the architectural positioning strategy is presented in **Figure 13**. In this figure, I assume that Firm X develops and produces a component and sells it to Firm Y, or the customer. From an architectural point of view, there are two basic questions. One is about Firm X's own product and/or production process; the other is about Firm Y's (i.e., the customer's) product and/or production process.

Figure 13 Four Basic Types of Architectural Positioning Strategy



The first question is whether Firm X's product and/or production process in question is integral or modular[3]. If integral, for example, and the organization in question possesses an integrative manufacturing capability, as mentioned earlier, my hypothesis is that the firm will tend to demonstrate a relatively high level of productive performance.

The second question is whether the customer's product and/or production process is integral or modular. If integral, Firm X's product (i.e., the components that Firm Y purchases from Firm X) is more likely to be a

[3] To be more precise, integrality/modularity of a product's architecture should be measured and plotted along the integral-modular spectrum. For simplicity of discussion, however, I assume that each product can be classified into either an integral or modular category.

customized component, the design of which is optimized to Firm Y's product requirements. Its production volume is therefore limited to a specific customer's sales, and its design tends to be controlled by the customer. Therefore, profit opportunity for such products may be limited because of a lack of economies of scale and stricter design control by the buyer.

If modular, on the other hand, Firm X's product is more likely to be a standard component, which Firm X designs semi-independently from its customers. Such a component may be used across different products of Firm Y (i.e., closed-modular) or across different customers (i.e., open-modular). There are more chances for Firm X to enjoy economies of scale and reduce cost. The design of the component is less transparent to customers. Therefore, if production of such a component requires firm-specific resource-capability or a patent, the seller may enjoy monopoly rent (i.e., higher profit). Thus, if the customer's product is modular, upon certain conditions, the seller of its components may have an opportunity to seek for higher profit than in the other case.

By combining the above two questions, I find four basic types of architectural positioning strategy (**Figure 13**).

(1) *Integral-inside-integral-outside*: Both Firm X and Firm Y (customer) are characterized by integral products and/or production processes.
(2) *Integral-inside-modular-outside*: Firm X's product and/or production process is integral, but that of its customer Firm Y is modular.
(3) *Modular-inside-integral-outside*: Firm X's product and/or production process is modular, but that of its customer Firm Y is integral.
(4) *Modular-inside-modular-outside*: Both Firm X and Firm Y (customer) are characterized by modular products and/or production processes.

Given a firm's organizational capability and environmental conditions, its products' profit performance may be different depending upon the types of architectural positioning. Also, the firm's profit-making strategy may differ depending upon which type of architectural positioning it chooses.

4-4 Architectural Positioning of Japanese Component Firms

Again, let's consider the case of typical post-war Japanese component firms, which established integrative organizational capability in manufacturing functions as a result of stable employment and transactions. Based on our previous framework of architecture-capability fit, I predict that such firms will enjoy a higher level of productive performance when they choose "integral-inside" positions. As mentioned above, there are two such types: (1) "integral-inside-integral-outside" and (2) "integral-inside-modular-outside." Whereas many Japanese firms with integrative capability tend to demonstrate high productive performance, their profit performance may differ between the "integral-inside-integral-outside" position and the "integral-inside-modular-outside" position.

More specifically, my prediction is that many of the post-war Japanese component firms chose the "*integral-inside-integral-outside*" position, and this is one of the reasons why their profit performance was relatively low compared with their high levels of productive performance. Typical examples include component and material businesses for the automobile. The passenger car has been a typical closed-integral product (Clark and Fujimoto, 1991). Over 90% of its components are purchased from suppliers that have specifically designed the components for a particular customer (e.g., Toyota) or a customer's particular product (e.g., Camry). In many cases, the automobile components themselves also have integral product-process architecture, and many of the Japanese component manufacturers have shown a high competitive advantage in productive performance (Womack et al., 1990; Nishiguchi, 1994; Dyer, 2000). And yet, their profit per sales is relatively low – around 5% at most in recent years. The situation is similar in the case of the Japanese steel-making and plastic material businesses for the automobile. Their productive performance tends to be high, but profit performance is low, compared with their Western counterparts.

My second prediction is that some of the post-war Japanese component firms that chose the "integral-inside-modular-outside" position will enjoy unusually high profit for a Japanese firm. Typical examples include standard key components for electronic products such as personal computers, whose product-process architectures tend to be modular or open. Some of the Japanese suppliers of such electronic products, such as Murata (ceramic condenser, etc.), TDK and Kyocera, enjoy well over a 15% return on sales when the business is favorable. A similar situation is observed at other high-profit companies in Japan, including Shimano (gear components for bicycle), Shin-etsu Chemical's silicon wafer business, and Mabuchi Motor (small motors). There is a common pattern that these companies share. On the one hand, their products and production processes tend to be integral, which is a source of their distinctive know-how and capability. On the other hand, their products are sold as relatively standardized materials or components, which many different customers buy. In other words, their architectural positioning is "integral-inside-modular-outside." Note that Intel's CPU business for personal computer is a typical example of the "integral-inside-modular-outside" positioning.

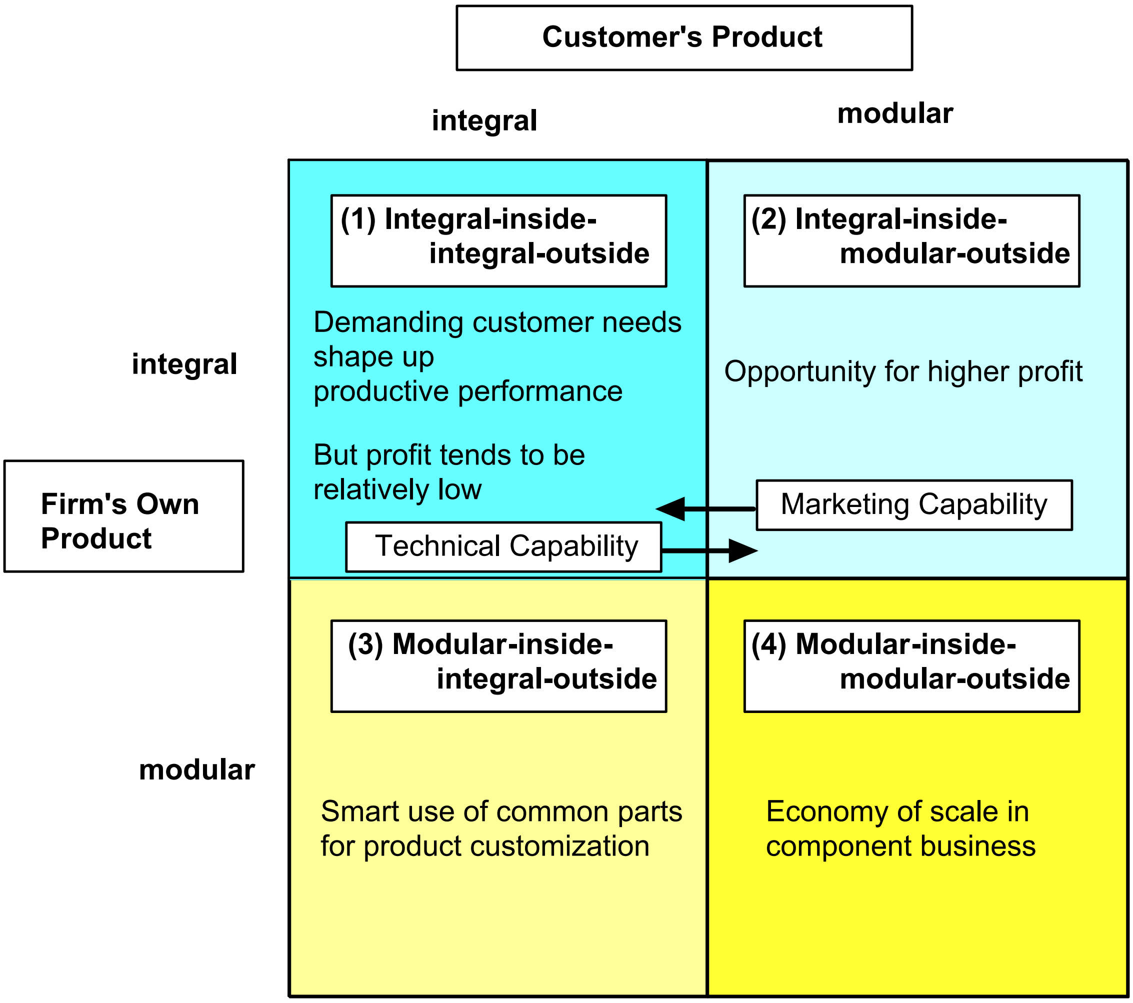
It is by no means my intention to insist that architectural positioning determines profit performance. Firms choosing the same architectural positioning may show different levels of profitability. It should be also noted that a firm cannot freely choose its architectural positions, as its customer chooses its product's architecture. For example, auto parts makers cannot easily escape from their "integral-inside-integral-outside" position as long as the auto assemblers (and ultimately the end users of the automobile) continue to choose the product to be integral.

And yet, architectural positioning of a firm's business may affect its profitability, given its capability and environment. For those Japanese companies with high integrative manufacturing capability, it would be particularly important to recognize the distinction between the "integral-inside-integral-outside" and "integral-inside-modular-outside" positions. The companies that have already accumulated their integrative capability and outperformed in productive performance in the "integral-inside-integral-outside" business may have to find ways to utilize their capability in "integral-inside-modular-outside" businesses.

Conversely, a company which is already enjoying a high profit performance in "integral-inside-modular-outside" businesses may also keep “integral-inside-integral-outside” business as a kind of “training site” for shaping up its manufacturing capability, although the latter may be less profitable. For example, Shimano is enjoying a high profit rate in its bicycle component business, but it also maintains a relatively small business for automobile components in order to shape up its cold forging technologies. A similar relationship is also found in major automobile tire companies, which keep both OEM tire business (integral-inside-integral-outside) and replacement tire business (integral-inside-modular-outside).

Thus, by keeping multiple architectural positions, the firm may benefit from synergy effects of cross-utilizing technological capabilities across businesses. We may call this *architectural portfolio strategy* (**Figure 14**).

Figure 14 Architectural Positioning and Portfolio Strategy



5 Toward Architecture-Based Industrial Policy

5-1 Limit of Industrial Policies for Full-set Protection

Let's conclude this paper by returning to the issue of industrial policies in Japan. The post-war Japanese industrial policy tended to be oriented to "full set" industrial development. Based on the keen sense that Japan does not have ample natural resource, and that high-value-added manufacturing sectors need to generate trade surplus in order to sustain the its entire economy, the government has tried to support virtually all major segments of the industry at all stages of their value chain. Such a full-set policy, however, often meant protecting the weaker part of the industries.

Since beginning of the 1990s, however, it has become increasingly unrealistic to maintain the full-set industrial policy. The explosive advancement of digital information technologies in this period made some part of the Japanese information and telecommunication products less competitive than their U.S. counterparts. Other Eastern Asian countries, including Korea, Taiwan and China, emerged as strong industrial centers for such products as low-end steel, DRAM and ASIC semiconductors, shipbuilding, bicycle, consumer electronics, and computer peripherals. Some European firms are expanding their exports of fashion and other brand-driven products to Japan in the middle of recession. It is now clear for the Japanese industrial policy-makers to abandon the full-set approach and to adopt a more focused one.

This means that the government has to infuse a strategic thinking into its industrial policy by discerning strength and weakness of the Japanese firms as an industrial agglomeration. The industrial policy-makers also need to select the sectors that fit their strength, identify best-practice firms in strategy and operation in each sector, establish alignment between the industrial policy and best-practice strategy of better firms, and separate the policy for further strengthening the strong sectors from that for protecting the weak. In a word, the Japanese government needs to adopt a *strategic industrial policy* in its true meaning.

The concept of product-process architecture, presented in this paper, may provide additional insights to the pursuit of such a strategic industrial policy. That is, compared with the traditional industrial classification, an alternative classification based on the difference in product-process architecture may be able to predict competitive advantages of Japanese firms more precisely.

Architecture-based industrial classification, based on objective measurement of integrality/modularity across the industrial sectors will help us make a more vivid and focused industrial policy. For example, assuming that post-war Japanese firms tended to build a high level of integrative manufacturing capability more often than the other part of the world, it would make more sense for the Japanese industrial policy makers to focus on its country's strength, or integral architecture sectors. More specifically, the architecture-based industrial policy may include the following:

(1) Help the Japanese firms maintain and strengthen their traditional organizational capability, or *integrative manufacturing capability*.
(2) Identify the sectors with *integral architecture*, in which integrative organizational capability of the Japanese firms brings about competitive advantages in productive performance more directly.
(3) Focus governmental efforts for industrial policy implementation to further strengthen competitiveness of these sectors with integral architecture, regardless of the stages of value chain (e.g., final assembled products, modules, parts, materials)
(4) Help the firms gain a new set of organizational capabilities to cope with products and processes with *open-modular architecture* in the long run.
(5) Help the firms improve *profit performance*, given their productive performance, with better strategic management, brand management, marketing management, and so on.

5-2 Case: The Functional Chemical Sector in Japan

One remarkable example is the case of the Japanese functional chemical industry. It has long been a commonsense that the Japanese chemical industry in general lacks international competitiveness due partly to insufficient scale and high material cost. However, the Japanese industrial statistics indicate that Japan's trade surplus of chemical products in 2000 was roughly 2 trillion yen, or nearly 20% of the Japanese overall trade surplus. In order to solve is puzzle, we have to distinguish the chemical industry into two parts according to their architectural difference.

On the one hand, traditional chemical industry tends toward modular process architecture – a collection of large-scale state-of-the-art equipment, as well as a high utilization rate, is basically sufficient for world-class competitiveness of a chemical plant. In his segment, the Japanese chemical firms struggled with smaller scale and lower utilization ratio and a high cost structure for a long time.

By contrast, so called "functional chemical" sector, which includes major semiconductor materials, is the area where some Japanese chemical firms, such as Shin-etsu Chemical and Sumitomo Bakelite, have enjoyed a significant competitive advantage and profitability. This is a segment in which process architectures tend to be integral, in that process design parameters need to be mutually adjusted for precisely achieving functional targets of each product. As predicted from the capability-architecture framework, integrative manufacturing capability of Japanese firms tends to bring about a high productive performance in the functional chemical sector. Besides, the functional chemicals for DRAM are often sold as standardized critical materials, so that the Japanese manufacturers can choose "integral-inside-modular-outside" position for higher profit.

Against this background, Japanese Ministry of Economy, Trade and Industry (METI) newly set up the Office for Functional Chemical Products as a separate bureau from its Chemical Industry Section in 2001. This separation of organizational units enabled METI to formulate a more vivid industrial policy for the functional chemical sector in 2002, which is better aligned to strategic initiatives of the leading Japanese chemical firms.

6 Conclusion

The present paper tried to apply *design-information view of firms and industries* to strategic management and industrial policy-making in the post-war Japan. It described products and productive resources as a combination of design information and its media. Such key concepts as production, product development, manufacturing capability, and productive performance were consistently reinterpreted as the creation and transmission of design information between productive resources, as well as the efficiency and accuracy of these efforts. *Product and process architecture* was defined as a basic design philosophy to match the functional and structural elements of the product and process respectively. It was also hypothesized that the fit between product-process architecture and *organizational capability* for handling design information affects the level of competitiveness performance. A concept of *architectural positioning* was also discussed to illustrate additional elements that may influence the relationships between productive performance and profit performance.

The preceding analysis may provide additional insights into strategic management and industrial policies. The hypothesis of *capability-architecture fit* may provide a microscopic foundation for the resource-capability view of strategic management. The notion of *architectural positioning strategy* may supplement Porter's market positioning strategy for explaining profit differences between firms, given their organizational capabilities.

Having now entered the 21st Century, both Japanese manufacturing firms and industrial policy makers need to focus more on their strength. The traditional economic theories of comparative advantage have emphasized the fit between the resource endowment of a country and resource-use intensity of an industry. In other words, the traditional view has focused on the media in which the design information is embodied – labor, physical capital, and so on. The present view, on the other hand, focuses on the design information itself, or the fit between the organizational capability of firms in a given country and the basic design approach (i.e., architecture) of an industry.

A tentative prediction of this design-information-architecture view of industry is that, to begin with, Japanese firms and industries should base their strategies on their traditional strength, or integrative organizational capability. They should also give first priority to those products with integral architecture at any stage of the value chain.

For future empirical research on architecture-based industry analysis, a method of measuring the integrality/modularity of a given product or production process needs to be established in order to make the preceding analysis more operational and objective. In other words, the next step is to establish architecture-based industrial classification.

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