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The Architectural Attributes of Auto Parts and Their Transaction Patterns in Japan's Automobile Industry

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Abstract

In this paper, we make a tentative study on the strategic choice of transaction patterns for the detailed design drawings of auto parts in the Japanese auto industry. Using the available taxonomy of transaction patterns from previous studies --- the drawing-supplied (DS) system, the drawing-entrusted (DE) system and the drawing-approved (DA) system, we further explore the conditions under which these patterns are chosen to achieve the efficiency of inter-firm cooperation in the new product development process. The inquiry into why diverse patterns can still be observed even within a transaction dyad (one auto maker and one supplier) motivates us to relate the architectural attributes of auto parts to the outsourcing decision for their detailed design. Results of our empirical study show that the functional modularity of auto parts had a positive effect on the outsourcing of design drawings.

Key Words:
Outsourcing; Detailed Design Drawing; Transaction Patterns; Architecture; Functional Modularity; Structural Modularity; Auto Parts; Japanese Auto Industry

1 Introduction

The significance of outsourcing has been widely recognized in the automobile industry, where auto assemblers are trying to be lean and agile. Within this area of research, the practices of supplier system management in the Japanese auto industry have been examined from the perspectives of both economics and management science (Aoki, 1988; Womack et al. 1990; Clark and Fujimoto, 1991; Nishiguchi, 1994; Fujimoto, 1997, 2001). The Japanese supplier system can be summarized as a triplet of long-term continuous transactions; fierce competition on capability building among a small number of suppliers; and the bundled outsourcing of design, manufacturing, quality assurance and other tasks to suppliers, in which each aspects complements the others (Fujimoto, 1997, 2001). Nevertheless, based on this widely accepted recognition, more detailed studies of the Japanese auto industry are necessary to provide deeper insights. Problems such as what to outsource and how to arrange the outsourcing are still high on the research agenda.

In this paper, we attempt to study the Japanese auto industry on a more detailed level by spotlighting the outsourcing patterns of detailed design drawings of auto parts. The available taxonomy in previous research --- the drawing-supplied (DS) system, the drawing-entrusted (DE) system and the drawing-approved (DA) system (Asanuma, 1989; Clark and Fujimoto, 1991; Fujimoto, 1997) are used as the subjects of our analysis.

Under the DS system, an auto assembler makes the detailed design of auto part and calls for suppliers to manufacture according to the design drawing. In contrast, under the DA system, it is the supplier that makes the detailed design based on general blueprint requirements received from an auto assembler. In this case, through the procurement of auto parts, an auto assembler in effect buys the design drawings of auto parts, which are embodied in the final product where design is bundled with other tasks such as manufacturing and quality assurance (Fujimoto, 1997; 2001). Finally, under the DE system, an auto assembler entrusts the making of the detailed design to a supplier, but on the other hand, claims the property right of the design drawings. This system can be considered as an intermediate mode between the contrasting cases of the DS system and the DA system. By the criterion of design's outsourcing, the DE system is the same as the DA system in that it is the supplier that makes the detailed design. While by the criterion of ownership of design drawings, the DE system is identical with the DS system; since it is the auto assembler which holds the property rights in both cases. Therefore, we can define two dimensions of the taxonomy of transaction patterns --- the boundary lines of design task assignment and ownership of design drawings. As shown in the Figure 1, the three patterns can be put into a 2X2 table. The DE system offers an interesting case in that it shows that with design outsourcing, the design task fulfillment and the ownership allocation do not always go hand in hand.

Figure 1 about here. Taxonomy of Transaction Patterns

Previous research has empirically shown that the overall performances of development projects in the auto industry has differed significantly between the US and Japan (Clark and Fujimoto, 1991). Whereas the DS system dominated in the US, the DA system was the major transaction pattern adopted in Japan. Although the gap has been narrowing in 1990s due to the widespread learning of Japanese auto assemblers' supplier management practices (Kamath and Liker, 1994), the strategic choice of transaction patterns remains an important research theme. The advantages of design outsourcing are evident in shortening lead-time, improving quality by design-for-manufacturing and achieving cost reduction; however the conditions under which the alternative patterns should be chosen still needs to be clarified.

In this paper, we carry out our analysis in a specific setting --- a dyadic transaction between a fixed pair of one auto assembler and one supplier in the Japanese auto industry, in which the collaborative inter-firm relationship has already been established. This setting specification stems from an intriguing case study made by Fujimoto in which diverse transaction patterns were observed between a single supplier (company A) and Toyota for the transactions of four representative auto parts (Fujimoto, 1997, p. 215). A longitudinal case study from 1970 to 1990 reveals that the *steering wheel* has maintained its dominant role as a DA part, and *interior parts* are stable as DS parts. In contrast, the transaction patterns of other auto parts have changed over the twenty-year period. *Weather strip* has evolved from being a DS part to a DE part, while *vibration proof rubber*, originating in the same DS parts category, has turned into a DA part. What factors are contributing to the variety of patterns observed in such a problem setting? This question pushes us to reexamine the issues concerning the outsourcing of auto parts designs.

The make-or-buy issue has been tackled from multiple perspectives such as transaction cost economics, the property rights approach and the resource-based view of firms. Transaction cost economics (TCE) and the property rights approach (PRA) put more weight on the institutional solution to the "hold-up" problem, which is caused by contract incompleteness and opportunistic behavior. While TCE emphasizes that vertical integration is more related to transaction attributes such as asset specificity (Williamson, 1979,1985; Klein et al. 1978), PRA stresses the implications of ownership allocation on the bargaining power of the transaction parties (Grossman and Hart, 1990; Hart, 1989). Instead of considering the contractual aspect of an inter-firm relationship, the resource-based view of the firm focuses on the resource endowments and accumulation of capability or knowledge within and between the firms (Richardson, 1972; Asanamua, 1989). Especially, Asanuma's research on the Japanese automobile and electronics industries classifies the roles played by suppliers with different "relational skill" when transacting with assemblers. Asanuma defines the relational skill as " the skill required on the part of the supplier to the specific needs of an auto maker". He states that when a supplier's relational design skill is high, the DA system is adopted, whereas otherwise, the DS system is chosen (Asanuma, 1989).

After examining the previous studies on the make-or-buy issue, we can see that no clear and direct answer is offered for our inquiry into why diverse transaction patterns of the detailed design drawings were observed in the dyadic transaction setting. Discussions concerning asset specificity and contract incompleteness are not pertinent when a long-term collaborative relationship is assumed as is the case in transactions we target. Similarly, the explanatory power of "relational skill" is also weakened in our dyadic setting, because between the same auto assembler and supplier, relational skill can be considered as a constant. So what may be the possible variables that can explain the choice of various transaction patterns? The simple observation that the patterns differ according to the auto parts that are transacted suggests we may relate the attributes of auto parts with their transaction pattern choices.

The next question is how we can specify the features of different auto parts. It is on this point that the product architecture perspective is introduced into our analytical picture. Defined as "the scheme by which the function of a product is allocated to physical components and by which the components interact" (Ulrich, 1995, p.420), the perspective of product architecture offers a language for bridging technological and management issues. In the remainder of this paper, we attempt to specify the architectural attributes of auto parts in terms of the degree of interdependence between auto parts within the design scheme of the automobile. After making this concept operationable by establishing some measurable indicators, we attempt to carry out a tentative hypothesis testing procedure that explores the relationship between the architectural attributes of auto parts and their transaction patterns.

The structure of this paper is as follows. In section 2, the related literatures on the make-or-buy issue are reviewed. Then, in section 3, we attempted to formulate the concept of the architectural attributes of auto parts. In section 4, we put forward some hypotheses on the choice of the outsourcing patterns from the perspective of architectural attributes of auto parts within a theoretical framework. In Section 5, an empirical hypothesis testing study is undertaken. Finally, after the empirical results are discussed in Section 6, conclusions, implications and future study directions are addressed.

2 Literature Review

2.1 Organization Economics on the Make-or-buy Problem:

The make-or-buy problem is generally considered as identical with the specification of a firm's boundaries from the perspective of organization economics. As the two representative approaches, transaction cost economics (TCE) and the property rights approach (PRA) both recognize the nature of the firm as "a nexus of contracts" (Jensen and Meckling, 1976). With transactions as the unit of analysis, their core proposition is that the boundaries of the firm are determined at the point where external contracts fail to govern the market exchanges.

Under what conditions are external contracts not efficient compared to vertical integration? Both TCE and PRA emphasize contract incompleteness in the face of the existence of relationship-specific investment. Since all possible contingencies cannot be written into the formal contracts ex ante and the specific investments are not verifiable to resort to third-party arbitration, market exchange is likely to be costly since renegotiations and bargaining at the ex post stage is inevitable. Nevertheless, each theory has its own distinct logic on how to resolve this contractual problem with different implications for empirical predictions (Holmstrom and Roberts, 1998).

2.1.1. Transaction Cost Economics (TCE):

In his classical paper of 1937, Coase asserts that the boundary of the firm is determined by the trade-off between "the cost of using the price mechanism" and the diminishing returns to management. Afterwards, Williamson further develops the Coasian insight in his comparative institutional analysis (CIA) framework. Two rudimentary behavioral assumptions --- bounded rationality and opportunism, and three dimensions of transaction attributes--- asset specificity, uncertainty and frequency of exchange, form the analytical framework. Especially when asset specificity is substantial, transaction costs incurred in the ex post stage tend to be high.[1] Since the contracts are only the incomplete kind, the party who invests in the specific assets will be vulnerable after investing. If the other party threatens to terminate the contract prematurely, the specific investment will be at stake since it has limited alternative use. Although market procurement can attain a high-powered incentive and avoid the bureaucratic disabilities of the prospect of production cost control, under such a situation, the "hold-up" problem caused by the specific investment and opportunistic behavior makes vertical integration a more efficacious governance structure. A high degree of uncertainty and frequency of transactions are also predicted to be positively associated with vertical integration.

Klein, Crawford and Alchian (1978) also predict that the advantages of increased vertical integration grow as assets become increasingly specialized. Their logic is that the quasi-rent value of the specific asset --- "the excess of its value over its salvage value, that is its value in its next best use to another renter", is vulnerable to appropriation through renegotiations and therefore makes vertical governance a preferred choice.

[1] Ex post transaction costs include: " ①'the maladaption costs' incurred when transactions drift out of the flexible field of agreement, ② 'the haggling costs' incurred if bilateral efforts are made to correct ex post misalignments, ③ the set up and running cost associated with the governance structures (often not the court) to which disputes are referred, and ④ the bonding costs of effective secure commitments" (Williamson, 1985, p. 21).

Empirical evidence supporting the theoretical hypotheses drawn from TCE has been provided in several seminal studies on the auto industry. Monteverde and Teece (1982a) made an investigation of 133 auto components manufactured by GM and Ford and found that the “specialized, nonpatentable technical know-how” associated with the development of any given auto component, which is measured by engineering efforts, positively affects the vertical integration of component production. Masten et al. (1989) extended the study of Monteverde and Teece by examining both physical and human capital’s effects on 133 auto parts in the U.S. auto industry. Their findings show that the physical capital does not have as strong an influence on vertical integration as does specialized technological know-how. In the Walker and Weber (1984) empirical study on the U.S auto industry, comparative production costs between buyer and supplier, volume uncertainty and supplier market competition (an indicator of asset specificity) are shown to have positive effects on vertical integration.

2.1.2. Property Rights Approach:

Beginning with the recognition that contracts are incomplete for relationship-specific investments, PRA addresses the likely inefficient investment of the specific assets in the following logic. Because of contract incompleteness at the ex ante stage of the transaction, renegotiations on the division of the payoff gained from the investments are inevitable at the ex post stage. As a result, with only limited bargaining power during the market transaction, the party which invests in the specific assets cannot get the full benefits of the investment. With the expectation of this consequence, the incentive for the investing party is impaired and the investment cannot be efficient. The solution offered by PRA to this investment problem is the common ownership of the specific assets, that is, vertical integration.

In this framework, ownership is defined as the “ex post residual right of control” (Grossman and Hart, 1986), which is when the “right to choose the missing aspects of usage resides with the owner of the assets” (Hart, 1989). As a device to deal with contract incompleteness, ownership allocation directly affects the ex post bargaining power and the division of the realized payoffs, and can therefore, affect the investment incentives for the specific assets.

In comparison, with the TCE framework, the property rights approach has several different points. First, specific physical assets, or non-human capital, is the only subject of discussion, while in TCE, four types of assets are categorized. In PRA, it is believed that human capital can be affected indirectly through the control of physical assets because of the impossibility of people being owned by others (Hart and Moore, 1990). Second, there is no prediction on the effect of the magnitude of asset specificity on the firm's boundary. Additionally, there is no detailed discussion on the transactional attributes. Therefore, though having conceptual explanatory power for the make-or-buy problem, PRA opens less opportunity for empirical testing (Holmstrom and Roberts, 1998). Thirdly, instead of speaking simply of vertical integration, the PRA framework shows that the party in the transaction which claims ownership of the specific assets is important. It states that the party whose investment can generate more added-value should own more assets.

In summary, both TCE and PRA provide the conditions for analyzing the boundary of the firm from the contractual perspective. The discussions focus on a dichotomy of markets and firms which is considered oversimplified in the real world. As Williamson acknowledges that "transactions in the middle range (between market and vertical integration) are much more common" (1985, p.83), the subcontracting practices in the Japanese auto industry actually provide a good example. Quite a few studies in the field of economics have been done on the "governance processes" that contribute to the competence of the Japanese auto assemblers, however all of these discussions have been made under the premise of how not to vertically integrate but rather outsource (Williamson, 1985; Aoki, 1988; Imai and Komiya, 1989; Richardson, 1993; Holmstrom and Roberts, 1998). The problem concerning the conditions under which the make-or-buy decisions are made is unclear in these studies. To answer this question, literatures on outsourcing management from the management science field offer some different insights.

2.2 Resource-based View of the Firm's Boundary and the Taxonomy of Transaction Patterns:

Differing with the view of the firm as a nexus of contracts, the resource-based view (RBV) recognizes the firm as a bundle of resources, which embrace anything that could be termed as strengths or weaknesses of a given firm (Wernerfelt, 1984; Barney, 1986; Kogut and

Zander, 1992). In stead of discussing the contractual difficulties (transaction costs) in markets caused by asset specificity, RBV attempts to explore the sources of the distinctiveness and the sustainable competitiveness of firms (Dierickx and Cool, 1989). Therefore, the nature of the firm is not the governance structure, but an entity endowed by a set of skills, complementary assets and organizational routines for coordination and learning (Dosi, Teece and Winter, 1990).

As for the boundary of the firm, it is said that the tacit skills, routines and other kind of resources that are hard to access through the market are accumulated within the firm. These so-called "core competence" is distinguished with the "non-core competence" which can be procured via open market (Prahalad and Hamel, 1990; Venkatesan, 1992). Make-or-buy decision making, therefore, depends on the attributes of resources. Besides the distinction of core and non-core resources, Richardson argues that the "similar" and "complementary" activities are generally integrated within the firm (1972). The former refers to the "activities that made demands on the same capabilities", and the latter means activities "that had to be matched in level or specification". Furthermore, Richardson goes beyond the dichotomous discussion of market and vertical integration and proposes that the inter-firm cooperation builds on "complementary but dissimilar" activities.

Extending the discussion beyond the dichotomy of market and vertical integration and tackling more details of the intermediate mechanism such as supply chains is one of the important contributions of RBV approach. Since our focus here is on the transactions of detailed design drawings of components in the assembly industry, we limit our survey to the scope of a supplier's involvement in the earlier stage of an assembler's product development process and review the taxonomy of transaction patterns.

Asanuma (1989) made a seminal study on the make-or-buy decision in the Japanese auto industry. Between spot market transaction and in-house making, two other ways of transacting --- the drawing-approved (DA) system and the drawing-supplied (DS) system are further explored. Asanuma asserts that "relation-specific skill" [2] is the underlying force to

[2] In his later work, Asanuma changed the term to "relational skill" which adapts the concept to the open network transaction setting (Asanuma, 1997).

drive the classification, which is defined as " the skill required on the part of the supplier to the specific needs of auto maker." According to the product development process in the auto industry, Asanuma divides relation-specific skill into four factors and arrays them in a vector presentation (X1, X2, X3, X4). In detail, the four capabilities required by auto assemblers are:

X1: development capability in response to the specifications from an auto assembler and the ability to make proposals on specification improvement,

X2: process development capability and cost reduction capability through value engineering efforts,

X3: quality and timely delivery assurance capability, and

X4: cost reduction capability in the production stage.

(1989, pp.22-24)

Therefore, with respect to the choice between the drawing-approved system and the drawing-supplied system, whether suppliers are equipped with capabilities related to the early stage of the development process is the central explanatory variable. Represented by the relational skill vector, the DS system corresponds to (0, X2, X3, X4), the DA system corresponds to (X1, X2, X3, X4) and the "gray zone" corresponds to (X1, 0, X3, 0) where "some parts that can properly be characterized as quasi DA parts. For them, core firms provide only rough drawings, entrusting completion of details to the suppliers concerned. These parts therefore share some elements of DA parts, although they retain the basic character of DS parts "(Asanuma, 1989, p.14).

Clark and Fujimoto (1991) offered a similar classification of auto parts and transaction patterns. The three kinds of auto parts are the supplier proprietary parts, the detail-controlled parts and the black-box parts. They use this taxonomy to compare the practices of product development on the project basis across the Japanese, American and European regions. Their empirical results showed that in the mid- to late 1980s, the black box parts amounted to 62% of the overall transactions between auto assemblers and their suppliers in Japan, while in U.S., the detail-supplied parts had the dominant share of 81%. This difference was mapped to a gap in lead time of four to five months between the two regions.

In the Fujimoto's later works (1997), the black-box parts are further divided into two categories: the drawing-approved (DA) parts and the drawing-entrusted (DE) parts. The latter is a refinement of the “gray zone” using the classification scheme of Asanuma. Nevertheless, rather than simply being a naming work, Fujimoto’s research further clarifies another dimension of the classification: the ownership allocation of design drawings. So the outsourcing issue of detailed design drawings of components contains the design task-assignment dimension and the drawing’s ownership dimension. In the cases of the DA and DS systems, the two outsourcing aspects of the detailed design are together in the same package. But under the DE system, the two aspects are separated. That is, assemblers outsource the detailed design tasks but claim the property right of the design drawings. Furthermore, Fujimoto reveals that design fees are always paid to suppliers once the design tasks are completed and supplier switching is possible at the following manufacturing stage.

Recent studies illustrate several other ways of categorizing suppliers and transaction relationships. Kamath and Liker (1994) classified suppliers into four types: partners, mature, child and contractual suppliers. Differing in capabilities, *partner suppliers* and *mature suppliers* are close to the *black-box parts suppliers*. While *partner suppliers* work jointly with OEMs from the very start of the development stage --- the concept development, mature suppliers usually wait for rough specifications from OEMs and complete the sequential tasks. “Child suppliers” are similar to the “detail-controlled parts suppliers” in that they only manufacture after OEMs provide them detailed specifications. Finally, *contractual suppliers* is identical with the *proprietary parts suppliers* in that they supply standard parts through a catalogue.

Commenting that the Clark and Fujimoto’s taxonomy provides a sparse taxonomy, rather than a systematic typology, Kaufman, Wood and Theyel (2000) propose a strategic supplier typology in another 2x2 table. With the discrete measure of “low” and “high” along both technology and collaboration dimensions, *commodity supplier* (L,L), *technology specialist* (H,L), *collaboration specialist* (L,H) and *problem-solving supplier* (H,H) are distinguished. Compared with Clark and Fujimoto’s classification, *collaboration specialist* corresponds to the *detail-controlled parts supplier*, *technology specialist* corresponds to *proprietary parts supplier* and the *problem-solving supplier* can be viewed as the *black-box supplier*.

In comparison with these classifications, the transaction pattern based on the works of

Asanuma, Clark and Fujimoto has several advantages and is therefore adopted as the object of analysis in this paper (shown in the 2X2 table in the previous section). Firstly, the nature of the transactions between assembler and supplier is explicitly specified as the make-or-buy decision on detailed design drawings. Although the idea has been implicitly embodied in the previous studies, the explicit recognition of this point is believed capable of establishing more systematic logic and offering new insight into the inter-firm relationships. Secondly, two dimensions of detail design outsourcing --- ownership allocation of design drawings and design task assignment is clarified to make the taxonomy systematic.

Having reviewed the literatures related to the make-or-buy decision from both the organizational economics and RBV fields, we return to the central inquiry of why diverse patterns were observed between a fixed pair of one auto maker and one supplier. It is interesting that no previous studies have addressed this problem. First, it is clear that the incomplete contract and asset specificity concepts have no explanatory power in our setting. Secondly, the relational skill embedded in the fixed pair of firms can be considered constant at a single point in time when the observation is made. Furthermore, even taking the evolution of the relational skill into account, we still find that the transaction patterns exhibit no tendency to converge. Therefore, the answer to our key question should be sought along some other logic. As mentioned in introduction, an intuitive answer can be obtained by relating the characteristics of auto parts to the transaction patterns. In order to specify the characteristics of auto parts, we borrow insights from the product architecture literature.

3 The Architectural Attributes of Auto Parts

3.1. Product Architecture Literature:

Product, defined as an artifact that is purposefully and deliberately designed, can be viewed as a system of components that performs specific functions (Simon, 1962; Ulrich, 1995; Baldwin and Clark, 2000). Product architecture, then, is recognized as a system design concept referring to the configuration or layout of how the components are arranged within a system (Henderson and Clark, 1990). Defined in more rigorous terms, product architecture is "the scheme by which the function of a product is allocated to physical components and by which the components interact" (Ulrich, 1995, P420.). The definition of product architecture reflects the two phases of the general design process --- "analysis" and "synthesis" as suggested by design theory (Suh, 1990; Liedtka, 2000). In the analytical phase, the decomposition of the design problem into subsets is carried out. In the ensuing stage of synthesis, the individual subsets are grouped and integrated to be a coherent harmonious whole. Therefore, the product architecture concept can be further specified in detail as proposed by Ulrich (1995). First, it contains the arrangement of functional elements. Second, it reflects the mapping from these functional elements or design parameters to physical components. Third, it defines the interfaces among interacting physical components, which specify how they fit together, connect, communicate and so forth (Baldwin and Clark, 2000).

Modularity is a dimension to measure the way of decomposition and interface specification in the design process. It is a continuum describing the mapping structure of the functional parameters to the physical components and the degree to which components are independent from each other. The typical modular product is characterized as (1) each component implements a single function (the so-called "one-to-one mapping"), and (2) the interfaces between the components are well defined or standardized. As a result, the product system tends to be of the loosely coupled kind and the mixing and matching of components can be carried out (Schilling, 2000). In contrast, a product with extremely low modularity has the properties that (1) its components always implement multiple functions (function sharing) or a single function requires multiple components working together to be achieved (the so-called "complex mapping"), and (2) interfaces among tightly coupled components are ill defined (Ulrich, 1995; Sanchez and Mahoney, 1996).

The notion of product architecture has inherent linkage with management issues because the decomposition and interface specification of product design are naturally related to the process of the division of labor and coordination in which design ideas are transformed into real products [3]. Especially, modular architecture has attracted much attention in the management science field recently.

[3] Using the terminology offered by Baldwin and Clark, design structure and task structure are "isomorphic" (2000, p. 46).

Sanderson and Uzumeri (1990), Garud and Kumaraswamy (1995) and Schilling (2000) suggest that the feasibility of mixing and matching can offer more product variation and new components can be substituted into a new configuration with little loss of functionality. Ulrich (1995) further proposes several implications of modular architecture on the engineering management issues, such as product change, product variety, component standardization, product performance and product development. Sanchez and Mahoney (1996) argue that the standardized interfaces of modular architecture enable embedded (or autonomous) coordination and facilitate effective learning. Furthermore, a loosely coupled system can reduce the cost and difficulty of adapting to a changing environment and thus increase the strategic flexibility of an organization (Sanchez, 2000). Langlois and Robertson (1992) discuss the implications of a modular system on both the supply and demand sides. On the supply side, a modular system can breed autonomous innovation and achieve rapid trial-and-error learning. On the demand side, it can increase product differentiation and blanket the product space more completely. Modularity can reduce the communications overhead on a team and permit reuse of modules from other designs and consequently, development expenses and cycle time can be reduced. Baldwin and Clark (2000) summarize the power of modularity as (1) increasing the range of manageable complexity, (2) allowing concurrent work, and (3) accommodating uncertainty. On the other hand, its potential negative side is also addressed. The standardized interface can act as a bottleneck for performance and modular architecture cannot achieve the same level of performance as a tightly coupled nonmodular system. In order to accommodate uncertainty in the product development process, it's also necessary to allow some degree of redundancy in the interface design.

As for the inter-firm transaction and outsourcing issue, Sharon and Eppinger (2001) relate the make-or-buy decision of auto component production to the complexity of automobile design. By complexity, they mean "(1) the number of product components to specify and produce, (2) the extent of interactions to manage between these components (parts coupling) and (3) the degree of product novelty" (p.189). Their results from an empirical study on the luxury-performance segment of the auto industry show that when complexity is high, vertical integration is more attractive. Nevertheless, their focus is on how complexity in product design affects production, and they don't address outsourcing of design. Baiman, Fischer and Rajan (2001) use an agency theory model to examine the relationship between product architecture and supply-chain performance metrics. They conclude that the "separated architecture", in which components are decoupled and there is no function sharing, can facilitate the performance measure of suppliers and thus relieve the external contractability problem. Although they offer insights on the measurement aspect of the outsourcing issue, they do not separate design and production. In this paper, we tackle the outsourcing of detailed design, which has not been discussed systematically in previous literatures.

3.2. Formulation of Architectural Attributes of Auto Parts:

We borrow the definition of product architecture of Ulrich (1995) that the mapping from functional elements to physical components and the interface specifications are two essential aspects. Product, then, can be viewed as the hierarchy of both functional parameters and physical components (Gopfert and Steinbrecher, 1999). The interactions among components are clarified here into two types. One is the functional interaction, which refers to the relationships among components to implement functions. This is embodied in the mapping process from functional elements to physical components. The other is the structural interaction, which refers to the relationship among components reflected in the physical interfaces.

The architectural attributes of auto parts are defined as the features of both functional and structural interactions among auto parts. As such, the concept shares the same fundamental spirit of product architecture and can be regarded as a redefinition of product architecture on the component level. In particular, the architectural attributes of one auto part are specified to refer to:

(1) The degree of interaction with other auto parts to achieve a given function, and

(2) The degree of interaction with other auto parts in terms of physical intervention.

Modularity can also be applied here as a dimension to measure the architectural attributes of auto parts in a continuum manner. Along our logic, modularity can also be decomposed into two sub-concepts, a functional one and structural one. Auto parts with higher functional modularity are those parts that implement simple functions and achieve their specified functions in a manner independent of other parts. Auto parts with higher structural modularity are the parts with relatively standardized physical interfaces with other parts. Contrarily, auto parts with lower functional and structural modularity are those parts that implement functional sharing with other parts and with physical interfaces that are tightly coupled and ill defined.

Before establishing a theoretical framework that relates the attributes of auto parts and the outsourcing of their detailed design, we have some points to clarify. Firstly, although defining architecture on the product system level and on the component level share the same fundamental spirit of functional decomposition and interface specification, in the case of the automobile, there are some differences according to the observe level. From the product system level, the automobile is usually perceived as an integral and complex product. But from the component level when discussing the architectural attributes, we can observe a variety of interfaces with differing degrees of modularity in the various sections of automobile. Therefore, contrary to the simple perception of the automobile, the product actually contains a portfolio of interactions among auto parts.

Secondly, since the architectural attributes of auto parts are endogenous variables during the product development process, they change over time. This also creates the problem of how to define the “component” of the product since there are different levels such as parts, components and subassemblies related to the hierarchical methodology of design (Ulrich, 1995; Simon, 1962). To avoid this problem, we view auto parts in a static way here and base our discussions on auto parts whose detailed design drawings are actually transacted between auto maker and supplier.

4. Theoretical Framework and Hypotheses

4.1. Problem Setting:

Again, the key inquiry of our study is why diverse transaction patterns of detailed designs of auto parts --- the drawing-supplied (DS) system, the drawing-entrusted (DE) system and the drawing-approved (DA) system --- are observed in a dyadic transaction setting in the Japanese auto industry. There are three main assumptions in this problem setting.

First, long-term transactions and a collaborative relationship between the auto assembler and supplier are assumed as the background of this analysis. Therefore, problems caused by incomplete contracts are not relevant in this study and the discussion is on a different analytical level from the classic make-or-buy inquiry on the alternative institution choice between market and vertical integration. The means by which firms can co-operate more efficiently is the main concern here. Second, the technological capabilities of the auto assembler and supplier are assumed to be constant at a sufficient level such that they do not influence the choices of transaction patterns of detailed design. The dyadic transaction setting supports this assumption. Third, although determined endogenously, the architectural attributes of auto parts are assumed to be static independent variables since our main concern is on the choice of transaction pattern.

4.2. Foundation of the Theoretical Framework:

Despite the difference in the analytical subject and level, the logical structure (not the content itself) of the transaction cost economics framework is borrowed for understanding the outsourcing of design in this study.

First, the TCE framework deals with the make-or-buy problem by placing more weight on the ex post stage of transactions, which is compatible with our make-or-buy concerns for detailed design of auto parts between a pair of firms. Second, the TCE framework aims to facilitate the comparative study of alternative institutions by aligning transaction attributes with various institutional arrangements. Its emphasis on the concept “fit” sheds light on our attempt to relate the architectural attributes of auto parts with the transaction patterns of designs. Third, the TCE framework makes the transaction the analytical unit, takes both production and transaction costs into consideration and identifies the trade-off between them that leads to solutions to the problem of institutional choice. This point is also useful for finding the solutions to our inquiry, although our analytical unit is auto parts design.

Using the basic logical structure of the TCE framework and taking into account of the essential differences in our problem setting, we build our new framework as follows.

Behavioral Assumptions and Nature of Design:

Opportunism no longer plays a critical role in our framework due to the assumption that a long-term collaborative relationship has already been established. Instead, the bounded rationality of human beings is particularly important for the design issues under scrutiny here. Due to limited knowledge of the cause-effect linkages in a new product, design is said to be concerned with the contingent state of how things might be (Simon, 1962). Therefore, the nature of design is a searching process in which the hypothesis-driven approach is used for understanding what a product is to achieve, the internal fit of its internal components and its external fit with its contexts (Alexander, 1964; Clark, 1989; Liedtka, 2000). Through iterative hypothesis generating and testing, new information is acquired and new possibilities are continually opened up.

Nature and Sources of Transaction Costs:

As the result of the behavior assumption above and the nature of the design process, in our framework the inter-firm transactions should not be seen as a governing structure to handle the problems of opportunism, but as a coordination mechanism to facilitate the development activities of new products. This point is especially pertinent when practices in the Japanese auto industry are under examination, since the contractual arrangements are not as emphasized by each party and bargaining at the ex post stage is not one of the main activities (Imai and Komiya, 1989; MacMillan, 1990). Consequently, transaction costs, in the generous sense that is referring to all the "costs of running the economic system" (Arrow, 1969, p.48), are better recognized as coordination costs, rather than as governance costs. These costs are incurred from both limited cognitive capability on cause-effect relationships and uncertainty regarding technological and market environment changes. In particular, two kinds of coordination costs can be distinguished. One is the measurement cost, the other is adjustment cost.

The measurement cost refers to the cost incurred to detect the responsibility for design quality problems when there is failure to achieve the desired performances in the testing stage. Since the division of labor concerning the design activities is carried out across the firm's boundary, to identify failures caused by particular parts and then allocate the responsibility to the supplier is essential to the inter-firm coordination during product development. The adjustment cost refers to the cost incurred by the design changes that are inevitable during the iterative trial-and-error process of design. Whether the design changes can be localized in a limited scope so that a chain effect is not triggered and the need for change does not spread out to the whole development agenda is important to inter-firm coordination efficiency.

Having specified the foundation upon which our discussion is made, in the following section, we build up our theoretical framework along the logical structure of TCE and propose several hypotheses.

4.3. Theoretical Framework and Hypotheses:

Similar to the hypotheses in the TCE framework, we suggest that the outsourcing of the detailed design of auto parts ought to be aligned with their architectural attributes in the way that best economizes coordination costs. Our argument is divided into two parts. First, the choices of the DS and DA systems are studied as two contrasting cases. Second, using the first part of the analysis as a benchmark, we extend the logic to the choice of the DE system, which is an intermediate mode.

4.3.1. The DS System versus the DA System:

As mentioned before, the DS system and the DA system are two contrasting cases that correspond to the in-house making and to the outsourcing of the detailed designs of auto parts respectively. As has been shown in the previous studies, the outsourcing of detailed designs has several advantages for productive efficiency in the product development process. First, It makes parallel or concurrent product engineering possible, which can shorten lead time (Clark and Fujimoto, 1991; Baldwin and Clark, 2000). Second, it facilitates design-for-manufacturing (DFM) activities, which can improve quality and cost performance (Whitney, 1988; Ulrich, 1995). By integrating the product and process design process, suppliers can exploit their know-how better to achieve the rationalization of design. Third, it can promote the front-loading of development tasks, which deal with uncertainty in the design process in a more efficient way (Thomke and Fujimoto, 2000). Fourth, it can provide a high-powered incentive in the product development process both for suppliers and the development staffs of an auto assembler (Williamson, 1985).

However, in contrast with these eulogies on outsourcing, we claim that these merits of outsourcing in new product development will not be realized without conditions. When detailed design tasks are assigned to outside suppliers, the potential costs of coordination must be considered. Even if the opportunistic behavior of suppliers can be well controlled, it is still necessary for an auto assembler to “measure” and “monitor” the activities of its suppliers. If quality or some other incompatibility problems arise, the auto assembler has to identify the source of the problems and localize the responsibility to the specific supplier. As noted before, there is the potential measurement cost. In addition, during the trial-and-error process of developing automobiles, unavoidable design changes are likely to cause the adjustment costs. While a few studies show the evidence that suppliers are willing to coordinate with each other such that the adjustment costs can be assumed by suppliers, the common perception suggests that the auto maker assumes a substantial proportion of adjustment costs. Therefore, there is a trade-off between the productivity benefits and the coordination costs when an auto assembler makes the choice of transaction pattern.

The modularity of auto parts design may be an effective measure for determining the dominant effect in the trade-off between productive efficiency and coordination costs. When the design of an auto part displays high modularity, we would expect the productive efficiency effect to be dominant as the productivity benefits in design and manufacturing can be realized with lower coordination costs. In such a case, due to the high functional modularity between auto parts, the measurement problem can be effectively resolved simply by requiring that all the parts be developed to conform to standardized interface protocols.[4] Also, due to the high structural modularity, design changes can be localized to individual suppliers with no need for accommodation across several suppliers. The foregoing discussion leads to the following hypothesis.

Hypothesis 1 (H1): Auto parts with high functional and structural modularity will be more likely to be transacted under the DA system, with both design tasks and ownership of design

[4] This statement shares some overlap with agency theory (Jensen and Meckling, 1976; Eisenhardt, 1989), which puts emphasis on the measurement problem when discussing the incentive mechanism. When tasks are programmable and the outcomes are less uncertain, ‘outcome-based’ contracts are likely to be adopted to induce the high-powered incentive. In the opposite case, ‘behavior-based’ contracts are likely to be used in which payoff is not related to the outcome and thus has a relatively low incentive effect.

drawings going to suppliers, given that the firm's capability factors remains constant.

In contrast, when the design of an auto part exhibits low modularity, we would expect the coordination cost effect to be dominant in the trade-off. When auto parts are closely interdependent with each other in achieving some particular function of an automobile (i.e., low functional modularity), the measurement problem will become severe. Just like the scenario of the "team production" (Alchian and Demsetz, 1972), it is hard to tell which one should be responsible for a possible problem in quality because whether a part performs its role well or not depends on its interaction with other parts. Additionally, adjustment costs will also increase due to close physical interdependence between auto parts (i.e., the low structural modularity). Design changes of a part are likely to require extensive accommodating changes in other interrelated parts. If the part with such attributes is transacted as a DA part, the benefit in productivity cannot be realized without substantial costs. Therefore, under such situation, the DS system is preferred. An auto assembler will carry out the detailed design to take the responsibility for handling design problems and only outsource the manufacturing activities to suppliers. This theoretical logic leads to the following proposition.

Hypothesis 2 (H2): The DS system is more likely to be chosen when the auto part's design exhibits both low functional and structural modularity, given that the firm's capability factor remain constant.

4.3.2. The Choice of the DE system:

The DE system has been shown to be an intermediate mode that exhibits the hybrid features of both the DA and DS systems. While the detailed designing of auto parts is entrusted to suppliers, the property rights of design drawings belong to auto assemblers. The system also bears the one-spot nature that there is not necessarily continuity between design and manufacture. The separation of design task outsourcing and drawings ownership can be considered a sort of institutional innovation. As revealed in our research interviews, the main purpose of this innovation by auto assembler is to take advantage of specialized know-how in suppliers to tackle challenging and uncertain design problems. As for the conditions for the choice of the DE system, we attempt to hypothesize from the perspective of auto parts modularity in the following discussion.

First, we suggest that relatively high structural modularity facilitates the outsourcing of design tasks. In a situation where the basic spatial and functional parameters can be specified in the design blueprint by auto assemblers, suppliers can conduct their design work in a relatively independent way to achieve the merits of parallel progressing of the development project. On the other hand, we suggest that auto parts with relatively low functional modularity leads to auto maker's ownership of design drawings. Although structural interfaces may be relatively well defined, the interdependency of auto parts to achieve a certain function causes uncertainty when localizing the design responsibilities to individual parts. Put in our specified terms, the measurement costs are high in such a situation. Furthermore, since the designs transacted under the DE system are technologically uncertain, design changes are very likely in the subsequent development process. If design drawings belong to suppliers, the freedom of auto assemblers to change designs is constrained and negotiations across firms become necessary, which makes coordination costs high. In response to this problem, an auto assembler changes the transaction of design drawings into a one-shot deal by paying the design fees to a supplier once the drawings are completed, which eliminates the possibility of sequential inter-firm interactions. Therefore, in order to utilize the design know-how of a supplier while at the same time attenuating the coordination problems, an auto assembler entrusts the design task to supplier while internalizing the coordination among the designs of auto parts.

This point can be better understood by examining an example in a case study by Fujimoto (1997), in which weather strips are transacted under the DE system. Although the spatial design parameters of the weather strip can be specified ex ante when the specifications of the body frame and the window glass parameters are determined, there is a high interdependence among the body frame, window glass and weather strip to fulfill the sealing function. When a leakage problem occurs, it is hard to tell which part should be held responsible. However, if the auto maker internalizes this coordination problem by taking the responsibility for design defects, complicated intervention across firms can be greatly reduced.

Therefore, as revealed by the theoretical logic and observation outlined above, the choice of the DE system can be hypothesized as follows.

Hypothesis 3 (H3): When the structural modularity of an auto part's design is relatively high, but the functional modularity of an auto part is relatively low, the DE system is likely to be chosen, given that the firms' capability factors remain constant.

In the next section, we present a hypothesis testing procedure that can be used to see how well our hypotheses are supported by empirical data.

5. Research Methodology

5.1. Sample Setting:

We specified our sample setting in a way similar to our problem setting in that we focus on the transactions between auto maker A, and one of its first-tier suppliers, to control for the firms' capability factors. Our sample consisted of 33 auto parts, which were chosen by the respondent.

5.2. Variables and Measures:

5.2.1. Transaction patterns:

Transaction patterns are measured on a nominal scale with three categories: (1) the drawing-supplied (DS) System, (2) the drawing-entrusted (DE) system, and (3) the drawing-approved (DA) System. The respondent was asked to identify the transaction pattern with respect to each auto part in the sample.

5.2.2. Architectural Attributes of Auto Parts:

To make the concept of architectural attribute operational in our empirical study, we constructed eight indicators to capture both functional and structural interdependence among auto parts. All of these variables are measured on a 5-point scale, with 1 indicating a "very low" level and 5 indicating a "very high" level.

(1) Functional Integration (FIN) --- the extent to which an auto part can implement its function

independently.

(2) Performance Measurability (PME) --- the degree of ease with which design quality problems caused by the sample auto part can be correctly identified in the testing and assembly process.

(3) Interface Commonality (ICM) --- the extent to which the structural interface design of the sample auto part can be shared across different auto models.

(4) Interface Complexity (ICP) --- the degree to which the structural interface design of the sample auto part is coupled with other parts in terms of the number of joint points.

(5) Design Independence (DIN) --- the extent to which the design of the sample auto part can be carried out independently and concurrently with other parts. This variable contains both functional and structural aspects of the auto part design.

(6) Design Commonality (DCM) --- the degree to which the design drawing of the sample auto parts can be reused in other auto models. DCM can be considered as an indirect indicator of both functional and structural aspects of auto parts design since the more modular a design is, the more likely the design can be mixed and matched in other models.

(7) Proximity to Core Function Sections of an Automobile (PCF) --- the degree of structural proximity between the sample auto part and the core functional sections of an automobile such as the body, engine and chassis.

(8) Proximity to Exterior/Interior Design of an Automobile (PEI) --- the degree of structural proximity between the sample auto part and the exterior and interior designs of an automobile.

5.2.3. Control Variables: the internal complexity of auto parts

Three indicators were designed to measure the internal complexity of auto parts on a 5-point scale.

(9) Functional Multiplicity (FMU) --- the assessment of how many functions the sample auto part contributes.

(10) Structural Complexity (SCM) --- the assessment of how complex the sample auto parts are in terms of their internal structure such as the number of parts used and the engineering hour used for manufacturing.

(11). Technologically Advanced Degree (TAD) --- the assessment of how advanced is the technology required to design the sample auto part. TAD also reflects the technological uncertainty related to the sample part. The number of patents related to the design and manufacturing of the auto part is one measure used for this indicator.

5.3. Data Collection:

We relied on an interview and questionnaire survey to collect data on the sample auto parts. First, a senior manager at the supplier (B) was contacted to seek permission to conduct our study. Once the study was approved, the questionnaire was emailed to the respondent for review of the question item design. In this way, the accuracy and relevance of the indicators and language was evaluated. Three weeks later, we made a visit to the supplier and conducted an interview with the respondent. The question items were once again checked --- ambiguities were removed and the face validity of the measures was examined. After the questionnaires on the 33 sample auto parts were completed, we obtained the data based on a confidentiality agreement with the respondent. Afterwards, we continued contacting the respondent via phone calls, faxes, and emails to review the responses, discuss the preliminary results of the data analysis, and resolve some questions related to inconsistencies between the data and our ex ante expectations.

Using the subjective perceptions of respondents for measurement during a questionnaire survey is common in the empirical research field (Monteverde and Teece, 1982; Masten et al., 1989; Walker and Webber, 1984; Clark, Fujimoto, 1991; Takeishi, 2001). Although perceptual measurement may raise concerns about bias and the reliability of the responses, the judgment of the respondent based on his long career experience and receiving confirmation from other engineers of the validity of the responses to be an appropriate approximation for the purposes this exploratory empirical study.

5.4. Method:

As the first step, a correlation analysis was conducted and the correlation coefficients matrix was derived. Second, we carried out a factor analysis on the 11 independent variables and extracted four factors. Finally, based on the results of factor analysis, a logistic regression of the four explanatory factors on the transaction patterns was conducted. Instead of using the factor scores directly, the means of the representative variables that have high weights for the same factor are used as the independent variables in the logistic regression models.

6. Results

6.1. Results of Correlation and Factor Analyses:

Table 1 presents the descriptive statistics and the correlation matrix. A relatively strong positive correlation exists between FIN and PME. This result supported our intention of using these indicators as the variables for reflecting the functional interdependence between auto parts. To our surprise, there was no correlation between ICP and ICM which were used to measure the physical interfaces between auto parts. This could suggest that there may be more than one dimension of the interface being measured. Additionally, consistent with our expectation, an extremely high correlation is observed among the variables indicating the internal features of auto parts design.

Insert Table 1. Descriptive Statistics and Correlation Matrix about here.

Next, to better understand the latent constructs in the measured variables, a factor analysis was conducted. Four factors were extracted that accounted for 66 percent of the variance, as is shown in Table 2.

Insert Table 2. Results of Factor Analysis about there.

The first factor consists of the FIN, PME and DIN variables, which captures the functional independence of the sample part. This factor shows that the auto parts in the sample implement their functions with few interactions with other parts, that their functional performance can be well measured and that a higher degree of freedom can be enjoyed during the design process. Therefore, we label this factor the *functional modularity factor*.

Factor 2 also contains three variables --- ICP, PCF and DCM. It reflects the complexity of the physical interfaces between the auto parts and the spatial proximity between the sample parts and the core functional sections of an automobile like the engine, body and chassis. It shows that the design commonality of auto parts across different car models is low. We can call this factor the *structural coupling factor*.

The third factor, which includes ICM, PEI and DCM, shows that auto parts are located close to the exterior and interior design of an automobile and both the interface and configuration designs of the auto parts are not likely to be shared among different car models. Due to the substantially high loading on variable PEI, we name Factor 3, the *styling design factor*.

Finally, the variables contained in Factor 4 have high positive values for the number of functions implemented by the sample parts (FMU), on the internal structural complexity of the sample parts (SCM) and on the advanced degree of technology required by the design and manufacturing of the sample parts (TAD). Since the factor apparently indicates the functional and structural complexity of the auto parts internally, we define this factor as the *internal complexity factor*. It is consistent with our expectation to use the internal features of the auto parts as a control variable.

6.2. Results of Logistic Regression Analysis:

To test our hypotheses, we use a logistic regression model to examine the relationship between the architectural attributes of the auto parts and the choice of the three transaction patterns. Instead of using factor scores directly, we use the means of the representative variables of each factor as the explanatory variables. Meanwhile, since the dependent variables in the logistic regression model are conventionally of the dichotomous kind, we ran five models for use in applying the logistic regression technique to analyze the choice of three transaction patterns. Table 3 shows the results.

Insert Table 3. Results of Logistic Regression about here.

In Model 1, the DS system is the dependent variable with the DE system and the DA system combined as the default. According to our logic, this model can be viewed as revealing the determination of the detailed design task outsourcing, since the DE and DA systems are the outsourcing cases while the DS system is case where the designing is done in-house. In Model 2, the DA system is the dependent variable with the DE and DS systems combined as the default. In this model, the determination of the ownership allocation of the detailed design drawings is examined since it is only under the DA system that suppliers claim the property rights of the design drawings. In Model 3, we left out the auto parts that were transacted under the DE system and studied the contrasting cases of the DS and DA systems using 22 of the sample auto parts. In Models 4 and 5, we focused on the choice of the DE system. Because of its intermediate nature, the DE system is studied separately first with the DS system, and then with the DA system as the defaults. The sample size was 25 in Model 4 after deleting the DS parts. In the same vein, 19 sample auto parts were used in Model 5 when the DA parts were left out.

Results of Model 1 show that only the “internal complexity factor” has a significantly negative influence on the choice of the DS system, when compared with the DE and DA systems (the so-called “black-box” systems). This indicates that the DS system is likely to be adopted when auto parts are less complex internally. In Model 2, the coefficients of the “functional modularity factor” and “the internal complexity factor” are positive and significant. The same results were obtained in Model 3. Both of these results indicate that the choice of the DA system is positively associated with auto parts that are internally complex and functionally independent from other parts.

Predicting the choice of the DE system, Model 4 shows the results when compared with the DA system. The DE system is associated with auto parts for which functional modularity is relatively low. On the other hand, when compared with the DS system in Model 5, “the internal complexity factor” significantly influenced the choice of the DE system.

In summary, the results of the logistic regression analyses partially support our hypotheses. First, Hypothesis 1 on the choice of the DA system was partially supported. The coefficient of the functional modularity factor was positively significant, but the coefficients of both the structural coupling factor and the styling design factors, which reflect the structural modularities of the auto parts, were not significant. Similarly, results on the DS system were also partially consistent with Hypothesis 2, since only the functional modularity factor showed a negative significant result. No significant result was shown for the factors reflecting structural modularity. As for Hypothesis 3 on the choice of the DE system, it was partially supported in that the functional modularity factor exhibited a negative significant result compared with the DA system. Moreover, the structural modularity factors were again revealed as irrelevant in explaining the transaction pattern choice. Finally, the internal complexity factor was shown to exert a significant positive influence on the choice of the DA and the DE systems, but to have significant negative influence on the choice of the DS system.

7 Discussion

Our results, which only partially supported, make us look back to the taxonomy of the transaction patterns, in which the design task assignment and the ownership of design drawings are the two dimensions. When plotting the results of the logistic regression analysis along the two significant explanatory factors, we can see that the functional modularity factor significantly influences the ownership of design drawings. When the functional modularity of auto parts is high, the DA system is likely to be chosen. On the other hand, the “internal complexity factor” of auto parts is negatively associated with the DS system and is positively related to the DA system and the DE system. While between the DE and DA system, there is no significant outcome concerning the internal complexity of auto parts. These results indicate that the internal complexity of auto parts may be a separating line between in-house design and design outsourcing regardless of the drawing ownership issue.

Insert Figure 2. Results of the Logistic Regression Analysis about here.

(1) Functional modularity and the ownership allocation of design drawings:

The result that functional modularity influences the ownership allocation of design drawings firstly verifies the logic in our theoretical framework that high modularity between auto parts to achieve a certain functional parameter of an automobile can economize the inter-firm coordination costs, especially the measurement costs. As design theory shows, the functional parameters specification or the establishment of functional structure is the first step in the design process (Pahl and Beitz, 1984; Clark, 1985; Ulrich, 1995; Baldwin and Clark, 2000). There reveals also the isomorphic relationship between the functional parameter determination and the task partitioning (Hippel, 1990; Eppinger, 1991; Baldwin and Clark, 2000). When the functional interfaces between auto parts are well defined and the functional parameters of each part are specified definitely, an auto maker can provide suppliers with a strong incentive by letting them claim the property right of design drawings. Under such a situation there is a good balance between a supplier's incentive and responsibility for design tasks and the merits of design outsourcing such as lead-time shortening, cost reduction and quality improvement can be realized. Put differently, this result implies that the functional modularity of auto parts and their detailed design outsourcing should be matched to achieve competence of supply chain.

(2). Why structural modularity had no impact on the transaction patterns?

Results from the empirical study show that the degree to which the physical interfaces between auto parts can be well defined does not seem to be important in deciding whether to outsource the detailed designing of auto parts. According to our framework, such an observation means that the adjustment costs incurred from design modifications may not cause a serious inter-firm coordination problem. This point was confirmed during the interview with the respondent who commented that the interface complexity of auto parts seldom posed problems during the design process.

The reasons for this result may lie in our sample setting of the Japanese auto industry, where the longstanding collaborative relationship between Supplier B and Auto Maker A could be assumed beforehand. Instead of engaging in time-consuming inter-firm negotiations when design changes need to be done during the development process, Japanese auto makers and their suppliers usually seek to solve the problems together. It should be pointed out that auto makers generally pay for the die costs to suppliers during the development stage, which can be considered as important means of alleviating the inter-firm frictions when design changes occur (Asanuma, 1997). Additionally, long-term communication and the frequent exchange of development staff between auto makers and suppliers also reduces the technological barriers to making design modifications. Therefore, given a shared cooperative attitude and accumulated technological know-how concerning changed in the design of auto parts between Japanese auto makers and suppliers, the adjustment costs incurred in the inter-firm transactions are not meaningful enough to explain the choice of the various transaction patterns. This result can further imply that the optimal physical interface design can be achieved by competitive Japanese auto makers if design changes can be conducted smoothly.

(3) Internal complexity of auto parts and design task outsourcing:

The result that the internal complexity of auto parts is positively associated with the outsourcing of detailed designing may be considered as an unusual result at first sight, since relatively simple parts should generally be outsourced. The reason for the result, however, lies in our data collection method and the design of the survey items. Since we acquired data from the supplier and asked how much advanced technology was required or the number of patents acquired for designing and manufacturing the auto part, as one of the indicators of the internal complexity of auto parts, this result actually describes the conditions for utilizing the supplier’s development capability. This interpretation is compatible with the argument by Asanuma (1989) that the more know-how suppliers accumulate for designing auto parts, the greater the likelihood that design outsourcing will be done by the auto makers. It also backs up the analysis of Fujimoto on the supplier system in Japanese auto industry that “bundled outsourcing” to suppliers can make them “build a certain integrative capability in the long run” and increase their likelihood of becoming “system suppliers” (Fujimoto, 2001, p. 23; Nishiguchi, 1994).

8. Conclusions

8.1 Conclusions and Implications:

Choosing a dyadic transaction setting to control factors such as asset specificity and relational skill, we discussed the make-or-buy decision for detailed design drawings of auto parts in the Japanese auto industry from the perspective of the architectural attributes. We borrowed the taxonomy of transaction patterns classified by Asanuma (1989) and Fujimoto (1997), but we further clarified two dimensions --- the transactions as the design task assignment and the ownership allocation of detailed design drawings. The inquiry into why diverse patterns were observed in the transactions between one auto maker and one supplier made us turn to the perspective of product architecture. We defined the architectural attributes of auto parts in terms of functional and structural modularity that reflect the degree of interdependency among auto parts within the automobile. Results of the hypothesis testing effort showed that the functional modularity of auto parts had a significantly positive effect on the outsourcing of the detailed design when a supplier claims ownership of design drawings. The internal complexity of auto parts showed a significantly positive effect on the outsourcing of design tasks to suppliers but was irrelevant with respect to the ownership dimension.

Our discussion of detailed design outsourcing in the Japanese auto industry can shed light on both practical and academic issues. First, the functional modularity of the design of auto parts should be taken into account when deciding the outsourcing of design tasks, together with other factors like asset specificity, capability or know-how, commitments, trust, and so forth. Balance should be secured between providing a high-powered incentive to a supplier, clearly defining responsibility and coordinating costs during the product development process. Matching between architectural attributes and the division of labor should be emphasized during decision making on outsourcing.

Second, the results contain some implications on the diverse trends of modularization occurring in the global automobile industry. So-called modularization as the concept was proposed during the 1990s mostly by European and American auto makers and suppliers, means supplying a larger chunk of a composite module with quasi-independent functions from either a first-tier supplier or from an internal sub-assembly line to the main assembly line (Fujimoto, 2001). From some previous research and our study here, it should be noted that the delivery of functional modules where the responsibility is clearly defined between the auto maker and suppliers emerged and developed into a systematic practice in Japan much earlier than the 1990s (Fujimoto, 1997, 2001). When the functional modularity of an auto part's design is high so that the scope of the supplier's responsibility can be clearly defined, the close communication within the long-term collaborative inter-firm relationships found in the Japanese auto industry is likely to achieve the optimal modularization that both achieves functional integration and avoids the redundant interface designs. The blind following of the global trend towards modularization to make larger chunks without other considerations may economize the assembly costs for auto makers, but improvements to design quality and consumer satisfaction cannot be assured. At the same time, profit margins of suppliers cannot be enlarged easily simply by incorporating more assembly tasks, and there is doubt as to the incentive of suppliers to carry out such kind of modularization. Therefore, the modularization decision also needs to be made such that it is compatible with the context of the larger supplier system, and furthermore firms in Japan should not conduct modularization at the sacrifice of the competitive advantage of the Japanese-style supplier system (Fujimoto, 2001; Takeishi and Fujimoto, 2002).

8.2. Research Limits and Future Study:

In our specific dyadic transaction setting, although factors such as supplier's capability and asset specificity are controlled so that the effect of architectural attributes of auto parts can be examined in an independent way, the likely sampling bias cannot be avoided. In addition, since the research data was limited in the Japanese auto industry, there is also the difficulty of generalizing of our findings to other industries with products that have a different design philosophy from the automobile. Furthermore, due to the explorative nature of our study, the constructs and measurement of the variables were imperfect. Therefore, further refinements on the empirical study method are needed. Finally, going forward the simultaneous examination of the choices of both architectural attributes and transaction patterns is also a challenging work that needs to be done. Rather than the static analysis of this paper, a dynamic viewpoint should be added when the interactions between the effective modularization and the changes of inter-firm transaction patterns are tackled. With the inherent linkage to organizational issues, the perspective of product architecture is believed to be promising raising new questions and providing new insights to the understanding of inter-firm relationships in new product development.

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Figures:

Figure 1　Taxonomy of Transaction Patterns of detailed design drawings

Ownership Allocation		Design Task Assignment: Outsource	Design Task Assignment: Make In-house
	Supplier	**Drawing-approved System (DA system)**	
	Auto Maker	**Drawing-entrusted System (DE system)**	**Drawing-supplied System (DS system)**

Figure 2. Results of Empirical Study

Functional Modularity Factor		Internal Complexity factor: High	Internal Complexity factor: Low
	High	**Design-approved System**	
	Low	**Design-entrusted** **Design-supplied**	

Table 1 Descriptive Statistics and Correlation Matrix

	Means	S.D.	FIN	PME	ICM	ICP	PCF	PEI	DIN	DCM	FMU	SCM	TAD
FIN	2.6669	0.2741	1										
PME	4.1515	0.2	0.3946 *	1									
ICM	2.6061	0.2645	0.2267	0.168	1								
ICP	2.1515	0.2	0.1485	0.0371	0.0967	1							
PCF	3.6667	0.2671	-0.0381	0.1001	-0.3364	0.4172 *	1						
PEI	3.2424	0.3258	-0.315	0.2251	-0.4128 *	-0.1457	0.2942	1					
DIN	1.9394	0.1991	0.1899	0.4763 *	0.1351	-0.2461	-0.228	-0.0169	1				
DCM	3.3939	0.2381	0.09601	-0.1053	0.4592 *	-0.41 **	-0.6304 **	-0.3466 *	0.3679	1			
FMU	3	0.1628	-0.4614 *	-0.4168 *	-0.3574	0.0914	0.1686	0.199	-0.0904	-0.1922	1		
SCM	3.4545	0.2503	-0.2812	0.1543	-0.4251 **	0.0491	0.1622	0.3069	0.3787 *	-0.2159	0.6149 **	1	
TAD	3.5455	0.1986	-0.3249 *	0.2131	-0.1254	0.019	-0.1439	0.1289	0.4234 *	-0.0728	0.4722 **	0.8001 **	1

Note:

*: Significant at 0.01 level;   **: Significant at 0.05 level.

Sample Size: N=33

Variable Measures:

1: very low; 2: fairly low; 3: average; 4: fairly high; 5: very high.

Table 2 Results of Factor Analysis

	Factor1	Factor2	Factor3	Factor4
FIN	**0.497**	0.128	-0.301	-0.298
PME	**0.881**	8.61E-02	0.211	2.09E-02
ICM	7.60E-02	-0.17	**-0.538**	-0.304
ICP	-1.99E-02	**0.778**	-0.301	5.82E-02
PCF	8.57E-02	**0.704**	0.311	-4.99E-02
PEI	8.04E-02	4.53E-02	**0.756**	8.87E-02
DIN	**0.538**	-0.401	-4.68E-02	0.37
DCM	5.52E-03	**-0.761**	-0.47	-0.109
FMU	-0.409	0.115	9.47E-02	**0.684**
SCM	0.142	7.66E-02	0.251	**0.935**
TAD	4.51E-02	-7.99E-02	0.105	**0.881**
Loading weight?	0.22389	0.17472	0.1384	0.13537

Table 3 Results of Logistic Regression Analysis

	Model 1 The DS System N＝33	Model2 The DA System N＝33	Model 3 The DA System (vs. the DS System) N＝22	Model 4 The DE System (vs. the DA System) N=25	Model 5 The DE System (vs. the DS System) N=19
Functional Modularity Factor	-1.9660	0.8714*	2.2851*	-0.9752	1.2358
	(1.3551)	(0.4830)	(1.2888)	(0.6017)	(1.1688)
Structural Coupling Factor	2.5081	-0.2638	-0.6245	-0.3367	-2.0680
	(1.8671)	(0.8818)	(1.1213)	(1.0916)	(1.6632)
Styling Design Factor	-1.1956	0.7132	-2.3127	-0.4714	0.3596
	(1.0504)	(0.6512)	(1.5956)	(0.6648)	(1.0788)
Internal Complexity Factor	-2.3211	0.9381*	2.2982*	-0.4960	1.6599*
	(1.1952)	(0.501)	(1.2717)	(0.5129)	(1.0015)
Constant	6.3799	-7.4522	4.1612	6.9113	-2.1215
	(5.2143)	(5.3052)	(4.0620)	(5.7777)	(5.1748)
Log. Likelihood	22.666	34.916	14.731	29.791	19.199