KNOWLEDGE PARTITIONING IN THE INTER-FIRM DIVISION OF LABOR: THE CASE OF AUTOMOTIVE PRODUCT DEVELOPMENT

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ABSTRACT

Drawing on an empirical study on automakers' management of supplier involvement in product development in Japan, this paper shows that when the design of a component is outsourced to a supplier, how much and what automakers know about the component matters for them to gain a better outcome. While the actual tasks of designing and manufacturing components could be outsourced, automakers should retain the relevant knowledge to obtain better component design quality. The paper argues that knowledge partitioning should be distinguished from task partitioning, and provides some implications for the knowledge-based theory of the firm.

The results indicate that effective pattern of knowledge partitioning differs by the nature of component development project in terms of technological newness. For regular projects, it is more important for the automaker to have a higher level of architectural knowledge (how to coordinate various components for a vehicle) than of component-specific knowledge, which is supposed to be provided by the supplier. However, when the project involves new technology for the supplier, it is important for the automaker to have a higher level of component-specific knowledge to solve unexplored engineering problems together with the supplier. In innovative projects, effective knowledge partitioning seems to demand some overlap between an automaker and a supplier, rather than efficient and clear-cut boundaries, which are optimal for regular projects. Such "fluid" nature of knowledge boundaries contingent on the project types poses a challenge for firms seeking both technological leadership as well as efficiency in established products.

Developing and maintaining knowledge about an outsourced component is by no means easy. When the actual design tasks are outsourced, automakers miss substantial opportunities to gain relevant knowledge through learning by doing. Also, obtained knowledge may be diffused among competitors through shared suppliers. Another problem for automakers is that component-specific knowledge is important for only limited cases (innovative projects). Even worse, component-specific knowledge has a trade-off relationship with architectural knowledge.

Such an inherent dilemma of managing knowledge, however, may provide some automakers with the opportunity to achieve sustainable competitive advantage. Additional analysis shows that one automaker managed both types of knowledge better than others in a manner that deals effectively with the dilemma. Its organizational mechanisms include career development policies, extensive documentation of technological information, internal training programs, and incentive schemes. The difficulty in implementing those mechanisms in a consistent and complementary manner seems to explain why there was a significant variance among automakers in knowledge level, even when the actual tasks were carried out by a shared supplier.

(414 words)

INTRODUCTION

Collaboration with external organizations could bring a firm such benefits as reducing the fixed costs, gaining flexibility, and capitalizing on specialists' expertise (Miles and Snow 1984, Jarillo 1988, Johnston and Lawrence 1988, Dertouzos, Lester and Solow 1989, Kanter and Myers 1991). Outsourcing has become an important strategy for many firms. Product development is no exception. The *Wall Street Journal* (April 22, 1997) reported that with many large companies scaling back internal research and development, small product-development companies were seizing a chance to pick up the slack, and large companies preferred to farm out their research and development to smaller companies. According to a survey with leading Western companies (Misawa and Hattori 1998), approximately 80% of their engineering tasks were carried out internally in 1998, whereas about 50% will be outsourced in 2000 according to their plans.

However, outsourcing has some downside risks. A firm dependent on external organizations' engineering capabilities may lose some negotiation power and become vulnerable in technological capability. Fine and Whitney (1996) and Fine (1998) suggested that it is important, therefore, to distinguish *dependence for capacity* and *dependence for knowledge*. In the former case, the company can carry out the task in question, but for some reasons extends its capacity by means of a supplier. In the latter case, the company needs the item but does not know how to do the task, and thus relies on a supplier. They argued that if a company is dependent for capacity but not for knowledge, it could live with outsourcing without substantial risks.

This argument implies that we should distinguish *task partitioning* (von Hippel 1989) — who does the tasks of design and manufacturing among organizations — from *knowledge partitioning* —who has knowledge for the tasks among organizations. It is knowledge partitioning, not task partitioning, that might matter more in effective outsourcing. This paper attempts to examine empirically whether it does really matter for competitive advantage, that a company has knowledge about the task outsourced, and if so, how it could keep such knowledge internally.

The empirical field is the Japanese automotive industry. A typical passenger car consists of more than 30,000 components and many suppliers are heavily involved in the development of new vehicles. Effective and efficient management of this complicated division of labor with suppliers is a challenging task and critical for an automaker's competitive advantage. Drawing on questionnaire survey data with the Japanese auto industry, this paper demonstrates that an automaker's knowledge about a component is positively related to the quality of the component design outsourced to a supplier. Also, based on some additional data and interviews, the paper shows that it is difficult for automakers to maintain knowledge internally about the outsourced component, and explores how an automaker outperformed others in knowledge management. A focus of investigation is put on organizational mechanisms for enhancing and maintaining engineering knowledge.

Theoretically this paper addresses the knowledge-based theory of the firm, which argues that the existence and boundaries of the firm could be better understood with special attention to knowledge (Demsetz 1991, Kogut and Zander 1992, 1996, Nonaka and Takeuchi 1995, Conner and Prahalad 1996, Foss 1996a, 1996b, Grant 1996). Although this study is not directly concerned with the boundaries of the firm, the findings provide some implications for the issue, by analyzing the boundaries of knowledge the firm should cover to be competitive. The results show that the boundaries of knowledge (knowledge partitioning) to be covered by automakers vary according to the nature of the project, either innovative or regular. Such “fluid” nature of knowledge boundaries and the difficulty of managing them seem to pose a challenge for firms seeking both technological leadership as well as efficiency in established products.

The remainder of this paper is organized as follows. First, I briefly review what previous studies have discussed about the role of knowledge in outsourcing. The next section, drawing on a questionnaire survey with suppliers, analyzes the relations between automakers’ knowledge level and the performance of component development with suppliers. The paper further goes on to explore, primarily based on interviews and a questionnaire survey with automakers, organizational mechanisms for managing knowledge inside automakers. I conclude with a discussion of this study’s implications, particularly for the knowledge-based theory of the firm, and of future research.

BACKGROUND

Most companies cannot design and manufacture their products without the help of external organizations. How to manage the division of labor with outside companies has long been a central issue for managers and researchers. Researchers have been paying growing attention to inter-firm relations since a newly conceptualized mode of economic organization began to attract attention in the early 1980s. In contrast with the modes of markets and of hierarchies, this new mode is characterized by cooperative, interdependent, and long-term relations among independent organizations. Many studies in a variety of disciplines have addressed the actual or potential advantages of the new mode of inter-firm relations (Miles and Snow 1984, Piore and Sabel 1984, Jarillo 1988, Johnston and Lawrence 1988, Powell 1990, Williamson 1991, Saxenian 1994, Dyer and Singh 1998). In recognition of the potential benefits from collaborative outsourcing, such as combining different competencies, sharing fixed costs, and gaining economies of scale, firms have been encouraged to outsource more activities. Growing pressure toward downsizing in the 1990s has further accelerated such initiatives.

In the case of automotive product development, Clark and Fujimoto (1991) revealed benefits from the so-called "black-box system," a practice of the inter-firm division of labor in which a supplier is involved in detailed engineering of individual components to be installed into a new vehicle based on an automaker's requirements. This practice, widely diffused in Japan, reduced overall development lead time and engineering hours, and thus contributed to Japan's competitive advantage (Clark 1989, Womack, Jones and Roos 1990, Clark and Fujimoto 1991). In recognition of such advantages, American and European automakers have adopted a similar approach and shifted more engineering responsibilities toward suppliers (Bertodo 1991, Ellison, Clark, Fujimoto and Hyun 1995, Liker, Kamath, Wasti and Nagamachi 1995, Dyer 1996b).

Yet, even when a corporation builds a close relationship with its partners, outsourcing always involves certain risks. Clark and Fujimoto (1991) pointed to major risks of the black-box system. Automakers dependent on suppliers' engineering capabilities may lose some negotiation power (Pfeffer and Salancik 1978, Porter 1980). Basic design and styling ideas may leak to competitors through shared suppliers. Losing engineering expertise in core component areas can render the firm vulnerable in technological capability over the long term.

At the center of this dilemma lies the issue of how to manage *knowledge* in outsourcing. Fine and Whitney (1996) and Fine (1998) identified two categories of dependency: *dependency for capacity* and *dependency for knowledge*. In the former case, the company presumably can make the item in question and may indeed already do so, but for reasons of time, money, space or management attention, chooses to extend its capacity by means of a supplier. In the latter case, the company presumably needs the item but lacks the skill to make it, and thus seeks an expert to fill the gap. The risk of being dependent for both capacity and knowledge is particularly high if the product architecture is integral (Urich 1995), such as in automobiles. In the case of a product with a modular architecture, it can typically be decomposed into subsystems that are nearly independent with one another and easy to outsource since one doesn't need extensive communication and coordination (Baldwin and Clark 1997). In the case of an integral product, however, when one doesn't know what one is buying or how to integrate it, the results could be failure since one will spend so much time on reworking and rethinking.

Fine and Whitney (1996) therefore argued that the firm should retain knowledge to avoid such risks. They described Toyota as an example of a company that is very conscious of the risk of outsourcing. Toyota has historically been dependent on its affiliated supplier, Denso, for knowledge about electronic subsystems. As electronics become more critical for vehicle development, however, the company has moved to develop electronic subsystems internally to regain knowledge of them, while continuing to outsource the subsystems to Denso and other suppliers. It is knowledge, not capacity, that determines the degree of risks in outsourcing.

Their argument implies that we should distinguish *knowledge partitioning* from *task partitioning* between firms. von Hippel (1989) pointed out the importance of task partitioning in innovation, that is, how an innovation project is divided into tasks and subtasks that can then be distributed among a number of individuals and perhaps among a number of firms. Task partitioning generally affects the costs of problem-solvers' efforts to achieve communication and coordination across task boundaries, thus influencing the efficiency and effectiveness of the innovation project. While von Hippel (1989) emphasized the structure of task, Fine and Whitney (1996) pointed to the importance of knowledge. To paraphrase Fine and Whitney's (1996) claim, firms need to consider not only how to partition tasks and distribute them among firms, but also how to partition sets of required knowledge and distribute them among firms to reduce potential risks of outsourcing and improve the efficiency and effectiveness of the innovation project. For example, when a firm divides one innovation project into two tasks and outsources one to a supplier, it may be important for the firm to keep the knowledge for the outsourced task within the organization, rather than outsourcing the knowledge together with the task. Attention to the difference between "what the firm does" and "what the firm knows" was also emphasized recently by Brusoni and Prencipe (forthcoming). Their case studies of aircraft engines and chemical plants showed that system integrators (buyers) covered a wider range of technological knowledge than that of activities performed in-house.

Previously, many researchers analyzed supplier relations and management in the auto industry (for example, Womack, Jones and Roos 1990, Clark and Fujimoto 1991, Cusumano and Takeishi 1991, Helper 1991, Nishiguchi 1994, Dyer 1996a, to name a few). However, their focus has primarily been on task partitioning (automakers could benefit from having suppliers carry out more engineering), inter-firm relations (automakers could benefit from establishing long-term, collaborative relationships with suppliers), or management of task coordination (automakers should communicate more frequently and solve problems more effectively with suppliers). Few researchers explicitly stressed the importance of knowledge (Liker, Kamath, Wasti and Nagamachi 1995, Fine and Whitney 1996), and their research has remained rather conceptual or descriptive. Empirical analysis of the linkage between knowledge and competitiveness has yet to be explored.

Special attention to the role and management of knowledge for outsourcing echoes with growing interests in knowledge in current management research. Penrose (1959) pointed out the importance of knowledge to understand the firm. Viewing the firm as a repository of knowledge and experience, she argued, in essence, that knowledge is the critical factor to explain the growth of individual firms. More recently, several researchers have argued that the existence and boundaries of the firm could be explained by the organization's advantage over the market to coordinate, combine, and integrate a variety of specialized knowledge, independent of transaction and monitoring costs (Demsetz 1991, Kogut and Zander 1992, 1996, Conner and Prahalad 1996, Grant 1996). Demsetz (1991) argued that firms exist because they can create conditions under which multiple individuals can use and integrate their special knowledge efficiently without undermining gains from specialized learning, and their vertical boundaries are determined by the economies of conservation of expenditures on knowledge. This is an attempt to build the theory of the firm, without assuming opportunism, by focusing on knowledge, although the debates still continue (Conner and Prahalad 1996, Foss 1996a, 1996b, Kogut and Zander 1996).

Building on the previous empirical and theoretical research on knowledge and outsourcing, this paper probes into the management of knowledge for outsourcing in the following sections. Specifically, I empirically examine Fine and Whitney's argument that a buyer's knowledge is critical for managing outsourcing in the context of the automobile industry. The question is *whether an automaker's knowledge is indeed important to achieve a better outcome from outsourcing the task of component development to a supplier*. And, if so, the second question is *how some automakers could know more about a component than others while outsourcing the task of component development*. These questions address whether and how knowledge could be a source of competitive advantage. They also address the knowledge-based theory of the firm by examining the boundary of knowledge the firm should cover to be competitive. The subsequent two sections deal with the two questions, respectively. [1]

IMPORTANCE OF KNOWLEDGE IN OUTSOURCING

Research Setting and Data

In this section, I analyze the importance of automakers' knowledge in managing suppliers' involvement in product development. In the practice of the black-box system (Clark and Fujimoto 1991), as described above, actual tasks of detailed design of individual components are carried out by outside suppliers based on the customer's requirements. The degree to which an automaker retains relevant knowledge for developing the component, however, varies by company. Liker, Kamath, Wasti and Nagamachi's (1995) survey reported that about 22 percent of U.S. subsystem suppliers complained that their customers lacked technical knowledge. About 9 percent of the Japanese suppliers made this complaint, and only about 5 percent of Toyota's suppliers mentioned such a complaint.

Component development projects with the black-box approach therefore provide an interesting research setting to examine the relationships between knowledge partitioning and the effectiveness of outsourcing management. Also, the automobile serves as an appropriate example, since its product architecture is relatively integral, rather than modular (Ulrich 1995). In the latter architecture, the buyer's knowledge is less likely to play an important role to have suppliers design good components (Fine and Whitney 1996).[2] Below, I examine if the level of an automaker's knowledge about a component is related to the output quality of component development design carried out by a supplier, based on quantitative data analysis.

A primary data source was a questionnaire survey to Japanese suppliers. The purpose of the supplier survey was to collect data on automakers' knowledge level, their patterns of supplier management, and component development performance, as observed by suppliers with multiple customers.[3] Each supplier was asked to select one component development project that was recently done for a new vehicle using the black-box approach, for each of its major customers. Those suppliers were a preferable data source to measure the level of each automaker's knowledge since they could comparatively observe their customers through everyday interactions. It should be noted, however, that the cases selected by the suppliers do not reflect a random sample, but may represent either "best practices" or cases for which the respondents had sufficient information to answer the questionnaire.

The survey was filled in by the person who was actually in charge of, and most familiar with, the selected development project, such as the Chief Engineer for the project. The final responses are presented in Table 1. Nine suppliers participated in the survey. Each supplier gave five cases on average, providing 45 cases in total.

**** INSERT TABLE 1 ABOUT HERE ****

I also conducted interviews both before and after the survey. The preliminary interviews were conducted to design the survey, and follow-up interviews to supplement the survey data and further probe into the background behind the survey results. More than 100 managers and engineers at both automakers and suppliers were interviewed.[4]

Variables

Derived from the survey data, I constructed variables to be used in the following statistical analysis. Details of variable construction and measurement are shown in Appendix 2. Each variable is briefly described below.

Dependent variable

CDQ (component design quality) is this study's dependent variable. It measures the design quality of the developed component (output performance), based on multiple items, including performance, cost, conformance quality and structural and functional coordination with other components[5]. Each item was evaluated by the respondent in terms of his/her satisfaction with the outcome, and the relative position in comparison with the same type of component used for competing vehicle models in the market, to capture both engineering excellence and market competitiveness.

Independent variable: Knowledge

The level of engineers' knowledge about the component is the key independent variable. Eighteen elements of knowledge that automakers' engineers are expected to have were identified through my preliminary interviews with automakers and suppliers. For each element, the respondent was asked how much the automaker's engineers, with whom he/she worked for the project, knew about the component. To aggregate these elements, I conducted a Principal Component Analysis. The analysis identified two sets of elements.[6] One set is composed of elements of knowledge about the component itself, including technology, cost, and manufacturing process. The other consists of elements of knowledge about structural and functional coordination with other components and design for manufacturing.

These two sets were derived from practitioners' views and empirical data, but they are very consistent with the dimension of knowledge proposed by Henderson and Clark (1991): component knowledge and architectural knowledge. The former is knowledge about a particular component in a system, and the latter about the way in which components are integrated and linked together into a coherent whole. In this study, therefore, I constructed two variables from the two sets of elements, and named them as **EKN1** (engineers' component-specific knowledge) and **EKN2** (engineers' architectural knowledge).[7] **EKN** (engineers' knowledge) is the mean of those two variables, thus indicating the level of total knowledge of the automakers' engineers to develop the component for vehicles. There are other dimensions of knowledge. One of them is tacit versus explicit (Polanyi 1966), which many scholars have considered critical. The implications of this study's results for the tacit/explicit dimension will be discussed in the final section.

Other independent variables

In addition to knowledge, there are some other factors that are likely to have an impact on the performance of component development projects. One area is the management of interaction between an automaker and a supplier during the project, including a problem-solving pattern and communication. Problem solving in a manner that integrates across different functions from the early stages has been identified as critical for effective product development (Clark and Fujimoto 1991, Iansiti 1998). **PSP** (problem-solving pattern) measures the level of early, integrated problem-solving processes with a supplier. This variable scores high when, for example, the supplier's initial price/cost estimate was examined very carefully by the automaker from the beginning of the project, and the automaker examined the supplier's manufacturing process and design for manufacturing at the earlier stage. Communication is another important factor for effective product development (Allen 1977, Ancona and Caldwell 1992, Brown and Eisenhardt 1995). **COM** (communication frequency) measures the frequency (in days per year) of mutual visits by the automaker's engineers and purchasing staff and the supplier's engineers and sales staff.

The nature of relationships between the automaker and the supplier might also affect component design quality. Two variables were constructed. **SLD** (the supplier's sales dependency on the automaker) measures the supplier's sales dependency on the automaker. **STK** (the automaker's ownership of the supplier's stock) is a dummy variable set to 1 if the automaker owned a part of the supplier's stock; otherwise 0.

In addition, two variables were constructed to control for task nature and engineering tools. **NWT** (technological newness of the project) is set to 1 if the supplier used a new technology in the component or its manufacturing process for the project; otherwise 0. **CMP** (computer system usage) measures the degree to which threedimensional CAD (Computer-Aided Design) and CAE (Computer-Aided Engineering) were used in the project.

Note that the performance of component development is likely to be affected by the level of supplier's capability. Also, the relationships between the performance and independent variables might be mediated by the type of components in question. In order to control for those factors, the score of every variable used in the following analysis was transformed by mean centering within each respondent supplier. The mean was removed, as shown below, by taking the difference from the mean. This transformation neutralizes supplier and component heterogeneity.[8]

$$X^*_{ij} = X_{ij} - \overline{X_j}$$

where

X^*_{ij} = the transformed score of indicator X by supplier j about the project with automaker i

X_{ij} = the original score of indicator X by supplier j about the project with automaker i

$\overline{X}_j$ = the mean score of indicator X by supplier j

Analysis: Knowledge and Outsourcing Performance

Table 2 shows the regression results for CDQ. Model (1) includes all the independent variables other than that for knowledge. The result shows that an integrated problem-solving pattern (PSP) and communication frequency (COM) both have a significant effect on CDQ, implying that management of interaction with the supplier is critical. A supplier's sales dependency on the automaker (SLD) has a positive and statistically significant coefficient. A higher sales dependency on the automaker would motivate the supplier to make more extensive efforts to satisfy that important customer, for example, by assigning more capable engineers to the project.

**** INSERT TABLE 2 ABOUT HERE ****

Model (2) adds the key research variable, EKN (engineers' knowledge). The result basically indicates that engineers' knowledge plays a significant role in gaining a better component design. Model (3) estimates the effect of sub-components of EKN. It turned out that engineers' architectural knowledge (EKN2) has a larger effect on CDQ than component-specific knowledge (EKN1). EKN1's coefficient is not statistically significant at the 10% level, and its standardized coefficient (beta) is 50% smaller than EKN2's.

Further analysis has uncovered a vital role of engineers' knowledge when a project involves new technology. Model (4) adds the interaction term of NWT and EKN to Model (2). While NWT has a negative sign, the interaction term has a positive sign. A change in R^2 from Model (2) to (4) is statistically significant at the 5% level. This seems to indicate that, while it is difficult to develop technologically new components, engineers' knowledge plays an important role to improve CDQ in such cases. It is even more interesting to observe in Model (5) that the magnitude of the interaction coefficient is larger for component-specific knowledge than for architectural knowledge. Again, a change in R^2 from Model (3) is statistically significant at the 5% level. This seems to indicate that engineers' component-specific knowledge has a more positive effect than architectural knowledge in the case of using new technology.[9]

Overall, the results support that having a higher level of knowledge is important for automakers to manage supplier involvement in product development.

Certainly task and knowledge are closely related and come together, as will be discussed soon. However, although the actual task of designing components was outsourced to suppliers, there was heterogeneity in the automakers' knowledge level and the difference had a significant effect on the performance of the outsourced project. The results imply that knowledge could and should be partitioned and managed separately from tasks.

Between the two types of knowledge, architectural knowledge seems to be more important than component-specific knowledge. If we understand that component-specific knowledge is provided by the supplier, who is involved in the project because of its expertise in the specific component, then a more critical role for architectural knowledge, which is supposed to be the automaker's domain and beyond the supplier's reach, would be a natural consequence. This finding is consistent with the following comment from my interviews:

> Sometimes a component developed for one automaker is better than for another. One reason is the difference in their level of knowledge of component coordination. A good component needs effective coordination, which is not the area of suppliers' expertise, but automakers' (supplier sales manager).

Yet, when we distinguished technologically new projects from regular ones, it turned out that effective partitioning of knowledge is different between them. For regular projects, only architectural knowledge needs to be covered by automakers. For innovative projects, however, component-specific knowledge is more critical to gain a higher CDQ. If an automaker wants to introduce vehicles with new component technologies ahead of competitors, it is important that its engineers have a high level of component-specific knowledge. The following comment supports this finding:

> Automaker X has recently changed their policy and has us involved in component development to a greater degree. They rely on us for designing the component and we have tried to satisfy their expectation. However, one big difference between this automaker and some other leading ones lies in the capability to evaluate the component. Automaker X seems to lack some knowledge and cannot deal with the state-of-the-art technology of our component. Inevitably this automaker has always lagged behind other leading automakers in installing technologically new components (supplier sales manager).

KNOWLEDGE MANAGEMENT

The foregoing findings raise a further critical question for managers: Given the importance of knowledge, how could some automakers create and maintain a higher level of knowledge than others? This question is addressed in this section.

Maintaining *knowledge advantage* over competitors is by no means an easy challenge particularly when the related tasks are outsourced to suppliers. First, knowledge is very often obtained through doing things (learning by doing). When the actual tasks of detailed design are carried out by outside suppliers, automakers miss substantial opportunities to gain relevant knowledge. Table 3 provides evidence, compiled from another set of our recent questionnaire survey with Japanese suppliers. It shows that as more tasks of engineering are shifted to suppliers, from the detail-controlled system to the black-box system, the level of automakers' knowledge tends to decline. This tendency was also witnessed in the following interview comment:

> In the past we shifted design responsibilities of some components to suppliers. We generally came up with some very good designs for a few years, immediately after suppliers got involved in component design. However, as our engineers' knowledge about the component faded away, the design quality seemed to fail to improve as expected. I think that we can achieve better designs when both the supplier and our engineers have extensive knowledge (automaker engineer).

Particularly, with task shifting, automakers lose component-specific knowledge to a larger degree than architectural, as shown in Table 3. This is not surprising. Whereas the task of detailed component design is outsourced, that of coordination largely remains the automaker's responsibility. More intriguing is the observation that automakers nevertheless lose architectural knowledge, too, with task shifting. This is probably because some portion of architectural knowledge is intertwined with component-specific knowledge in the case of such integral products as the automobile. As suppliers take more responsibility for component design, some of architectural knowledge also shifts away to them.

**** INSERT TABLE 3 ABOUT HERE ****

Second, even if an automaker has a high level of knowledge, it may be diffused to competitors through shared suppliers. According to my interviews, some suppliers intentionally transfer technological and managerial information from one automaker to another, and some automakers try to learn new technology and effective practices from others through the common suppliers.[10]

When we recognize the inherent difficulty to keep the knowledge advantage while outsourcing actual tasks to shared suppliers, it is intriguing to find in the data set analyzed in the previous section that some automakers had a higher knowledge level than others although they all outsourced to the same supplier. What mechanisms lie behind better management of knowledge at some automakers? This question is particularly interesting from the viewpoint of strategy research, which has been concerned with the inimitability of competitive advantage. My follow-up interviews and an additional questionnaire survey with automakers have hinted at the following answers.

One approach to enhance architectural knowledge is to rotate individual engineers across different types of components over time. Through hands-on experience in designing other related components or in managing supplier involvement for them, individual engineers could obtain a high level of architectural knowledge and coordinate effectively with other engineers. It has been reported that in Japanese companies, engineers are more frequently transferred across different functional areas than in the U.S (Aoki 1990, Lynn, Piehler and Kieler 1993). This difference was sometimes attributed to the better capability of internal coordination in the innovation process (Nonaka and Takeuchi 1995, Kusunoki and Numagami 1997).

Figure 1 exhibits career patterns of Japanese automakers' engineers. This is based on my questionnaire survey with eight automakers in Japan, which was carried out in summer, 1997. Eight types of components were specified and individual engineers in charge of those components at each automaker were asked how long he/she had been involved in engineering those and other types of components over his/her career. The figure plots the number of years of experience in designing components by individual respondent engineers. The vertical axis measures the number of years for engineering the particular component specified. The horizontal axis measures the number of years for engineering any type of component. In this scatter plot, when engineers tended to stay with the same component for the duration of their work at the firm (engineers as specialists), we observe most cases closer to the diagonal. If engineers tended to change their assignments over time (engineers as generalists), in contrast, cases are found closer to the horizontal axis.

**** INSERT FIGURE 1 ABOUT HERE ****

Due to small sample size (8 for each automaker, 63 in total), it is difficult to find distinctive patterns among automakers. Yet, my observation of this plot and interviews with each automaker together seem to suggest some differences in policies on engineer rotation. While some automakers such as Companies C and G rotated their engineers relatively frequently (few engineers stay with the same component more than seven to ten years), others such as Companies A and F had their engineers devoted to a particular component for many years.

Why is it that the latter automakers did not rotate their engineers more frequently in order to improve their architectural knowledge? According to my interviews, automakers cannot promote individual engineers' broader experiences too much. Rotating individual engineers across many components quickly may impede their accumulation of component-specific knowledge. In fact, an estimated correlation coefficient between EKN1 (engineers' component knowledge) and EKN2 (engineers' architectural knowledge), -0.152 (p=.320), indicates a slight, though not statistically significant, trade-off between the two types of knowledge. Many automakers recognized the importance of rotating engineers but could not implement such a policy consistently because functional managers did not want to have their experienced engineers transferred to other areas of components. To lose experienced engineers would lead to lower efficiency and poor output quality. It is not easy for automakers' engineers to have a high score for the both types of knowledge.

However, there is an automaker whose engineers scored higher for both architectural and component-specific knowledge on average, as shown in Table 4 (Items

1, 2, and 3). To investigate how this automaker (A3) could manage knowledge better than others, I analyzed the automaker questionnaire survey mentioned above, as well as interviews with engineering people at automakers. The results, which are summarized in Table 4, indicate that this automaker took the following approach.

This firm had a definite policy of rotating engineers across different components over a certain period of time, which helped their engineers build architectural knowledge through hands-on experience. Note that this policy was implemented rather strictly — those engineers who had never been rotated across different engineering functions were not eligible for promotion to managers, with the exception of those who chose to be a specialist (see below). Such strict implementation was necessary to overcome functional managers' protests to rotation policy.[11] At other automakers such protests were more tenacious and the rotation of engineers was implemented in an inconsistent or ad hoc manner, according to my interviews. This difference can be confirmed by the automaker questionnaire survey, mentioned above. Eight engineers from each automaker were asked whether they had experience in designing any component that was structurally or functionally related to the component currently assigned. All the respondents of this automaker (A3) answered yes. Some engineers of other automakers, for example, 50% of the respondents from A4, did not have such an experience (see Table 4, Item 4).

**** INSERT TABLE 4 ABOUT HERE ****

While providing individual engineers with opportunities to gain architectural knowledge through their career path, this automaker established other mechanisms to improve and maintain component-specific knowledge. First, the range of rotation was limited. Engineers in the chassis design division, for example, were transferred usually within the same division and rarely to other divisions, such as the engine or body design division. Component-specific knowledge obtained in previous assignments hence remained somewhat relevant for a newly assigned component.

Second, this firm recently introduced a new career path in which individual engineers had the choice to stay with the same component over a very long period of time as a specialist. Before this policy was introduced, opportunities for promotion at this company opened up only for those who had been rotated across different functions. The new policy provided engineers with two different paths for promotion, and encouraged two types of knowledge within the organization. Such dual career paths were not available at other automakers (see Table 4, Item 8).

Third, this automaker attempted to accumulate component-specific knowledge through design standards and know-how reports. As Aoshima (1996) and Cusumano and Nobeoka (1998) showed, archival-based mechanisms are effective in retaining component-specific knowledge. When engineers were assigned to a new component, they could refer to those written documents prepared by their predecessors as a source of component-specific knowledge and could also take internal training classes for the component. Such training classes were not offered at other automakers (see Table 4, Item 7). When I asked A1 how their engineers usually acquired engineering knowledge after being assigned to a new component, the answer was, “They learn from suppliers.” Such an approach does not seem to allow individual engineers to gain enough knowledge to evaluate and manage suppliers.

Forth, at A3, individual engineers were evaluated by their superiors in terms of their contribution to advancing component-specific technologies, rather than achieving good coordination with other components for a particular vehicle development project. According to my questionnaire survey and interviews with automakers, this automaker, in sharp contrast with others, put heavy emphasis on individual component technologies rather than on the final products (vehicles) in the incentive structure, thus motivating engineers to deepen their component-specific knowledge. One reason for this incentive scheme is that it is generally more difficult for superiors to evaluate individual engineers' contributions to a vehicle than to a component. As shown, again, in Table 4 (Item 6), the incentive weight allocated to component-specific contribution was highest at this automaker.

Other automakers could not emphasize component-specific contributions too much. It may encourage engineers to disregard architectural knowledge. Such risk was overcome at A3 by strict rotation policy. Also important were strong and capable product managers, who were in charge of coordinating problems across engineering functions and integrating components into a vehicle toward his/her own product concept (the so-called Heavyweight Product Manager (Clark and Fujimoto 1991)). At this automaker, they played an important role to bind individual engineers into a coherent project team. Table 4 (Item 5) shows that the relative power of product manager over functional manger was strongest at this automaker, according to the automaker survey.

By combining those organizational mechanisms, this automaker seems to have been able to enhance both architectural and component-specific knowledge. Individual mechanisms identified above seem relatively simple and straightforward. They do not require unique devices or special investment. However, engineering rotation with long-term consistency calls for strict implementation to overcome objections from functional managers. Also, accumulating component knowledge constantly and transforming it into explicit information to be passed on to colleagues requires the everyday effort of individual engineers. When individual engineers are immersed with problem solving for current projects under extensive time pressure, such activities are often given lower priority and easily ignored. Even more difficult is to put these mechanisms together in a systematic and complementary manner to improve two types of knowledge, which are trading off each other.

It is these obstacles and difficulties that seemed to prevent other automakers from catching up A3 in knowledge management for outsourcing. Only with extensive internal efforts can automakers somehow maintain an advantage over competitors in both architectural and component-specific knowledge, when the tasks of component engineering are outsourced to shared suppliers.

It is important to note that the investigation above on how to acquire knowledge without doing tasks has still remained obscure. Organizational mechanisms identified at A3 are supposed to motivate and help engineers to gain and transfer knowledge. Incentive schemes and supporting systems for knowledge development, transfer, and maintenance within the firm are certainly important. But the mechanisms by which individual engineers could acquire the knowledge without performing the tasks by themselves are not fully explained yet. My follow-up interviews suggest some means, such as more questioning the supplier by the automaker's engineers, some shadow engineering on the automaker's side (doing some tasks partially by themselves), and motivating suppliers to display their technologies more openly by solving problems together and by establishing mutual trust. Yet these findings are still very sketchy, and more investigation is needed.

CONCLUSION

This paper has demonstrated the importance of knowledge for effective outsourcing. While the actual tasks of designing and manufacturing components could be outsourced, the relevant knowledge should be retained internally to gain higher quality component design. Automakers should distinguish knowledge partitioning from task partitioning, as argued by Fine and Whitney (1996) and Fine (1998), and need careful management of knowledge.

The results indicate that an effective pattern of knowledge partitioning differs according to the nature of component development projects in terms of technological newness (Table 5). For regular projects, architectural knowledge is more important than component-specific knowledge. This is probably because the latter type of knowledge is supposed to be provided by the supplier, who specializes in the component. Knowledge could thus be partitioned efficiently between an automaker and a supplier based on the specialty of each party.

**** INSERT TABLE 5 ABOUT HERE ****

However, when the project involves new technologies, it is important for the automaker to have a higher level of component-specific knowledge to solve unexplored engineering problems together with the supplier. What automakers should know varies according to the nature of projects. Also, although this study cannot provide empirical evidence, my interviews suggest that for projects involving new technologies, a supplier also needed a higher level of architectural knowledge to solve problems jointly with an automaker. Building up architectural knowledge about the component — knowledge about how the component should be integrated for a particular vehicle — was recognized as a critical success factor for suppliers to win design competitions. In innovative projects, these findings imply that effective knowledge partitioning seems to demand some overlap between an automaker and a supplier, rather than efficient and clear-cut boundaries. As Nonaka (1990) pointed out, the innovation process may often require redundancy and overlapping in organizational structure and processes.

Of course, some automakers could choose to follow other automakers' leadership in component technologies due to limited capabilities or by strategic choice. They could rely on suppliers' expertise and focus on, for example, frequent communication and integrated problem solving with suppliers to obtain a better component design within the existing technologies. They could focus on architectural knowledge, not so much on component-specific knowledge, and pour the resources thereby saved into other strategic purposes. But for those automakers that want to be a leader in both technological race and regular component design, effective management of both types of knowledge is critical. The problem is that component-specific knowledge is important only for limited cases (innovative projects). Even worse, component-specific knowledge trades off with architectural knowledge, which is more important for regular projects.

The difficulty and dilemma of managing two types of knowledge while outsourcing the actual tasks, however, give an automaker like A3 the chance to achieve an inimitable competitive advantage, if it could somehow manage knowledge effectively through organizational mechanisms. Endeavor of knowledge management provides a firm with an opportunity to survive and prosper. As described above, the approach taken by the automaker indicates that effective knowledge management involves a wide range of organizational mechanisms, including career development policies, extensive documentation of technological information, internal training programs, and incentive schemes. The difficulty in implementing these mechanisms in a consistent and complementary manner seems to explain, at least partially, why there is a significant variance among automakers in knowledge level. Such organizational mechanisms could be an important source of competitive advantage for automakers even when they outsource substantial tasks of engineering to shared suppliers.

What do these findings imply for the knowledge-based theory of the firm? The results imply that the boundaries of knowledge the firm should cover need to be distinguished from those of tasks, though they are related to each other very closely. Or, as Brusoni and Prencipe (forthcoming) state, "the knowledge boundaries of the firm fundamentally differ from the boundaries of the firm as defined by make-buy decisions."

The finding that architectural knowledge, that is, knowledge about linking components into a coherent whole, matters more than component-specific knowledge in regular projects is consistent with the argument that the firm exists because it combines, coordinates, and integrates different kinds of specialized knowledge with organizational mechanisms rather than market transactions. Architectural knowledge is more context-specific (optimizing component design for a specific vehicle model), and thus more tacit in nature. Tacit knowledge doesn't suit market transactions well. Architectural knowledge, therefore, could be the raison d'être of automakers and a source of their competitive advantages. On the other hand, automakers may not need to internalize component-specific knowledge, which is more explicit.

Yet, such an argument isn't valid for the projects involving new technologies, for which component-specific knowledge is critical. This is because component-specific knowledge is not established and articulated during the project since it is new for everyone. An automaker needs to know more about the component to solve the types of problems that it has never had together with a supplier. The product has yet to be established, and thus cannot substitute for knowledge (Demestz 1991). Once the project is done, and the new technology and knowledge are materialized into the physical component, however, the component-specific knowledge loses its value for the automaker's competitive advantage in subsequent projects. The knowledge becomes more explicit and is easily diffused among competitors through the shared supplier and reverse-engineering of the component. Thus, while the firm boundaries of task (task partitioning) are the same, the boundaries of knowledge to be covered by automakers (knowledge partitioning) change according to the nature of the project, like an ebb (regular projects) and flow (innovative projects). It is such "fluid" boundaries of knowledge and the difficulty of managing them that seem to pose a challenge for those firms seeking both leadership in innovation and efficiency in established products.

While this study provides the foregoing insights, we need further research to deepen our understanding of effective management of knowledge in the inter-firm division of labor. Three issues are particularly important. First, the importance of knowledge and effective patterns of knowledge partitioning may depend upon the design architecture of the product (Ulrich 1995, Fine 1998). As mentioned earlier, the automobile is a product with relatively integral architecture. In more modular products, one could hypothesize that the buyer does not need extensive knowledge management since their components are more independent from others and their interfaces are more manageable and often standardized. Yet, interestingly, Brusoni and Prencipe (forthcoming) show that even in modular products the buyer's knowledge does matter very much. We need to build more empirical, wide-ranging studies of products with different architectures.

Second, this study's evidence on organizational mechanisms for effective knowledge management remains somewhat anecdotal. It seems fruitful to explore more cases in different industries and settings with more systematic data and analysis in order to understand organizational mechanisms for effective knowledge management for outsourcing. For instance, products with rapidly changing technologies may require different organizational mechanisms for knowledge management. Also, as mentioned before, more investigation is needed on mechanisms of acquiring knowledge without performing the related tasks.

Third, we should examine the relationships between task boundaries and knowledge boundaries. In this study, the task boundaries were given (the decision to outsource actual component design had already been made). Although knowledge boundaries and task boundaries are different and have their own logic for decision-making, they are closely related and the decisions involving them should be made with special attention to their relationships. Doing the tasks provides major opportunities of gaining relevant knowledge. Gaining more general and abstract knowledge, on the other hand, would facilitate the division of labor (Arora and Gambardella 1994). Analysis of the relationships between the two types of boundaries and their dynamic interactions is of great value both practically and theoretically.

Further research in these directions should make contributions to our understanding of knowledge management for effective outsourcing as well as for the existence, boundaries, and competitiveness of the firm.

REFERENCES

Allen, Thomas J. (1977). *Managing the Flow of Technology*. Cambridge, MA: MIT Press.

Ancona, Deborah G. and David F. Caldwell (1992). "Bridging the Boundary: External Process and Performance in Organizational Teams." *Administrative Science Quarterly* 37:634-665.

Aoki, Masahiko (1990). "Toward an Economic Model of the Japanese Firm." *Journal of Economic Literature* XXVIII (March):1-27.

Aoshima, Yaichi (1996). "Knowledge Transfer across Generations: The Impact on Product Development Performance in the Automobile Industry." Unpublished Ph.D. Dissertation, Sloan School of Management, MIT.

Arora, Ashish and Alfonso Gambardella (1994). "The Changing Technology of Technological Change: General and Abstract Knowledge and the Division of Innovative Labour." *Research Policy* 23: 523-532.

Bertodo, R. (1991). "The Role of Suppliers in Implementing a Strategic Vision." *Long Range Planning* 24 (3):40-48.

Baldwin, Carliss Y. and Kim B. Clark (1997). "Managing in an Age of Modularity." *Harvard Business Review* (September-October): 84-93.

Brusoni, Stefano and Andrea Prencipe (forthcoming). "Unpacking the Black Box of Modularity: Technologies, Products, and Organizations." *Industrial and Corporate Change*.

Brown, Shona L. and Kathleen M. Eisenhardt (1995). "Product Development: Past Research, Present Findings, and Future Directions." *Academy of Management Review* 20 (2):343-378.

Clark, Kim B. (1989). "Project Scope and Project Performance: The Effect of Parts Strategy and Supplier Involvement on Product Development." *Management Science* 35 (10):1247-1263.

Clark, Kim B. and Takahiro Fujimoto (1991). *Product Development Performance: Strategy, Organization, and Management in the World Auto Industry*. Boston, MA: Harvard Business School Press.

Conner, Kathleen R. and C. K. Prahalad (1996). "A Resource-based Theory of the Firm: Knowledge Versus Opportunism." *Organization Science* 7(5): 477-501.

Cusumano, Michael A. and Kentaro Nobeoka (1998). *Thinking beyond Lean: How Multi-Project Mananagement is Transforming Product Development at Toyota and Other Companies*. New York, NY: Free Press.

Cusumano, Michael A. and Akira Takeishi (1991). "Supplier Relations and Management: A Survey of Japanese, Japanese-Transplant, and U.S. Auto Plants." *Strategic Management Journal* 12 (8):563-588.

Demsetz, Harold (1991)."The Theory of the Firm Revisited." In Oliver E. Williamson and Sidney G. Winter (eds.), *The Nature of the Firm : Origins, Evolution, and Development*. NY: Oxford University Press, pp. 159-178.

Dertouzos, Michael L., Richard K. Lester, Robert M. Solow, and The MIT Commission on Industrial Productivity (1989). *Made in America: Regaining the Productivity Edge*. Cambridge, MA: MIT Press.

Dyer, Jeffrey H. (1996a). "Specialized Supplier Networks as a Source of Competitive Advantage: Evidence from the Auto Industry." *Strategic Management Journal* 17 (4):271-291.
Dyer, Jeffrey H. (1996b). "How Chrysler Created an American Keiretsu." *Harvard Business Review* 74 (4):42-56.
Dyer, Jeffrey H. and Harbir Singh (1998). "The Relational View: Cooperative Strategy and Sources of Interorganizational Competitive Advantage." *Academy of Management Review* 23 (4): 660-679.
Ellison, David J., Kim B. Clark, Takahiro Fujimoto, and Young-suk Hyun (1995). "Product Development Performance in the Auto Industry: 1990s Update." Working Paper 95-066, Harvard Business School.
Fine, Charles H. (1998). *Clockspeed: Winning Industry Control in the Age of Temporary Advantage*. Reading, MA: Perseus Books.
Fine, Charles H. and Daniel E. Whitney (1996). "Is the Make-Buy Decision Process a Core Competence?" Paper submitted to MIT IMVP Sponsors' Meeting in Sao Paulo, Brazil.
Foss, Nicolai J. (1996a). "Knowledge-based Approaches to the Theory of the Firm: Some Critical Comments." *Organization Science* 7(5): 470-476.
Foss, Nicolai J. (1996b). "More Critical Comments on Knowledge-based Theories of the Firm." *Organization Science* 7(5): 519-523.
Fujimoto, Takahiro, Takashi Matsuo and Akira Takeishi (1999). "Diffusion and Changes of Automobile Parts Procurement Practices: A Report on a Questionnaire Survey for Japanese First-tier Parts Suppliers (in Japanese)." Tokyo University, Faculty of Economics. Discussion Paper CIRJE-J-17.
Grant, Robert M. (1996). "Toward a Knowledge-based Theory of the Firm." *Strategic Management Journal* 17:109-122.
Helper, Susan (1991a). "Strategy and Irreversibility in Supplier Relations: The Case of the U.S. Automobile Industry." *Business History Review* 65 (Winter):781-824.
Henderson, Rebecca M. and Kim B. Clark (1990). "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms." *Administrative Science Quarterly* 35 (1):9-30.
IRC (1994). *Automotive Parts Sourcing in Japan*. (in Japanese) Nagoya, Japan: IRC.
Iansiti, Marco (1998). *Technology Integration: Making Critical Choices in a Dynamic World*. Boston, MA: Harvard Business School Press.
Jarillo, J. Carlos (1988). "On Strategic Networks." *Strategic Management Journal* 9:31-41.
Johnston, Russell and Paul R. Lawrence (1988). "Beyond Vertical Integration — the Rise of the Value-Adding Partnership." *Harvard Business Review* 66 (4):94-101.
Kanter, Rosabeth Moss and Paul S. Myers (1991). "Interorganizational Bonds and Intraorganizational Behavior: How Alliances and Partnerships Change the Organizations Forming Them." In Amitai Etzioni and Paul R. Lawrence (eds.), *Socio-Economics: Toward a New Synthesis*. Armonk, NY: M.E. Sharpe, pp.329-344.
Kogut, Bruce and Udo Zander (1992). "Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology." *Organization Science* 3(3): 383-397.
Kogut, Bruce and Udo Zander (1996). "What Firms Do? Coordination, Identity, and

Learning." *Organization Science* 7(5): 502-518.
Kusunoki, Ken and Tsuyoshi Numagami (1997). "Intrafirm Transfers of Engineers in Japan." In Akira Goto and Hiroyuki Odagiri (eds.), *Innovation in Japan*. Oxford, U.K.: Oxford University Press, pp. 173-203.
Liker, Jeffrey K., Rajan R. Kamath, S. Nazli Wasti, and Mitsuo Nagamachi (1995). "Integrating Suppliers into Fast-Cycle Product Development." In Jeffrey K. Liker, John E. Ettlie, and John C. Cambell (eds.), *Engineered in Japan*. New York, NY: Oxford University Press, pp. 152-191.
Lynn, Leonard H., Henry R. Piehler, and Mark Kieler (1993). "Engineering Careers, Job Rotation, and Gatekeepers in Japan and the United States." *Journal of Engineering and Technology Management* 10 (1&2):53-72.
Miles, Reymond E. and Charles C. Snow (1984). "Fit, Failure and the Hall of the Fame." *California Management Review* 26 (3):10-28.
Misawa, Kazufumi and Ken-ichi Hattori (1998). "R&D Outsourcing to Create Core Competence (in Japanese)."*Kenkyu Kaihatsu Manejimento [R&D Management]* 8(6): 4-12.
Nishiguchi, Toshihiro (1994). *Strategic Industrial Sourcing: The Japanese Advantage*. New York, NY: Oxford University Press.
Nonaka, Ikujiro (1990). "Redundant, Overlapping Organization: A Japanese Approach to Managing the Innovation Process." *California Management Review* 32(3): 27-38.
Nonaka, Ikujiro and Hirotaka Takeuchi (1995). *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation*. Oxford, U.K.: Oxford University Press.
Penrose, Edith T. (1959). *The Theory of the Growth of the Firm*. Oxford: Basil Blackwell.
Pfeffer, Jeffrey and Gerald R. Salancik (1978). *The External Control of Organizations*. New York, NY: Harper & Row.
Piore, Michael J. and Charles F. Sabel (1984). *Second Industrial Divide: Possibilities for Prosperity*. New York, NY: Basic Books.
Polanyi, Michael (1966). *The Tacit Dimension*. New York, NY: Anchor Day.
Porter, Michael E. (1980). *Competitive Strategy: Techniques for Analyzing Industries and Competitors*. New York, NY: Free Press.
Powell, Walter W. (1990). "Neither Market Nor Hierarchy: Network Forms of Organization." In Barry M. Staw and Larry L. Cummings (eds.), *Research in Organizational Behavior* (Vol. 12). Greenwich, CT: JAI Press, pp. 295-336.
Saxenian, Annalee (1994). *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*. Cambridge, MA: Harvard University Press.
Takeishi, Akira (forthcoming). "Bridging Inter- and Intra-Firm Boundaries: Management of Supplier Involvement in Automobile Product Development." *Strategic Management Journal*.
Ulrich, Karl (1995). "The Role of Product Architecture in the Manufacturing Firm." *Research Policy* 24:419-440.
von Hippel, Eric (1990). "Task Partitioning: An Innovation Process Variable." *Research Policy* 19: 407-418.
Williamson, Oliver E. (1991). "Comparative Economic Organization: The Analysis of Discrete Structural Alternatives." *Administrative Science Quarterly* 36:269-296.

Womack, James P., Daniel T. Jones, and Daniel Roos (1990). *The Machine that Changed the World*. New York, NY: Rawson Associates.

Table 1: Questionnaire Survey Responses

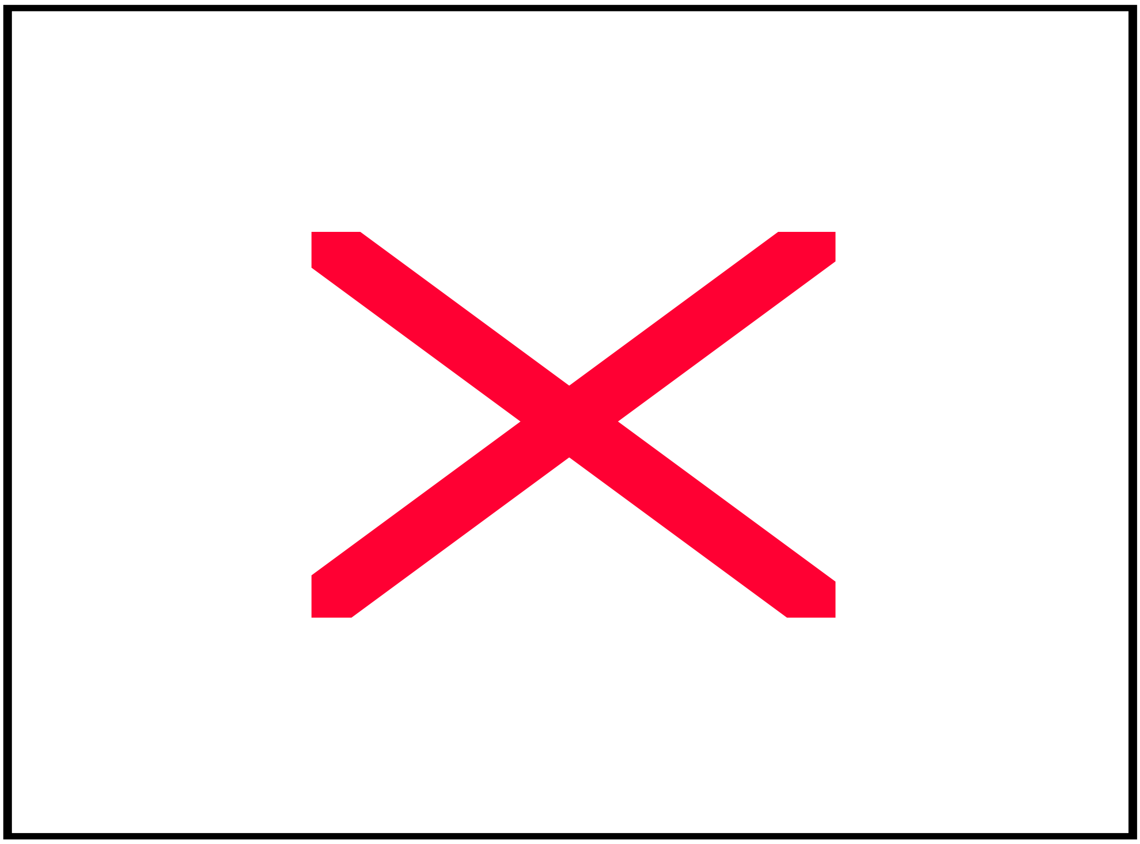
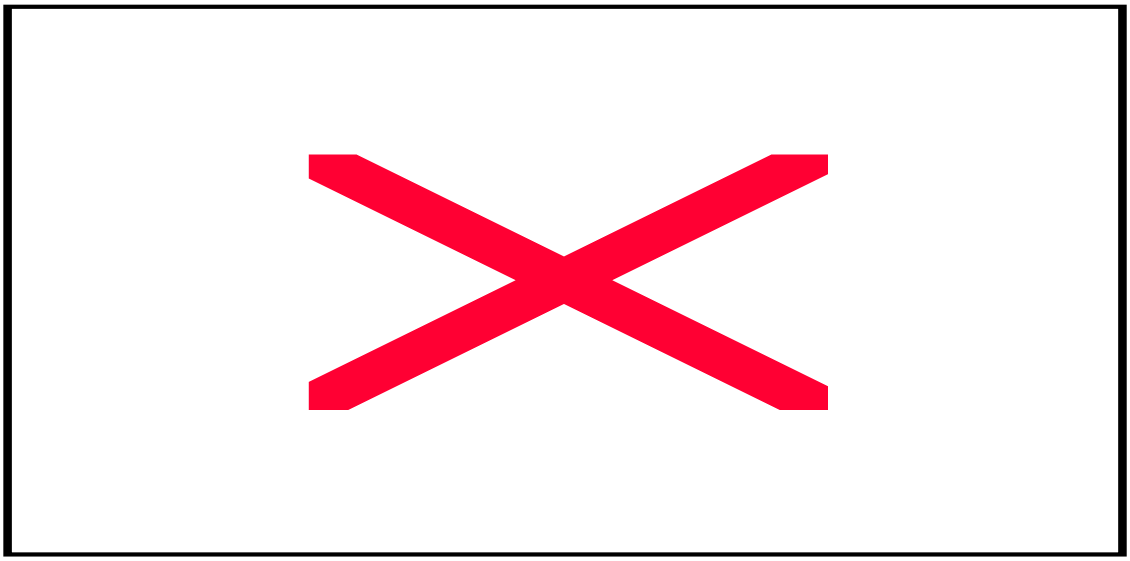


Table 2: Regression Results for Component Design Quality

Table 3: Level of Automakers' Knowledge about Component and Suppliers' Role in Component Development



Source: A questionnaire survey with Japanese first-tier suppliers. The survey was conducted in March 1999. Suppliers were asked to answer how much their main customer (automaker) knew about the component (scale: 5= very much; 1= not very much).
Detail-controlled: components developed entirely by automakers. Black box: basic design was done by automakers and detail engineering was by suppliers. Supplier proprietary: developed entirely by suppliers.
Component-specific knowledge is about product technology, manufacturing quality, cost, and production technology. Architectural knowledge is about coordination with other components and ease of installation at automakers' assembly lines.
For the details and results of the survey, see Fujimoto, Matsuo, and Takeishi (1999).

Table 4: Knowledge Level and Organizational Mechanisms for Knowledge Management by Automakers

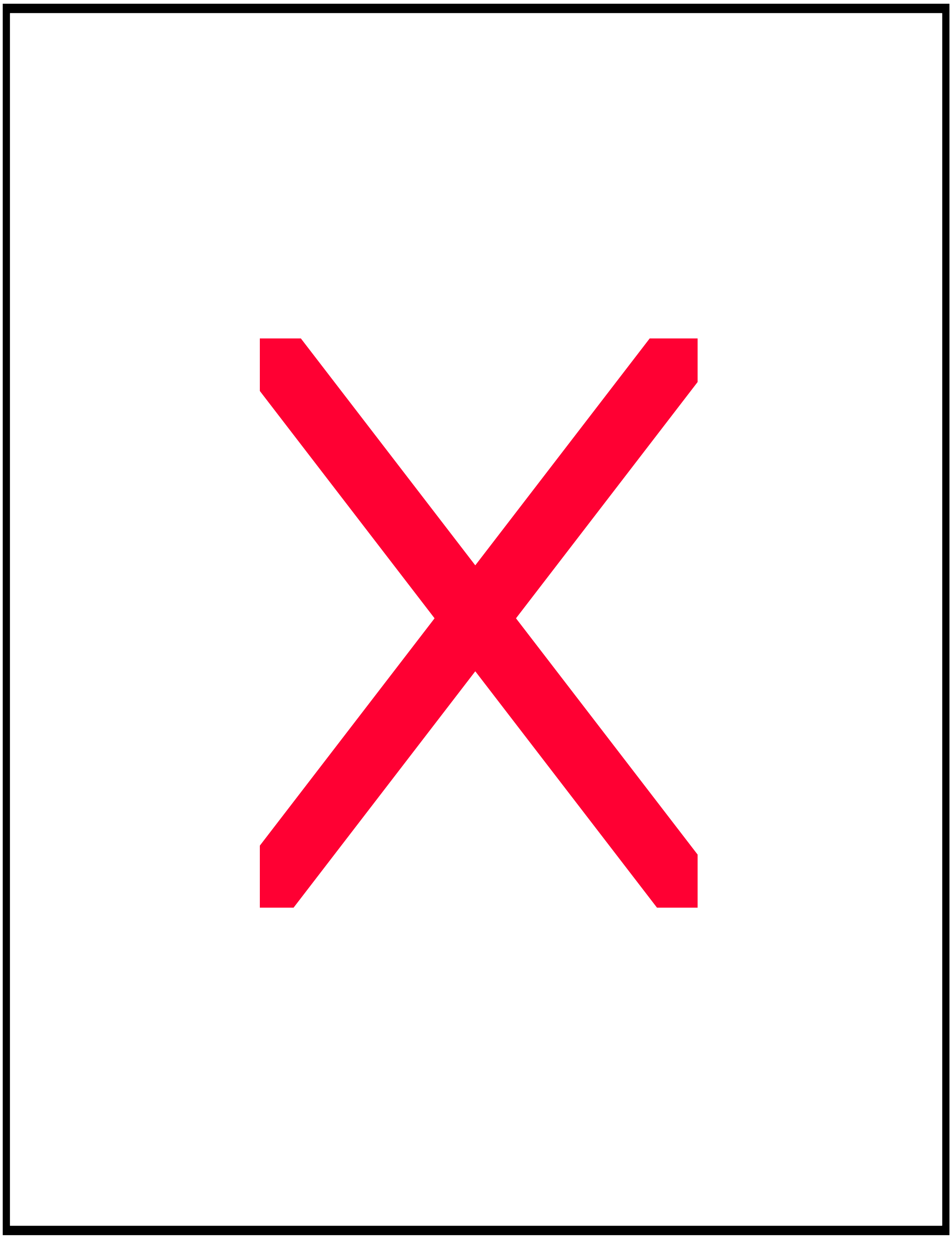
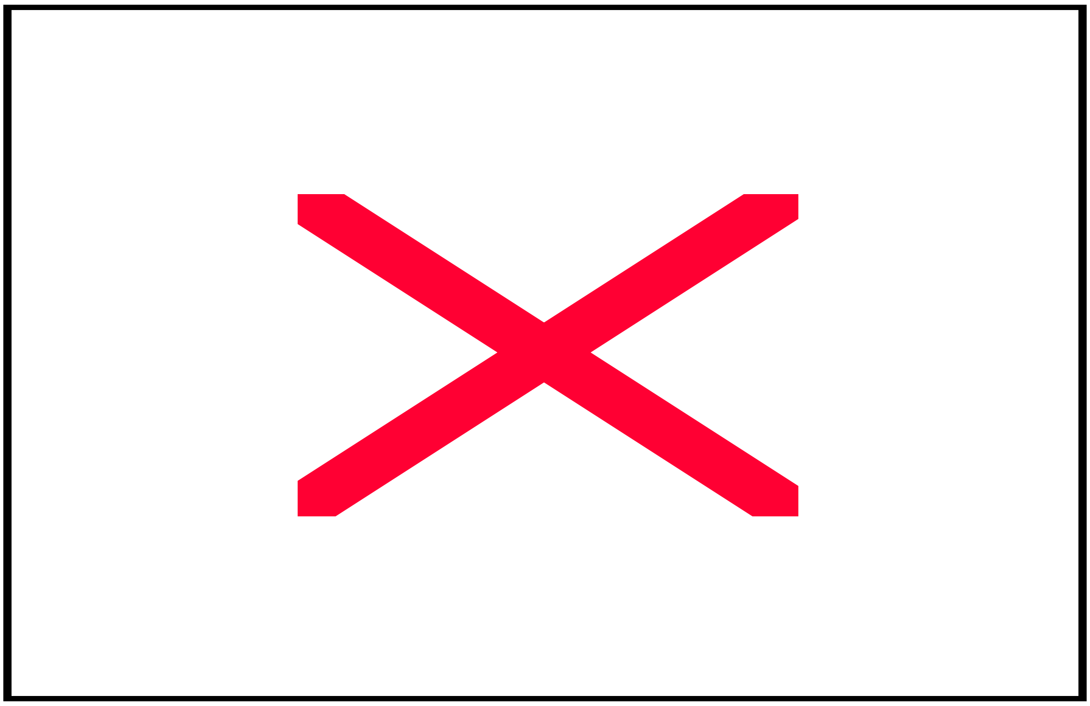


Table 5: Suggested Pattern of Effective Knowledge Partitioning

Project type	Effective pattern of partitioning	Automaker should have	Supplier should have*
Regular project (using established technologies)	Efficient (clear-cut) partitioning	Architectural knowledge	Component-specific knowledge
Innovative project (using new technologies)	Overlapping partitioning	Architectural and component-specific knowledge	Architectural and component-specific knowledge

Note: * Based on my interviews with automakers and suppliers, not derived from the statistical analysis of this paper's data set.

Figure 1: Engineers' Career Pattern by Automaker



Source: A questionnaire survey with eight Japanese automakers. The survey was conducted in July 1997. I specified eight types of components, and an engineer at each automaker in charge of each of those components answered how many years he/she designed the specific component (vertical axis) and how many years he/she designed any type of component (horizontal). Due to a confidentiality agreement, the names of components and respondent automakers cannot be disclosed.

APPENDIX 1: Survey Procedure and Data

Based on IRC's (1994) data on component transactions in the Japanese auto industry, I selected 15 suppliers that satisfied the condition that at least seven Japanese automakers, and four of the top five (Toyota, Nissan, Honda, Mitsubishi, and Mazda) purchased a component from the supplier in 1993. After I contacted and visited them, nine suppliers agreed to participate in the survey with a strict confidentiality agreement, and I distributed the survey to them in April 1997.

Each supplier was asked to select one component development project which was recently done for a new vehicle, for each of its major customers. While the component for each supplier was specified by me, sample automakers and projects were selected by the respondents. The survey was filled in by the person who was actually in charge of and most familiar with the selected development project, such as the Chief Engineer for the project.

After having collected the survey, I made a second visit to the respondent suppliers to review the responses, resolve any questions and inconsistencies, and discuss preliminary results of the data analysis. One concern was whether I could compare automakers within each supplier's responses since different individuals answered about different automakers and some might have adopted a different standard to describe an automaker's pattern. To handle this potential problem, I asked the survey coordinator at each supplier, who was in most cases a head of the supplier's engineering group and thus familiar with most automakers, or other appropriate persons in the company, to review if there were any "strange" answers, and if detected they were corrected.

Due to my confidentiality agreement with the respondents, I cannot disclose the names of firms and component types in the sample. There are eight types of components, with one answered by two suppliers. The components include those related to the engine, brake, chassis, body, and electrical systems. Most suppliers were either the largest or second largest supplier in Japan in production volume for the component.

The year of market introduction of the sample vehicles ranges from 1989 to 1997, with most introduced during the past five years (mean: 1995). All the sample suppliers had designed and manufactured the components for each automaker in the sample for more than ten years. All the suppliers stated that they expected that the automaker would continue to procure the component from them as long as production of the vehicle continues (that is, until the next model change). Thus the inter-firm relationships in the sample could be regarded as long-term. The mean of the supplier's design ratio is 73%, implying that approximately three-quarters of the detailed drawings were made by the supplier.

In summary, the sample provides appropriate data to empirically examine recent practices of supplier involvement between Japanese automakers and suppliers with long-term relationships.

APPENDIX 2: Variable Construction

Most variables used in the statistical analysis were constructed based on a data set from the supplier survey. Multiple items (indicators) were designed to measure various aspects of each construct and were included in the survey questions. Items used for each variable are shown in the following Appendix Table.

To examine if there are underlying key dimensions within a set of indicators for a construct, a principal component analysis was conducted. When I found multiple dimensions that are both statistically significant and conceptually meaningful, subcomponent variables were constructed, as in the case of EKN (EKN1 and EKN2). For each dimension for a construct, the items having a higher coefficient with the dimension were grouped, and the mean of those items' original scores was defined as a subcomponent variable (e.g. EKN1 and EKN2). The mean of those subcomponent variables was defined as the main variable (e.g. EKN) for the construct.

Another possible approach is to use the principal component scores, instead of original scores. In order to check the robustness of the analysis, I have constructed another set of variables using this approach and conducted another series of regressions for sensitivity analysis. It turned out that the basic results for the main research variables remain the same. Thus the primary results and discussions presented in this paper remain unchanged when the second approach is adopted.

It should be noted that many variables are based on the respondents' perceptions. Perceptual measurement raises a concern with bias and reliability of the responses. However, those variables for the automakers' knowledge level and supplier management patterns are otherwise difficult to measure, and the respondent suppliers are in the best position to observe the level and patterns through everyday operations. Also, the respondents were asked to evaluate outside organizations (customers) rather than their own organization and colleagues, mostly for recent projects, with the strict confidentiality agreement. These conditions and procedures are expected to have reduced the risk of bias and improved the reliability.

Appendix Table: Variable Specification and Measurement

Variable	Specification	Measurement
CDQ: Component Design Quality	The mean score of 13 items for both satisfaction and relative position	**Q**: How would you evaluate the component developed in this project in terms of (1) your satisfaction with the outcome of the project; and (2) relative position in comparison with the same type of component used for competing vehicle models in the market? (Responses on 5-point scale for "satisfaction" with 1= unsatisfied; 3= somewhat satisfied; 5= very much satisfied, and 6-point scale for "relative position" with 1= much worse (the bottom quarter in rank); 2= below average (the third quarter in rank); 3= average; 4= above average (the second quarter in rank); 5= much better (the top quarter in rank); 6= the best) 1. Functional performance 2. Structural simplicity (fewer constituent parts) 3. Technological innovativeness 4. Structural coordination with other parts 5. Functional coordination with other parts 6. Lower costs 7. Light weight 8. Durability 9. Design for manufacturability (for your process) 10. Design for manufacturability (for assembly) 11. Manufacturing quality 12. Maintainability 13. Fit to the target customers' needs (Cronbach's alpha: 0.858)
PSP: Integrated problem solving	The mean score of 18 items	**Q**: How much would you agree with the following statements as the description of the project's development process? (Responses on 5-point scale with 1= strongly disagree; 5= strongly agree) (*=scale was reversed) 1. The automaker's early engineering requirements were too vague and your company didn't have a clear direction for design.* 2. The automaker's requirements started with a certain range of design tolerance and then the range gradually narrowed. 3. The initial requirements were not stable and changed substantially in the subsequent stages.* 4. The target price initially given by the automaker took full consideration of engineering requirements. 5. The automaker's cost data on which the initial target price was based were accurate and updated. 6. Your initial price/cost estimate was examined very carefully by the automaker from the beginning. 7. Engineering activities and price setting were not linked well and conducted independently.* 8. When the automaker changed its requirements, the target price was also revised accordingly. 9. The automaker examined your manufacturing process and design for manufacturability from earlier stage (before the first prototype). 10. The automaker's earlier engineering requirements took full consideration of structural and functional coordination with other components. 11. The automaker's earlier engineering requirements took full consideration of manufacturability for their assembly process. 12. Structural and functional coordination of the component remained as critical, unsolved problems until later stage (after the first mass trial).* 13. Earlier examination of foreseeable problems enabled smooth engineering activities after starting prototype reviews. 14. Earlier examination of foreseeable problems enabled smooth engineering activities after starting mass trial reviews. 15. Design changes after the first mass trial were for seeking further perfection and were within a foreseeable range. 16. Cost reduction for achieving the target price caused unforeseeable, major design changes after the first mass trial.* 17. Problems with manufacturability for assembly caused unforeseeable, major design changes after the first mass trial.* 18. Component coordination problems caused unforeseeable, major design changes after the first mass trial.* (Cronbach's alpha: 0.812)

Variable	Specification	Measurement
COM: Communication Frequency	The mean number of days per year for mutual visits between the automaker and the supplier	**Q**: How frequently did the following visits for the project happen during the development process? Please indicate the average frequency during the project, by circling one number. (0= never; 1= once per two or three months or less; 2= monthly ; 3= twice, three times, or less per month; 4= weekly; 5= twice, three times, or less per week; 6= almost everyday) 1. The automaker's engineers visited your engineering site 2. The automaker's engineers visited your production site 3. The automaker's buyers visited your engineering site 4. The automaker's buyers visited your production site 5. Your engineers visited the automaker 6. Your sales people visited the automaker (Cronbach's alpha: 0.798)
EKN: Engineers' knowledge	The mean of EKN1 and EKN2	
EKN1: Component-specific knowledge	The mean score of 15 items	**Q**: How would you describe the level of knowledge of the automaker's engineers, with whom you and your colleagues worked for the project, compared with the level of your and your colleagues' knowledge? (Responses on 5-point scale with 1= much lower; 3=about the same; 5= much higher) 1. Materials of the component 2. Functional design of the component 3. Structural design of the component 4. Durability design of the component 5. Core technology of the component 6. Design for manufacturing (for your company's process) 7. Customers' needs and preference about the component 8. Manufacturing process of the component 9. Production management of the component 10. Quality management of the component 11. Constituent parts costs of the component 12. Material costs of the component 13. Manufacturing process costs of the component 14. Labor costs of the component 15. Other costs of the component (Cronbach's alpha: 0.932)
EKN2: Architectural knowledge	The mean score of 3 items	**Q**: the same as above. 1. Design for manufacturing (for the automaker's assembly) 2. Structural coordination with other components 3. Functional coordination with other components (Cronbach's alpha: 0.764)
SLD: Sales dependency on the automaker	The supplier's sales volume to the automaker/ the supplier's total sales volume of the component (%)	Based on industry data on 1996 transactions, published by IRC (1997).
STK: stock ownership by the automaker	Set to 1 if the supplier's stock is owned wholly or partially by the automaker	Based on the supplier's annual report.
NWT: Technological newness	Set to 1 if one of the answers to the two questions at right is "4"; otherwise 0	**Q**: How would you describe the engineering newness of the project? Please circle one number? 1. Minor modification (changes were less than 20%) of a component design that had been already developed at your company. 2. Major modification (20-80%) of a component design that had been already developed at your company. 3. Completely new design (more than 80%), but its design was based on a technology that had been demonstrated in another project. **4.** Technologically new to your company and a completely new design. **Q**: How would you describe the process newness of the project? Please circle one number?

Variable	Specification	Measurement
		1. Existing process layout and equipment with minor modification of dies and tooling. 2. Existing process layout and equipment with new dies and tooling. 3. New process layout and equipment, but based on established process engineering, in your company. 4. Technologically new process to your company and completely new process layout and equipment.
CMP: Computer usage	Ratio (%) of "yes" for the answers to the four questions at right	**Q**: Did your company use the following computer and information systems for the project? (1. yes; 2. no) 1. Drawing by 3-D CAD 2. Simulation and evaluation by CAE 3. Provide engineering drawings by 3-D CAD data to the automaker 4. Receive engineering information by 3-D CAD data from the automaker

[1] This study starts with a deductive approach by empirically examining the validity of Fine and Whitney's (1996) argument. However, the paper then proceeds with an inductive manner to explore how companies manage knowledge. In this sense, the paper employs a mix of deductive and inductive approaches.
[2] However, Brusoni and Prencipe (forthcoming) argue that even in modular products the buyer's knowledge is critical. I will touch on this point in my conclusion.
[3] The survey procedure is described in Appendix 1.
[4] The same data set was used for another analysis, which focused on the linkage between internal organization and outsourcing. For this analysis, see Takeishi (forthcoming).
[5] It is important to understand that a component needs structural and functional coordination — fitting and working well together — with other components within the vehicle to achieve a high level of product integrity (Clark and Fujimoto 1991). Structural coordination is necessary to achieve, for example, efficient packaging of components in a given space. Functional coordination is necessary to achieve various functional targets, such as maximizing handling and ride performance, and minimizing noise and vibration. The key is that better coordination cannot be achieved by merely putting good individual components together; related components should be integrated with mutual adjustments, due to the automobile's integral architecture.
[6] See Appendix 2 for the procedure to categorize the elements of knowledge.
[7] Architectural knowledge generally includes knowledge about the entire architectural structure of a product, whereas in this study it refers only to knowledge about the linkage between a component and other components in a product.
[8] This transformation, however, lowers variances in the sample as a whole, and may thus bias statistical examination. To deal with this concern, I took two alternative approaches to controlling for supplier/component heterogeneity, and have found the three approaches provide similar results. For details see Takeishi (forthcoming).
[9] The standardized coefficient for NWTxEKN1 (component-specific knowledge) is 100% greater than for NWTxEKN2 (architectural knowledge). When only one interaction term was entered, rather than two together, the difference in R^2 between the equation with the interaction term and without (Model (3)) is significant at the 5% level for NWTxEKN1, but not at the 10% level for NWTxEKN2. These results also indicate that component-specific knowledge plays a more important role than architectural knowledge for those projects involving new technology.
[10] Automakers may want to procure components exclusively from dedicated suppliers that supply the components to a single customer. Yet with this approach, automakers cannot benefit from suppliers' economies of scale and diversified expertise obtained through business with multiple customers.
[11] This automaker was one of these companies whose cases were mostly found closer to the horizontal axis in Figure 1. Due to the confidentiality agreement, the company codes of Table 1, Table 4, and Figure 1 are different.