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

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ABSTRACT

This paper demonstrates the importance of knowledge for effective management of outsourcing. Drawing on an empirical study on automakers' management of supplier involvement in product development in Japan, this paper shows that the level of own knowledge is critical for automakers to gain better outcome from engineering outsourcing. While the actual tasks of designing and manufacturing components could be outsourced, automakers should retain the relevant knowledge to obtain better quality of component design. Knowledge partitioning should be distinguished from task partitioning.

Furthermore, 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 automakers 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 suppliers. 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 overlaps between an automaker and a supplier, rather than efficient and clear-cut boundaries.

This paper further reveals that some automakers manage knowledge better than others by combining various organizational mechanisms, including career development policies, extensive documentation of technological information, internal training programs, and incentive schemes. Difficulty of implementing those mechanisms in a consistent and complementary manner seems to explain why there is a significant variance among automakers in knowledge level.

(254 words)

INTRODUCTION

Outsourcing has become an important strategy for many firms. Collaboration with external organizations could bring the firm benefits like reducing the fixed costs, gaining flexibility, and capitalizing on specialists' expertise (Miles and Snow 1984; Jarillo 1988; Johnson and Lawrence 1988; Dertouzos, Lester and Solow 1989; Kanter and Myers 1991). 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. Attention to the role and management of knowledge for outsourcing echoes growing interests in knowledge in current management research.

However, there has been little empirical investigation on the relationships between knowledge and outsourcing. Many questions have yet to be explored. How much is knowledge indeed critical for effective outsourcing? What types of knowledge are particularly important to retain? How could firms maintain knowledge while outsourcing the actual tasks of manufacturing and design? In an attempt to answer these questions, this paper empirically examines the importance of knowledge in the management of inter-firm division of labor for product development, and explores how firms manage critical knowledge internally. The field is the Japanese automotive industry. A typical passenger car consists of more than 30,000 components and many suppliers are heavily involved in 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.

The remainder of this paper is organized as follows. First, I briefly review what previous studies have discussed on the role of knowledge in outsourcing. The next section, drawing on a set of questionnaire survey data, analyzes whether knowledge is related to the performance of component development with suppliers. The paper further goes on to explore, primarily based on interviews, why some automakers outperform others in managing knowledge for effective outsourcing. A focus is put on organizational mechanisms for enhancing and maintaining engineering knowledge. The results provide some implications for sources of inimitable competitive advantage. The paper concludes with a discussion of implications of this study and 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. A growing number of researchers have studied inter-firm relations since a newly conceptualized mode of economic organization began to attract attention in the early 1980s. This new mode is typified by cooperative, interdependent, and long-term relations among independent organizations and it contrasts with the modes of markets and of hierarchies. Many studies in a variety of disciplines have addressed the actual or potential advantages of the new mode of inter-firm relations (Williamson 1991; Powell 1990; Piore and Sabel 1984; Saxenian 1994; Miles and Snow 1984; Johnson and Lawrence 1988; Jarillo 1988). 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 towards 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 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 and Fujimoto 1991; Womack, Jones and Roos 1990). 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 1996).

Yet, however close relations a corporation builds 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. Fine and Whitney (1996) argued that if the firm retains knowledge, then outsourcing poses few 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, but as electronics becomes more critical for vehicle development it has moved to develop electronic subsystems internally to regain knowledge of them. 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. To paraphrase Fine and Whitney's (1996) claim, firms need 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. When a firm divides one innovation project into two tasks and outsources one to a supplier, for example, 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.

Building on this argument, this paper aims at probing into knowledge management for outsourcing, a research theme that has attracted limited attention. There has been little empirical analysis of the relationships between outsourcing and knowledge. I would like to fill this void, though partially, by addressing two research questions. First, how much is knowledge indeed important for effective management of outsourcing? Second, how do firms manage knowledge internally while outsourcing relevant tasks to external suppliers? The subsequent two sections deal with these questions, respectively.

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 a "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 automaker'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 customer 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 a "black-box approach" therefore provide an interesting research setting to examine the relationships between knowledge partitioning and the effectiveness of outsourcing management. I examine if the level of an automaker's knowledge about the component is related to the output quality of component development, 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.[1] Each supplier was asked to select one component development project that was recently done for a new vehicle with 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. The survey was filled in by the person who was actually in charge of, and most familiars with, the selected development project, such as the Chief Engineer for the project. Table 1 reports the final responses. 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. In particular, the follow-up interviews with automakers focused on the organizational mechanisms each automaker employed to manage knowledge for component development within its engineering department. More than 100 managers and engineers at both automakers and suppliers were interviewed.

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, costs, conformance quality and structural and functional coordination with other components. 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 component development is the key independent variable. Eighteen elements of knowledge that automakers' engineers are expected to have were identified through my interviews with automakers and suppliers. They were then categorized into two types.[2] One is component-specific knowledge and the other is architectural knowledge. **EKN1** (engineers' component-specific knowledge) measures the level of knowledge specific to a component, including technology, cost, and manufacturing process. **EKN2** (engineers' architectural knowledge) measures the level of knowledge about structural and functional coordination with other components and design for manufacturing. This variable indicates the level of knowledge about the engineering coordination between the component and other related components, and was thus named architectural knowledge (Henderson and Clark 1990).[3] **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.

Other independent variables

In addition to knowledge, there are some other factors that are likely to have impact on the performance of component development projects. One area is the pattern of interaction between an automaker and a supplier during the project, including problem-solving pattern and communication. Problem solving in a manner that integrates across different functions from the early stages has been identified critical for effective product development (Clark and Fujimoto 1991, Iansiti 1998). **PSP** 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** (the frequency of face-to-face communication between the automaker and the supplier) 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 for inter-firm relations. **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 level of three-dimensional CAD (Computer-Aided Design) and CAE (Computer-Aided Engineering) usage for 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 normalized across responding suppliers. It was normalized by removing each supplier's mean, which varies across suppliers reflecting the differences in suppliers' capabilities and the nature of component types. The mean was removed, as shown below, either by taking a difference from the mean, or a ratio to the mean in the case where the magnitude of a variable's score differs substantially across suppliers:

$$X^*_{ij} = X_{ij} - \overline{X_j} \quad \text{or} \quad X^*_{ij} = X_{ij} / \overline{X_j}$$

where

X^*_{ij} = the normalized 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 reports the regression results for CDQ. Model (1) includes all the independent variables other than that for knowledge. The result shows that integrated problem-solving (PSP) and communication frequency (COM) have both 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 (EKN) plays a significant role to gain 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 plays a more positive effect than architectural knowledge in the case of using new technology.[4]

Overall, the results support that having a higher level of knowledge is important for automakers to manage supplier involvement in product development. This implies that knowledge partitioning should be separately designed from task partitioning. 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 component-specific knowledge is more critical to gain a higher CDQ for innovative projects. 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 both architectural and component-specific knowledge. This finding echoes the following comment:

> Automaker X has recently changed their policy and has us involved in component development to a greater degree. It relies 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 next critical question for managers. Given the importance of knowledge, how could automakers create and maintain a higher level of knowledge than others? This is this paper's second question and 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 more than often obtained through doing things (learning by doing). When 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 surveys with Japanese suppliers. It shows that as more tasks of engineering are shifted to suppliers, from a "detail-controlled system" to a "black-box system," the level of automakers' knowledge tends to decline. This tendency was also witnessed in the following comment of an interviewee.

> 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).

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

Second, even if an automaker could have 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.[5]

When we recognize the inherent difficulty to keep 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 have a higher knowledge level than others despite the fact that they shared the same suppliers with competitors. 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 inimitability of competitive advantage. My interviews, in particular with automakers, have hinted at the following answers.

One approach to enhance architectural knowledge and thus to improve coordination among engineering functions is to rotate individual engineers across different types of component over time.[6] Through own hands-on experiences in designing other related components in the past, 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 (Lynn, Piehler and Kieler 1993; Aoki 1990). 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 they 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 measures the number of years for engineering any types of components. In this scatter plot, when engineers tend to stay with the same components however long they work at the firm (engineers as specialists), we should observe most cases closer to the diagonal. If engineers tend to change their assignments over time (engineers as generalists), in contrast, cases should be 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, if any, 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 rotate their engineers relatively frequently (few engineers stay with the same component more than seven to ten years), others such as Companies A and F have their engineers devoted to a particular component for many years.

Why is it that the latter automakers do not rotate their engineers more frequently in order to improve their architectural knowledge? According to my interviews, automakers cannot pursue individual engineers' broader experiences too much. Rotating individual engineers across many components quickly may impede their accumulation of component-specific knowledge. Many automakers recognize the importance of rotating engineers but cannot implement such a policy consistently because functional managers do not want to have their engineers transferred to other areas of components. To lose experienced engineers may lead to lower efficiency and poor output quality. 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 relation between the two types of knowledge. It is not easy for automakers' engineers to have a high score for the both types.

However, there is an automaker whose engineers score higher for both architectural and component-specific knowledge on average. My comparative interviews with eight automakers indicate that this automaker took the following approach.

On the one hand, this firm had a definite policy of rotating engineers across different components over a certain period of time. This helped their engineers build architectural knowledge through hands-on experiences. 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' protest to rotation policy.[7]

On the other hand, 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 usually transferred within the division and rarely transferred to other divisions, such as the engine and body design divisions. 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 could stay, if they want, 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 promoted two types of knowledge within the organization.

Third, this automaker attempted to accumulate component-specific knowledge through design standards and know-how reports. When engineers were assigned to a new component, they could refer to those documents prepared by their predecessors as a source of component-specific knowledge and also could take internal training classes for the component. Such training classes were not frequently offered at other automakers.

Forth, individual engineers were evaluated by their superiors in terms of their contribution to advancing component-specific technologies, rather than to coordination for particular vehicle development projects. According to my questionnaire survey and interviews with automakers, this automaker, in sharp contrast with others, put heavy emphasis on components over the final product in the incentive structure, thus financially encouraging 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' contribution to a vehicle than to a component.[8]

By combining those organizational mechanisms, this automaker seems to have been able to enhance both architectural and component-specific knowledge. Individual mechanisms identified above are 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 fully capture the benefits and improve two types of knowledge, which are in trade-off relationships with each other. It is these obstacles and difficulties that prevent some automakers from catching up others in knowledge management for outsourcing. It is only with extensive internal efforts that automakers can somehow maintain knowledge advantage over competitors even when tasks of engineering are outsourced to shared suppliers.

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 obtain better quality of component design. Knowledge partitioning should be distinguished from task partitioning, thus requiring careful management, as argued by Fine and Whitney (1996) and Fine (1998).

Furthermore, the results indicate that an effective pattern of knowledge partitioning differs by the nature of component development project in terms of technological newness (Table 4). 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 specialized in the component. Knowledge could thus be partitioned efficiently between an automaker and a supplier based on the specialty of each party.

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

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. Also, although this study cannot provide statistical evidence, my interviews suggest that for projects involving new technologies, suppliers also needed a higher level of architectural knowledge to solve problems jointly with the automaker. Building up architectural knowledge about the component — knowledge on how the component should be integrated for a particular vehicle — was recognized as a critical success factor for suppliers to win design competition. In innovative projects, these findings imply that, effective knowledge partitioning seems to demand some overlaps 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 because of limited capabilities or 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. But for those automakers that want to be a leader in the technological race, effective management of their own knowledge is critical. As described above, the approach taken by an 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 of 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. Organizational mechanisms that are designed and implemented well to improve both architectural and component-specific knowledge thus could be an important source of competitive advantage for automakers even when they outsource substantial tasks of engineering to shared suppliers.

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. Two 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). We need empirical studies in other industries where product architecture is based on modular design, for example. Second, this study's evidence on organizational mechanisms for effective knowledge management remains 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.

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Table 1: Questionnaire Survey Responses

Supplier (company code)	# of projects in responses	Automakers in responses (company code)									
		AA	**AB**	**AC**	**AD**	**AE**	**AF**	**AG**	**AH**	**AI**	**NA**
SA	6										6
SB	5	1	1		1		1			1	
SC	5	1	1	1	1				1		
SD	7		1	1	1	1	1	1		1	
SE	5	1	1	1		1			1		
SF	4		1	1	1				1		
SG	5	1		1	1				1	1	
SH	3	1		1			1				
SI	5	1	1	1	1				1		
Total	45	6	6	8	6	2	3	1	5	3	6

The names of the suppliers and the automakers in the sample cannot be disclosed due t
a confidentiality agreement with the respondents.
Sample components include those related to engine, brake, chassis, body, and electrical systems.
NA = not available because SA did not reveal the name of the automakers in its sample.

Table 2: Regression Results for Component Design Quality

Model #	(1)		(2)		(3)		(4)		(5)	
Intercept	-0.115		0.157		0.160		-0.087		-0.088	
PSP : Integrated problem-solving pattern	0.304 (0.113)	**	0.256 (0.111)	**	0.247 (0.113)	**	0.381 (0.113)	***	0.376 (0.118)	***
COM : Communication frequency	0.017 (0.004)	***	0.021 (0.005)	***	0.022 (0.005)	***	0.018 (0.004)	***	0.018 (0.005)	***
SLD : Sales dependency on the automaker	0.158 (0.064)	**	0.145 (0.061)	**	0.146 (0.062)	**	0.113 (0.058)	**	0.117 (0.061)	*
STK : Stock ownership by the automaker	-0.200 (0.120)		-0.174 (0.115)		-0.177 (0.116)		-0.092 (0.111)		-0.101 (0.120)	
NWT : New technology	-0.134 (0.172)		-0.199 (0.167)		-0.204 (0.169)		-0.315 (0.161)	*	-0.310 (0.177)	*
CMP : CAD/CAE usage	-0.124 (0.330)		-0.179 (0.316)		-0.160 (0.321)		-0.196 (0.293)		-0.168 (0.303)	
EKN : Engineers' knowledge			0.297 (0.137)	**			0.132 (0.142)			
EKN1 : Component-specific knowledge					0.115 (0.095)				0.019 (0.089)	
EKN2 : Architectural knowledge					0.173 (0.081)	**			0.092 (0.082)	
NWT x**EKN**							1.274 (0.484)	**		
NWT x**EKN1**									0.683 (0.352)	*
NWT x**EKN2**									0.579 (0.476)	
Adjusted R square	0.366		0.422		0.412		0.502		0.481	
R square change							(4)-(2) 0.078	**	(5)-(3) 0.080	**

N=45.
Standard errors in parentheses.
* : p-value < 0.1; ** : p-value < 0.05; *** : p-value < 0.01.

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

supplier's role in component development	n	component-specific knowledge	architectural knowledge
detail-controlled	16	4.24	4.22
black box	128	3.61	3.89
supplier proprietary	6	2.71	3.09
total	151	3.61	3.78

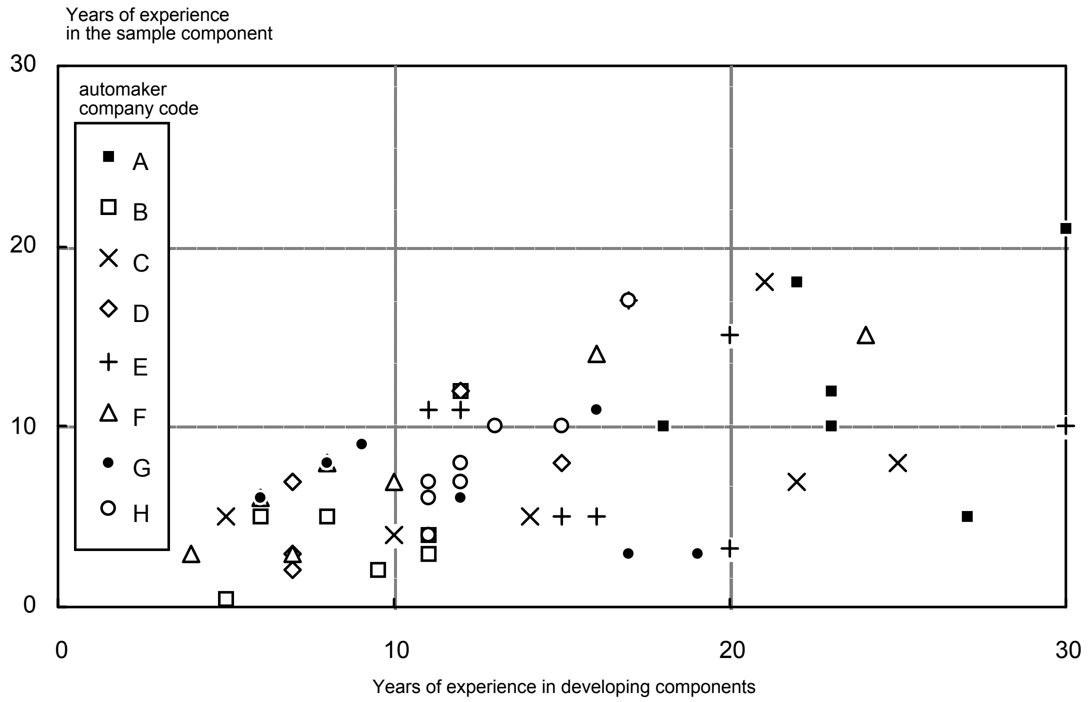
Source: A questionnaire survey with Japanese first-tier suppliers. The survey was conducted in March 1999. Suppliers were asked to answer how much their main customer (automaker) knew about the component (scale: 5= very much; 1= not very much).
Detail-controlled: components developed entirely by automakers.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

Table 4: 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 Make



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 component (vertical axis) and how many years he/she designed any types of components (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 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 has 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 own organization and colleagues, mostly about 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 was 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.* *(to be continued)* 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
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 components 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. *(to be continued)* 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.

Variable	Specification	Measurement
		Q: How would you describe the process newness of the project? Please circle one number? 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] The survey procedure is described in Appendix 1.

[2] See Appendix 2 for the procedure to categorize the elements of knowledge.

[3] 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. Component coordination and product integrity of a vehicle are, therefore, in a sense, two sides of the same coin, although product integrity requires more than component coordination; it also requires, for example, good styling and fit with customer's needs. 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.

[4] The standardized coefficient for NWTxEKN1 (component-specific knowledge) is 50% larger 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.

[5] Automakers may want to procure exclusively from dedicated suppliers, which supply the component to a single customer. Yet in this approach automakers cannot benefit from suppliers' economies of scale.

[6] Another well-known approach to improve architectural knowledge within an engineering division is to have a capable and influential product manager who could coordinate and solve problems across engineering functions for a vehicle development project, the so-called "heavyweight product manger" (Clark and Fujimoto 1991). For the importance of capable product managers and the difficulty to nurture them, see Clark and Fujimoto 1991.

[7] This automaker was one of those companies whose cases were mostly found closer to the horizontal axis in Figure 1.

[8] Note that, according to my interviews, at all the automakers, individual engineers' performance evaluation is done by their functional managers, not product managers.