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BRIDGING INTER- AND INTRA-FIRM BOUNDARIES: MANAGEMENT OF SUPPLIER INVOLVEMENT IN AUTOMOBILE PRODUCT DEVELOPMENT

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Outsourcing has become an important strategy for many firms. Yet, firms need to compete with their competitors who also outsource and may share the same suppliers. This article explores how a firm could outperform others in managing the division of labor with a supplier in product development. Drawing on the empirical data collected from the Japanese auto industry, this paper shows that an automaker needs capabilities to coordinate various activities both externally with a supplier and internally within its own organization, in order to gain better component development performance. Overall, the results imply that outsourcing does not work effectively without extensive internal effort. Copyright © 2001 John Wiley & Sons, Ltd.

INTRODUCTION

Managers have continually struggled with the question of where to set the boundary between what work takes place inside vs. outside a company, what kind of relations to build with suppliers, and how to manage the division of labor with them. Outsourcing has recently become an important strategy for many firms, partly due to an increased pressure towards downsizing and a growing recognition of possible advantages of cooperative inter-firm relations (Miles and Snow, 1984; Jarillo, 1988; Johnston and Lawrence, 1988; Kanter, 1989; Dertouzos, Lester, and Solow, 1989). Outsourcing some internal activities and building cooperative, interdependent, and long-term relations with suppliers and alliance partners are considered to give the participating firms some benefits such as combining different competencies, sharing fixed costs, and gaining economies of scale (Kanter and Myers, 1991).

Yet, however close relations a corporation builds with its partners and however capable the partners are, the firm still has to compete with other firms who are seeking similar close relations with their capable partners. Some partners may even be shared by competing firms. *How could a company outperform competitors who also have cooperative relations with their partners?* Without addressing this question, a firm cannot gain a sustainable competitive advantage from outsourcing. This paper intends to make a contribution to management research on inter-firm relations, product development, and competitive advantage by analyzing how some automakers manage more effectively than others the division of labor with suppliers who play critical roles in automobile product development.

A typical passenger car contains more than 30,000 parts. Although original equipment manufacturers such as General Motors and Toyota assemble final vehicles, outside suppliers are often involved in design as well as manufacturing, and may account for 70 percent of manufacturing costs and 50 percent of engineering costs at some auto

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companies (Clark and Fujimoto, 1991). This means that the competitiveness of an automobile producer is highly dependent on the capability of its suppliers and how effectively the producer manages the division of labor with these suppliers. Many studies in the past have shown that Japanese firms have had particularly efficient and effective supplier systems, and that these supplier networks have played a major role in the international competitiveness of the Japanese automobile industry (Abernathy, Clark, and Kantrow, 1983; Cole and Yakushiji, 1984; Cusumano, 1985; Womack, Jones, and Roos, 1990; Cusumano and Takeishi, 1991; Nishiguchi, 1994; Helper and Sako, 1995). A critical element of Japanese practices is to involve suppliers, from the early stages, in the design of components for a new vehicle (Asanuma, 1988, 1989; Clark, 1989; Clark and Fujimoto, 1991). Following Japanese practices, many non-Japanese automakers have reduced the number of their suppliers and have required the suppliers to be more involved in product development, thus shifting the responsibility of design and engineering to outside specialists.

Despite this growing recognition of the importance of supplier involvement, previous researchers have not fully explored detailed, systematic analyses of effective management of supplier involvement in product development. Empirically, this paper attempts to probe this relatively unexplored area, drawing on the data collected from the Japanese auto industry. This paper identifies certain organizational patterns in problem solving, communication, and knowledge that enable some automakers to gain higher component design quality even when a supplier is shared by competing automakers. Most important, an automaker needs capabilities to effectively coordinate diverse activities both externally with a supplier and internally within its organization—that is, capabilities to bridge both *inter*-firm and *intra*-firm boundaries. Theoretically, the paper demonstrates the importance of linking inter-firm and intra-firm level variables to analyze interorganizational division of labor.

The remainder of this paper begins with a brief literature review. The next section lays out an analytical framework and hypotheses. The subsequent section describes the research design and the data. The results of analysis are then presented and discussed.The paper concludes with a discussion of implications of this study and future research.

LITERATURE REVIEW

Advantages of collaborative inter-firm relations

An increasing 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 (Piore and Sabel, 1984; Powell, 1990; Aoki, 1990; Williamson, 1991).

In the field of strategy, according to Jarillo (1988), researchers were relatively slow to incorporate the concept of cooperative inter-firm relations into their research, probably because the concept did not easily fit with the basic paradigm of competitive strategy. As Martin, Mitchell, and Swaminathan (1995) pointed out, strategy theorists once tended to view suppliers and buyers primarily as antagonists seeking to appropriate the profits of existing business activities in an industry chain. Yet, as evidence accumulated on the advantages of a cooperative mode, both practitioners and strategy researchers have paid increasing attention to networking, alliances, and cooperative inter-firm relations. Some strategy researchers have argued that firms with collaborative inter-firm relations could be more competitive than those without (Miles and Snow, 1984; Jarillo, 1988; Johnston and Lawrence, 1988). Gomes-Casseres (1996) further argued that growing collaboration among firms generated new forms of rivalry. Business rivalry could often occur between sets of allied firms, which he called ‘constellations,’ rather than between individual firms.

Product development, a crucial activity for a firm’s competition and survival, is an area that benefits from collaborative relations with partners, including customers (von Hippel, 1988), research communities (Allen, 1977; Henderson and Cockburn, 1994), competitors (Gomes-Casseres, 1996), and suppliers (Gold, 1987; Mabert, Muth, and Schmenner, 1992). Involving suppliers in product development allows a firm to reduce its workload, to focus on the activities that take advantage of its areas of competence, and to capitalize on the supplier's competence and potential for scale economies. Thus supplier involvement can provide the firm with considerable benefits. Imai, Nonaka, and Takeuchi (1985), for example, observed that the extensive use of supplier networks had a positive effect on the speed and flexibility of product development in Japanese industries such as automobiles, copiers, cameras, and personal computers. With a high level of specialized technical skill, suppliers could respond to their customers' sudden requests quickly and effectively.

Eisenhardt and Tabrizi (1995) reported mixed effects of supplier involvement on product development speed in the global computer industry. Supplier involvement had a positive effect on speed in mainframe and minicomputer products, but not in personal computer and peripheral products. They argued that in less predictable products such as personal computers, early involvement might be difficult to achieve because there is less certainty which suppliers will be used. In contrast, in more predictable, mature products such as mainframe computers, suppliers are likely to be clear early on and it is preferable to involve them early in the process. Similarly, positive effects of supplier involvement have been observed in the auto industry.

Many auto industry studies showed that effective supply chain management, which has been most often observed in Japan, involved close, trusting relationships with long-standing suppliers who were intimately involved with development as well as production of components (Asanuma, 1988, 1989; Womack *et al.*, 1990; Nishiguchi, 1994; Dyer, 1996a; Helper, 1996). Clark and Fujimoto (1991) shed much light on how outsourcing product development activities through 'black-box parts,' where a supplier conducts detailed engineering based on functional specifications provided by an automaker, reduces overall project lead time and engineering resources required for product development, and thus contributes to Japanese advantage.

Recognizing the advantages of Japan's approaches to supplier management in product development, American and European automakers have begun to adopt the Japanese practices (Bertodo, 1991; Ellison *et al.*, 1995; Liker *et al.*, 1995). This means that they are giving increased responsibility to suppliers and asking them to be involved in product development more deeply at an earlier stage in new vehicle development. Probably the most visible examples of such initiatives have been at Chrysler. The decision to improve partnerships along the supply chain seems to have significantly helped Chrysler on its return to growth and profitability (Dyer, 1996b).

Unexplored perspectives

Previous studies have contributed to a better understanding of the nature and advantages of collaborative inter-firm relations and supplier involvement in product development. However, they have not fully explored the next critical question—how a firm could outperform competitors who also have collaborative relations with their partners. When the mode of cooperative inter-firm relations has been acknowledged and diffused among organizations, additional research on differences *within* this mode is needed. The growing literature on strategic alliances, the 'virtual corporation,' buyer–supplier relations, and technology collaboration has indicated the importance of external integration and outsourcing (Teece and Pisano, 1994). However, the problem of how to manage external integration and outsourcing for competitive advantage has remained unsolved. This is also the situation with existing literature on product development. Reviewing the literature, Brown and Eisenhardt (1995) concluded that, while some studies of product development had shown that the participation of suppliers was important, the empirical literature was imprecise in testing the link between supplier involvement and performance, and was not clear exactly as to how or when suppliers should become involved in the development process.

What are possible sources of differences among firms that follow a collaborative mode of inter-firm relations? One of the potentially promising areas of investigation is in firms' own capabilities. Recently, a stream of strategy research has paid growing attention to organizational capabilities as a source of competitive advantage. Complementary to the view that emphasizes market and industry structure for competitive analysis (Porter, 1980), this stream, driven by the 'resource-based view of the firm,' stresses the importance of firm-specific capabilities as a source of inimitable and thus sustainable competitive advantage (Wernerfelt, 1984; Barney, 1986; Itami, 1987;

Dierickx and Cool, 1989; Prahalad and Hamel, 1990; Peteraf, 1993). Along with this stream, researchers have increasingly paid attention to features of internal organization, such as organizational structure, managerial processes, routines, and values, as a basis of firm-specific capabilities and competencies that are difficult for other firms to buy or imitate (Leonard-Barton, 1992; Teece and Pisano, 1994; Henderson and Cockburn, 1994).

Such a perspective of emphasizing firm-specific organizational capabilities hints at possible benefits from linking the analysis of internal organization to the research of inter-firm division of labor and relations, and reminds us of the issue of the level of analysis. As Rousseau (1985) pointed out, in studying organizations, researchers must explicitly address the role of level in organizational phenomena, and must properly specify their analytical model. According to Van de Ven and Ferry (1980), there are three levels of analysis for studying interorganizational relationships: (1) pairwise or dyadic interorganizational relationships, (2) interorganizational sets, and (3) interorganizational networks. In the context of automaker–supplier relations, the dyadic level analyzes relations between one automaker and one supplier. The set level analyzes relations between one automaker/supplier (a focal organization) and its multiple suppliers/customers. The network level analyzes relations among multiple automakers and multiple suppliers, including not only direct but also indirect relations.

While those three levels are certainly important and have been studied, many students of interorganizational relations have overlooked another level of analysis: internal organization. We could study inter-firm division of labor and relations by analyzing inside a focal organization (either an automaker or a supplier, or both). It is natural to pay attention to the factors external to a firm when researchers study the firm's collaborative activities with its external organizations. However, as Wheelwright and Clark (1992) pointed out, even where the primary source of technology is external, the firm needs some internal capabilities to evaluate the external work and to integrate it into the internal operations. When treating the firm as a black box, researchers would miss a critical area for the analysis of the inter-firm division of labor.

Hillebrand (1996), who stressed the importance of linking external and internal cooperation for the study of supplier involvement in product development, argued that internal and external cooperation had been studied entirely independent of each other.[1] Similarly, Kanter and Myers (1991) pointed out that while many analysts had described the conditions giving rise to alliances and the problems they entail, there had been remarkably little scholarly attention in the business policy area to the organizational behavior implications that ensue when a firm conducts more activities in collaboration with another firm.[2] In research on supplier involvement in the auto industry, only a few empirical studies have paid attention to automakers' internal organization for supplier involvement, and their attention has remained limited (Clark and Fujimoto, 1991; Liker *et al.*, 1995).

Research on product development has focused on internal organization as the level of analysis, whereas research on supplier relations has centered on inter-firm dyadic relations and sets. Positioned at an intersection of those two research domains, research on supplier involvement in product development should benefit from linking those different levels of analysis. Just as we need both the industry-based and the firm-based views to study strategy (Henderson and Mitchell, 1997), we need analysis at both the inter-firm and the intra-firm levels to study strategic management of outsourcing. This paper takes such an approach in building an analytical framework in the next section.

[1] He observed, for example, that Smith, Carroll, and Ashford (1995), in their introduction to the special issue of *Academy of Management Journal* on 'Intra- and Interorganizational Cooperation,' treated the two subjects as separate.

[2] It should be noted that there has been some research that links interorganizational relations and internal organizations, such as the research on boundary-spanning roles and activities (Thompson, 1967; Aldrich and Herker, 1977; Adams, 1980), organizational buying behavior (Strauss, 1962; Webster and Wind, 1972; Barclay, 1991), and interorganizational bargaining (Kochan, 1975). These researchers have focused on the relations between the characteristics of boundary units and the focal organization's behavior and environment. They discussed, for example, how environmental uncertainty affects the role and influence of a boundary unit in an organization, and how internal conflicts affect the decision of an organization's buying center or bargaining unit. They have not, however, turned toward internal organization's effects on performance and competitiveness of the inter-firm division of labor.

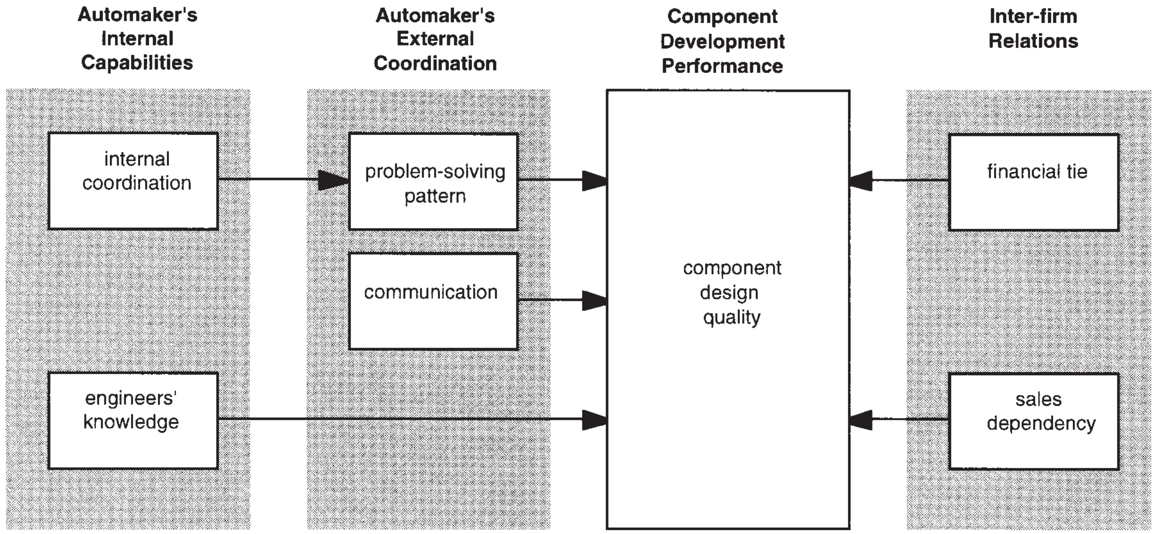

Figure 1. Analytical framework. Note: Controlling factors such as the supplier's capabilities and component types are omitted for simplicity

ANALYTICAL FRAMEWORK AND HYPOTHESES

Figure 1 illustrates this study's analytical framework. It contends that effective component development (higher component development performance) is associated with an automaker's external coordination with a supplier (problem solving and communication), internal capabilities (internal coordination and knowledge), and the nature of automaker–supplier relations, when controlled for the supplier's capability, the nature of the task, and other factors. The main dependent variable of this framework is the performance of a component development project jointly conducted by an automaker and a supplier. While component development performance measures are multidimensional, including operational efficiency (e.g., development speed (lead time) and engineering productivity (engineering hours)) and output effectiveness (e.g., component design quality), this paper focuses on design quality.

This framework examines the relations between component development performance and automakers' patterns for managing diverse activities for component development both externally and internally. Although some elements in this framework have been analyzed by previous studies, this study is probably the first attempt to systematically examine the linkages between different elements of supplier management and performance in a single framework to capture strategic implications. A key feature of this framework is its attention to both inter-firm and intra-firm levels. Note that the boundary of the firm is not addressed in this framework. It is given that an automaker outsources some portion of detailed design of a component to a supplier. Also, the inter-firm relations are assumed to be collaborative to the degree that an automaker has a supplier involved in component development.[3]

Now let me turn to each element and present hypotheses to be examined in this study.

Integrated problem solving

To jointly develop a component, an automaker and its supplier are involved in various tasks (Table 1), and the automaker needs to coordinate those tasks effectively with the supplier. One key element for such external coordination is the automaker's problem-solving pattern with the supplier. A central message of Clark and Fujimoto (1991) is the importance of *integrated problem solving* in product development. Viewing product development as a system of inter-

[3] Helper (1996) showed that suppliers are more likely to participate in product development when an automaker shows a certain commitment to the relationships. However, since there are some differences in the nature of inter-firm relations even when a supplier is involved, the effect of inter-firm relations on product development performance is analyzed.

Table 1. Component development tasks

	Automaker's tasks	Supplier's tasks	Joint tasks
Planning stage	Creation and presentation of development concept (performance, functions, and requirements)	Proposal on the best way to realize the development concept	Finding optimum fit between vehicle development concept and component design
Development and prototype stage	Presentation of the development objectives (schedule, specification, and target cost) Approval and issue of approved drawing Evaluation of component in complete vehicle Confirmation of ease of installation Feedback of the evaluation results Issue of design changes	Kaizen proposals Detailed design Drafting of approved drawing and detailed cost estimate Prototype production and cost estimate Tests on individual components' performance and functions Assessment of manufacturability under mass production conditions Implementation of design changes VE, Kaizen Cost and weight management	Setting development objectives Assessing ease of component installation on vehicle assembly line Agreement on the prototype production method Implementation of cooperative VE Confirmation of mass production specifications
Production preparation stage	Sourcing decision Tooling order Preparation of basic inspection standards Final confirmation of the ease of installation Production validation tests (on the vehicle)	Implementation of tooling Production validation tests (on individual component) Preparation of detailed inspection standards	Supply contract signed (including quality assurance) Assessment and improvements of mass production processes

Note: This table shows typical task assignments for 'black-box components.' VE = Value Engineering.
Source: Adapted with some modifications from Japan Automobile Manufacturers Association, Inc. and Motor & Equipment Manufacturers Association (1991).

connected problem-solving cycles, Clark and Fujimoto demonstrated that effective product development requires the integration of problem-solving activities across different functional groups and engineering disciplines from the earlier stages of development. Without such integration, the automaker could not achieve a high level of product integrity (Clark and Fujimoto, 1991) in an efficient manner. While their message was implied to apply to effective development of a new vehicle, it is also suggestive for effective component development.

Required for effective component development is integrated problem solving for component coordination and product-process and design-cost linkages. First, 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.[4] The key is that better coordination cannot be achieved by merely putting good individual components together; related components should be integrated with mutual adjustments. Second, effective component development needs to link *product and process* engineering as well as *design and cost* consideration in order to achieve a lower

[4] An individual component should be coordinated with other related components both structurally and functionally. 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. 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.

cost, a better design for manufacturability, and a higher conformance quality. In other words, a better design of a component requires solving engineering problems in a manner that integrates the design of related components, the manufacturing process, and cost management.

Furthermore, such integration should be pursued from the earlier stage of component development. Front loading of problem-solving activities would allow engineers to examine potential problems as much as possible at the earlier stage. Such efforts could reduce otherwise unnecessary design changes at the later stages, which are more costly particularly after releasing tooling orders, improve design and manufacturing quality, and shorten engineering lead time (Fujimoto, 1997).

Hypothesis 1: A component development project in which an automaker exercised a higher level of early, integrated problem solving with a supplier should exhibit a higher level of component design quality.

Communication

Along with problem solving, communication is another key variable for product development research (Brown and Eisenhardt, 1995). The importance of both internal and external communication for the performance of product development organizations has been long emphasized by various researchers (Allen, 1977; Ancona and Caldwell, 1992).

Obviously, when a supplier is involved in product development, effective coordination through frequent communication between the automaker and the supplier is critical to successful product development. Dyer (1996a) reported that Toyota and Nissan had more frequent face-to-face contact with their suppliers than U.S. automakers, and that this contributed to their shorter model cycle. He also found that the two Japanese automakers had more guest engineers at their sites than the U.S. firms, indicating the importance of extensive communication between co-located engineers.

Hypothesis 2: A component development project in which an automaker and a supplier communicate face-to-face more frequently should exhibit a higher level of component design quality.[5]

Knowledge

Although outsourcing product development to suppliers can bring many benefits as reported, it does not come without risks. Clark and Fujimoto (1991) pointed out that assemblers dependent on suppliers' engineering capabilities may lose some negotiation power, and losing engineering expertise in core component areas can render a car maker vulnerable in technological capability over the long term. Without appropriate knowledge, which is one of the key elements associated with organizational capabilities (Leonard-Barton, 1992; Nonaka and Takeuchi, 1995), automakers cannot evaluate suppliers' products and capabilities and thus they can become more dependent on them.

As Fine and Whitney (1996) have argued, it is important, therefore, to distinguish *dependence for capacity* and *dependence 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 supplier to fill the gap. It is possible for automakers to retain knowledge, even while outsourcing the components in development and manufacturing, if its dependency is for capacity, not for knowledge.

Empirically, Liker *et al.'s* (1995) survey revealed that about 22 percent of U.S. subsystem suppliers complained that their customer lacked technical knowledge. In comparison, about 9 percent of the Japanese suppliers made this complaint, and only about 5 percent of Toyota's suppliers mentioned such. This indicates that the level of component knowledge indeed varies among automakers.

Hypothesis 3: A component development project in which an automaker's engineers had a higher level of knowledge about the component should exhibit a higher level of component design quality.

[5] Communication frequency, however, may not always be an indicator of effective management—more communication may be an indication that there are more problems to solve or a lack of mutual understanding. Observing more frequent communication between U.S. automakers and their suppliers than the Japanese in their survey data, for example, Liker *et al.* (1995) argued that frequency of communication does not necessarily reflect the quality of the communication. This issue will be empirically examined later.

Internal coordination

Another important element of automakers' internal capabilities is internal coordination. The literature on boundary spanners and organizational buying behavior has shown that those units that deal with external organizations face conflicts with other units within its organization. Adams (1980) pointed out that boundary-spanning units face two types of conflicts—one with outsiders and the other within insiders—and are 'at the crunode of a dynamic, dual conflict in which elements of one conflict become inputs to a second conflict, of which some elements become new inputs to the first, perhaps for several cycles.' Also, Hillebrand (1996) argued that in order to perform well in external cooperation, the firm has to cooperate internally as well. In other words, to effectively carry out product development with suppliers, an automaker needs to resolve conflicts not only *externally* with a supplier but also *internally* among various internal departments.

Supplier involvement in product development requires much more extensive coordination within firm boundaries than the traditional arm's-length relationships. In the traditional relationships, suppliers are rarely involved in product development and primary interactions between an automaker and its supplier are assigned to the former's purchasing department and the latter's sales department. To manage supplier involvement, by contrast, various groups and departments inside an automaker need to coordinate various tasks with each other. The coordination involves engineering, purchasing, production, and quality assurance departments.

Coordination within the organization is not an element of direct interactions with external suppliers. However, without effective internal coordination, an automaker cannot achieve a higher level of integrated problem solving with a supplier. Internal coordination would thus affect component development performance indirectly through problem-solving pattern.

Hypothesis 4: A component development project in which an automaker exercises a higher level of internal coordination should exhibit a higher level of integrated problem solving.

Inter-firm relations

Another important factor is the nature of inter-firm relations between an automaker and a supplier. As discussed in the previous section, many studies have paid close attention to this element.

There are multiple dimensions for inter-firm relations. One is the degree of an automaker's ownership of a supplier. In Japan, it is not uncommon for an automaker to own a certain portion of its supplier's stock. It is likely that when the automaker has some financial control of the supplier, it can control the supplier's behavior and the component's price, thus positively affecting supplier management and performance. Another dimension is a supplier's sales dependency on an automaker. When a supplier is highly dependent on an automaker in sales, the automaker may have power to ask more of the supplier's efforts in component development (Pfeffer and Salancik, 1978), thus positively affecting performance.

Hypothesis 5a: When an automaker owns a part of a supplier's stock, a component development project should exhibit a higher level of component design quality.

Hypothesis 5b: The higher a supplier's sales dependency on an automaker, the higher the level of component design quality of a component development project.

Note that many studies have found the importance of the long-term nature of the relations. However, this study is primarily concerned with differences within the mode of long-term relations, and there was indeed little variance in this dimension among Japanese automakers in this study's sample. This study therefore does not pay attention to the length of inter-firm relations.

SAMPLE AND DATA

Sampling design

The empirical setting is the Japanese auto industry, which has some advantages for this study's sample. First, since the Japanese auto industry pioneered supplier involvement in component development, the practice has been widely diffused. Second, Japanese automakers and suppliers are widely seen to have cooperative, long-term inter-firm relations, hence providing a convenient empirical field for exploring differences in managing collaborative inter-firm relations.

When the subject involves a pair of firms, rather than a single firm, empirical research needs a careful sampling design. To control for the impact of the difference in suppliers' capability and component types, I selected those suppliers that design and manufacture their components for many automaker customers, and collected from those suppliers data on differences among automakers in their supplier management patterns, capabilities, and performance. When a particular supplier provides the same component to a number of automakers, the performance difference among those automakers in component development performance would be more attributable to the variance in their patterns and capabilities for supplier management. Those suppliers are a preferable data source since they can comparatively observe their customers through everyday interactions.

This sampling design, however, does have some disadvantages. First, it excludes certain types of components from the sample. Those components where automakers procure components from dedicated suppliers cannot be included in the sample. To reduce the possibility of idiosyncratic data dependent on the type of component, I made an effort to include a variety of components within this constraint. A second possible disadvantage is that component manufacturers serving many customers may transfer critical technological and managerial information from one automaker to others, thereby reducing the variance among automakers. In fact, according to my interviews, one supplier's strategy is to first develop a new technology with a leading automaker and then use it for others later. Another supplier even teaches effective ways of managing suppliers to some automakers based on its experiences with leading automakers. Also, some automakers intentionally ask suppliers to bring only component designs already verified by other leading automakers.

However, if the data from this sampling design find some differences among automakers, it can provide more robust evidence to identify strategic elements of automakers' supplier management. It is interesting to identify what kinds of capabilities and knowledge are inimitable even when there are favorable opportunities for auto companies to learn from competitors through the mechanism of common suppliers. This sampling design therefore provides a preferable, if not perfect, setting for a natural experiment to examine the proposed framework in a conservative manner.

Research methods and data

Since most of the necessary data are not publicly available, this study relied on interviews with automakers and suppliers, and a questionnaire survey to suppliers as the primary methods of data collection. Company documents and publicly available materials are also used as supplementary sources.

The purpose of the supplier survey was to collect data on automakers' supplier management patterns and component development performance, as observed by suppliers with multiple customers. Based on IRC's (1997) data on component transactions in the Japanese auto industry, I selected 15 suppliers, which 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 1996. After I contacted and visited them, nine suppliers agreed to participate in the survey with a strict confidentiality agreement. I distributed the survey to them in April 1997. Each supplier was asked to select one component development project that was recently done for a new vehicle, for each of its major customers. While the component for each supplier was specified by me, 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.

Table 2 reports the final responses. Each supplier gave five cases on average, ranging from three to seven and providing 45 cases in total. All nine Japanese automakers are in the sample, but some of them have few cases. 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 engine, brake, chassis, body, and electrical systems. Most suppliers were either the largest or second largest

Table 2. Supplier questionnaire 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	7	6	2	3	1	5	3	6

The names of the suppliers and the automakers in the sample cannot be disclosed due to the 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.

supplier in Japan in production volume for the component.[6]

The year of market introduction of the sample vehicles ranges from 1989 to 1997, with most introduced during the past 5 years (mean: 1995). All the sample suppliers had designed and manufactured the components for each automaker in the sample for more than 10 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 percent, 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.

I also conducted 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.

[6] The characteristics of the sample suppliers were as follows: the market share in the component ranges from 20 percent to 54 percent (mean: 35%), and the approximate number of employees from 700 to 10,000 (3800).

Variables

Table 3 lists the variables to be used in the following statistical analysis. Details of variable construction and measurement are explained in Appendix 1. Below I briefly describe key research variables.

CDQ (component design quality), this study's dependent variable, 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.

PSP measures the level of early, integrated problem-solving process 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. 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

Table 3. List of variables

Area	Construct	Variable
Component development performance	Design quality	CDQ: Design quality of the component
A's external coordination with S	A's problem-solving pattern with S	PSP: A's early, integrated problem-solving pattern with S
	Communication	COM: Communication frequency between A and S
A's internal capabilities	Level of A's engineers' knowledge	EKN: Engineers' knowledge EKN1: Component-specific knowledge EKN2: Architectural knowledge
	Level of A's internal coordination	INC: Internal coordination INC1: Internal coordination within engineering depts INC2: Internal coordination between eng. and purchasing INC3: External consistency toward S
Inter-firm relations	S's dependency on A	SLD: S's sales dependency on A
	Financial tie	STK: A's ownership of S's stock
Task and tools	Technological newness	NWT: Technological newness in product or process of the component for S
	Computer usage	CMP: Level of CAD/CAE usage for the component development

A: automaker; S: supplier.
A variable with a number at the end is a subcomponent of the variable of the same name without a number.
Details of variable specifications and measurement are described in Appendix 1.

the automaker's engineers and purchasing staff and the supplier's engineers and sales staff.

EKN measures the knowledge level of the automaker's engineers about the component, and is the mean of two subcomponents: engineers' component-specific knowledge (EKN1) and architectural knowledge (EKN2). EKN1 measures the level of knowledge specific to a component, including technology, cost, and manufacturing process. EKN2 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 component's coordination and linkage with other components, and was thus named architectural knowledge (Henderson and Clark, 1990).[7] INC measures the level of the automaker's internal coordination, and consists of three subcomponents: internal coordination within engineering departments (INC1), internal coordination between engineering and purchasing departments (INC2), and external consistency of the automaker's various engineering functions and purchasing department toward the supplier during the project (INC3).

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.

Two control variables were constructed: NWT and CMP. NWT (technological newness of the project) is set to 1 if the supplier used a new technology in product or 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.

There remain two other factors that might affect component design quality. Whether an automaker can develop a better component is partly dependent on the capability of the partner supplier in component development and manufacturing, and the nature of the component in ques-

[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.

tion. In fact, ANOVA results indicate that in some variables the variance *between* respondent suppliers was significantly greater than *within* (see Appendix Table 2), suggesting heterogeneity across suppliers (components). To control for supplier (component) effect, each variable was transformed by mean centering within each respondent supplier. This treatment, for which the sampling was designed, neutralizes supplier (component) heterogeneity, and thus directly examines this study's main research interest: variance in automakers' supplier management and its effect on performance when a supplier is shared with competitors. However, on the other hand, this transformation lowers variance 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 heterogeneity.[8] As discussed in Appendix 2, all the three approaches provided similar results. In the following sections, I focus on the findings from the first approach.

RESULTS

Component design quality

Table 4 reports the regression results for CDQ. The results of Model 1 basically support Hypotheses 1, 2, and 3: integrated problem-solving pattern (PSP), communication frequency (COM), and the level of engineers' knowledge (EKN) are all positively related to component design quality (CDQ), with other things being equal. As shown in Appendix Table 3, COM has a negative correlation coefficient with PSP and EKN, suggesting that communication may sometimes be needed because engineers did not have enough knowledge about the component (low EKN) or did not solve the problems in an integrated manner (low PSP). However, the regression results imply that when PSP and EKN are controlled for, more frequent communication would lead to better performance. The finding that these three variables for automakers' patterns of supplier management are all important in developing a better component echoes the following comments by interviewees:

> Company A is a relatively small automaker in Japan, and its engineers do not have a high level of technological knowledge about our component. This company's strategy is communicating a lot. Their engineers come to our site and our engineers visit their site much more frequently than in the case of other automakers. We think that's their strategy to compensate for their limited engineering knowledge (supplier engineer).

> Automaker B's engineer for our component had extensive knowledge of the component, and was a great communicator, coming frequently to our site not only to have business meetings but also to play golf and 'karaoke' with our engineers. Yet the outcome of the project was far less satisfactory for us. It was largely due to his style of project management. He occasionally changed his requirements drastically in the later stage of the project for one reason or another, such as using a newly available technology. We could not spend enough time to examine and verify such changes and ended up with a problematic component design (supplier engineer).

In Model DQ1, supplier's sales dependency on the automaker (SLD) has a positive and statistically significant coefficient. 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. This supports Hypothesis 5b.[9] On the other hand, the automaker's ownership of the supplier's stock (STK) has a negative effect on component design quality, contrary to Hypothesis 5a, although not statistically significant. My follow-up interviews suggested that a financial tie with an automaker may make the supplier feel secure about the business with the automaker. More secured business would not induce as much effort as when the supplier does not have a financial tie and has

[8] I would like to thank a referee for identifying this issue and suggesting alternative means.

[9] Nobeoka (1995) found that the larger the number of a supplier's customers is, the better the supplier performs, since the supplier could take advantage of greater scale economy and diversified customer information. Nobeoka examined the relationship between the number of customers and the financial performance for a supplier, whereas this study (Hypothesis 5b) dealt with the relationship between the percentage of a supplier's sales for a customer and the component development performance. Thus the two studies cannot be compared directly. Yet, there seems some contradiction between them, since a wider scope of customers would usually reduce the sales dependency on each customer. Unfortunately, I could not examine the effect of customer scope in this study, since shared suppliers were selected by design and therefore there was no variance in customer scope for each sample component.

Table 4. Regression results for component design quality

Model #	DQ1	DQ2	DQ3	DQ4
Intercept	0.040	0.041	0.026	0.029
NWT: New technology	−0.179	-0.185	-0.290*	-0.270
	(0.162)	(0.163)	(0.158)	(0.175)
CMP: CAD/CAE usage	-0.172	-0.149	-0.190	-0.152
	(0.306)	(0.310)	(0.287)	(0.296)
SLD: Sales dependency	0.857***	0.870***	0.675**	0.720**
on the automaker	(0.296)	(0.299)	(0.287)	(0.304)
STK: Stock ownership	−0.173	−0.177	−0.097	−0.114
by the automaker	(0.110)	(0.111)	(0.108)	(0.116)
PSP: Integrated problem-	0.242**	0.231**	0.362***	0.358***
solving pattern	(0.107)	(0.109)	(0.112)	(0.116)
COM: Communication	0.021***	0.022***	0.018***	0.019***
frequency	(0.004)	(0.005)	(0.004)	(0.004)
EKN: Engineers'	0.291**		0.139	
knowledge	(0.133)		(0.139)	
EKN1: Component-		0.104		0.013
specific knowledge		(0.092)		(0.096)
EKN2: Architectural		0.175**		0.099
knowledge		(0.078)		(0.080)
NWT × EKN			1.181**	
			(0.479)	
NWT × EKN1				0.686*
				(0.343)
NWT × EKN2				0.444
				(0.475)
Adjusted R^2	0.457	0.450	0.523	0.507
R^2 change			(DQ3)–(DQ1)	(DQ4)–(DQ2)
			0.066**	0.068*

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

to compete with other potential suppliers to win the business.

Model DQ2 estimates the effect of sub-components of EKN. It has 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 percent level, and its standardized coefficient (beta) is 60 percent smaller than EKN2's. If we understand that component-specific knowledge is provided by the supplier, who is involved in the project because of its expertise in the 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.

Further analysis has uncovered a vital role of engineers' knowledge when a project involves new technology. Model DQ3 adds the interaction term of NWT and EKN to Model DQ1. While NWT has a negative sign, the interaction term has a positive sign. A change in R^2 from Model DQ1 to DQ3 is statistically significant. 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 DQ4 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 DQ2 is statistically significant. This seems to indicate that engineers' component-specific knowledge plays a more positive effect than architectural knowledge in the case of using new technology.[10] How important technological lead-

[10] The standardized coefficient for NWT × EKN1 (component-specific knowledge) is 100 percent larger than for

ership at the component level is in today's auto industry is beyond this study's scope. However, if an automaker wants to lead in or keep up with component innovations, it is important that its engineers have a high level of both architectural and component-specific knowledge.

Integrated problem-solving process

As shown above, an automaker's problem-solving process with a supplier (PSP) has a significant effect on component design quality. An early, integrated problem-solving process enables the automaker and the supplier to examine and solve many problems, including not only those specific to the individual component design but also those related to coordination with other components, cost–design linkage, and design for manufacturing, from an earlier stage of the development project. Engineers cannot foresee and solve every possible problem at the beginning, but front loading would allow engineers to avoid otherwise unnecessary problems in later stages and thereby focus on more value-added problem solving. For example, supplier engineers commented in my interview:

> We cannot avoid design changes at the later stage, whoever the customer is. That's our life. However, the quality of design changes varies by automaker. When a customer emphasizes early problem solving, we are quite busy at the earlier stage but we have a smooth process at the later stage and the production launch goes smoothly. We have to make many design changes for such customers, but the purpose is to improve the design quality from 80 percent to 100 percent satisfaction. If a customer leaves many problems unsolved until the later stage, we are very busy approaching the deadline just making design changes to satisfy the minimum design quality (supplier engineer).

> One automaker has us involved earlier than others. We are called in while the vehicle's styling is not fixed in order to invite the voice of the supplier who will actually manufacture the component. Other automakers tend to have suppliers involved after or just before fixing the styling, probably partly for confidentiality reasons. Earlier involvement helps us propose a better idea, and the automaker incorporates it into the development and examines many problems at the earlier stage (supplier engineer).

> When we are required to make too many design changes at the later stage, we cannot come up with a good design, nor achieve cost reductions. If we could solve more problems at the earlier stage, we could come up with a better design with fewer constituent parts, and this would lead to lighter weight, lower cost, and higher conformance quality (supplier engineer).

What factors would facilitate an integrated problem-solving pattern? Table 5 displays regression results for integrated problem-solving process (PSP). Model PS1 shows that integrated problem-solving process (PSP) is positively related to the level of internal coordination (INC). The results support Hypothesis 4 and demonstrate the importance of internal capability for effective supplier management.[11] Interviewees at some suppliers explained that they were sometimes required to make design changes at a later stage because some automakers found it easier to request the supplier to make adjustments than to coordinate internally with other engineering departments even if the latter approach could bring about a better solution. This observation indicates that a limited ability for internal coordination is likely to hamper an effective problem-solving process with the supplier. In Model PS1, SLD has a positive and significant effect on the problem-solving pattern. This may suggest that a higher sales dependency would facilitate the automaker's integrated problem-solving process

NWT × EKN2 (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 DQ2) is significant at the 5 percent level for NWT × EKN1 (adjusted R^2 was 0.509, when this term was included), but not at the 10 percent level for NWT × EKN2 (0.464). These results also indicate that component-specific knowledge plays a more important role than architectural knowledge for those projects involving new technology.

[11] It should be noted, however, that internal coordination may not always positively affect component design quality. As shown in Appendix Table 3, INC has a negative correlation with COM (communication frequency), indicating that higher INC is associated with lower COM, which would lead to lower CDQ (Table 4), other things being equal. The negative correlation between INC and COM may be observed because when an automaker's engineers spent more time on internal coordination, they do not have enough time for external communication (another possible reason would be that effective internal coordination would reduce the necessary amount of communication with a supplier). In fact, when INC is regressed directly on CDQ, INC has a positive but not statistically significant coefficient, whereas when it is regressed together with COM on CDQ, it has a positive and statistically significant one. To capitalize on a higher level of internal coordination, an automaker needs to keep the level of communication with a supplier.

Table 5. Regression results for integrated problem-solving process

Model #	PS1	PS2
Intercept	0.012	0.012
NWT: New technology	−0.151	−0.071
	(0.223)	(0.227)
CMP: CAD/CAE usage	0.407	0.470
	(0.421)	(0.420)
SLD: Sales dependency on the automaker	0.789**	0.936**
	(0.389)	(0.397)
STK: Stock ownership by the automaker	−0.065	−0.103
	(0.150)	(0.151)
INC: Internal coordination	0.337***	
	(0.104)	
INC1: Coordination within engineering		0.215*
		(0.118)
INC2: Engineering–purchasing coordination		0.210**
		(0.080)
INC3: External consistency		−0.131
		(0.088)
Adjusted R^2	0.247	0.259

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

through the supplier's higher commitment and/or the automaker's higher power to request more information and efforts of the supplier from the beginning.

Model PS2 estimates the effect of three sub components of internal coordination: INC1 (coordination within engineering), INC2 (coordination between engineering and purchasing), and INC3 (external consistency of engineering and purchasing departments toward the supplier). The results show that coordination both within engineering and between engineering and purchasing has a positive and statistically significant effect on PSP, while external consistency does not.

Sources of heterogeneity

The foregoing analysis provides two sets of intriguing findings. One is the relationships among variables, as identified and discussed above. The other is the fact that there still remain variances across projects as well as across automakers in supplier management patterns despite the sample projects and automakers share the sample suppliers.[12] As mentioned before, 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.

Why do we still observe heterogeneity under those apparently favorable conditions for understanding and copying effective practices? 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 revealed that some practices are difficult to imitate since they often involve long-term career development policies, conflict with

[12] To examine if there is any 'automaker effect' I included dummy variables for automakers in the regressions discussed above. None of them, whether entered separately or together, and whether with supplier management variables or without, were statistically significant. I also examined the differences among automakers in their scores for key supplier management variables. Most of the differences were not statistically significant at the 10 percent level according to the Bonferroni test, probably because the sample size for each automaker was limited (one to seven). However, my interviews with suppliers confirmed that there were some distinctive differences among automakers. A couple of particular automakers outperformed others in some critical supplier management variables in their observation, and those particular automakers were consistently better than others on average in supplier management variables in the survey results, although the differences were not statistically significant.

existing corporate values, and trade-offs with other objectives.

For example, a well-known approach to improve internal coordination within an engineering division is to have a capable and influential product manager who could coordinate and solve problems across engineering functions, the so-called 'heavyweight product manger' (Clark and Fujimoto, 1991). However, heavyweight product managers are required to play various roles, such as a direct market interpreter, multilingual translator, direct engineering manager, and concept infuser, and they tend to have been trained as apprentices by senior project managers over a long period of time (Clark and Fujimoto, 1991). Such a wide range of expertise cannot be obtained within a short period of time. As Dierickx and Cool (1989) point out, a particular asset involves 'time compression diseconomies' and thus provides early-mover advantages.

Also, the influence or power of project managers is not determined solely by formal organizational structure. At some automakers, where product managers exercise relatively strong power, there is a tradition that stresses the importance of product managers in product development. One interviewee at such an automaker said, 'In our company, product leaders have had absolute power for a long time.' However, at other automakers, traditional values have long emphasized technological superiority in individual technologies, providing functional managers with more authority and power in relation to individual engineers. In such cases, it is difficult for product managers to establish influence. As Leonard-Barton (1992) argues, values and norms constitute a critical dimension of a firm's core capability but can also be a source of core rigidity. When a firm needs technical skills, which are traditionally less well respected in the company, such a tradition has an inhibiting effect. Those automakers that have historically valued functional expertise would find it difficult to imitate the practice of heavyweight product managers, even if the effectiveness of this practice is well publicized.

Another approach to improve coordination among engineering functions and enhance architectural knowledge is to rotate individual engineers across different types of components over time (Nonaka and Takeuchi, 1995; Aoki, 1990; Kusunoki and Numagami, 1997). Through own 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. However, as in the case of capable product managers, it takes time for an automaker to have individual engineers experience a wide range of component types. Furthermore, 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, if development projects are carried out by engineers without much experience in the assigned components, efficiency and output quality may be sacrificed. In fact, a scatter plot of architectural and component-specific knowledge in Figure 2 shows a slight, though not statistically significant, trade-off relation between two types of knowledge. It is not easy for automakers' engineers to have a high score for both types.

However, there is an automaker whose engineers score higher for both architectural and component-specific knowledge on average. According to my interviews, this automaker has a definite policy of rotating engineers across different components over a certain period of time. Yet, this automaker also takes other measures to retain component-specific knowledge. First, the range of rotation is limited. For example, engineers in the chassis design division are usually transferred within the division and rarely transferred to other divisions, such as the engine and body design divisions. Also, this firm recently started to establish a new career path where individual engineers could stay, if they want, in the same component over a very long period of time as a specialist. Further, this automaker attempts to accumulate component-specific knowledge through documentation such as design standards and know-how reports. When engineers are assigned to a new component, they take internal training classes for the component. Such training classes are not frequently offered at other automakers. In this manner, this automaker seems to have been able to enhance both architectural and component-specific knowledge. Without a set of these long-term, well-balanced mechanisms and policies, an automaker cannot have a high level of both architectural (EKN2) and component-specific knowledge (EKN1), thus scoring high in total (EKN).

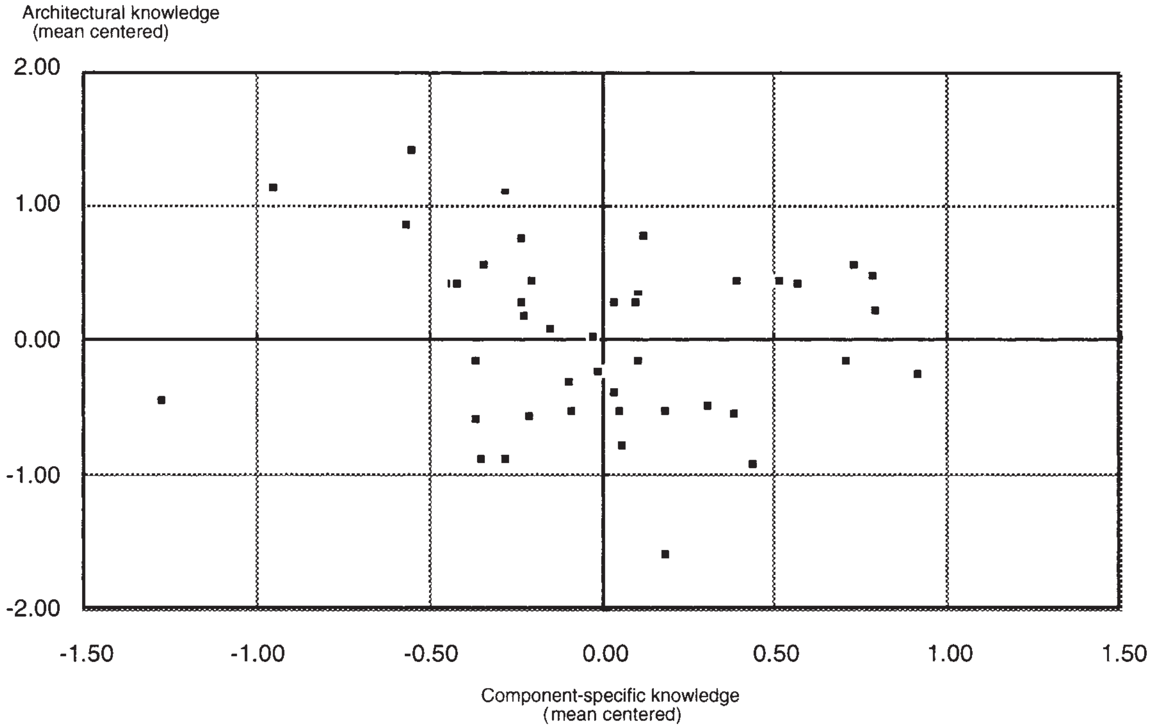

Figure 2. Architectural knowledge vs. component-specific knowledge. Note: Correlation coefficient between the two types of knowledge is -0.1517 ($p = 0.320$). Source: supplier survey

CONCLUSION

Overall, the results imply that *outsourcing does not work effectively without extensive internal effort*. To gain competitive advantage from outsourcing, managers should '*Ask not what your suppliers can do for you; ask what you can do with your suppliers*.' The quality of the component design developed jointly by an automaker and a supplier is related to three areas of the automaker's supplier management: problem-solving pattern, communication pattern, and knowledge level. In particular, the automaker's early, integrated problem-solving process with the supplier, frequent face-to-face communication between the automaker and the supplier, and the level of architectural knowledge for component coordination by the automaker's engineers, all have a positive effect on component design quality. The analysis has further indicated that the automaker's integrated problem-solving process with the supplier is related to effective internal coordination inside the automaker's organization—within various engineering functions and between engineering and purchasing functions, implying that effective external coordination needs effective internal coordination.

While collaborating with suppliers would probably bring an organization some benefits such as reducing fixed costs and using specialists' expertise, a firm still needs to develop, maintain, and improve its own capabilities to effectively coordinate diverse activities both externally with a supplier and internally within its own organization in order to outperform competitors. To build those capabilities, automakers need to design and implement a wide set of organizational mechanisms. These mechanisms cover both internal and external management, both top managers (influential product managers) and front engineers (individual engineers with broader task experiences), and from personnel policies (engineers' career development) through project management (integrating problem solving) to corporate values (informal influence of product managers). Because these mechanisms may often involve long-term efforts, conflict with existing corporate values, and face trade-offs with other objectives, it is difficult for some automakers to imitate effective practices and capabilities in spite of favorable conditions for learning from competitors through shared suppliers.

The nature of inter-firm relations also has some impact on component design quality by affecting the supplier's motivation. The more dependent the supplier is on the automaker for sales, the more effort the supplier seems to make. Interestingly, an automaker's ownership of a supplier's stock has a negative, though not statistically significant, effect on performance, probably because the financially tied relationships make the supplier feel more secure.[13]

The finding that integrative capabilities (architectural knowledge, integrated problem solving, and internal coordination) are a critical source of competence implies that firms should take into consideration how to hold such capabilities internally when determining its boundaries. When a firm relies heavily on outside suppliers for integrative capabilities, it may lose its ability to differentiate itself from competitors who may also share the same suppliers. This argument sounds a warning about the recent trend at some automakers to procure from ‘system’ or ‘module’ suppliers, who design, coordinate, and supply a larger set of components as a system/module.[14] This trend, on the other hand, could be beneficial to suppliers.

Different from Lawrence and Lorsch (1967) and Henderson and Cockburn (1994), who showed that both integrative capabilities and specialized capabilities for individual functions and components (component-specific knowledge) are important, this study has found that automakers' component-specific knowledge is generally less important for component design quality in regular projects. This is because this study deals with the inter-firm division of labor in which component-specific knowledge is mainly provided by the supplier. Indeed, this is one important reason why suppliers are involved in development. Yet, at the same time, component-specific knowledge seems to play an important role for projects using new technologies. Efficient partitioning of knowledge domains between an automaker and a supplier may not work effectively for developing technologically new components. This observation is consistent with Cohen and Levinthal's (1990) concept of absorptive capacity. They argued that some firms conduct basic research because such investment in deep, specialized knowledge equips the firm with the capacity to evaluate, assimilate, and apply new technologies to commercial ends when the technologies are available outside. In a similar vein, this study's results suggest that although component-specific knowledge is not important for every project, investment in this knowledge would enable the automaker to quickly evaluate and use new component technologies when available.

This study has demonstrated the importance of linking different levels of analysis. Not only *inter-firm* variables, on which most existing inter-organizational research has focused, but also *intra-firm* variables are important in studying the inter-firm division of labor and relations. This finding echoes recent argument in strategy research that both the industry-based view and the firm-based view are important for understanding competitive advantage (Henderson and Mitchell, 1997). Teece and Pisano (1994) argued that both internal coordination and external coordination are important for the firm's competence. This study has indicated that they are related to each other—the former facilitates the latter. Internal coordination is important not only for managing the intra-firm division of labor (Lawrence and Lorsch, 1967; Clark and Fujimoto, 1991; Henderson and Cockburn, 1994) but also for managing the inter-firm division of labor.

While this study provides the foregoing implications, one should carefully examine how generally applicable some of this study's findings are. Also, some questions have remained unanswered.

[13] This does not necessarily mean that a financial tie has only a negative effect on component development performance. Automakers tend to give a larger sales volume to financially affiliated suppliers (see a positive correlation between SLD and STK in Appendix Table 3), and a higher sales dependency encourages more efforts of the supplier. Also, according to my interviews, a close, long-term relations based on a financial tie would allow the automaker and the supplier to have more open, earlier, and extensive exchange of information. Yet, the statistical results suggest that when those possible benefits of financial ties are controlled for, a financial tie by itself may have a negative effect, or, at least, does not have a positive effect, due to a reduced competitive pressure. Some Western automakers have reduced the number of suppliers drastically, moving from competitive sourcing from multiple suppliers toward single sourcing from a particular supplier. The results of this study point out a possible danger of such policy: limited competitive pressure may reduce the supplier's motivation.

[14] For example, the *Financial Times* reported that because suppliers of vehicle parts have been concentrated in the hands of just a few specialists, vehicle makers are questioning the benefits to them of this trend (Financial Times Review of the Auto Industry, June 12, 1997: 1). This concern apparently is based on the issues of losing architectural knowledge and competitive pressure by relying on a very limited number of system suppliers.

First, this study draws on supplier relations in the Japanese auto industry. Although focusing on Japan has some advantages as discussed before, one may be concerned that the Japanese supplier management may be an outlier and thus less relevant for other countries. Yet, as previous studies have shown, non-Japanese automakers and suppliers have been building up similar relations, and also outside the auto industry there is considerable historical evidence of non-Japanese firms that have emphasized stable vertical relationships (Martin, Swaminathan, and Mitchell, 1998). In this sense the implications of this paper are applicable outside Japan wherever firms need to compete while outsourcing critical activities to their suppliers. On the other hand, generalization across industries should be done more carefully. A high level of integrative capabilities, for example, may not be always important. The importance of such capabilities depends on the nature of the product as well as innovation. For products based on modular design with standardized interfaces (Ulrich, 1995), such as personal computers and bicycles, architectural knowledge may be of little importance, and an effective pattern of supplier management may be different from what this study has identified (Fine, 1998). Also, when a firm faces an innovation which involves changes in the product architecture, existing architectural knowledge may become an impediment, rather than an asset, since architectural knowledge is often deeply embedded in the firm's organizational values, structure, and processes, and cannot be easily changed (Henderson and Clark, 1990; Leonard-Barton, 1992).

Second, this study examined relatively simple hypotheses on relations among component development performance, automakers' internal capabilities, and automaker–supplier relations, based on a cross-sectional data set. However, it is likely that these factors interact with each other in a more complicated and dynamic manner.[15] For example, a certain nature of inter-firm relations would allow automakers to improve certain internal capabilities, which then improve the quality of inter-firm relations in the next stage. We need to further investigate how much and what types of internal capabilities and inter-firm relations are important for the effective inter-firm division of labor in what situations, and how they interact with each other over time. Extending this study to different types of products and industries in a dynamic setting is a promising direction for future research. Furthermore, it should be remembered that the decision to outsource was given and out of scope in this study. The examination of the relationship between the outsourcing decision and the level of internal capabilities would be an important area of further research.

Finally, this study did not examine the cost of policy implementation. Although certain practices are found effective for component design quality, I cannot evaluate the impact of those practices on financial performance without cost analysis. And costs should be measured at both the automaker and the supplier. For example, additional analysis, though not reported in this paper, has indicated that the automaker's knowledge level and communication frequency, both of which contribute to component design quality, result in the supplier's longer engineering hours and thus entail more costs for the supplier. Also, while this study demonstrated the importance of having a high level of both architectural and component-specific knowledge, it has remained unknown whether it is possible to pursue both types of knowledge without incurring heavy costs. Without full cost-benefit analysis, effectiveness of particular management practices cannot be fully examined. It is difficult to fully capture costs and benefits, but such analysis should be critical and deserves extensive research efforts.

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[15] More complicated relations among variables could be examined by a structural modeling approach, such as LISREL. However, the small size of this study's sample does not allow me to take such an approach. Instead, this study has focused on examining hypotheses derived from past research in a straightforward way.

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APPENDIX 1: VARIABLE CONSTRUCTION AND MEASUREMENT

Most variables used in the statistical analysis were constructed based on data 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 Appendix Table 1.

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) and INC (INC1, INC2, and INC3). 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[16] 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.

It should be noted that many variables are based on the respondents' perceptions. Perceptual measurement raises a concern with bias and reliability of measurement. However, those variables for the automakers' supplier management patterns are otherwise difficult to measure. The respondent suppliers were in the best position to observe the patterns comparatively through everyday operations with multiple customers.

There could be common measure bias.[17] The same respondent was asked to answer subjective questions about both the level of component development quality and the determinants of the quality. For example, item 17 in PSP resembles item 10 in CDQ (see Appendix Table 1). It would be preferable if we could measure component development performance more objectively from an independent source. However, respondent suppliers were very strict about confidentiality. They answered the survey on the condition that the names of sample models and customers be kept anonymous. This restriction made it impossible for me to seek data sources outside respondent suppliers. Also, whereas performance of vehicle development could be measured based on publicly available information, such as market shares, sales growth, and consumer reports, similar data were not available for individual components. Given these constrains, the supplier survey was the only data source available to measure most constructs of this study.[18]

The following nature and procedures of the survey seem to have reduced the risk of bias, and improved reliability. First, the respondents were asked to evaluate outside organizations (customers) rather than own organization and colleagues, mostly about recent projects, with the strict confidentiality agreement. This could exclude some bias often inherent in self-evaluation. Second, individual projects were answered by different engineers within each sup-

[16] Another 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.

[17] I thank a referee for pointing out this concern.

[18] To check the common measure bias problem, I excluded some of problematic items from PSP (items 16, 17, 18) and reran the regressions. The results remained the same. Also, I found that PSP was positively correlated with the percentage of the supplier's engineering hours spent before releasing prototype drawings out of total hours (correlation coefficient = 0.342, p-value = 0.04), a measure of how much problem-solving activities were carried out in the earlier stages of component development. This correlation indicates that PSP was consistent with a quantified (less subjective) measure of one dimension of early, integrated problem-solving pattern. Finally, my interviews with both automakers and suppliers confirmed the importance of problem-solving patterns for effective supplier management. Overall, these examinations and qualitative data suggest that common measure bias was not a serious problem in this study.

plier. This secured independence within a respondent supplier's answer. Third, at the same time, all the answers were checked by one person at the supplier, who did not fill in the survey but was familiar with many projects, such as general manager of the engineering division, to examine if there was any strange (unreliable) answer due to the peculiar judgment of a particular respondent. No correction was needed for the answers used in this study.

Appendix Table 1. 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 manufacturing from an 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)
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 preferences for 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 manufacturing (for the automaker's assembly) 2. Structural coordination with other components 3. Functional coordination with other components (Cronbach's alpha: 0.764)
INC: Internal coordination	The mean of INC1, INC2, and INC3	
INC1: Internal coordination within eng. depts	The mean score of 6 items	Q: How much would you agree with the following statements as the description of knowledge sharing and coordination between various functions within the automaker for this project? (Responses on 5-point scale with 1 = strongly disagree; 5 = strongly agree) 1. Engineers within the same component engineering group shared knowledge (e.g., experiences in other projects) well. 2. The component engineering and advanced engineering of the component and related technology shared knowledge well. 3. The component engineering and other related engineering groups were coordinated effectively for structural coordination. 4. The component engineering and other related engineering groups were coordinated effectively for functional coordination of the component. 5. The component engineering and other related testing groups were coordinated effectively for function coordination.

		6. The component engineering and process engineering were coordinated effectively for manufacturability for assembly process. (Cronbach's alpha: 0.871)
INC2: Internal coordination between eng. and purch.	The mean score of 2 items	Q: the same as above. 1. The component engineering and purchasing shared knowledge for cost management well. 2. The component engineering and purchasing were coordinated effectively for cost management. (Cronbach's alpha: 0.793)
INC3: External consistency toward supplier	The mean score of 2 items	Q: the same as above. (* = scale was reversed) 1. What your company heard from the automaker's various engineering functions lacked consistency.* 2. What your company heard from the automaker's engineering and purchasing lacked consistency.* (Cronbach's alpha: 0.678)
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. 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

APPENDIX 2: SUPPLIER (COMPONENT) HETEROGENEITY

Important factors that were not directly measured in my empirical data set are supplier capability and component types. Appendix Table 2 reports ANOVA results to see whether the scores (untransformed) differ across respondents. It shows the variance *between* respondent suppliers was significantly larger than *within* in COM (communication frequency), EKN (engineers' knowledge), EKN1 (component-specific knowledge), and CMP (CAD/CAE usage). This indicates heterogeneity in supplier capability and/or component types. For example, in one component, a supplier needed a longer period of interaction (higher COM) with an automaker throughout the project because various design changes in other parts of the vehicle demanded design adjustment of the component. Yet, in another component, a supplier needed few meetings (lower COM) to fix the requirements, and could do its job without much communication with the automaker. Also, one supplier had very high ability in component engineering, and its knowledge level was much higher than any automakers' (lower EKN), while another did not have any knowledge advantage, since many automakers regarded the component technology critical and thus maintained its knowledge (higher EKN).

Such heterogeneity should be controlled for when the proposed hypotheses are empirically examined. To deal with this issue, this study employed three approaches. The first one was variable transformation by mean centering within each respondent supplier. The results were reported and discussed in the text. The second one was a fixed-effects model, using dummy variables for respondent suppliers. The third one was to build a variable for supplier capability. I used the market share of the supplier in the component's OEM market in Japan in 1996 (source: IRC, 1997) as a proximate measure of supplier capability, assuming that a higher share in the market indicates higher capability in engineering the component. Each approach has advantage and disadvantage. The first approach (mean centering) can control for supplier/component heterogeneity and is consistent with this study's main interest, but lowers variance of each variable and thus causes statistical concern. The second (fixed effects model) can control for supplier/component heterogeneity unambiguously, but costs eight degrees of freedom. The third could allow us to find and interpret the effect of supplier heterogeneity more directly. However, the market share captures only part of the supplier capability. Also component heterogeneity cannot be controlled for.[19]

Appendix Table 3 reports descriptive statistics and correlations for both transformed (mean-centered) and untransformed (original) variables. Appendix Tables 4 and 5 exhibit regression results for CDQ and PSP, respectively, based on the three approaches. The results were almost identical across the three approaches. The findings and discussions based on the first approach were thus robust. Note that in the second approach the coefficient of EKN was not statistically significant without supplier dummies (Model DQ5), but became significant at the 10 percent level with fixed effects (Model DQ6). Also the coefficient of COM increased from 0.013 to 0.022. These changes imply that EKN and COM differed across suppliers/components, as confirmed by ANOVA results in Appendix Table 2.

[19] There are eight types of components in the sample. The inclusion of seven component dummies in the third approach only gives the same results as the second approach, which included eight supplier dummies. Note that the supplier's market share had no variance (was fixed) within each supplier.

Appendix Table 2. ANOVA results

Variable	Between-supplier mean square d.f. = 8	Within-supplier mean square d.f. = 36	F-ratio
CDQ: Component design quality	0.21	0.15	1.41
PSP: Integrated problem-solving pattern	0.37	0.20	1.79
COM: Communication frequency	283.86	131.00	2.17*
EKN: Engineers' knowledge	0.43	0.16	2.79**
EKN1: Component-specific knowledge	0.68	0.25	2.77**
EKN2: Architectural knowledge	0.29	0.48	0.60
INC: Internal coordination	0.43	0.35	1.22
INC1: Coordination within engineering	0.60	0.41	1.47
INC2: Engineering—purchasing coordination	0.84	0.64	1.30
INC3: External consistency	0.61	0.72	0.84
SLD: Sales dependency on the automaker	0.01	0.02	0.48
STK: Stock ownership by the automaker	0.16	0.13	1.25
NWT: New technology	0.07	0.06	1.06
CMP: CAD/CAE usage	0.37	0.02	18.64***

$N = 45$
*p-value <0.1; **p-value <0.05; ***p-value <0.01

Appendix Table 3. Descriptive statistics and correlations

	Descriptive statistics				Correlations													
	Mean	S.D.	Min.	Max.	CDQ	PSP	COM	EKN	EKN1	EKN2	INC	INC1	INC2	INC3	SLD	STK	NWT	CMP
CDQ: Component	3.30	0.40	2.50	4.18														
design quality	0.00	0.35	–0.87	0.80														
PSP: Integrated	3.28	0.48	1.89	4.33	0.42***													
problem-solving pattern	0.00	0.41	–1.03	0.97	0.36**													
COM:	14.12	12.60	1.04	46.25	0.31**	–0.02												
Communication frequency	0.00	10.35	–18.20	33.90	0.36**	–0.25												
EKN: Engineers'	3.14	0.45	2.00	4.10	0.02	0.14	–0.29*											
knowledge	0.00	0.36	–0.87	0.63	0.10	0.30**	–0.52***											
EKN1: Component-	2.42	0.57	1.20	3.60	–0.06	–0.07	–0.02	0.68***										
specific knowledge	0.00	0.45	–1.27	0.92	0.04	0.03	–0.13	0.50***										
EKN2:	3.85	0.67	2.00	5.00	0.08	0.25*	–0.38**	0.78***	0.07									
Architectural knowledge	0.00	0.62	–1.60	1.40	0.09	0.32**	–0.51***	0.78***	–0.15									
INC: Internal	2.95	0.60	1.75	4.42	0.33**	0.50***	–0.33**	0.34**	0.00	0.47***								
coordination	0.00	0.58	–1.40	1.43	0.21	0.49***	–0.44***	0.43***	0.02	0.48***								
INC1: Coordination	3.25	0.67	2.00	4.83	0.27*	0.31**	–0.38**	0.44***	0.08	0.53***	0.76***							
within engineering	0.00	0.58	–1.40	1.43	0.11	0.33**	–0.48***	0.64***	0.19	0.60***	0.77***							
INC2: Engineering–	2.66	0.82	1.00	4.00	0.27*	0.48***	–0.17	0.15	–0.07	0.26*	0.85***	0.30**						
purchasing coordination	0.00	0.73	–1.43	1.30	0.22	0.46***	–0.26*	0.13	–0.12	0.23	0.86***	0.34**						
INC3: External	3.57	0.84	2.00	5.00	0.21	0.10	–0.23	0.34**	0.02	0.44***	0.49***	0.55***	0.28*					
consistency	0.00	0.77	–1.70	1.30	0.09	0.07	–0.19	0.49***	0.10	0.49***	0.42***	0.56***	0.18					
SLD: Sales	0.20	0.15	0.01	0.63	0.34**	0.22	–0.16	0.08	0.02	0.09	0.12	0.11	0.10	0.26*				
dependency on the automaker	0.00	0.14	–0.21	0.43	0.40***	0.32**	–0.10	0.16	0.09	0.12	0.12	0.14	0.06	0.22				
STK: Stock	0.16	0.37	0	1	–0.04	–0.04	0.06	0.01	0.02	0.00	0.10	0.06	0.11	0.04	0.20			
ownership by the automaker	0.16	0.37	0	1	–0.08	–0.01	0.13	–0.11	–0.07	–0.07	0.00	0.01	–0.01	–0.07	0.21			
NWT: New	0.07	0.25	0	1	–0.14	–0.33**	–0.03	0.08	0.06	0.06	–0.25*	–0.12	–0.27*	0.09	0.05	0.13		
technology	0.07	0.25	0	1	–0.20	–0.22	0.07	0.10	0.05	0.08	–0.28*	–0.15	–0.28*	0.06	–0.04	0.13		
CMP: CAD/CAE	0.30	0.29	0.00	1.00	–0.07	–0.14	–0.08	–0.27*	–0.23	–0.17	–0.17	–0.05	–0.21	–0.05	0.04	–0.02	0.19	
usage	0.00	0.13	–0.25	0.43	–0.09	0.07	–0.11	0.15	0.15	0.06	–0.10	–0.09	–0.08	0.05	–0.01	–0.01	0.11	
SPS: Supplier's	35.06	10.66	19.50	54.00	0.13	–0.10	–0.41***	0.12	0.07	0.10	0.18	0.18	0.11	0.26*	0.15	0.12	0.07	–0.29*
share in the component	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

$N = 45$
Upper = original variables (untransformed), lower = transformed variables (mean centering)
*p-value <0.1; **p-value <0.05; ***p-value <0.01 (two-tailed test)

Appendix Table 4. Regression results for component design quality

	Variable transformation (mean centering)				Fixed effects model					Direct measure of supplier capability			
Model #	DQ1	DQ2	DQ3	DQ4	DQ5	DQ6	DQ7	DQ8	DQ9	DQ10	DQ11	DQ12	DQ13
Intercept	0.040	0.041	0.026	0.029	1.859	1.135	1.149	1.274	1.340	0.853	0.834	0.890	0.813
NWT: New technology	–0.179 (0.162)	–0.185 (0.163)	–0.290* (0.158)	–0.270 (0.175)	–0.039 (0.222)	–0.230 (0.202)	–0.211 (0.204)	–7.137* (3.515)	–5.689 (3.408)	–0.088 (0.201)	–0.109 (0.200)	–4.105 (3.169)	–2.713 (2.968)
CMP: CAD/CAE usage	–0.172 (0.306)	–0.149 (0.310)	–0.190 (0.287)	–0.152 (0.296)	0.023 (0.189)	–0.149 (0.339)	–0.123 (0.344)	–0.203 (0.324)	–0.134 (0.310)	0.257 (0.187)	0.255 (0.186)	–0.207 (0.190)	0.076 (0.182)
SLD: Sales dependency on the automaker	0.857*** (0.296)	0.870*** (0.299)	0.675** (0.287)	0.720** (0.304)	0.948** (0.367)	0.863** (0.333)	0.878** (0.337)	0.548 (0.356)	0.563 (0.339)	0.832** (0.333)	0.856** (0.331)	0.705** (0.345)	0.731** (0.319)
STK: Stock ownership by the automaker	–0.173 (0.110)	–0.177 (0.111)	–0.097 (0.108)	–0.114 (0.116)	–0.126 (0.143)	–0.227 (0.140)	–0.232 (0.141)	–0.077 (0.153)	–0.072 (0.146)	–0.196 (0.131)	–0.201 (0.130)	–0.125 (0.141)	–0.136 (0.131)
PSP: Integrated problem-solving pattern	0.242** (0.107)	0.231** (0.109)	0.362*** (0.112)	0.358*** (0.116)	0.272** (0.117)	0.253** (0.120)	0.241* (0.122)	0.310** (0.117)	0.431*** (0.128)	0.322*** (0.107)	0.289** (0.109)	0.357*** (0.109)	0.402*** (0.108)
COM: Communication frequency	0.021*** (0.004)	0.022*** (0.005)	0.018*** (0.004)	0.019*** (0.004)	0.013*** (0.004)	0.022*** (0.005)	0.022*** (0.005)	0.019*** (0.005)	0.017*** (0.005)	0.019*** (0.004)	0.021*** (0.005)	0.018*** (0.005)	0.018*** (0.004)
EKN: Engineer's knowledge	0.291** (0.133)		0.139 (0.139)		0.060 (0.125)	0.292* (0.147)		0.208 (0.147)		0.107 (0.114)		0.061 (0.119)	
EKN1: Component-specific knowledge		0.104 (0.092)		0.013 (0.096)			0.101 (0.102)		–0.030 (0.104)		–0.019 (0.083)		–0.068 (0.078)
EKN2: Architectural knowledge		0.175** (0.078)		0.099 (0.080)			0.177** (0.086)		0.066 (0.086)		0.122 (0.080)		0.068 (0.077)
NWT × EKN			1.81** (0.479)					2.104* (1.065)				1.232 (0.970)	
NWT × EKN1				0.686* (0.343)					2.561*** (0.864)				2.171*** (0.762)
NWT × EKN2				0.444 (0.475)					–0.254 (0.767)				–0.710 (0.663)
SPS: Supplier's share in the component										0.016*** (0.005)	0.017*** (0.005)	0.018*** (0.005)	0.019*** (0.005)
Supplier dummies						Entered	Entered	Entered	Entered				
Adjusted R^2	0.457	0.450	0.523	0.507	0.281	0.494	0.486	0.541	0.587	0.415	0.423	0.542	0.512

$N = 45$
Standard errors in parentheses
$^{*}p$-value <0.1; $^{**}p$-value <0.05; $^{***}p$-value <0.01

Appendix Table 5. Regression results for integrated problem-solving pattern

	Variable transformation (mean centering)		Fixed effects model			Direct measure of supplier capability	
Model #	PS1	PS2	PS3	PS4	PS5	PS6	PS7
Intercept	0.012	0.012	2.210	1.913	2.115	2.488	2.579
NWT: New technology	–0.151	–0.071	–0.409	–0.202	–0.082	–0.352	–0.280
	(0.223)	(0.227)	(0.265)	(0.282)	(0.288)	(0.263)	(0.273)
CMP: CAD/CAE usage	0.407	0.470	–0.066	0.377	0.439	–0.169	–0.152
	(0.421)	(0.420)	(0.223)	(0.473)	(0.471)	(0.230)	(0.234)
SLD: Sales dependency on the automaker	0.789**	0.936**	0.639	0.843*	1.018**	0.723*	0.820*
	(0.389)	(0.397)	(0.437)	(0.442)	(0.451)	(0.433)	(0.448)
STK: Stock ownership by the automaker	–0.065	–0.103	–0.119	–0.098	–0.157	–0.092	–0.117
	(0.150)	(0.151)	(0.178)	(0.193)	(0.195)	(0.176)	(0.179)
INC: Internal coordination	0.337***		0.341***	0.321*		0.363***	
	(0.104)		(0.110)	(0.118)		(0.110)	
INC1: Coordination within engineering		0.215*			0.210		0.200*
		(0.118)			(0.133)		(0.116)
INC2: Engineering–purchasing coordination		0.210**			0.212**		0.230**
		(0.080)			(0.091)		(0.086)
INC3: External consistency		–0.131			–0.148		–0.099
		(0.088)			(0.099)		(0.097)
SPS: Supplier's share in the component						–0.010	–0.008
						(0.006)	(0.006)
Supplier dummies				Entered	Entered		
Adjusted R^2	0.247	0.259	0.252	0.323	0.252	0.277	0.263

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