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Suppliers' Performance and Transactions with Customers: Role of the Advanced R&D Collaboration between Automakers and Suppliers in the Japanese Automotive Industry

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法政大学イノベーション・マネジメント研究センター
The Research Institute of Innovation Management, HOSEI UNIVERSITY

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Yoshinori Konno

Associate Professor, Faculty of Business Administration,

Hosei University

1. Introduction

In many industries, the importance of the R&D collaboration is rapidly increasing now a day, because technologies have been more complicated and changed far more rapidly, market needs have further upgraded, the variety of goods have increased substantially and product lifecycles have been shortened drastically (e.g., Wheelwright and Clark, 1992). Also knowledge for researching, developing and commercializing new products has increased extremely (e.g., Badaracco, 1991). Consequently it is no longer realistic for any one company alone to cover all product development processes, and moreover, it is now essential for all companies to collaborate with others in order to improve the quality, to reduce the cost, and to shorten the lead-time of R&D (e.g., Henderson and Cockburn, 1994).

The Japanese auto sector is one of the industries wherein inter-firm collaboration in product development processes plays a key role. The typical passenger car contains 20,000 to 30,000 components. As much as 70% of these components are provided by outside suppliers. These outside suppliers are often involved in design as well as manufacturing and may account for 50% or more of engineering costs.

In addition, a car is a typical product for integral architecture. Functional and structural interdependency is complicated between components comprising a car. The interfaces between these components are not standardized. It is difficult to develop an excellent car without knowledge of the entire car or individual components. In the Japanese auto industry, automakers accumulate knowledge on the entire vehicle, while automotive suppliers store knowledge on individual components. When new technologies or new-concept components are developed, automakers and suppliers must make joint development arrangements in order to integrate their knowledge (e.g., Takeishi, 2003).

In this respect, numerous studies in Japan and abroad since the mid-1980s have drawn a conclusion (e.g., Womack et al., 1990; Clark and Fujimoto, 1991; Cusumano and Takeishi, 1991; Nishiguchi, 1994; Dyer, 1996; Sako, 1996; Sako and Helper, 1998; Wasti and Liker, 1999): “Japanese automakers have maintained their respective long-term cooperative business relations with a limited number of suppliers and are conducting close information exchanges and coordination with them, based on their strong mutual trust. Very close collaboration between automakers and their respective suppliers have covered even product development processes. This is the source of the Japanese auto industry’s international competitiveness.” Moreover, since vehicle development lead times have shortened, research and development collaboration between automakers and their respective suppliers have been further enhanced (e.g., Konno, 2002).

However, vehicle development projects are not limited to improvements in existing technologies. They may include the development of advanced technologies for new-concept automotive components and new elemental technologies (e.g., materials). This type of technology development is known as advanced research and development (R&D). Advanced R&D of new technologies may precede or be integrated with new vehicle development projects.

Some studies have mentioned that automakers and their respective suppliers cooperate closely even for such advanced R&D activities (e.g., Ueda, 1995). However, most of the earlier studies analyzed individual product development projects and discussed factors affecting them, such as development lead times, development man-hours, and product quality, thereby failing to cover collaboration between automakers and their respective suppliers in the development of advanced technologies. Some studies that covered such collaboration were limited to qualitative analyses, lacking quantitative analyses.

Therefore, this paper first aims to specify the realities of recent collaboration between Japanese automakers and their respective suppliers in the development of advanced technologies in a quantitative manner. Second, this paper aims to generate and limitedly test hypotheses on the relationship between suppliers' collaboration with automakers in advanced technology development and suppliers' performances, focusing mainly on the suppliers’ transaction networks with customers (automakers).

The remainder of this paper unfolds as follows. First, in Section 2, we briefly review the related literature to specify problems that this paper addresses. We analyze the realities of advanced technology development collaboration, based on data of automakers' co-patent applications in Section 3, based on our questionnaire survey data in Section 4. Section 5 generates hypotheses, and Section 6 tests the hypotheses through a statistical analysis. Section 7 covers the conclusion and discussions.

2. Literature Review

2.1. Studies on R&D Collaboration between Japanese Automakers and Their Respective Suppliers

A great number of empirical studies have found that the R&D collaboration management of Japanese automotive industry had special features that wasn't seen in other countries.

First of all, at least in the 1980's, the in-house production ratio of Japanese automakers was comparatively lower than those of US and European automakers. Also, the Japanese components suppliers provided more parts development and design competency as compared to their US and European counterparts. This played an important role in strengthening the Japanese automaker's ability to design and develop vehicles with less manpower and within a shorter timeframe.

For example, Clark and Fujimoto (1991) estimated that the more extensive involvement of suppliers and the strong supplier relationships of Japanese automakers accounted for one-third of their advantage in product development hours in the second half of the 1980s. They also statistically demonstrated that suppliers also appeared to account for four to five months of the Japanese advantage in product development lead-time.

Secondly, the Japanese automotive industry's manufacturer-supplier business relationships tended to be longer lasting, continuous, and cooperative. The Japanese automakers provided its respective suppliers with detailed evaluation and technical guidance in both production technology and product technology. Suppliers could expect stable, mid/long-term contractual relationships as well as some sort of technical assistance from automakers. Therefore, they were able to safely make facility investment or strengthen the R&D system, and they also tended to commit to reducing cost and improving quality on a long-term basis for their clients.

For example, Asanuma(1989) and Cusumano and Takeishi(1991) shown that contracts between Japanese automakers and first-tier suppliers tend to last as long as the production of the components in question continue (usually until the next model change, or about four years). Furthermore, although there are possibilities of competition for a new contract against other suppliers when model changes happen, the relationship (i.e., a bundle of the contracts) with the automaker tended to last beyond the term of each individual contract. In other words, for a given components category (e.g., lamp), the transactions of suppliers for each automaker tended to be fairly stable for a long time.

Sako(1996), for example, shows that the Japanese suppliers participating in a suppliers' association tend to make longer-range transactions with the automaker and invest more in R&D. She insisted, an important mechanism that the Japanese automakers tend to utilize for technology transfer and information sharing is the suppliers' association (kyoryoku-kai) organized by each Japanese assembler. Dyer and Nobeoka(2000) also argued that Toyota's supplier association (Kyoho-kai) functions quite effectively in information sharing, joint problem-finding and problem-solving.

Lastly, in Japan, automakers and suppliers also frequently exchanged information and often worked together in resolving problems. Any modification in the final phase of a product development project consumes far more time and cost than in the initial phase. Therefore, it is important for automakers to have close communications with their suppliers from an early stage of projects and adopt suppliers' ideas when fixing component specifications. In this respect, it was especially common for suppliers to take the "Design-in" approach, in which they would dispatch their employees to client sites as "guest engineers" who would participate in joint development projects. This close and frequent communication between automakers and suppliers enabled them to identify and solve problems at an early stage of development, which consequently resulted in high-quality production and development.

Instead of comparing automaker-supplier R&D collaboration in Japan, Europe and the United States, Takeishi (2003) looked into differences between Japanese automakers regarding R&D collaboration. This study found that 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 also 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.

In short, Japanese automakers have outsourced R&D operations more aggressively than their U.S. and European counterparts and have far closer communications with their respective suppliers for developing new products. Such closer communications have allowed automakers and their respective suppliers to find and solve problems in early stages, contributing much to improving their product development performances and the Japanese automotive industry's international competitiveness.

2.2. A Definition of "Advanced Technology Development"

However, vehicle development projects are not limited to specific development projects for specific car models. They include the development of advanced technologies for new-concept automotive components and new elemental technologies. We define this type of development activities as “advanced technology development.”

Generally, in practice, companies' R&D operations are divided into four phases -- "basic research" for production of new scientific knowledge, "applications research" translating such knowledge into prototypes for applicable technologies, "advanced development," and "product development" for preparation of products for market sales and production processes. "Advanced development" is positioned between the final portion of "applications research" and the initial portion of "product development," serving as a bridge between research and development divisions (Fujimoto, 2001). Even if laboratories[1] in charge of basic and applications research produce excellent elemental technologies, these technologies may usually have problems and be difficult to commercialize without additional efforts. Those technologies often have to be upgraded through operations including the development of mass production technologies for lowering production costs and of technologies for improving resistance to heat, vibration, pressure, dust, water and oil, and so on. Covering these operations is “advanced development.”

In the Japanese auto industry, development operations before design approvals are also called "advanced development" in practice (Fujimoto, 2001). In general, "advanced development" projects cover not only the improvement of existing technologies but also the development of new-concept automotive components and new elemental technologies (including new materials, devices[2] and production technologies) and require significantly long lead times. Therefore, these projects are set to begin before operations to design specific car models.

Such advanced development begins at various timings depending on components, technologies and automakers. Roughly speaking, in many cases advanced development begins two to four years before mass production of a specific vehicle and in other cases four to eight years before it. In the former case, specific car model are set as goals for the advanced development operations. In the latter case, however, advanced development is carried out based on the technology roadmaps, specific car models are not necessarily set as goals.

The advanced development starts for four-to-eight-year goals, with below three cases; (1) engines, transmissions, suspensions and other core components covering basic vehicle performances are concerned, (2) major component changes (to modules or systems) are planned, or (3) large-scale materials changes

[1] Applications and basic research bases for three leading Japanese automakers are Toyota Central R&D Labs., Inc. for Toyota in Nagakute, Aichi Prefecture, the Research Center for Nissan in Yokosuka, Kanagawa Prefecture, and the Fundamental Technology Research Center of Honda R&D Co. for Honda in Wako, Saitama Prefecture.

[2] Out of sub-parts of automotive components, electronic sub-parts (including semiconductors for controlling automotive components) with specific functions are called "devices" in this paper.

are planned. R&D operations for technologies to be commercialized in more than eight years may be classified as applications or basic research.

In practice, the concept of “advanced technology development” in this paper roughly corresponds to “advanced development,” although strictly speaking the former covers some portions of basic and application research. Hereinafter, the term of "advanced technology development" is treated as the same as "advanced development."

2.3. Moves for Collaboration in Advanced Technology Development

Generally, management for collaboration in advanced technology development is far more difficult than the outsourcing of ordinary “product development” activities. There are three reasons behind this.

First, in advanced technology development projects, the most serious concern for both parties (automakers and suppliers) is “diffusion risk” or “knowledge spill-over risk” for the information exchanged through collaboration partners. For example, if a certain multiclient supplier, although not intentionally, leaks critical information about client A to client B, it could result in losing a technological edge of client A over client B. In the automotive industry, suppliers that have developed new technologies for automakers may have incentives to sell components containing these new technologies to other automakers in order to promptly recover development costs. If automakers' new technologies swiftly become available for their rivals through such sales promotion efforts by their suppliers, however, these automakers' opportunity losses may be enormous[3]. As a matter of course, automakers may be able to prevent technology spillovers by concluding NDA (Non-Disclosure Agreements) with their suppliers. Even if parties signed NDA, however, it is difficult to prove illegal activity or wrongdoing on an objective basis.

Furthermore, under joint technology development projects, it could be difficult for both parties to evaluate each other's efforts or contributions. Automakers and their respective suppliers can develop new useful technologies only by sharing cutting-edge technologies and know-how and by repeating trials and errors while maintaining close exchange of information. As such process of knowledge transfer, fusion and creation is interactive, very complex and invisible, it is extremely difficult to manage. In addition,

[3] By the time a component is reverse engineered by competitors, a typical automaker will still be ahead in product development time, typically by months, maybe even years. Since the development of a new vehicle may take more than 18 months after a design approval, the first automaker may be expected to maintain technological superiority for at least more than two years. However, critical information that leaks out to competitors at the product development stage through suppliers utilizing the same or similar designs or technologies for different customers causes that first automaker to face a steep loss in its first-mover advantages.

even if an automaker and a supplier succeeded in generating new innovative technologies, it is difficult to measure how much of the contribution was made by which party, or how much of the resulting profits should be attributed to which party. This "measurement problem" is the second reasons.

Third, because of a high level of uncertainty in advanced technology development projects, both parties could find it difficult to precisely forecast in advance what each of them need to do, to what extent, and what level of resources need to be provided. Therefore, a change of plans is often inevitable, and with them conflicts occur between the two parties.

In conclusion, it is very difficult for automakers and suppliers to control the advanced technology development projects only through contracts. In order to have successful collaboration in advanced technology development, "higher-level management of the inter-firm relationships" beyond the contractual relationships is necessary. Building up strong mutual trust based on close communications under long cooperative relations are firstly required, and making up a lot of co-routines for collaboration such as guidelines for the way to manage project team across boundaries, to disclose technology and know-how mutually, to revise a plan again, to negotiate the distribution of a result, and so on, are also inevitable (e.g., Sako, 1992; Dyer, 1996).

Japanese automakers, however, have expanded their scope of collaboration with their suppliers into advanced technology development activities. For example, Toyota Motor Corp. created the fourth development center (run mainly by the Higashifuji Laboratory) in September 1992 to enhance advanced development of elemental technologies for engines and electronics. Nissan Motor Co. opened the Nissan Advanced Technology Center in May 2007 to consolidate and enhance advanced development functions.

Advanced development has also spread to cover collaboration between automakers and their respective components suppliers. Some studies (e.g., Konno, 2002; Konno, 2004; Fujimoto, Ku, Konno, 2006; Konno, 2007a; Konno, 2007b) note that automakers and their respective components suppliers have enhanced their collaboration in advanced development.

In the past, automakers and their respective components suppliers had given priority to management of in upgrading component cost efficiency, quality and development lead times to satisfactory levels in specific car model development projects. In contrast, collaboration between automakers and their respective components suppliers at present has expanded to cover advanced development beyond specific car model development projects. Advanced development itself has grown more important.

There are three factors behind the expansion of collaboration between automakers and their respective components suppliers in advanced technology development.

The first factor is that new car development lead times have become even shorter. Japanese automakers have been shortening lead times for new vehicle development again since the second half of the 1990s (Nobeoka and Fujimoto, 2004). At present, the average lead time for new vehicle development after design approvals is 18 to 20 months for full model changeovers or 10 to 12 months for derivative models. Therefore, major technical problems must be solved before the commencement of new vehicle development projects so that mainly adaptive designs are made in the product/process engineering phase after design approvals. If not, components development may fail to fall within a lead time for the development of new vehicle.

The second factor is that new materials development and introduction, downsizing and weight reductions, computerization, information and other technological innovations have made fast progress amid a rapid increase in development costs for automakers. Such fast progress in innovations has forced automakers to cooperate with their respective components suppliers in the development of advanced and alternative technologies excluding a limited range of core technologies.

For example, a lot of new modules and systems have been rapidly introduced. While components are treated in spatially and physically larger units than in the past, moves have increased to functionally integrate small parts within such units. New design concepts for components also have been proposed and implemented one after another. In order to improve vehicles' basic functions (running, turning and stopping), safety and comfortableness, automakers have tended not only to upgrade the performance of the engine, braking, steering, suspension and other individual systems and individual parts but also to link multiple relevant systems together. Furthermore, over the past decade, automakers have switched from metallic materials to plastic materials, from steel to aluminum, and from conventional steel sheets to high-tensile sheets in a bid to reduce vehicle weights and improve fuel efficiency.

The last factor is that a lot of leading automotive components suppliers have improved their R&D capabilities recently. Many leading automotive components suppliers created laboratories or divisions for basic research and advanced development in and after the first half of the 1980s. Regarding technologies inherent to components, suppliers have generally outperformed automakers in research and development capability.

As Konno(2008) shows, primary components suppliers' joint patents with automakers account for only 5-10% of these components makers' total patent applications. The remaining 90-95% of components makers' patent applications represent their independent R&D achievements. Furthermore, for example, even Toyota has sent their employees as “guest engineers” to leading components markers. These indicate component makers' excellent technological capability.

The development of new-concept components and of new technologies that are involved in them may require fundamental changes in manufacturing methods, equipment and assessment standards as well as designs. Therefore, massive time and resources must be put into R&D operations. Furthermore, a process is required to well mix automakers' knowledge (architectural knowledge) about entire vehicles with components makers' knowledge (component knowledge) inherent to individual components (Takeishi, 2003). It is thus indispensable for automakers and their respective components suppliers to collaborate in the development of advanced technologies while sharing cutting-edge technologies and know-how (e.g. Konno, 2007a; Konno; 2007b).

2.4. Unexplored topics

As mentioned above, some studies have found that Japanese automakers and their respective suppliers have cooperated even in advanced technologies operations that have grown more important in the Japanese automotive industry. However, most of the past studies have limited their research coverage to factors affecting development lead times, development man-hours and products quality regarding specific development projects for specific products, such as the Mark X launched in 2007. Some studies that covered collaboration between automakers and their respective component suppliers in advanced technology development were limited to qualitative analyses, lacking quantitative analyses.

Therefore, this paper first aims to analyze as quantitatively as possible the reality of recent collaboration between Japanese automakers and their respective suppliers in developing advanced technologies. This paper will conclude that since collaboration between automakers and their respective suppliers has been expanding into the development of advanced technologies, suppliers that have the capability to participate in such development projects have developed closer relations with automakers than others.

Second, this paper aims to generate and test hypotheses on the relationship between suppliers' collaboration with automakers in advanced technology development and suppliers’ performances, based on the inference from the "social network theory." This paper will conclude that suppliers that can cooperate with their respective main customer automakers in advanced technology development, while at the same time maintain business relations with a wide range of other customers, tend to outperform other suppliers.

3. Analysis of Automakers’ Joint Patent Applications

This section examines between automakers and their respective suppliers in the development of advanced technologies through an analysis of automakers' joint patent applications.

3.1. Data Source

In this Section, nine Japanese automakers' patent applications that were filed to Japan's Patent Office over 12 years between 1993 and 2004 and released in the official patent gazette were subject to the analysis. The nine automakers included Toyota Motor Corp., Nissan Motor Co., Honda Motor Co., Mitsubishi Motors Corp., Mazda Motor Corp., Suzuki Motor Corp., Daihatsu Motor Co., Fuji Heavy Industries Ltd., and Isuzu Motors Ltd. Applicants (multiple applicants for one patent application are all counted as applicants), publication numbers, application dates, names, international patent classification (first invention information subclasses), inventors, and other patent application data were entered into a spreadsheet software. Then, we conducted a patent map analysis of joint patents or patents for which applications were filed jointly by automakers and their suppliers.

Joint patent applications are those for which both automakers and their respective suppliers are applicants in connection with the development of advanced technologies that can be identified as novel or inventive. Thus, joint patents represent inventions to which both automakers and their suppliers have contributed[4]. Therefore, there may be small inaccuracies with the utilization of joint patent applications as an indicator of successful advanced technology collaboration[5].

3.2. Overview of Automakers' Patent Applications

First, we would like to review the overall trend. Figure 1 indicates the total number of patent

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[4] Inventions subjected to patent applications are published in the official gazette 18 months after these applications have been filed with Japan's Patent Office. Applications enter an examination process only if applicants request examination and pay examination fees. If novelty or inventiveness isn't identified in inventions, patents are not awarded. This means that patents are only awarded to a minor portion of patent applications.

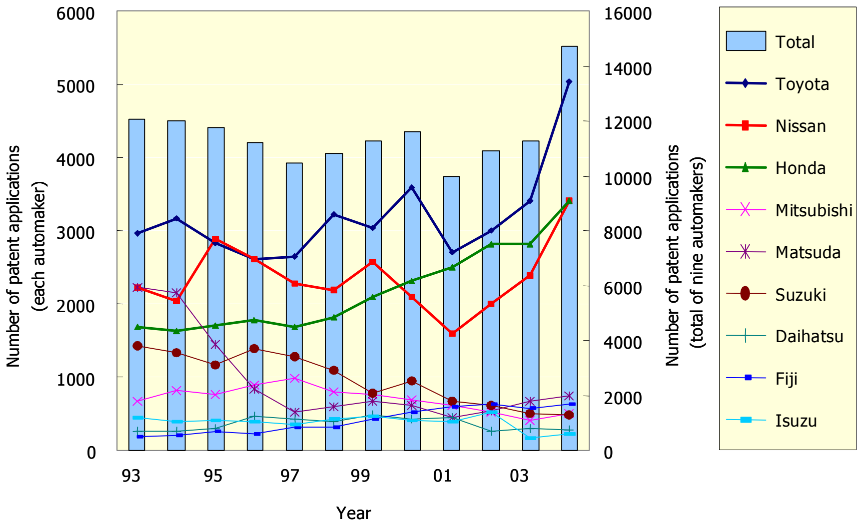
Many applications are filed for defensive purposes. Manufacturing know-how and other technologies that may be difficult for rivals to imitate are not necessarily subject to patent applications. Due to these factors, there are various limitations on using patent data for a performance index.

However, no alternative objective indicators exist for successful advanced technology development. Moreover, since patent applications are filed at some cost, technologies subject to patent applications have probably been screened by applicants and can be expected to feature some kind of novelty or inventiveness. In this sense, patent data utilized as an indicator of successful advanced technology development may be permitted.

[5] Multiple applicants for a single patent may not necessarily have made the same contributions to a particular invention. The applicants often assess their respective contributions to an invention subject to their patent application and agree on how to share gains from the patent, as "Toyota 70% and Denso 30%". Although such agreements is not apparent in patent application data, all applicants should have made some contribution to the invention. In this sense, there may be small inaccuracies with the utilization of joint patent applications as an indicator of successful advanced technology development collaboration.

applications for each of the nine automakers between 1993 and 2004.

Figure 1: Patent Applications



The figure shows that the nine automakers' total patent applications began to increase around 2002 and scored a sharp increase in 2004. Breaking down these patent applications by automaker, we find that Toyota, Nissan, and Honda account for a dominant share of the total. The three firms accounted for approximately 60%–70% of the nine automakers' total patent applications. In 2004, the three firms' share rose to 80%. Patent applications from the others have been falling or leveling off. Thus, Toyota, Nissan, and Honda have effectively been leading the development of advanced technologies in the Japanese auto industry.

3.3. Overview of Automakers' Joint Patent Applications

Next, we would like to review the overall trend of patent applications filed jointly by automakers and their respective suppliers. Figure 2 indicates the total number of joint patent applications for the nine automakers and their share of total patent applications between 1993 and 2004.

Figure 2 shows that the total number of joint patent applications and the nine firms' share of the total patent applications have continued at a rough upward trend, although some fluctuations were observed for some years. Notably, joint patent applications appear to have increased since the total patent applications of the nine firms began to rise in 2002. The joint patent applications' share of the total also indicates a rough upward trend.

Figure 3 indicates the number of joint patent applications and the share of the total for the three largest Japanese automakers—Toyota, Nissan, and Honda—between 1993 and 2004. This figure indicates that Toyota features a greater number of joint patent applications and a higher share of the total patent applications than the other two[6].

Figure 4 indicates the number and percentage share of patent applications that each of the three largest automakers filed jointly with two or more suppliers.

A patent application filed by three or more companies may represent not only dyad collaboration between an automaker and one of its suppliers but also horizontal collaboration between suppliers. The number and percentage share of such co-patents can be seen as an indicator of their tendency to coordinate many large-scale advanced R&D collaboration projects that have to unite two or more different component and elemental technologies. In this type of large-scale advanced technology development collaboration, management is more difficult. Since suppliers who participate in it are not direct competitors (technical expertise is different) but are potential competitors with each other, suppliers often aren't willing to share intellectual property to with other parties, resulting in a project failure.

This figure shows that Toyota features a far higher number and percentage share than the others for joint patent applications involving three or more applicants. Of course, Toyota has mainly filed co-patents with Toyota-affiliated suppliers such as Toyota Central R&D Labs. Inc., Denso Corp., and Aisin Seiki Co. However, Toyota's R&D collaboration partners have not been limited to its affiliates. Toyota has also made aggressive efforts to coordinate many large-scale R&D projects that include two or more non-affiliate suppliers. In one case, Toyota filed joint patent applications for some telecommunications technologies in 1999 aiming to get a defect-standards with five other suppliers—three (Aisin AW Co., Denso Corp., Fujitsu Ten Ltd.) are Toyota-affiliated suppliers and two (Pioneer Corp. and Matsushita Electric Industrial Co.) are non- affiliated suppliers.

In short, Japanese automakers have thus expanded collaboration with their respective suppliers into the development of advanced technologies. Amid this general trend, Toyota has also made aggressive efforts to coordinate the joint style advanced technology development projects that include two or more suppliers and horizontal collaboration between suppliers. In terms of quantitative achievements through such collaboration, Toyota has progressed far ahead of other Japanese automakers.

[6] Figures 3 and 4 do not make adjustments for Toyota's joint patent applications with Toyota Central R&D Labs. Inc. and Honda's joint applications with Honda R&D Co., although these R&D firms have personnel exchanges with their respective parent companies and are positioned as consolidated subsidiaries forming a component of their respective parents' R&D divisions. This means there is some upward bias for these companies. However, even if such adjustments are made, a conclusion here may remain unchanged.

Figure 2: Joint Patent Applications of Nine Automakers and Their Share of the Total

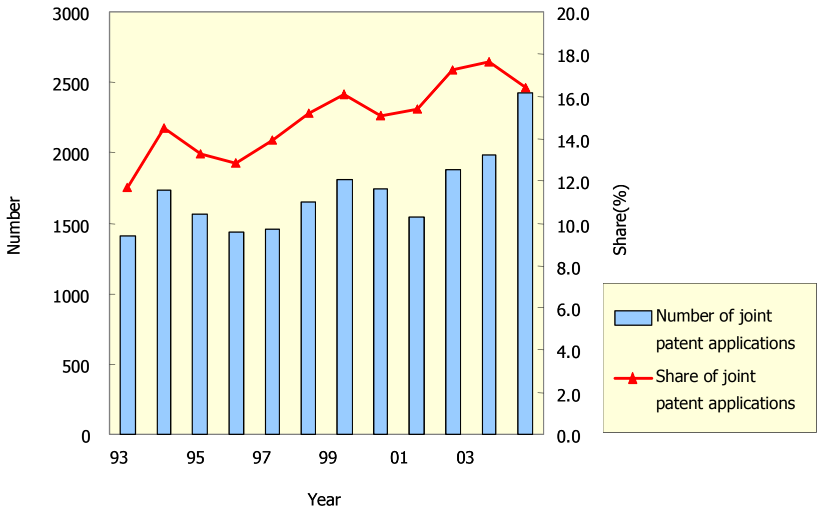


Figure 3: Joint Patent Applications and the Share of the Total for Each Automaker

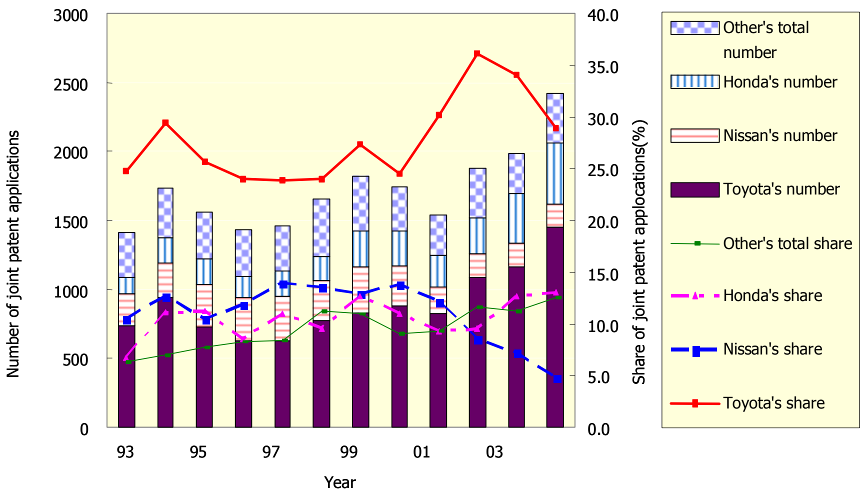
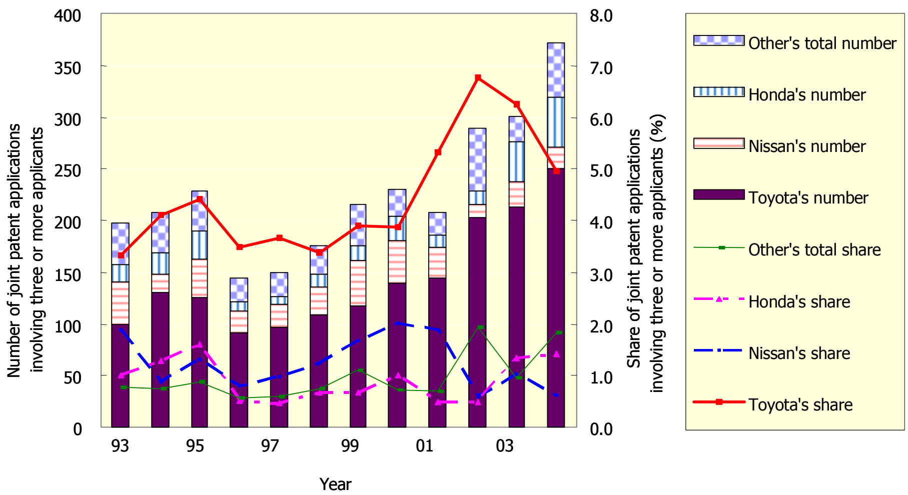


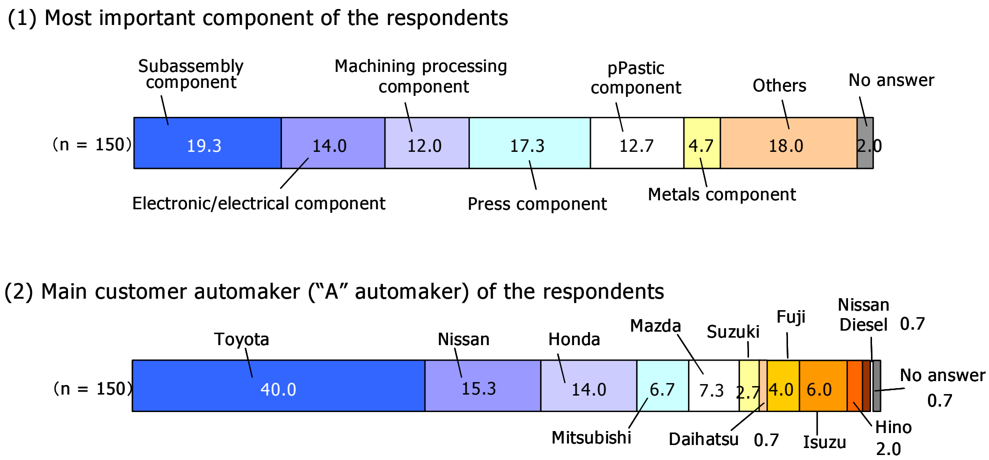
Figure 4: Joint Patent Applications Involving Three or More Applicants for Each Automaker



4. Analyzing Suppliers' Questionnaire Surveys

As indicated in the previous section, collaboration between automakers and their respective suppliers in the development of advanced technologies has been expanding in the Japanese auto industry. In a bid to examine how business relations between automakers and their respective suppliers have changed in line with such expanding collaboration, we would like to analyze a questionnaire survey of first-tier automotive suppliers that was conducted in November 2003 with Mr. Takahiro Fujimoto, a professor of Tokyo University, and Mr. Ku Seunghwan, then assistant professor at Kyoto Sangyo University.

Figure 5: Outline of Component Transactions (1)



4.1. Survey Data Sources and Outline

In the above questionnaire survey, we sent questionnaires to 340 first-tier automotive suppliers among the members of the Japan Auto Components Industries Association. Of these, 150 firms returned responses, resulting in a response rate of approximately 44.1%.

In the questionnaire, the suppliers were first requested to select their most important product (component). Then, they were asked about their business relations with their main customer automaker regarding their most important product (component). The components chosen as the most important are spread over seven categories: subassembly components, electronic/electrical components, machining processing components, press components, plastic components, metals (molding/casting) components, and others. Of the total, subassembly components accounted for 19%; press components, 17%, and electronic and electrical components, 14%. The main customer automaker mentioned by the questionnaire respondents were Toyota (40%), Nissan (15%), Honda (14%), Mitsubishi (7%), and Matsuda (7%). These percentages roughly represent their respective domestic auto production shares.

Of the suppliers, 58% stated that they "undertook more than half of the development workload" themselves. When queried on the change in the percentage over the past four years, 56% responded that they observed an upward trend. These results reveal that many suppliers are responsible for a rather high ratio of the component development.

With regard to the suppliers' transactions with automakers, 69% belonged to the "approved drawing components[7]," 17% belonged to the "assigned drawing components[8]," and 10% belonged to the "detailed-controlled drawing components[9]." "Supplier proprietary components" were subjected to 3% of these transactions. These data indicate that suppliers participated in detailed engineering as part of the development of components in more than 86% (combining the approved drawing components and assigned drawing components) of the total transactions.

With regard to competition, 67% of the responding suppliers stated that they were selected by development competitions. Some 23% stated they received exclusive orders from automakers. The remaining 11% cited biddings.

The respondents were also requested to select the most important capability from the five alternatives for winning a competition. The most important capability, selected by 53%, was proposing and developing new component technologies or new-concept components beyond the improvement of existing technologies. The second most important capability, selected by 23%, was lowering costs through manufacturing process improvements. The third, selected by 17%, was reducing costs through design improvements. The fourth, selected by 4%, was developing components in accordance with specifications provided by automakers. The fifth, selected by 3%, was guaranteeing quality and just-in-time delivery.

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[7] Under the approved drawing components' practice, a supplier conducts detailed engineering based on rather rough specifications provided by the customer automaker. After the automaker approves the drawings, the supplier owns the final drawings and produces components based on it for delivery to the automaker. See Asanuma (1989) and Fujimoto (1999).

[8] Under the assigned drawing components practice, a supplier conducts detailed engineering based on the customer automaker's basic drawing. The automaker owns the final drawing. This type of component is positioned between the approved drawing components and the detailed-controlled drawing components. See Fujimoto (1999).

[9] Under the detailed-controlled drawing components practice, an automaker undertakes detailed engineering for a component. Further, the automaker owns the final drawing and presents it to a supplier for production. See Asanuma (1989) and Fujimoto (1999).

Figure 6: Outline of Component Transactions (2)

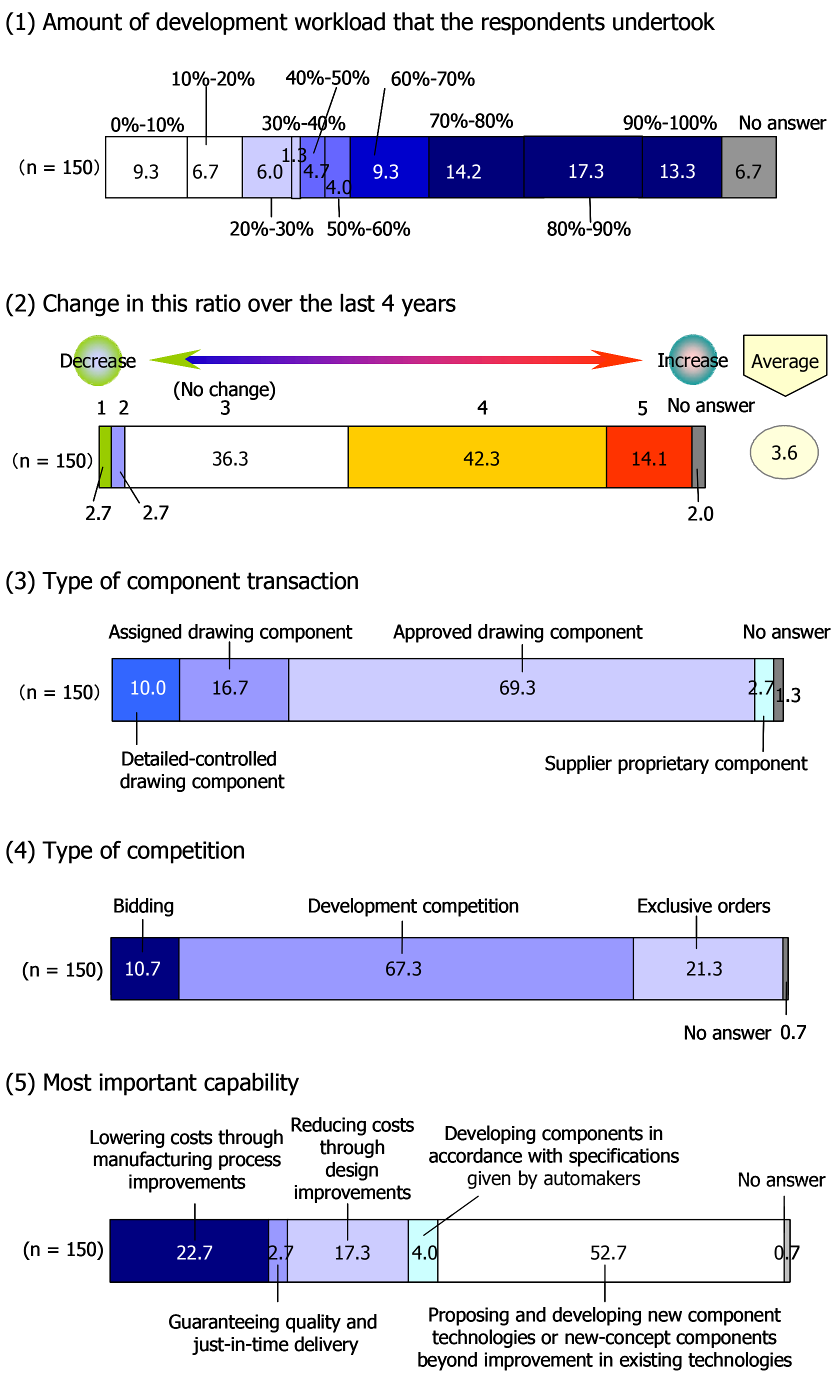
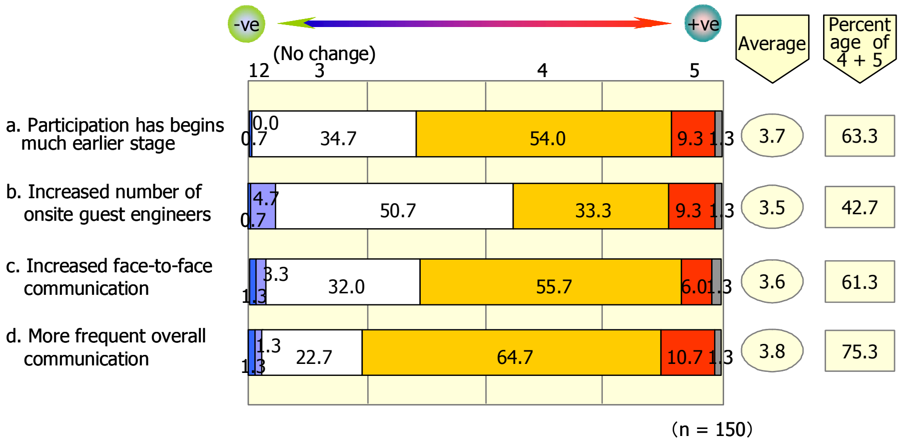


Figure 7: Outline of Component Transactions (3)

(1) Change in relationship with "A" automaker over the last four years,



Regarding the relationship with a main customer automaker, 63% of the responding suppliers selected "Started to participate in development activities from a much earlier stage than before," 43% selected "We have increased the number of onsite guest engineers who work at the main customer automaker," 62% selected "Face-to-face communication during the development process increased," and 75% selected "There was more frequent overall communication (includes all forms of communication—emails, phone calls, and face-to-face)." These results suggest that the relationship between suppliers and their main customer automakers is becoming tighter and closer with regard to R&D activities.

In the recent Japanese auto industry, as indicated above, major suppliers have deepened relations with their main customer automakers. Meanwhile, in order to survive fierce competition, suppliers are required to have the capability to develop new cutting-edge components or technologies beyond improvements in existing technologies.

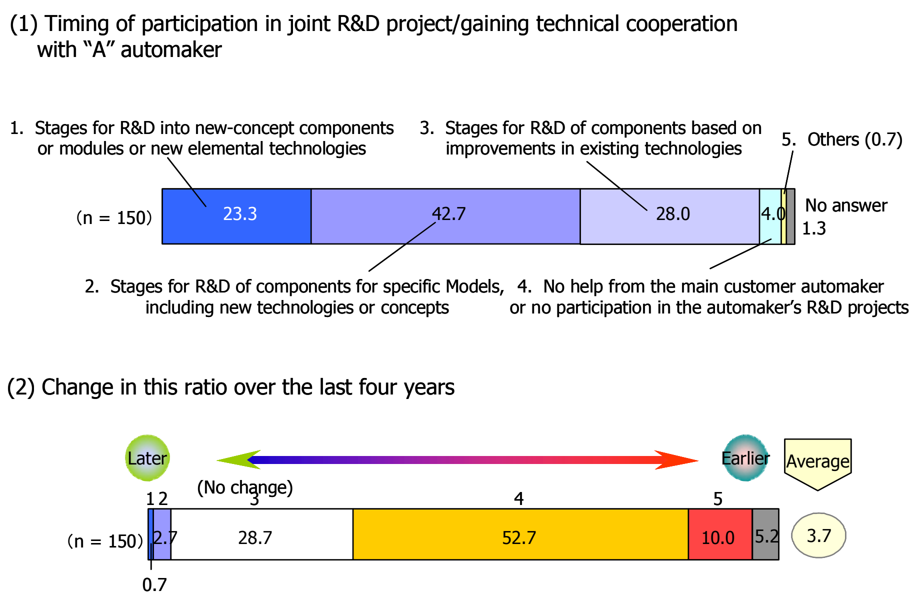
4.2. Stages for R&D

Next, we would like to examine the reality of collaboration in the development of advanced technologies.

Responses to Question 1 on the stages for R&D collaboration with a major customer automaker or receiving assistance from such collaboration are compiled in Figure 8. Of the total responding suppliers, 23% selected "Stages for R&D into new-concept components or modules, or new elemental technologies (such as new materials), including pilot studies on technologies that are not planned for specific models"; 43% selected "Stages for R&D of components for specific models, including new technologies or concepts beyond improvements in existing technologies or products"; 28% selected "Stages for R&D of components based on improvements in existing products"; 3% selected "No help from the main customer automaker or no participation in the automaker's R&D projects"; and 1% for "Others." Based on discussions in Section 2, the advanced technology development collaboration is identified for the first and second cases.

And when queried about any change in the timing of starting collaboration over the past four years, 63% stated that they began to cooperate with the main customer automakers at an earlier time than in the past.

Figure 8: Stages for R&D Cooperation

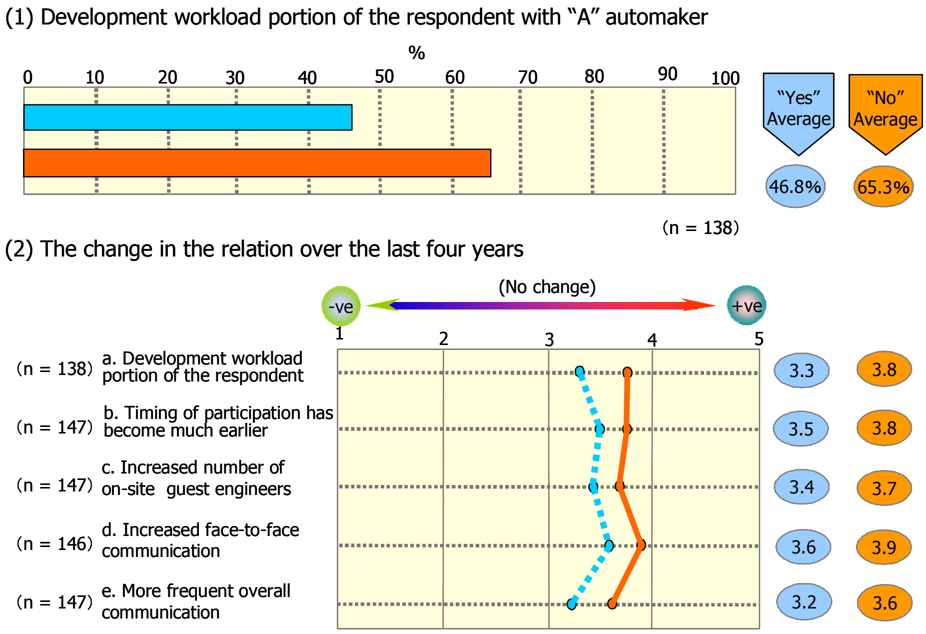


Consequently, a majority of suppliers are now cooperating with their respective customer automakers even in the development of advanced technologies at an earlier time than before.

4.3. R&D and Inter-firm Relations

Next, we used the questionnaire survey data to consider any differences between suppliers that cooperate and those thadvanced technology developmento not cooperate with the main customer automakers in the development of advanced technologies.

Figure 9: Advanced technology R&D Cooperation and Business Relations



The suppliers' average workload portion of their joint R&D operations with their main customer automakers was significantly higher (the significance level at 1% in *t*-test) for suppliers cooperating with automakers in advanced technology development than for those refraining from such collaboration. With regard to any change in such workload portion over the past four years, the former (suppliers cooperating with automakers in advanced technology development operations) pointed to a more significant expansion (1%) than the latter (those refraining from such collaboration). With regard to relations with main customer automakers, the former feature collaboration in earlier R&D stages (1%) as compared to the latter, a faster increase (5%) in face-to-face communications, a faster increase (5%) in overall communications, and a greater expansion (1%) in onsite guest engineers stationed at automakers. These data suggest that suppliers cooperating with automakers in advanced technology development operations have closer relations with automakers than those refraining from such collaboration.

4.4. Suppliers' Capabilities and collaboration with Automakers in Advanced Technology Development

Next, we would like to examine the relationship between suppliers' capabilities and their collaboration with automakers in advanced technology development activities.

From the resources-based view of the firm, the core elements of resources and capabilities thadvanced technology developmentefine corporate competitive advantage are knowledge and know-how accumulated in the companies (e.g., Teece et al., 1997; Barney, 1997). This may mean that the higher the knowledge and know-how accumulated in a supplier, the more likely it is for that supplier to be permitted to participate in advanced technology development. Therefore, the following hypothesis is proposed:

The greater the knowledge and know-how accumulated in a supplier, the more likely it is for that supplier to be permitted to participate in advanced technology development.

We have utilized the abovementioned supplier questionnaire survey data for verification. As incomplete responses were excluded from the data, the number of samples or responding suppliers for this analysis came to 145.

As an indicator of advanced technology development collaboration as a dependent variable of the working hypothesis, we have constructed a dichotomous variable—"1" for the first and second responses to "Question 1" in Section 4.2 and "0" for the third and fourth responses. One respondent selected the fifth alternative ("Others") and was excluded from the samples because no details were provided.

As for the suppliers' knowledge levels as the defining variable, "component-specific knowledge" is separated from "architectural knowledge", based on Takeishi (2003)[10]. For control variables, we have used the "technology change" for controlling changes in the relevant component technologies, the "external interdependency" for controlling the external architecture characteristics of relevant components, and the "internal interdependency" for controlling the internal architecture characteristics of the components, based on earlier studies such as Takeishi (2003), Nobeoka (1999), and Han (2002). For details including original questions that constitute variables, see Table 1.

The logit analysis has been used for the verification of the hypothesis since the explained variable is

[10] "Component-specific knowledge" is the knowledge of performances, costs, and production processes for specific components. "Architectural knowledge" is the knowledge of the coordination of components that are structurally and functionally related to each other (Takeisihi, 2003).

a dichotomous variable. Table 2 indicates averages of major variables, standard deviations, and the correlation matrix. Table 3 shows the results of the logit analysis.

First, Model 1 of Table 3 indicates that the suppliers' component-specific knowledge has a positive effect on their collaboration with automakers in advanced technology development. The effect is observed at a 10% significance level. This means that the working hypothesis has been supported in regard to component-specific knowledge. Second, the model indicates that component-specific knowledge is more important than architectural knowledge for suppliers to be permitted to collaborate with automakers in advanced technology development. Architectural knowledge is thus insignificant. Third, the model also indicates that the technology change as a control variable has a positive effect at a 1% significance level and the external interdependency has a positive effect at a 5% significance level. These indications mean that the faster the technology change and the more interdependent the components compared to others, the higher is the probability for suppliers to be permitted to cooperate with automakers from the advanced technology development stage. This finding is an interesting theme for future study.

Thus, these results suggest that suppliers that are identified as having relatively higher-level component-specific knowledge and the capability to develop advanced technologies or new components beyond improvements in existing technologies are more likely than other suppliers to have cooperated with automakers from the advanced technology development stage and have eventually developed closer business relations with automakers.

4.5. Progressive practice of Toyota's Suppliers

The analysis in Section 3 found that Toyota has progressed ahead of other Japanese automakers in collaboration with suppliers in the development of advanced technologies. Therefore, this subsection examines the differences between suppliers whose main customer automaker is Toyota (Toyota's suppliers) and the other suppliers.

Figure 10 shows a comparison of the responses provided by Toyota's suppliers and the others to "Question 1" in Section 4.2. Of Toyota's suppliers, those in the first category accounted for more than 35%. This percentage more than doubled the level for the other suppliers. Of Toyota's suppliers, those in the second category also accounted for more than 35%. This percentage is slightly lower than that for the other suppliers; however, a combination of the first and second categories for Toyota's suppliers was 16.2 percentage points higher than for the other suppliers. The difference between Toyota's suppliers and the others was at a 1% significance level.

Model 2, in which a Toyota dummy is added to Model 1 of Table 3, indicated the Toyota dummy's positive effect at a 5% significance level even after all the other variables were controlled. Moreover, Model 2 indicated that the addition of the Toyota dummy improved the regression's explanation power. In short, Toyota's suppliers are more likely than the others to participate in the main customer's advanced technology development projects. The probability gap was calculated at approximately 36 percentage points.

In this way, Toyota's joint R&D operations with major suppliers from the advanced technology development stage are more aggressive than the other automakers.

Table 1: Explanations of Variables

Variable	Specification	Note
Participation in the advanced technology development	The dichotomous variable is set at "1" for Alternatives 1 or 2 of the five listed on the right side and at "0" for Alternatives 3 or 4.	**Question:** In what stage of component R&D operations at the major customer automaker do you participate or gain help from the customer? (Choose one alternative) 1. Stages for R&D into new-concept components or modules, or new elemental technologies (such as new materials), including pilot studies on technologies that are not planned for specific models 2. Stages for R&D of components for specific models, including new technologies or concepts beyond improvements in existing products. 3. Stages for R&D of components based on improvements in existing products. 4. No help from the main customer automaker or no participation in the automaker's R&D projects 5. Others (Specifically:)
Component-specific knowledge	Average score of responses to 10 right questions	**Question**: What is your estimated level of knowledge about the following points compared to the levels for automakers? (A five-point Likert scale for each question) a. Functional design b. Structural design c. Material design d. Durability design e. Core technology f. Manufacturing process g. Quality control h. Manufacturing cost i. Material cost j. Components cost
Architectural knowledge	Average score of responses to 8 right questions	**Question**: What is your estimated level of knowledge about the following points compared to the levels for automakers? a. Final customers' needs and preferences regarding Component X (main component) b. Automakers' manufacturing processes (particularly, availability for assembling) c. Functional coordination with other components d. Structural coordination with other components **Question**: What is your estimated level of knowledge compared to the levels for automakers about the following points regarding "other components" linked closely to Component X? a. Knowledge of engineering b. Knowledge of production c. Knowledge of evaluation d. Knowledge of costs
Technology change	Score of responses to the right question	**Question**: How do you evaluate the following item in comparison with other components in general? a. Technological changes are fast
External interdependency	Total of the following scores of responses to right questions: External interdependency = -a-b-c+d-e+f	**Question**: How do you evaluate the following items in comparison with other components in general? a. External interfaces are standardized within the company. b. External interfaces are standardized within the industry (adopted at two or more companies). c. Component X functions independently (can be designed without considerations to functions of other components) d. Component X functions multidimensionally. e. Component X is structurally independent (can be designed without considerations to structures of other components).
Internal interdependency	Total of the following scores of responses to right questions: Internal interdependency = g+h	**Question**: How do you evaluate the following items in comparison with other components in general? g. If a subcomponent design is modified, most other subcomponent designs must be modified. h. If a mix of materials is modified even slightly for Component X, the production method and production process conditions (pressure, temperature, timing, time, procedures, etc.) must be modified considerably.
Toyota dummy	A dummy variable set at 1 for Response 1 of responses to right questions and 0 for any other response	**Question**: What is you main customer automaker? (Choose one) 1. Toyota 2. Nissan 3. Honda 4. Mitsubishi 5. Mazda 6. Suzuki 7. Daihatsu 8. Fuji 9. Isuzu 10. Hino 11. Nissan Diesel 12. Others

Table 2: Descriptive Statistics and the Correlation Matrix of Major Variables

	Variable	AV	SD	1	2	3	4	5	6	7
1	Participation in the advanced technology development	0.67	0.47	1.00						
2	Component-specific knowledge	3.80	0.61	0.23	1.00					
3	Architectural knowledge	2.97	0.67	0.06	0.22	1.00				
4	Technology change	3.43	0.79	0.28	0.14	0.07	1.00			
5	External interdependency	-4.57	3.21	0.24	0.01	-0.11	0.18	1.00		
6	Internal interdependency	6.77	1.52	0.02	0.10	0.12	0.06	0.04	1.00	
7	Toyota dummy	0.39	0.49	0.15	0.01	-0.11	-0.19	0.03	-0.06	1.00

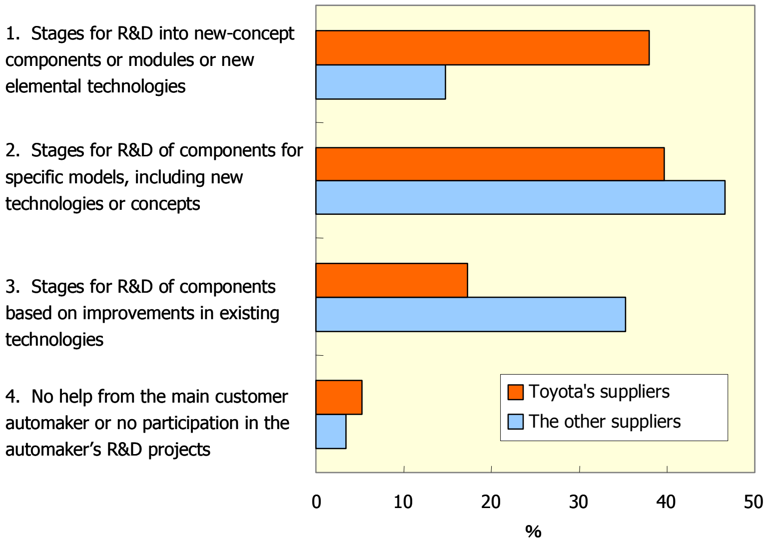
If the absolute value of a correlation coefficient≧0.22 then it is significant at the 1% level, and if the absolute value is ≧0.18 then it is significant at the 5% level.

Table 3: Logit Analysis Results

Model	1			2		
Explained variable	Participation in the advanced technology development					
	β	S.E.	*p*	β	S.E.	*p*
Component-specific knowledge	0.52	0.30	0.08	0.49	0.30	0.10
Architectural knowledge	0.13	0.27	0.63	0.19	0.28	0.49
Technology change	0.65	0.26	0.01	0.80	0.27	0.00
External interdependency	0.16	0.07	0.02	0.16	0.07	0.02
Internal interdependency	-0.05	0.13	0.71	-0.03	0.13	0.81
Toyota dummy				1.02	0.43	0.02
Constant term	-2.76	1.55	0.08	-3.81	1.65	0.02
-2logL	162.9			156.9		
Negelkerke R2	0.19			0.24		
Sample size	145			145		

A yellow cell means p < 0.10

Figure 10: Differences between Toyota's Suppliers and the Others



5. Hypotheses

This section, based on the knowledge as mentioned above, generates and limitedly tests hypotheses on the relationship between suppliers' collaboration with automakers in advanced technology development and suppliers' performances.

5.1. Inference from the "Social Network Theory"

Most of past literature focused on the cooperative nature of dyadic inter-firm relationships between automakers and suppliers in Japan. It has been said that Japanese automakers are inclined to have long-term and collaborative relationship with restricted number of components suppliers, which have been described as "Keiretsu System." However, some researches indicate that such kind of exclusive image of "Keiretsu System" is wrong. On average, each Japanese automaker procures each component from a certain number of suppliers, and each supplier sells the same component to a certain number of automakers (e.g., Takeishi and Cusumano, 1995; Fujimoto, 1999; Nobeoka, Dyer, and Madhok, 2002). Therefore, in the Japanese automotive industry, there is a complicated network of inter-firm relationships consisting of multiple automakers and component suppliers.

Furthermore, Japanese automotive industry of today has been struck by an unprecedented tide of structural reform reflecting slowdown in automotive demand and sharp rise of oversea production. Suppliers are shifting from a situation depending on a specific automaker for most of sales but trying to extend their customer base. Therefore, we regard the entire pattern of Japanese automakers-suppliers relationship not as one-to-one structure but a kind of network form.

The "social network theory" is highly suggestive for us to consider how such component transaction network would affect suppliers' performances. The social network theory has many points, however, one of its core points is that actors' actions and outcomes are substantially influenced by the ongoing pattern of relationships maintained with other actors. In particular, a network in which an actor is embedded potentially provides it with access to information, resources, markets, and technologies (e.g., Powell, Koput, and Smith-Doerr, 1996; Uzzi, 1996). This means that the configuration of a network in which an actor is embedded -- (1) what network the actor forms along with other actors and (2) what position the actor takes in the network -- can define the quality and quantity of information the actor acquires and influence its behaviors, resources, capability-building processes and performances (e.g., Gulati, 1998).

There are two major views about what network configuration is desirable for actors. Kogut (2000) used the concept of "rent" to explain benefits that certain network configurations would bring about and modeled the rents emerging from two different representative network configurations. One is the "Coleman rent" that stems from a network where members are closely and directly linked to each other. Since a small number of actors linked closely to each other in such network configuration develop mutual confidence, common standards and routines for solving problems, their exchange of fine-grained information and implicit knowledge can be promoted to produce the rent. Another is called the "Burt rent," which emerges from a network including a large number of members linked indirectly to each other. Such network configuration contains a great number of "structural holes" - the positions between other actors who are not directly linked-, therefore allows members to have contact with a diverse range of actors and acquire additional new non-redundant information, producing the rent.

Although the two network configurations seemingly differ much from each other, the information acquiring from different network configurations is characteristically different and favorable for different purposes (e.g., Rowley, Beherens, and Krackhardt, 2000; Ahuja, 2000). If so, there is no contradiction between them. In fact, Burt (2001) said a combination of the two network configurations can maximize actors' performances. This means that an actor should have close contacts with a small number of actors in order to acquire fine-grained information or implicit knowledge, while at the same time should have relations with a wide range of diverse actors in order to acquire additional new non-redundant information.

This inference gives very important implications for an analysis of the relationship between auto components transaction network and suppliers' performances. Given the above discussions, suppliers that have developed close business relations with a limited range of customers, while at the same time maintained some relations with a wide range of customers, can be expected to acquire substantial fine-grained and non-redundant information and achieve excellent performances.

Next, this inference will be developed into hypotheses for the Japanese automotive components industry.

5.2. Defining Auto Parts Transaction Network Configurations

Network configurations are usually measured by the number of nodes (actors), the number of ties between nodes, their density and the like. But this paper attempts to define auto parts transaction network configurations by two factors -- (1) "the relationship between a certain supplier and its main customer automaker" and (2) "diversification of a certain supplier's customer base (the scope of customers in which the supplier deals with)."

The "social network theory" suggests, if network configurations are different, gaps may emerge between actors in the quality and quantity of information they obtain and in their performances. Given the above discussions, suppliers that have developed close business relations with a main customer automaker, while at the same time maintained some relations with a wide range of customers, can be expected to acquire substantial fine-grained and non-redundant information and achieve excellent performances.

In the following section, this assumption is put into a real context to generate more specific hypotheses.

5.3. Business Relationships between Suppliers and Their Main Customers

Definitely, information, which is passed on from automakers who are customers to their supplier, plays a major role in the suppliers' performance. In fact, it is commonly observed to have automakers supervise suppliers on product management and quality control. On the other hand, it is often seen among suppliers to receive technical experts from partner automakers or send their own engineers to customer automakers for training. Moreover, it is crucial for suppliers to gain information, directly and indirectly, through daily transactions, about technical trends, rivals' actions, and up-to-date needs of automakers and consumers.

In addition, as noted in Sections 3 and 4, major Japanese automakers have growingly tended to closely cooperate with their respective main suppliers in new vehicle development projects from their initial phases. Participating in advanced technology development projects has become decisively important for suppliers in accumulating technological know-how[11].

Most important in learning from customers is the relationship with the main customer, in this case the automaker. Virtually, suppliers' contacts are most frequent with main customers, and main customers' job priorities are higher. It is common that product development projects aimed at main customers play a major role in building up new core products or production systems. Hence, learning from main customers has a much larger influence on the supplier's performance than learning from other customers.

However, even when automaker B is the main customer for supplier A, this does not simply allow supplier A to draw significantly valuable information from automaker B. Among Japanese car manufacturers, each auto component is usually procured from more than one supplier, and in doing so they refer to a list in which suppliers are rated in detail by competence and background. As for automakers, especially in advanced technology development projects where highly confidential information needs to be shared, their tendency is stronger to partner-up with their core suppliers. Therefore, as long as supplier A is not treated as a core supplier by automaker B, A will hardly gain valuable information from B: Advantages gained through learning from a main customer will be reserved.

On the contrary, when tight relationships between automakers and suppliers are maintained, in which both companies regard each other as a main partner, trust grows and opportunistic breach of information becomes unlikely: Information of higher confidentiality can be exchanged. Thus, suppliers regarded as important by main customers take more advantage of the learning process compared with suppliers that are not.

As for this point, the analysis in Section 4.2 indicates "a supplier's participation in automakers' advanced technology development" is a key explanatory factor for deciding whether a suppliers is regarded by its main customer as a core partner. Thus, a supplier who can participate in their main customer's advanced technology development projects tends to enjoy relative high performance.

5.4. Customer Scope

Another thing that is important with regard to a supplier's performance is to broaden the scope of

[11]In developing component technologies, suppliers usually collaborate with automakers more or less, instead of implementing R&D operations independently. The biggest reason for such collaboration is that automakers' knowledge and know-how ("architectural knowledge") are indispensable for the development of component technologies. Another major reason is the reduction of testing costs. Even if a supplier alone conducts the advanced R&D operations of auto components, these components will have to be installed on real vehicles for various tests before their certification and commercialization. Because such tests cost much, it isn't realistic for suppliers to shoulder all such huge costs. Therefore, it is important for suppliers to take part in automakers' vehicle development projects and have these automakers shoulder reasonable portions of testing costs.

customers.

First, this is because dealing with many numbers of automakers would allow suppliers access to much non-redundant information, compared to suppliers who limit the number of customers. Additionally, developing and producing virtually the same components for different automakers will engage more numbers of test runs and improvement activities during product design and production design procedures, thus quite possibly increasing the learning effect and experience effect of the supplier.

Suppliers may also take advantage of transactions with a wide range of automakers to acquire diverse technological information. As many technological innovations have been achieved in the auto components industry over recent years, suppliers have been faced with growing uncertainties about technology development. If suppliers deal only with a limited range of automakers, they may become preoccupied with views of these automakers and fail to make correct forecasts about future technologies.

Second, experiencing numerous customer dealings would increase the ability of "knowledge transfer" in suppliers. Generally, with some exceptions, it is not easy to develop, produce and deliver auto components to different automakers without modification, even with the same components. Therefore, in order to transfer knowledge gained through dealings from one customer to another, it is critical to adapt the knowledge to different contexts. Such process involves much questioning and learning-by-doing of "what can be used from knowledge already gained and what ought to be changed," and more transactions offer suppliers more learning opportunity in this matter.

Third, we must consider "learning bias". When suppliers are depending too much on transactions with a specific automaker, suppliers are apt to overestimate their own competence, naturally because the opportunity to gain objective information needed to comprehend their competence is scarce.

Moreover, among various activities going on in a firm, most are repeated and form patterns. Through continuous repetition, activities which proved to be successful are selected and accumulated within the firm as "organizational routine"; such being standard procedures, computer programs, pattern of communication, various know-how, and so on. Generally speaking, in auto components transactions, suppliers repeat problem-solving in efforts to meet the demands of customer automakers, to accumulate successful cases and form routine. Routine allows higher efficiency of operation, however, if the suppliers' learning opportunities are reserved to few customer dealings, it would bias the learning process. This is because the supplier might put too much strength on learning the knowledge and experience useful in dealing with the main customer alone and neglect other learning.

In fact, suppliers can increase opportunities to obtain information for their objective assessment of their real strengths in the industry by dealing with a wide range of automakers. A supplier thadvanced technology developmentelivers components to multiple automakers can grasp levels of its technological capability, quality, cost and delivery in the industry by comprehending customers' assessments. This kind of information is extremely important for suppliers to decide on priority areas to which their limited business resources should be allocated.

Likewise, learning bias might occur in “basic corporate behavior principles.” Suppliers who restrict business to specific limited numbers of customers in the long run may possibly narrow down and get stuck to one idea of what they regard as business opportunity.

Thus, we believe that a supplier’s performance is improved through business relations with a variety of automakers.

5.5. Mutually Complementing Relationship between “Supplier’s Participation in their Main Customer’s advanced technology development projects” and “Customer Scope”

We further expect that, from the discussions in Sections 5.4 and 5.5, suppliers’ importance in main customers’ eyes and the scope of customers are mutually complementing. In other words, meeting either one alone would be insufficient.

Thus, from the above discussion, we can derive a hypothesis: Suppliers who can participate in their main customer’s advanced technology development, while at the same time maintain business relationships with a number of other customers, tend to surpass other suppliers in their performance.

6. Statistical Analysis

6.1. Data and Sample

Same as Section 4, this section makes an analysis using data from a questionnaire survey of first-tier automotive parts suppliers that we conducted in November 2003. This analysis does not strictly test the hypothesis given in the previous section but enhances the plausibility of the hypothesis.

As mentioned in Section 4, we sent questionnaires to 340 first-tier automotive suppliers, and 150 firms returned responses. However, in testing the hypotheses in Section 6.2, this study excluded samples lacking indispensable answers to questions for calculating the following variables. As a result, the number of samples for this analysis decline to n=61.

Here, each components transaction is also treated as the unit of analysis. Suppliers' component transaction network configurations differ from one component to another (Konno, 2001). As demonstrated by Han (2002), a transaction mode for one component is different from that for another component, even if transactions are made between the same supplier and automaker. Automakers' purchasing policies may also differ even for the same components (Nobeoka, 1997). Most first-tier suppliers develop and produce various type components and their groups of customer automakers and customer-by-customer breakdowns of sales differ from one component to another. Given these various factors, it is considered desirable to use each component transaction as the unit of analysis in testing the cause-effect relationship assumed in this paper.

6.2. Descriptions of Variables

The OLS regression analysis has been used for the verification of the hypotheses. To save description space, details including original questions for the variables used in the following analysis are summarized in Table 5.

This study used the profit performance of suppliers as the dependent variable to measure supplier performance (unit of analysis is each component dealings). More specifically, we use “the ratio of operating profit to sales (OPS)”, the average operating profit divided by average sales for the latest four years. Although the profit ratio is affected by various factors within and outside a company, however, we think that it is a permissible indicator, given the objective of our study.

As the first independent variable, “a supplier’s participation in its main customer’s advanced technology development (PATD)" is used for indicating “the characteristics of relationship between a supplier and its main customer automaker.” This variable is the same as that used in Section 4.4. According to discussions in Section 5.2, this variable is expected to have a positive effect on the operating profit ratio.

As the second independent variable, "customer scope (CS)" is used for indicating “how wide a supplier's customer base is." This variable is calculated by deducting from 1 the value of a Herfindahl index, which is calculated as the sum of the squares of automakers' percentage shares of a supplier's component sales. For example, "customer scope" value for a supplier thadvanced technology developmentelivered 53% of its total sales of a component to Toyota, 27% to Mazda, 1% to Suzuki, 8% to Daihatsu and 1% to Fuji is calculated as 0.63 = 1 - 0.37 ($0.53^2 + 0.27^2 + 0.11^2 + 0.08^2 + 0.01^2$). Each supplier was asked to specify such percentages on a questionnaire survey sheet.

This variable stands between 0 and 1, and increases as "customer scope" widens. According to discussions in Section 5.3, this variable is also expected to have a positive effect on the operating profit ratio.

As the third independent variable, we’d like to adopt the interaction term of these two variables -- "a supplier's participation in its main customer's advanced technology development (PATD)" and "customer scope (CS)." But if the three variables are simultaneously put into a regression, the multicollinearity problem occurs. Furthermore, because PATD is a discrete variable and sample size is small, even the standard method avoiding this "interaction term problem" (the method introduced by Cronbach (1987)[12]) has failed to be used. Therefore, the following primitive method has been used: First, CS variables are divided into two categories -- one for cases where the variable is "larger" than an average value and another for cases where the variable is "smaller" than an average. Second, since PATD variables are also divided into two categories -- "participate" and "not participate," four cells are constituted: (PATD, CS) = ("participate (P)," "larger (L)"), ("participate," "smaller (S)"), ("no participation (N)," "larger (L)"), ("no participation (N)," "smaller (S)"). The first three of the four cells have been adopted as independent variables. According to discussions in Section 5.4, suppliers' performances are expected to be maximized when PATD is "P" with CS being "L."

Based on discussions in this section, the following three working hypotheses come out for testing:

Hypothesis 1*: PATD has a positive effect on OPS.*

Hypothesis 2*: CS has a positive effect on OPS.*

Hypothesis 3*: (PATD, CS) = ("P", "L") has a maximum positive effect on OPS.*

6.3. Control Variables

Finally, in order to control for other factors that might influence the profit performance of a supplier, we applied a lot of control variables including components level variables and corporate level variables.

Among component-level variables, this study has first adopted "each supplier's average component sales (SCS)" for the latest four years (log value) to control scale economies.

Second, "the number of rivals in the component market (NRC)" has been introduced as a variable to control the effect of the market's competitiveness.

Third, "each supplier's component sales growth (CSG)" for the past four years has been adopted to control the effect of the profit performance that rises in line with sales growth.

Fourth, this study has adopted a "technology change (TC)" variable for controlling the magnitude of changes in relevant component technologies, an "external interdependency (EI)" variable for controlling the external architecture characteristics of relevant components and an "internal interdependency (II)"

[12] The method introduced by Cronbach(1987) calls for deducing mean from each dependent variable (modifying the average into zero) and introducing the two modified variables and their interaction term.

variable for controlling the internal architecture characteristics of the components[13].

Fifth, in order to control the influence by the idiosyncratic nature of each assembler (e.g., differences in supplier management practices) that could result in gaps in suppliers' performance, dummy variables regarding "each supplier's respective main customer automakers" have been given to eight of the nine Japanese automakers. The eight are Toyota, Nissan, Honda, Mitsubishi, Mazda, Suzuki, Daihatsu, Fuji and Isuzu. No variable has been given to Daihatsu.

Sixth, in addition, this study has adopted the "degree of sub-parts commonality (DSPC)", the "degree of production process commonality (DPPC)", the "rate of in-house made production equipment (RIME)", and the "rate of sub-parts outsourcing (RSPO)" as variables to control other factors that could seriously affect suppliers' profit performances.

This study also has used three corporate-level control variables -- log value of "total sales (TS)", the "ratio of non-automotive components sales to total sales (RNCS)" and "each component's percentage share of total sales (PST)."

6.4. Results

Table 6 shows descriptive data and correlation matrices for the variables used in this study other than dummy variables. It shows that the average ratio of operating profit to sales (OPS) for suppliers in the sample is 4.5%. Worthy of attention here is a negative relationship between PATD and CS at the 1% level. This means a trade-off between these two independent variables. Therefore, suppliers that "participate in their main customer automakers' advanced technology development, while at the same time maintain business relations with other customers," may be rather exceptional.

Table 7 shows the results of the OLS (ordinary least squares) regression analysis. Model 1 contains two independent variables (PATD and CS), whereas Model 2 contains three independent variables -- (PATD, CS) = ("P", "L"), ("P", "S"), ("N", "L"). Model 1 (a) and Model 2 (a) contain only component-level control variables, whereas Model 1 (b) and Model 2 (b) include both component-level and corporate-level control variables.

First, although not indicated in Table 7, an adjusted R-square of the base model of (a) is 0.17, and an

[13] Some variables were adopted to control the technological characteristics of relevant components. First, components were divided into seven categories (mechanical subassemblies, electronic and electrical components, mechanically processed components, pressed parts, plastic parts, molding/casting parts and others) and dummy variables were given to six categories excluding "others." Then, the OLS (ordinary least squares) regression analysis including "external interdependency" and "international interdependency" as substitute for the above seven technological categories was conducted. Analysis results indicated few differences. Therefore, this study here introduces only the models into which the "external interdependency" and "internal interdependency" have been put.

adjusted R-square of the base model of (b) is 0.13. Whereas, after adding the independent variables, the adjusted R-square of each model is bigger than the adjusted R-square for each base model. This result means that the explanation power of the regression formula improves after each independent variable is added, suggesting these independent variables used in this analysis have sufficient effects on OPS.

Second, Model 1 shows that PATD has a positive effect on OPS, however, this effect is weak and far below a significant level. This means that Hypothesis 1 fails to be supported. Although reasons are unknown, we assume, one reason may be that a supplier's participation in an advanced technology development project alone requires massive spending that could be recovered through later component sales. Therefore, in a short term, “participation in an advanced technology development project” alone may have even negative impact on profit performance.

Third, Model 1 indicates that CS has a strong positive effect on OPS. A significant level of the variable is $p<0.05$ for (a) and $p<0.01$ for (b). Thus, Hypothesis 2 is supported.

Fourth, Model 2 shows that the variable of (PATD, CS) = (“P”, “L”) has a maximum positive effect on OPS. The significant level of the variable is $p<0.05$ for both (a) and (b). Thus, Hypothesis 3 is supported. For reference, Figure 11 shows the number of suppliers and the partial regression coefficients for four cells.

The statistical analysis in this section indicates: (1) that a supplier's participation in its main customer automaker's advanced technology development alone is not necessarily advantageous for improving the supplier's profit performance, (2) that a supplier’s performance is improved through business relations with multiple automakers, and (3) that a supplier that participates in its main customer's advanced technology development, while at the same time maintains business relations with multiple other automakers, tend to outperform other suppliers who don’t have do this. In short, both relationships simultaneously are necessary for suppliers.

Table 4: Explanations of Variables

Variables	Calculation method	Relevant question
Ratio of operating profit to sales (OPS)	A response to the right question is divided by 100.	Q: Will you specify the ratio of operating profit to sales for Component X at your company (average for the latest four years, %)?
Customer scope (CS)	This variable is calculated by deducting from 1 the value of a Herfindahl index, which is calculated as the sum of the squares of automakers' percentage shares of a supplier's component sales.	Q: Will you specify all Japanese automakers' percentage shares of your company's Component X sales (for the latest fiscal year) ? These percentage figures should add up to 100%.
Average component sales (log value) (SCS)	Based on a response to the right question.	Q: Will you specify sales of Component X at your company (an average for the latest four years, in millions of yen)?
Number of rivals in the component market (NRC)	A response to the right question.	Q: How many companies including your company manufacture Component X? (Latest number of companies)
Component sales growth (CSG)	A response to the right question is divided by 100.	Q: Will you specify the sales growth for Component X at your company (the average annual growth rate for the four latest years, %)?
Degree of sub-parts commonality (DSPC)	A response to the right question is divided by 100.	Q: Will you specify the degree of commonality of sub-parts for Component X (on a cost basis, %)?
Degree of production processes commonality (DPPC)	A response to the right question is divided by 100.	Q: Will you specify the percentage of the common portion of all production processes for Component X (on a man-hour basis, %)?
Rate of in-house made production equipment (RIME)	A response to the right question is divided by 100.	Q: Will you specify the ratio of in-house made production equipment to the total of major production equipments for Component X (based on the number of equipments, %)?
Rate of sub-parts outsourcing (RSPO)	A response to the right question is divided by 100.	Q: Will you specify the rate of outsourcing for sub-parts for Component X (on a cost basis, %)?
Main customer dummy	Dummy variables regarding suppliers' main customer automakers are given to eight Japanese automakers excluding Daihatsu. (The samples (n=61) did not include any supplier that has a main customer other than the nine Japanese automakers.)	Q: What is your main customer automaker for Component X? (Circle one company) 1. Toyota 2. Nissan 3. Honda 4. Mitsubishi 5. Mazda 6. Suzuki 7. Daihatsu 8. Fuji 9. Isuzu 10. Hino 11. Nissan Diesel 12. Others
Total sales (log value) (TS)	Based on responses to the two right questions.	Q: Will you specify sales of Component X (the annual average for the latest four years, in millions of yen)? Q: Will you specify Component X's share of your company's total sales (the annual average for the latest four years, %)?
ratio of non-automotive components sales to total sales (RNCS)	A response to the right question is divided by 100.	Q: Will you specify the ratio of sales other than the auto industry to total sales (on a sales basis, the average for the latest four years, %)?
each component's percentage share of total sales (PST)	A response to the right question is divided by 100.	Q: Will you specify Component X's share of total sales at your company (the average for the latest four years, %)?

(Note) Descriptions are omitted for variables covered by Table 2.

Table 5: Descriptive Statistics and the Correlation Matrix of Major Variables

	Variable	AV	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	OPS	0.04	0.05	1.00															
2	PATD	0.69	0.46	−0.09	1.00														
3	CS	0.40	0.29	0.34	−0.24	1.00													
4	SCS	8.47	1.69	0.02	0.26	0.31	1.00												
5	NRC	0.15	0.40	−0.03	0.05	−0.16	0.02	1.00											
6	CSG	8.92	12.59	−0.07	−0.14	−0.19	−0.15	0.02	1.00										
7	TC	3.46	0.77	−0.35	0.32	−0.23	0.06	0.12	−0.17	1.00									
8	EI	−4.59	3.01	−0.12	0.38	−0.12	0.27	0.05	−0.01	0.22	1.00								
9	II	6.75	1.64	0.13	0.00	−0.03	0.06	0.07	−0.21	0.07	0.06	1.00							
10	DSPC	0.27	0.22	−0.08	−0.07	0.00	−0.06	−0.06	−0.12	−0.07	−0.26	0.06	1.00						
11	DPPC	0.41	0.29	−0.16	0.03	0.11	−0.07	0.04	−0.19	0.03	−0.12	0.04	0.47	1.00					
12	RIME	0.50	0.32	−0.06	−0.05	0.09	−0.16	0.03	−0.01	−0.21	0.04	0.13	0.10	−0.07	1.00				
13	RSPO	0.33	0.28	−0.29	0.07	−0.07	−0.06	0.03	0.00	0.20	0.05	−0.16	0.15	0.00	−0.03	1.00			
14	TS	10.22	1.66	−0.04	0.16	0.22	0.78	0.04	−0.23	0.12	0.33	0.05	−0.14	−0.13	−0.15	0.08	1.00		
15	RNCS	0.23	0.29	−0.02	−0.21	0.23	−0.17	−0.15	0.18	−0.07	−0.10	−0.15	−0.08	−0.10	0.04	0.29	0.04	1.00	
16	PST	0.29	0.26	0.09	0.04	0.21	0.44	0.01	0.05	−0.03	−0.02	0.07	0.04	0.05	−0.07	−0.06	−0.11	−0.26	1.00

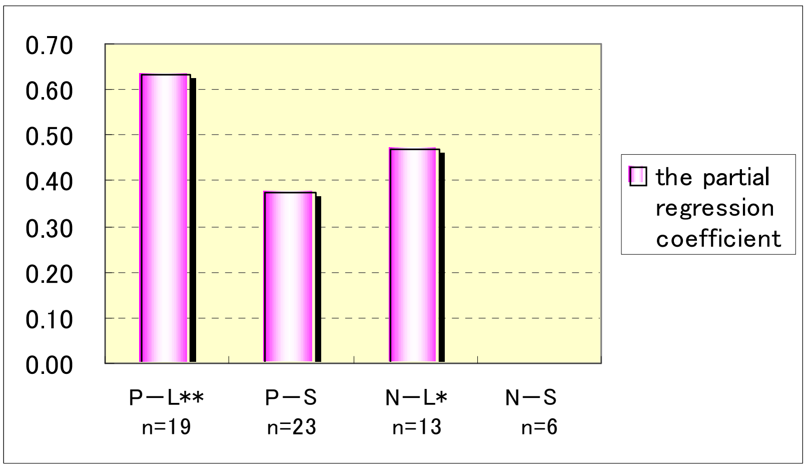
(Note) If the absolute value of a correlation coefficient≧0.24 then it is significant at the 1% level, and if the absolute value is ≧0.17 then it is significant at the 5% level.

Table 6: OLS Regression Analysis Results (n=61)

Model		1(a)		1(b)		2(a)		2(b)	
Independent variable		OPS		OPS		OPS		OPS	
		β	t	β	t	β	t	β	t
PATD	Independent variable	0.02	1.41	0.02	1.38				
CS	Independent variable	0.07	2.65 **	0.07	2.74 ***				
P−L	Independent variable					0.07	2.38 **	0.08	2.59 **
P−S	Independent variable					0.04	1.33	0.05	1.65
N−L	Independent variable					0.06	1.95 *	0.07	2.29 **
SPS		−0.01	−1.94 *	−0.02	1.19	−0.01	−1.99 *	−0.01	−1.07
NRC		0.00	−0.50	0.00	0.26	0.00	−0.45	0.00	−0.53
CSG		0.00	0.27	0.00	0.08	0.00	0.04	0.00	−0.04
TC		−0.02	−2.03 **	−0.02	2.01 *	−0.02	−1.87 *	−0.02	−1.85 *
EI		0.00	−0.10	0.00	0.07	0.00	−0.02	0.00	0.21
II		0.01	1.57	0.01	1.43	0.00	1.24	0.00	1.08
DSPC		0.02	0.67	0.02	0.55	0.01	0.30	0.01	0.22
DPPC		−0.05	−1.95 *	−0.05	2.06 **	−0.04	−1.78 *	−0.05	−1.97 *
RIME		−0.04	−1.99 *	−0.04	1.83 *	−0.04	−1.98 *	−0.04	−2.00 *
RSPO		−0.04	−1.55	−0.04	1.34	−0.04	−1.60	−0.04	−1.40
Toyota	Main customer dummy	0.08	2.17 **	0.08	2.25 **	0.08	2.14 **	0.08	2.32 **
Nissan	Main customer dummy	0.07	2.04 **	0.08	2.13 **	0.07	1.77 *	0.07	1.98 *
Honda	Main customer dummy	0.08	2.20 **	0.09	2.36 **	0.08	1.96 *	0.08	2.12 **
Mitsubishi	Main customer dummy	0.03	0.77	0.03	0.72	0.03	0.60	0.03	0.65
Mazda	Main customer dummy	0.07	1.60	0.07	1.67	0.07	1.68	0.08	1.79 *
Suzuki	Main customer dummy	0.05	0.88	0.05	0.75	0.05	0.88	0.06	0.93
Fuji Heavy	Main customer dummy	0.05	1.08	0.05	1.05	0.04	0.86	0.04	0.85
Isuzu	Main customer dummy	0.07	1.54	0.08	1.84 *	0.07	1.57	0.08	1.78 *
TS				0.00	0.40			0.00	0.08
RNCS				−0.02	0.96			0.00	0.01
PST				0.04	0.78			0.05	0.92
Constant		0.07	0.96	0.08	0.90	0.09	1.11	0.10	1.14
F value		1.97		1.78		1.79		1.65	
*Adjusted R*2		0.24		0.23		0.22		0.21	
N		61		61		61		61	

* for p<0.10, ** for p<0.05, *** for p<0.01

Figure 11: OLS Regression Analysis Results (n=61)



7. Conclusion and Discussions

7.1. Cooperation in Advanced technology Development and Inter-company Relations

The above analyses indicated that Japanese automakers and their respective suppliers have expanded their collaboration into the development of advanced technologies over the past decade.

In the Japanese automotive market, the automakers need to realize sufficient functionality and product quality at a low price. Furthermore, for example, the automakers need to realize not only the basic drive, turn, stop, and gasoline mileage functions but also user-friendliness, huge baggage area, airbags, active safety, and CO_2/NO_X reduction features. Thus, today, automotive technology development races have become more and more complicated.

For most of the automotive components, technological innovations are rapid, including development and utilization of new materials (particularly a shift from metals to plastics) and advanced IT technologies, miniaturization, and reducing weight of a vehicle. In addition, a shift has made rapid progress to “modules” and “systems” over the recent years. The new design concepts for automotive components have been proposed one after another and some have been put into practice.

Under these circumstances, automakers have been prompted to cooperate with their suppliers for the development of advanced technologies (e.g., Konno and Okuda, 2005). Such conditions have apparently exerted a great impact on business relations between automakers and their suppliers.

Furthermore, the analysis in Section 6 indicates a supplier who participates in their main customers’ advanced technological development and has broader scope of business relationships tends to outperform other suppliers who don’t have this. In other words, it is significant for suppliers to broaden customer scope, but if with the sacrifice of existing relation with the main customer, it is not a preferable option.

In fact, suppliers face many advanced technology issues which can only be dealt with in collaboration with automakers. Therefore, it is crucial for suppliers to prove important in the eyes of main customers and gain more access to confidential and important information on technology and needs, or join co-development projects on new technology.

However, this alone will not be sufficient. “Participation in an advanced technological development project” alone means “pure investments” that can only be recovered through later component sales. In addition, if suppliers reserve the number of customers, they could get caught in “learning bias” or become too dependent on specific customer company and lose the attitude of developing and exercising their own strategies. Moreover, in order to manage transactions among different firms, suppliers must be able to adapt the technology or product platform of a specific product to meet different customers’ demands. Such competence would only develop, and improve, through learning by doing in numbers of actual dealings with customers. Thus, it is crucial for a supplier not only to participate in its main customers' advanced technology development projects, while at the same time broadening transactions with other various customers.

7.2. Progressive practice of Toyota’s Suppliers and Future Problems

Furthermore, even amid this general trend, our findings indicate that Toyota has progressed ahead of other automakers. Toyota has cooperated with major suppliers from the advanced technology development stage more aggressively than other automakers. Its quantitative achievements in this regard are far more than those of the other automakers. Toyota has also proactively coordinated the joint style advanced technology development projects that include two or more suppliers (which include horizontal collaboration between suppliers).

Since automotive technologies have been advancing rapidly, Toyota’s excellent production and product development operations cannot guarantee its future competitiveness. If it fails to develop advanced technologies, even Toyota could be outperformed by the others. Given Toyota’s recent success, it seems that the network that Toyota has constructed for collaboration with suppliers in the development of advanced technologies might have contributed to the firm’s international competitive edge.

The progressiveness of the network that Toyota has built for collaboration with suppliers in the development of advanced technologies indicates the firm’s excellent management of collaboration. This paper does not address details of automakers’ management of collaboration with suppliers in the development of advanced technologies. However, this is a very interesting theme.

In the future, multifaceted surveys should be conducted to examine the management of collaboration in advanced technology development.

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イノベーション・マネジメント研究センター
The Research Institute for Innovation Management

法政大学イノベーション・マネジメント研究センター
The Research Institute for Innovation Management, HOSEI UNIVERSITY

〒102-8160 東京都千代田区富士見 2-17-1
TEL: 03(3264)9420　FAX: 03(3264)4690
URL: http://www.hosei.ac.jp/fujimi/riim/
E-mail: cbir@adm.hosei.ac.jp