Impacts of the Information-technology Revolution on Japanese Manufacturer-supplier Relationships[*]

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Abstract

'Vertical keiretsu', characterized by suppliers' willingness to make customized investments and their long-term relationships with manufacturers, had been recognized as an important source of strength in Japanese industries. Our model predicts that, in contrast to the recent popular argument, the information-technology revolution can strengthen 'vertical keiretsu'. This is because the efficiency of designing customized parts is significantly enhanced if suppliers undertake a substantial level of IT investments such as the introduction of 3D CAD systems, and the customized nature of such investments could reduce the number of potential suppliers. Our interviews with Japanese manufacturers provide a support to this prediction.

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1. Introduction

Japanese manufacturer-supplier relationships have been intensively studied throughout the 1980s, and a number of researchers have identified the cooperative relationships based on long-term relationships and suppliers' willingness to make customized investments as their key features. Namely, Japanese manufacturers purchase intermediate products (or parts) repeatedly from a limited number of suppliers on a long-term basis, and the suppliers are willing to make investments specific to their purchaser in order to produce customized parts.[1] Asanuma (1989) studied the Japanese automobile and the electric machinery industries and found that these two features are closely interrelated. According to his observations, as the extent of customization increases, the manufacturer-supplier relationships tend to become longer-term and more stable.

The Japanese manufacturer-supplier relationships characterized by these features have often been called 'vertical keiretsu', and regarded as a major source of strength in Japanese manufacturing industries. The MIT Commission on Industrial Productivity concluded, based on a number of case studies conducted in the late 1980s, that US manufacturers should establish Japanese-type cooperative relationships with their suppliers in order to regain their productive edge (see Dertouzos, Lester and Solow, 1989). Since 1989, Chrysler Corporation had made a substantial effort to establish Japanese-type relationships with its suppliers. Dyer (1996) observed that, as a result, suppliers increased their investment in dedicated assets – plants, equipment, systems, processes, and people dedicated exclusively to serving Chrysler's needs.

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[1] For example, Dyer and Ouchi (1993) found, based on their comparative study of the Japanese and the US automobile industries, that the Japanese suppliers were willing to invest in customized equipment and customer-specific human capital (e.g., let their own engineers develop significant partner-specific knowledge), and locate their plants quite close to the manufacturer. Nishiguchi (1994) obtained similar findings from his extensive comparative study of British and Japanese subcontracting in the electronics industry. According to Aoki (1988), only three firms exited from the association of first-tier Toyota suppliers between 1973 and 1984, whereas 21 firms entered. See also, e.g., McMillan (1990), Cusumano and Takeishi (1991), and Fujimoto (1998).

In contrast, a number of people recently asserted that recent advances in information technology (call it the IT revolution hereafter) would dramatically change the basic nature of Japanese manufacturer-supplier relationships. For example, a leading economist in Japan argued in a recent newspaper article that Japanese manufacturers would change the nature of parts required for their products from customized parts to standard parts, and would procure them from a larger number of potential suppliers through the internet rather than from a limited number of suppliers within their own corporate groups (or 'keiretsu').[2]

How will the IT revolution impact on manufacturer-supplier relationships? Will 'vertical keiretsu' disappear in Japan? This is an important question when we consider the sources of strength of manufacturing industries in the New Economy. We address this question both theoretically and empirically. We first consider an interaction between a manufacturer and suppliers in a two-period setting. In each period, the manufacturer determines the design of its final product, which in turn specifies the functional requirements for parts. We say that the manufacturer chooses a customized interface with a part if the product design requires that the design of the part should be tailored to the specific requirements of the manufacturer. Otherwise, we say that it chooses the standard interface. A customized interface requires customized parts whereas the standard interface requires standard parts.[3] The value of a customized part for the manufacturer is higher than that of the standard part, but, in order to produce customized parts, a supplier must make investments customized to the manufacturer.

We incorporate two major effects of the IT revolution into our framework. First, the prevalence of the internet reduces the downstream firm's cost for contacting and communicating with potential suppliers. Second, the efficiency of designing customized parts

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[2] Asahi Newspaper on September 18, 2000.

[3] This formulation is consistent with the concept of product architecture developed in the product design literature. For instance, Ulrich (1995) distinguishes between a modular architecture and an integral architecture, and asserts that firms have substantial latitude in choosing a product architecture. He argues that components (or parts) of a product tend to be standardized when a modular architecture is chosen.

can be substantially improved by taking advantage of the IT revolution, 3D CAD (Three-dimensional Computer-Aided Design) systems in particular, which enhance the efficiency for engineers of manufacturers and suppliers to coordinate their design activities. The realization of such efficiency, however, requires higher levels of customized investments. For instance, suppliers need to introduce and maintain a 3D CAD system that is tailored to that of their purchaser. See Section 3 for more details on these effects.

Our model predicts two distinct patterns for impacts of the IT revolution on manufacturer-supplier relationships. On one hand, the IT revolution can induce the manufacturer to choose the standard interface, and contact and communicate with a larger number of potential suppliers for purchasing the standard parts. This is consistent with the recent popular argument as described above; that is, due to the IT revolution, ‘vertical keiretsu’ would become weaker or even disappear from many Japanese manufacturer-supplier relationships.

However, our analysis suggests that this is only one side of the coin. It also predicts that, after the IT revolution, the manufacturer can either continue to choose a customized interface or switch from the standard interface to a customized interface, and procure customized parts from a smaller number of potential suppliers who make higher levels of customized investments. In other words, ‘vertical keiretsu’ could become stronger due to the IT revolution. The nature of product development process, which differs across products, seems to be an important factor that determines which type of the impact to emerge. That is, the latter pattern is more likely if the importance of close coordination among engineers made possible by 3D CAD systems is sufficiently high for a given product, and the former pattern is more likely otherwise.

We have conducted interviews with ten large Japanese manufacturing firms concerning impacts of the IT revolution on their relationships with suppliers, and identified both of the two predicted patterns described above. Concerning the second pattern, five out of ten manufacturers expected that, as a result of the IT revolution, they would purchase customized parts from a smaller number of potential suppliers. In other words, these manufacturers expect that ‘vertical keiretsu’ type relationship with their suppliers would become stronger for some kinds of parts due to the IT revolution. This finding is in contrast to the recent popular argument described above. Also, we have identified a similar pattern in the US automobile industry from our preliminary interviews.

The rest of the paper is organized as follows. Section 2 presents a two-period model of an interaction between a manufacturer and suppliers, in which the manufacturer chooses an interface of its product with a part from a customized interface or the standard interface. Section 3 first considers the Subgame Perfect Nash Equilibria (SPNE) of the model, and then analyzes a variant of the model that incorporates the two effects of the IT revolution in our framework. The comparison of the equilibrium of the original model and the variant of the model yields predictions of our model concerning impacts of the IT revolution on manufacturer-supplier relationships. Section 4 presents findings from our interviews with ten Japanese manufacturing firms concerning impacts of the IT revolution on their relationships with suppliers. Section 5 summarizes and concludes.

2. The Model

We consider an interaction between a downstream firm and upstream firms (indexed by $i = 1, 2, \ldots$) in a two-period setting. There is free entry of upstream firms, and firms are all risk neutral. In each period, the downstream firm produces one unit of a final product, and the production requires one unit of intermediate product (call it ‘part’) produced by an upstream firm. In each period, the downstream firm chooses an interface between its final product and the part; it chooses either a customized interface or the standard interface. A customized interface requires a customized part, whereas the standard interface requires the standard part. The value of the standard part for the downstream firm is g (> 0). If the downstream firm chooses a customized interface, it announces the required level of quality (or value) of the customized part, which is denoted q (> 0). This is consistent with the following observation by Asanuma (1985a, b; 1989) who studied the Japanese automobile and electric machinery industries in details: When a manufacturer develops a new model, in many cases the manufacturer announces the functional requirements of a customized part, and several suppliers compete against each other for developing a part that meets the requirements at lower production costs.

In order to produce a customized part, in each period an upstream firm must make a given level of a fixed customized investment (denoted $f > 0$). In order to meet the quality requirement q (> 0), it also makes a level of a variable customized investment, denoted x (≥ 0), which determines the quality of the customized part by $h(x) + \mu$.[4] Here, $h(\cdot)$ is a twice continuously differentiable function with $h'(x) > 0$ and $h''(x) < 0$ for all $x \geq 0$, $h'(0) = +\infty$, $h'(+\infty) = 0$ and $h(0) \geq g$; and $\mu = \lambda$ (> 0) if the upstream firm made a customized investment in the previous period and $\mu = 0$ otherwise.[5] This specification captures the idea that an upstream firm can more efficiently develop a customized part due to learning by doing if it experienced the development in the previous period. Assume that these investments are verifiable, and that the downstream firm can subsidize the customized investment.[6]

In order to procure a part from a supplier, the downstream firm must contact and communicate with potential suppliers by incurring communication costs of y (> 0) per upstream firm. We assume that the value of y is sufficiently small so that the downstream firm can make a positive expected profit in equilibrium.[7] Each upstream firm i's production cost per part (whether a customized part or the standard part) in period t is given by $c - \varepsilon_{it}$ per

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[4] An example of the variable customized investment includes working hours of engineers for designing customized parts. An alternative assumption for the fixed customized investment is that the investment is valid for two periods. The qualitative nature of the results would be unchanged under the alternative assumption.

[5] Given the quality requirement q (> 0), the required level of a variable customized investment is $h^{-1}(q - \mu)$ if $q \geq h(0) + \mu$ and 0 otherwise.

[6] Dyer and Ouchi (1993) pointed out that Japanese manufacturers often send consultants (paid by the manufacturers) to work with the supplier (often for months) to improve productivity and quality. A manager of an NEC supplier explained, 'We were always in competition with another supplier to produce the lowest-cost, highest-quality circuit boards. NEC would often provide assistance to both of us by sending in teams of engineers to help us improve. … '

[7] A sufficient condition for this is $y < g - c + 1/2$.

unit, where c (> 0) is a constant and ε_{it} is a random variable. We assume that ε_{it} is identically and independently distributed according to a uniform distribution between 0 and 1, and $c – 1 > 0$. We also assume $c \leq g – 1$. This assumption implies that the production cost is sufficiently small relative to the value of the part, and so the downstream firm purchases a part (customized or standard) with probability one through procurement auction in equilibrium.

Each period t (= 1 or 2) consists of three stages. For simplicity, assume that all players share a common discount factor equal to one.

[Stage 1] The downstream firm chooses either a customized interface or the standard interface, and contacts and communicates with potential suppliers by incurring communication costs of y (> 0) per upstream firm. The choice becomes common knowledge. If the downstream firm chooses a customized interface, it announces the required level of quality (or value) of the customized part, denoted q (> 0). Also, the downstream firm can announce a level of subsidy, denoted s (≥ 0). The subsidy will be paid in the next stage to each upstream firm that makes a sufficient level of the customized investment for achieving the required level of quality q (> 0).

[Stage 2] If the downstream firm chose a customized interface in the previous stage, each potential supplier determines whether or not to make the required level of customized investment, which is $f + h^{-1}(q – \mu) – s$ if $q \geq h(0) + \mu$ and $f – s$ otherwise. The decision becomes common knowledge.

[Stage 3] The random variable ε_{it} is realized and observed only by upstream firm i. The downstream firm can then purchase a part (either a customized part or the standard part, depending on its choice of interface in the first stage) from a potential supplier (whom it contacted and communicated with in the first period) through a procurement auction. The auction is designed by the downstream firm so as to maximize its expected profit.

3. Analyses

In this section, we first consider the Subgame Perfect Nash Equilibria (SPNE) of the model described above, and characterize the equilibria in Proposition 1. We then consider a variant of the model that incorporates two effects of the IT revolution in our framework, and characterize the equilibria of the variant of the model in Proposition 2. Propositions 1 and 2 together yield predictions concerning impacts of the IT revolution on manufacturer-supplier relationships. Throughout the analysis, we define *Customized-equilibrium* (*C-equilibrium*) and *Standard-equilibrium* (*S-equilibrium*) as follows:

C-equilibrium: In each period, the downstream firm chooses a customized interface and contacts and communicates with n_C (≥ 1) potential suppliers, and all of them make the required level of customized investments. The downstream firm purchases a unit of the customized part from a potential supplier that has realized the lowest production cost. The identity of upstream firm(s) that make customized investments is unchanged across periods.

S-equilibrium: In each period, the downstream firm chooses the standard interface and contacts and communicates with n_S (≥ 1) potential suppliers. It purchases a unit of the standard part from a potential supplier that has realized the lowest production cost.

Note, all proofs are in Appendix A.

<u>Proposition 1</u>: For any given parameter values, there exists a value $\overline{f}$ (> 0) such that, holding all parameter values except f fixed, the model exhibits the *Customized-equilibrium* (*C-equilibrium*) if $f < \overline{f}$ and the *Standard-equilibrium* (*S-equilibrium*) if $f > \overline{f}$, where $n_S \geq n_C$ holds.

An upstream firm must make a customized investment in order to produce customized parts. Since the investment pays off later only for an upstream firm who wins the procurement auction, a relatively small number of upstream firms make customized investments in the C-equilibrium. In contrast, since the production of the standard part does not require customized investments, the downstream firm can choose one supplier from a larger number of potential suppliers if it chooses the standard interface. Hence, the expected value of the lowest production cost among potential suppliers is higher in the C-equilibrium than in the S-equilibrium. Given free entry of upstream firms, the higher production cost and the cost of customized investments are reflected in the higher equilibrium price of the customized part. On the other hand, the downstream firm can enhance the market value of its final product by using a customized part. Under this trade-off, if the level of the fixed customized investment is sufficiently low, a customized interface becomes more attractive option for the downstream firm and so the model exhibits the C-equilibrium.

In the C-equilibrium, a limited number of potential suppliers make customized investments in the first period, and one that has realized the lowest production cost is chosen as a supplier for the period. The same upstream firms make customized investments again in the next period due to learning by doing concerning customized investments. This equilibrium captures observations of Japanese manufacturer-supplier relationships made by a number of researchers throughout the 1980s. That is, as discussed in Introduction, Japanese manufacturers typically purchase parts from a limited number of suppliers who are willing to make investments specific to their purchaser in order to produce customized parts, where the identity of these suppliers is relatively unchanged over time.

Furthermore, the C-equilibrium captures ‘multiple vendor policy’, which has been employed by many Japanese manufacturers. According to a series of careful and comprehensive case studies of the Japanese automobile and electric machinery industries by Asanuma (1985a, b; 1989), when a manufacturer develops a new model, the manufacturer typically lets several potential suppliers compete against each other for winning an order of a customized part. Given functional requirements announced by the manufacturer, they compete against each other for meeting the requirements at the lowest possible production cost. At the end of the development period, one supplier wins the contest and becomes the sole supplier of the part throughout the life span of the model. The competition is repeated when the manufacturer develops a new model.

In reality, most products have multiple interfaces with parts, and manufacturers choose a customized interface for some interfaces and the standard interface for others. The former choice is captured by the C-equilibrium and the latter by the S-equilibrium in our theoretical framework. Although transactions of customized parts have attracted much attention in Japanese manufacturer-supplier relationships, many Japanese manufacturers also procure a substantial amount of standard parts. For example, out of ten Japanese manufacturing firms we interviewed, seven firms told us that they procured a non-negligible amount of standard parts (see Section 4 for more details).

Next, we consider a variant of the model which incorporates the following two effects of the IT revolution in our framework. First, the prevalence of the internet reduces the manufacturer's cost for contacting and communicating with potential suppliers. Malone *et al*. (1987) argued, in their comparative analysis of electronic markets and electronic hierarchies, that buyers incur substantial coordination costs if they procure inputs through markets, because they must gather and analyze information from a variety of possible suppliers. They then pointed out that the use of information technology seems likely to decrease these costs, because the essence of coordination involves processing information.[8]

Second, the efficiency of designing customized parts can be substantially improved by taking advantage of the IT revolution, 3D CAD (Three-dimensional Computer-Aided Design) systems in particular. Baba and Nobeoka (1998) argue that 3D CAD systems have substantial impacts on the process and the efficiency of product development. 3D CAD systems enable designers and engineers to fully visualize their products and easily exchange information on product design. Furthermore, they can view an assembled set of components before physical prototypes are made (called 'digital pre-assembly'). This substantially enhances the efficiency for engineers of manufacturers and suppliers to coordinate their design activities especially at an early stage of product development, which plays a crucial role for achieving product integrity (Clark and Fujimoto, 1991).[9] The realization of such efficiency, however,

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[8] See also, e.g., Bakos (1997), Barua et al. (1997) and Lucking-Reiley and Spulber (2001) for similar arguments.

[9] Clark and Fujimoto (1991) observed in the Japanese automobile industry that engineers from suppliers and those from a manufacturer communicated with each other very closely in designing better customized parts. See also Clark (1989) and Dyer and Ouchi (1993).

requires higher levels of customized investments. For instance, suppliers need to introduce and maintain a 3D CAD system that is tailored to that of their purchaser.[10]

In the variant of the model, everything is the same as in the original model except the following: First, the downstream firm's communication cost is given by $y' \equiv y - \Delta_y$ instead of y, where $0 < \Delta_y < y$. Second, in order to produce a customized part, each upstream firm has an option of making an IT-customized investment (for which investment in 3D CAD systems is the most important example) by incurring a higher level of fixed customized investment $f + \Delta_f$ where $\Delta_f > 0$. Under this option, the value of the customized part is determined by $\theta h(x) + \mu$ rather than $h(x) + \mu$, where $\theta > 1$. The parameter θ captures the extent to which the efficiency of designing customized parts is improved through closer coordination among engineers of the manufacturer and suppliers made possible by the IT-customized investment. Note that the efficiency of the IT-customized investment is increasing in θ and decreasing in Δ_f. Proposition 2 characterizes the equilibria of this variant of the model.

Proposition 2: (i) For any given parameter values, there exists a value $\bar{\bar{f}}$ (> 0) such that, holding all parameter values except f fixed, the variant of the model exhibits the *C-equilibrium* if $f < \bar{\bar{f}}$ and the *S-equilibrium* if $f > \bar{\bar{f}}$, where $n_S \geq n_C$ holds.
(ii) For any given parameter values, there exists a value θ' (> 1) such that
(a) if $f < \bar{\bar{f}}$, all potential suppliers make IT-customized investments in the *C-equilibrium* if and only if $\theta > \theta'$,
(b) $\bar{\bar{f}}$ is increasing in θ for all $\theta > \theta'$ while $\bar{\bar{f}}$ is independent of θ for all $\theta < \theta'$, and
(c) $\bar{\bar{f}}$ is decreasing in Δ_f if $\theta > \theta'$ while $\bar{\bar{f}}$ is independent of Δ_f if $\theta < \theta'$.

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[10] As an example, US automobile manufacturers use different 3D CAD systems (DaimlerChrysler uses CATIA, Ford uses I-DEAS, and General Motors uses Unigraphics). Also, in Japanese automobile industry, Toyota uses CADCEUS, Nissan uses I-DEAS and Honda uses CATIA.

Costs for introducing a 3D CAD system (including training costs) are substantially higher than those for a 2D CAD system. Greco (2000) points out that many companies still use 2D CAD systems due to the high costs for introducing 3D CAD systems.

The first part of Proposition 2 is analogous to Proposition 1. That is, if the level of the fixed customized investment is lower than the threshold $\bar{\bar{f}}$, the downstream firm chooses a customized interface in each period and so the variant of the model exhibits the *C-equilibrium*, whereas it exhibits the *S-equilibrium* otherwise. The second part investigates how the threshold $\bar{\bar{f}}$ is affected by the efficiency of the IT-customized investment. In the *C-equilibrium*, all potential suppliers make IT-customized investments if the IT-customized investment is sufficiently efficient (that is, if $\theta > \theta'$). Given $\theta > \theta'$, the threshold $\bar{\bar{f}}$ is increasing in θ and decreasing in Δ_f. In other words, as the efficiency of the IT-customized investment increases, it becomes more likely that the variant of the model exhibits the *C-equilibrium*.

In the next proposition, we investigate impacts of the IT-revolution in our framework by comparing the equilibrium of the original model and the equilibrium of the variant of the model.

Proposition 3: For a given set of parameter values, the equilibrium of the original model and the equilibrium of the variant of the model exhibit one of the following four patterns:

	Original model	Variant of the model
Pattern I	*S-equilibrium*	*S-equilibrium*
Pattern II	*C-equilibrium*	*S-equilibrium*
Pattern III	*S-equilibrium*	*C-equilibrium*
Pattern IV	*C-equilibrium*	*C-equilibrium*

As discussed in Introduction, a number of people recently asserted that pattern II above would be the major impact of the IT revolution on Japanese manufacturer-supplier relationships. The prediction here is that, as a result of the IT revolution, ‘vertical keiretsu’ would become weaker or even disappear from many Japanese manufacturer-supplier relationships. The number of potential suppliers increases after the IT revolution in pattern II as well as in pattern I.

However, our analysis indicates that this is only one side of the coin. It predicts that pattern III or IV can also be an impact of the IT revolution. Prediction here is that, after the IT revolution, the manufacturer either continues to choose a customized interface or switches from the standard interface to a customized interface. The number of potential suppliers decreases after the IT revolution in pattern III, and it can also decrease in pattern IV.[11] The reason is that, in order to take advantage of the IT revolution, each potential supplier may be required to make a higher level of customized investments, which in turn reduces the optimal number of potential suppliers. Namely, as a result of the IT revolution, manufacturers could procure customized parts from a smaller number of potential suppliers who make higher levels of customized investments. In other words, ‘vertical keiretsu’ could become stronger due to the IT revolution.

The importance of close coordination among engineers made possible by 3D CAD systems seems to differ across products. Elaborating on Ulrich (1995), Fujimoto (2000; 2001) distinguishes two types of products based on the nature of their product-development processes; ‘integral architecture’ type and ‘modular architecture’ type. For the former type product, the optimal design of one component is closely dependent on the design of other components, and so close coordination among engineers of different components are crucial for achieving product integrity. Automobile is an example of such product. On the other hand, for the latter type product, the optimal design of one component is relatively independent of the design of others, and so close coordination among engineers is less important. Personal computer is an example of such product.

Recall that, in our framework, parameter θ captures the efficiency of the IT-customized investment such as the investment in 3D CAD systems. Hence, θ seems to be

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[11] We have worked out examples (see Appendix B) in which the number of potential suppliers decreases after the IT revolution in pattern IV. However, we have been unable to show that this is the general result.

relatively large for ‘integral architecture’ type product and small for ‘modular architecture’ type product. Proposition 2 then indicates that pattern III or IV is more likely for ‘integral architecture’ type product such as automobile, whereas pattern I or II is more likely for ‘modular architecture’ type product such as personal computer. In other words, ‘vertical keiretsu’ would become weaker or even disappear due to the IT revolution for ‘modular architecture’ type product, whereas the IT revolution could even strengthen ‘vertical keiretsu’ for ‘integral architecture’ type product.

4. Interview results

In this section we present findings from our interviews with ten Japanese manufacturing firms concerning impacts of the IT revolution on their relationships with suppliers. Among the ten firms, one is in the automobile industry, one is in the construction machinery industry, one is in the heavy industry, one is in the apparel industry, and six are in the electric machinery/electronics industry. Regarding the size of the firms, three firms have employees between 2,000 and 10,000, three firms between 10,001 and 30,000, and four firms above 30,000. Also, three firms have annual sales between 1,500 and 5,000 (million US$), four firms between 5,001 and 25,000, and three firms above 25,000.

For each firm, we interviewed a general manager or a manager of their procurement division or procurement strategy division, and/or a general manager or a manager who is responsible for its computer system for procurement (see Appendix C for details). Note, in what follows, the term ‘parts’ is meant to include intermediate products, and we used the following definitions in our interviews:

Customized parts: Parts whose designs and functions are tailored to the specific needs of a manufacturer, and whose values would be substantially lower if they were used by another manufacturer.

Standard parts: Parts whose designs and functions are standardized, and whose values would be approximately equal across different manufacturers in the same industry.

We first asked the following question in order to identify the ratio of customized and standard parts they procure.

Question 1: Among all parts your firm purchases from suppliers, what percentage (in terms of monetary value) would you estimate to be standard parts?

Then, concerning standard parts, we asked the following questions:

Question 2-1: Concerning standard parts, is your firm utilizing (and/or planning to utilize) the internet in order to enhance the effectiveness of procurement?

Question 2-2: If the answer to Question 2-1 is yes, does that result in an increase in the number of potential suppliers of standard parts?

Next, we asked how the recent advances in information technology would affect their procurement of customized parts. All interviewees pointed out that it could substantially improve the efficiency for designing customized parts. In particular, all firms except the one in the apparel industry mentioned that 3D CAD systems substantially improve the efficiency for their engineers and suppliers' engineers to coordinate their design activities. We then asked the following questions:

Question 3-1: In order to enhance the efficiency for designing customized parts by taking advantage of the recent advances in information technology (call it the IT revolution hereafter), do your suppliers need to make a substantial level of investments customized to your firm?

Question 3-2: If the answer to Question 3-1 is yes, does that result in a reduction in the number of potential suppliers of customized parts?

Finally, we attempted to find out whether or not the IT revolution would induce them to change the nature of their parts by asking the following two questions:

Question 4: In order to take advantage of the IT revolution, has your firm changed (and/or is your firm going to change) the nature of some parts from customized parts into standard parts?

Question 5: Same as Question 4 above, except 'from standard parts into customized parts?'

The interview results are presented in Table 1 on the next page. The results indicate that, in contrast to the recent popular argument described in Introduction, ‘vertical keiretsu’ type relationships could continue or become stronger due to the IT revolution. According to the interviewees’ responses to Question 1, the majority of parts that they purchase from suppliers are customized parts. In response to Question 4, seven out of the ten firms told us that the IT revolution would not induce them to switch any customized parts to standard parts. The other three firms also said that, although they would switch a certain fraction of their customized parts to standard parts, other customized parts would remain unaffected. In our theoretical framework, this pattern is captured by pattern IV (see Proposition 3), in which the manufacturer continues to choose a customized interface after the IT revolution.[12]

Furthermore, five firms out of the ten firms answered ‘yes’ to both Question 3-1 and 3-2. This pattern is consistent with our prediction that, as a result of the IT revolution, manufacturers could purchase customized parts from a smaller number of potential suppliers who make higher levels of customized investments than before the revolution. Concerning 3D CAD systems, there are several widely available 3D CAD systems such as CATIA, I-DEAS, Pro/ENGINEER and Unigraphics. If a manufacturer uses CATIA, its suppliers also need to introduce CATIA in order to enhance the efficiency of designing customized parts. This is a substantial customized investment especially for small suppliers (see footnote 10), and so it could be infeasible for them to invest in multiple 3D CAD systems for different manufacturers. As a result, manufacturers purchase customized parts from a smaller number of suppliers. That is, ‘vertical keiretsu’ type relationships could become stronger due to the IT revolution.

On the other hand, our interview results also indicate that, consistent with the recent popular argument, ‘vertical keiretsu’ type relationships could become weaker or even disappear for certain parts. According to the interviewees’ responses to Question 1, seven firms purchase a non-negligible amount of standard parts. Five out of the seven firms told us

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[12] Our model also predicts that the IT revolution can induce manufacturers to switch their standard parts to customized parts (pattern III). In our interviews, only one firm (Firm G) told us that this would happen.

Table 1 Interview Results from Ten Japanese Manufacturing Firms (September, 2000)

Question	Firm A	Firm B	Firm C	Firm D	Firm E
(1) Percentage of standard parts.	Nearly 0%	10%	Nearly 0%	Small portion	30%
(2-1) Usage of the internet for procuring standard parts.	No	Yes	No	No	Yes
(2-2) The internet procurement increases the number of potential suppliers.	n/a	Yes	n/a	n/a	Yes
(3-1) The level of IT-customized investments by your suppliers is high.	Yes	No	Yes	Yes	Yes
(3-2) The high IT-customized investments reduces the number of your potential suppliers.	No	n/a	Yes	Yes	Yes
(4) Switch from customized parts to standard parts.	No	No	No	No	No
(5) Switch from standard parts to customized parts.	No	No	No	No	No

Question	Firm F	Firm G	Firm H	Firm I	Firm J
(1) Percentage of standard parts.	10%	25%	10%	Nearly 0%	Small portion
(2-1) Usage of the internet for procuring standard parts.	Yes	Yes	Yes	No	Not sure
(2-2) The internet procurement increases the number of potential suppliers.	Yes	Yes	Yes	n/a	n/a
(3-1) The level of IT-customized investments by your suppliers is high.	No	No	Yes	Yes	Yes
(3-2) The high IT-customized investments reduces the number of your potential suppliers.	n/a	n/a	Yes	Yes	Not sure
(4) Switch from customized parts to standard parts.	Yes	Yes	Yes	No	No
(5) Switch from standard parts to customized parts.	No	Yes	No	No	No

Note: Firm A (automobile industry), Firm B (construction machinery industry), Firm C (heavy industry), Firm D (apparel industry), Firm E – J (electronic machinery/ electronics industry).

in response to Question 2-1 and 2-2 that, for standard parts, they are utilizing (and/or planning to utilize) the internet in order to enhance the effectiveness of procurement, which results in an increase in the number of potential suppliers of standard parts. Furthermore, three firms (firm F, G and H) told us in response to Question 4 that they would switch a fraction of their customized parts to standard parts in order to take advantage of the internet procurement. For example, an interviewee of Firm F estimated that they would switch 20% of their customized parts to standard parts. In our theoretical analysis, these results are captured by patterns I and II.

In summary, consistent with our theoretical predictions, we have identified two impacts of the IT revolution through our interviews. On one hand, manufacturers utilize the internet in order to procure the standard parts from a larger number of potential suppliers at lower prices. In some cases, they switch some of their customized parts to the standard parts in order to take advantage of this. This is consistent with the recent popular argument concerning the impacts of the IT revolution on Japanese manufacturer-supplier relationships as discussed in Introduction. On the other hand, they also utilize the recent advances in information technology (3D CAD systems in particular) for enhancing the efficiency of designing customized parts. This often requires their suppliers to make a higher level of customized investments, and, as a consequence, manufacturers purchase customized parts from a smaller number of potential suppliers. In other words, ‘vertical keiretsu’ type relationship can become stronger due to the IT revolution.

A similar pattern has also been identified in the US automobile industry through our preliminary interviews which we conducted as a member of a Japanese governmental mission to the United States in October 2000. On one hand, US automobile manufacturers utilize the internet in order to enhance the efficiency of procurement. In particular, they have recently established Covisint, a joint venture of Commerce One, DaimlerChrysler, Ford, General Motors, Nissan, Oracle and Renault, which is an e-marketplace designed to let automakers find the best price possible for parts from participating suppliers (Kemp, 2001). On the other hand, they also utilize the recent advances in information technology, 3D CAD systems in particular, for enhancing the efficiency of designing customized parts. US automobile manufacturers have adopted different CAD systems (CATIA for DaimlerChrysler, I-DEAS for Ford, and Unigraphics for General Motors), and so a supplier needs to acquire the same CAD system as the one adopted by its customer in order to design customized parts (see, e.g., Braunstein, 1999; Chalmers, 1999; Bundusky, 2000). In our preliminary interviews, a couple of automobile manufacturers told us that, as a result of their increasing reliance on CAD systems, they would purchase customized parts from a smaller number of suppliers because, for many suppliers, it would be financially infeasible to acquire and maintain multiple CAD systems.

5. Summary and Conclusion

Japanese manufacturers' cooperative relationships with their suppliers, based on long-term relationships and suppliers' willingness to make customized investments, have often been called 'vertical keiretsu' and are widely recognized as an important source of strength in Japanese industries. In the 1980s, it had often been argued that US manufacturers should establish Japanese-type cooperative relationships with their suppliers in order to regain their productive edge. In contrast, a number of people recently asserted that the recent advances in information technology would dramatically change the basic nature of the Japanese manufacturer-supplier relationships. Namely, Japanese manufacturers would change the nature of parts required for their products from customized parts to standard parts, and procure them from a larger number of potential suppliers through the internet rather than from a limited number of suppliers within their own corporate groups (or 'keiretsu'). How will the IT revolution impact on manufacturer-supplier relationships? Will 'vertical keiretsu' disappear in Japan? This is an important question when we consider the sources of strength of manufacturing industries in the New Economy.

This paper addressed this question both theoretically and empirically. We first considered a simple theoretical framework that incorporated the two major effects of the IT revolution. First, the prevalence of the internet reduces the downstream firm's cost for contacting and communicating with potential suppliers. Second, the efficiency of designing customized parts can be substantially improved by taking advantage of the IT revolution, 3D CAD (Three-dimensional Computer-Aided Design) systems in particular, which enhance the efficiency for engineers of manufacturers and suppliers to coordinate their design activities. The realization of such efficiency, however, requires higher levels of customized investments. For instance, suppliers need to introduce and maintain a 3D CAD system that is tailored to that of their purchaser.

Our model predicted two distinct patterns for impacts of the IT revolution on manufacturer-supplier relationships. On one hand, consistent with the recent popular argument, the IT revolution can induce the manufacturer to choose the standard interface, and contact and communicate with a larger number of potential suppliers for purchasing the standard parts. On the other hand, it also predicts that, after the IT revolution, the manufacturer can either continue to choose a customized interface or switch from the standard interface to a customized interface, and procure customized parts from a smaller number of potential suppliers who make higher levels of customized investments. In other words, ‘vertical keiretsu’ could become stronger due to the IT revolution.

We then conducted interviews with ten Japanese manufacturing firms concerning impacts of the IT revolution on their relationships with suppliers, and identified both of the two predicted patterns described above. Concerning the second impact, five out of ten manufacturers expected that, as a result of the IT revolution, they would purchase customized parts from a smaller number of potential suppliers. In other words, in contrast to the recent popular argument, these manufacturers expected that ‘vertical keiretsu’ type relationship with their suppliers would become stronger for some kinds of parts due to the IT revolution.

We admit that the strength of our evidence is limited because it is based on interviews with ten Japanese manufacturing firms rather than rigorous statistical analyses based on a random sample of a reasonable size. We however believe that the paper indicates a new direction for future empirical investigations concerning the impacts of the IT revolution on manufacturer-supplier relationships. In a future research, we plan to conduct such an empirical investigation based on a questionnaire survey of a large number of manufacturers.

Appendix A

Proof of Proposition 1: Consider a stage 3 subgame in period t (= 1 or 2), where the downstream firm chose a customized interface and announced (q, s) in stage 1, and n (≥ 1) potential suppliers made the required level of customized investments in stage 2. The downstream firm has no incentive to announce q such that $q < h(0)$, and so we restrict our attention to q such that $q \geq h(0)$. We analyze an optimal procurement auction designed by the downstream firm, by applying standard results of auction theory (see, e.g., Myerson, 1981; and Klemperer, 1999 for a survey).

The procurement auction can be translated into the following standard setting in auction theory: There is one seller who has a single object to sell. The seller faces n bidders indexed by $i = 1, \ldots, n$. Each bidder i's value estimate for the object, denoted t_i, is known only to bidder i, and is independently and identically distributed according to a uniform distribution between $q - c$ and $q - c + 1$, where $q - c > 0$. The seller's personal value estimate for the object is common knowledge and given by $t_0 = 0$.

We apply Myerson (1981) (see in particular page 66-7), and obtain the following result: The seller's reserve price in an optimal auction is Max $[q - c, (q - c + 1)/2]$, which is equal to $q - c$.[13] Then, in an optimal auction,

(i) if $n \geq 2$, the bidder with the highest valuation purchases the object. The expected amount of money the bidder pays to the seller is the second highest valuation among the n bidders.

(ii) if $n = 1$, the sole bidder purchases the object by paying $q - c$.

This result indicates that, in our optimal procurement auction,

(i) if $n \geq 2$, a potential supplier with the lowest realization of the production cost sells a customized part to the downstream firm. The expected payment the supplier receives from the downstream firm is equal to the second lowest realization of the production cost among the n potential suppliers.

(ii) if $n = 1$, the sole potential supplier sells a customized part to the downstream firm and receives c as a payment.

This in turn means that, before the realization of ε_{it} is observed by each upstream firm i, each potential supplier's expected profit from an optimal procurement auction is

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[13] Note, $c \leq g - 1$ (by assumption) and $q \geq h(0)$ imply $c \leq q - 1$, which in turn implies $q - c \geq (q - c + 1)/2$.

$$\frac{1}{n}[(c-\frac{n-1}{n+1})-(c-\frac{n}{n+1})]=\frac{1}{n(n+1)},$$

noting that the expected value of jth order statistic from a uniform distribution between 0 and 1 is j/(n+1).

We now establish the following claim.

Claim 1: Suppose that the downstream firm chooses a customized interface in period t. The maximum expected profit it can make in that period is Max [π_C* + ϕ, 0], where $\phi = \lambda$ if t = 2 and $\phi = 0$ if t = 1, and π_C* is the maximum value of the following maximization problem:

$$\underset{\{x,s,n\}}{Max} \quad h(x)-n(x+f+y)-(c-\frac{n}{n+1})\equiv \pi_C(x,n;y)$$

$$subject\ to \quad x+f-s=\frac{1}{n(n+1)},\ (x,s)\in\Re^2_+, n\ is\ a\ natural\ number.$$

(Note that x + f – s = 1/[n(n + 1)] $\Rightarrow$ π_C(x, n; y) = h(x) – n(s + y) – [c – (n – 1)/(n + 1)].)

Proof: We first show that the solution exists to the maximization problem. Define χ(z) by h'(χ(z)) = z, where z ≥ 1. For any given n, let x*(n) and s*(n) denote optimal values for x and s, respectively. Note that h(x) is increasing in x, and the objective function is independent of s. This implies that x*(n) = χ(n) and s*(n) = χ(n) + f – 1/[n(n+1)] if χ(n) + f – [1/n(n+1)] ≥ 0, and x*(n) = 1/[n(n+1)] – f and s*(n) = 0 otherwise. The optimal value of n is then the solution to the following problem (call it the modified problem).

$$\underset{\{n\}}{Max} \quad h(x^*(n))-n(x^*(n)+f+y)-(c-\frac{n}{n+1})$$

$$subject\ to \quad x^*(n)=Max[\chi(n),\frac{1}{n(n+1)}-f], and\ n\ is\ a\ natural\ number.$$

Define ψ(z) ≡ h(χ(z)) – z[χ(z) + f + y] – [c – z/(z + 1)], where z ≥ 1. By definition of χ(z), we have ψ'(z) = – [χ(z) + f + y] + 1/(z + 1)^2. Hence, there exists a value z' (≥ 1) such that ψ(z) is monotone decreasing in z for all z ≥ z'. Note also that there exists a natural number n' such that 1/[n(n + 1)] – f < 0 for all n ≥ n'. These imply that the modified problem has a solution, denoted n* (≥ 1). Then, π_C* = π_C(x*(n*), n*; y).

Now suppose that the downstream firm chooses a customized interface in period t, and announces (q, s) in order to maximize its expected profit in period t. Also, suppose that, for t = 2, sufficiently large number of upstream firms made customized investments in the previous period. Let m (≥ 0) denote the number of potential suppliers that make the required level of customized investments in period t. Suppose m ≥ 1. Above analysis of an optimal procurement auction in stage 3 implies that $h^{-1}(q - \phi) + f - s \leq 1/[m(m+1)]$ must hold for m (≥ 1) upstream firms to make the required level of customized investments, and the downstream firm's profit maximization implies that $h^{-1}(q - \phi) + f - s = 1/[m(m+1)]$ holds. Then, the downstream firm's expected profit in period t is

$$\begin{aligned} q - m(s + y) - [c - (m - 1)/(m + 1)] &= q - m\{s + y + 1/[m(m + 1)]\} - [c - m/(m + 1)] \\ &= h(x) + \phi - m(x + f + y) - [c - m/(m + 1)], \end{aligned}$$

where $x \equiv h^{-1}(q - \phi)$. This implies that, if $m \geq 1$, $\pi_C^* + \phi \geq 0$ must hold and the maximum expected profit the downstream firm can make in period t is $\pi_C^* + \phi$. On the other hand, if $\pi_C^* + \phi < 0$, $m = 0$ and the maximum expected profit is zero. *Q.E.D.*

Now suppose that, in period t, the downstream firm chooses the standard interface and contacts and communicates with n (≥ 1) potential suppliers. In stage 3, through an optimal procurement auction,

(i) if $n \geq 2$, a potential supplier with the lowest realization of the production cost sells the standard part to the downstream firm. The expected payment the supplier receives from the downstream firm is equal to the second lowest realization of the production cost among the n potential suppliers.

(ii) if $n = 1$, the sole potential supplier sells the standard part to the downstream firm and receives c as a payment.

Hence, the downstream firm's expected profit in period t is given by

$$\pi_S(n; y) \equiv g - ny - [c - (n - 1)/(n + 1)].$$

Since $\pi_S(n; y)$ is strictly concave in n, there exists a natural number n** (≥ 1) such that $\pi_S(n; y)$ takes the maximum value when $n = n^{**}$. Let $\pi_S(n^{**}; y) = \pi_S^*$. Note that the value of y is sufficiently small (by assumption) so that $\pi_S^* > 0$ holds.

We now establish the following claim.

Claim 2: The model exhibits the C-equilibrium if $\Pi_C^* > \Pi_S^*$ and the S-equilibrium if $\Pi_C^* < \Pi_S^*$, where $\Pi_C^* \equiv 2\pi_C^* + \lambda$ and $\Pi_S^* \equiv 2\pi_S^*$.

Proof: Suppose that the downstream firm chooses a customized interface and contacts and communicates with n* suppliers in stage 1 in both periods, and announces $q = h(x^*(n^*))$ and $s = s^*(n^*)$ in stage 1 in period 1 and $q = h(x^*(n^*)) + \lambda$ and $s = s^*(n^*)$ in stage 1 in period 2, where $x^*(.)$, $s^*(.)$ and n* are as defined above. Note that $x^*(n^*) + f - s^*(n^*) = 1/[n^*(n^*+1)]$

holds, and that under the announcement, the required level of customized investment is $x^*(n^*) + f - s^*(n^*)$ in period 1. Also, in period 2, the required level of customized investment is $x^*(n^*) + f - s^*(n^*)$ for upstream firms that made customized investments in the previous period, and a value strictly greater than $x^*(n^*) + f - s^*(n^*)$ for other upstream firms. Then, n^* upstream firms make the required level of customized investments in each period, and the identity of upstream firms that make customized investments is unchanged over periods. The downstream firm's expected profit is π_C^* in period 1 and $\pi_C^* + \lambda$ in period 2. Note that π_C^* and $\pi_C^* + \lambda$ are the maximum expected profits the downstream firm can make by choosing a customized interface in each period. On the other hand, if it chooses the standard interface in each period, it contacts and communicates with n^{**} potential suppliers and makes the expected profit of π_S^* in each period. Finally, the downstream firm cannot be better off by choosing the standard interface in one period and a customized interface in the other.
Q.E.D.

Note that $h(0) \geq g$ and $h'(0) = +\infty$ together imply $\pi_C^* > \pi_S^*$ if $f = 0$, and that π_C^* is decreasing in f whereas π_S^* is independent of f. Also, there exists f' (> 0) such that $\pi_C^* < 0$ for all $f > f'$. Hence, for any given parameter values, there exists a value $\bar{f}$ (> 0) such that, holding all parameter values except f fixed, $\Pi_C^* > \Pi_S^*$ if $f < \bar{f}$ and $\Pi_C^* < \Pi_S^*$ if $f > \bar{f}$.

Next, we prove $n^{**} \geq n^*$ (which means $n_S \geq n_C$). Suppose, to the contrary, $n^{**} < n^*$. We have $\pi_S(n^*; y) < \pi_S(n^{**}; y)$, which implies

$$- n^*y + (n^* - 1)/(n^* + 1) < - n^{**}y + (n^{**} - 1)/(n^{**} + 1).$$

Then, we have

$$\begin{aligned}\pi_C(x^*(n^*), n^*; y) &= h(x^*(n^*)) - n^*(s^*(n^*) + y) - [c - (n^* - 1)/(n^* + 1)] \\ &< h(x^*(n^*)) - n^{**}(s^*(n^*) + y) - [c - (n^{**} - 1)/(n^{**} + 1)] \equiv \pi_C''.\end{aligned}$$

Note that $n^{**} < n^*$ implies $x^*(n^*) + f - s^*(n^*) \leq 1/[n^{**}(n^{**}+1)]$. This means that the downstream firm can make π_C'' (> $\pi_C(x^*(n^*), n^*; y) = \pi_C^*$) as its expected profit in period 1 by choosing a customized interface, contacting and communicating with n^{**} suppliers, and announcing $(q, s) = (h(x^*(n^*), s^*(n^*))$. This contradicts Claim 1. *Q.E.D.*

Proof of Proposition 2: We first establish the following claim.

Claim 3: In the variant of the model, suppose that the downstream firm chooses a customized interface in period t. The maximum expected profit it can make in that period is $\mathrm{Max}[\pi_C{}'^{*} + \phi,\ \hat{\pi}_C^{*} + \phi,\ 0]$, where $\phi = \lambda$ if t = 2 and $\phi = 0$ if t = 1, $\pi_C{}'^{*}$ is same as $\pi_C{}^{*}$ defined in Claim 1 except that y in the maximization problem is replaced by $y' \equiv y - \Delta_y$, and $\hat{\pi}_C^{*}$ is the maximum value of the following maximization problem:

$$\underset{\{x,\,s,\,n\}}{Max} \quad \theta h(x) - n(x + f + \Delta_f + y') - (c - \frac{n}{n+1}) \equiv \hat{\pi}_C(x, n; y')$$

$$subject\ to \quad x + f + \Delta_f - s = \frac{1}{n(n+1)},\ (x, s) \in \Re_+^2,\ n\ is\ a\ natural\ number.$$

Proof: Through the procedure analogous to the proof of Claim 1, we can show that the solution exists in the maximization problem.

Now suppose that the downstream firm chooses a customized interface and announces (q, s) in order to maximize its expected profit in period 2. Also, suppose that sufficiently large number of upstream firms made customized investments in the previous period. Let m (≥ 0) denote the number of potential suppliers that make the required level of customized investments in period 2. The downstream firm has no incentive to announce q such that $q < h(0) + \lambda$, and so we restrict our attention to q such that $q - \lambda \geq h(0)$. Assume $m \geq 1$. Note that, if a potential supplier who made a customized investment in the previous period makes the required level of customized investment, it chooses an IT-customized investment if and only if $h^{-1}(q - \lambda) \geq h^{-1}((q - \lambda)/\theta) + \Delta_f$ holds. Then, through the same logic as in the proof of Proposition 1, we find that $\mathrm{Min}\ [\ h^{-1}(q - \lambda),\ h^{-1}((q - \lambda)/\theta) + \Delta_f] + f - s = 1/[m(m+1)]$ must hold, where the left hand side of the equation is the required level of customized investment. Then, the downstream firm's expected profit in period 2 is

$$q - m(s + y') - [c - (m - 1)/(m + 1)]$$
$$= q - m\{\mathrm{Min}\ [\ h^{-1}(q - \lambda),\ h^{-1}((q - \lambda)/\theta) + \Delta_f] + f + y'\} - [c - m/(m + 1)].$$

Suppose $h^{-1}(q - \lambda) \geq h^{-1}((q - \lambda)/\theta) + \Delta_f$, and let $x \equiv h^{-1}((q - \lambda)/\theta)$. Then, the downstream firm's expected profit in period 2 is $\hat{\pi}_C(x, m; y') + \lambda$, where $x + f + \Delta_f - s = 1/[m(m+1)]$. The maximum possible expected profit in period t is then $\hat{\pi}_C^{*} + \lambda$. Suppose $h^{-1}(q - \lambda) < h^{-1}((q - \lambda)/\theta) + \Delta_f$, and let $x \equiv h^{-1}(q - \lambda)$. Then, the downstream firm's expected profit in period 2 is $\pi_C(x, m; y') + \lambda$, where $x + f - s = 1/[m(m+1)]$. The maximum possible expected profit in period 2 is then $\pi_C'^* + \lambda$. Finally, if m = 0, the downstream firm's profit in period 2 is zero. This completes the proof for t = 2 case. The proof for t = 1 case is analogous. *Q.E.D.*

Define $\hat{\Pi}_C^* \equiv 2\hat{\pi}_C^* + \lambda$, $\Pi_C'^* \equiv 2\pi_C'^* + \lambda$ and $\Pi_S'^* \equiv 2\pi_S'^*$, where $\pi_S'^*$ is same as π_S^* defined in the proof of Proposition 1 except that y in the maximization problem is replaced by y'. Through a similar procedure as in the proof of Claim 2, we find the following: The variant of the model exhibits the S-equilibrium if $\Pi_S'^* > \text{Max}[\Pi_C'^*, \hat{\Pi}_C^*]$ and the C-equilibrium if $\Pi_S'^* < \text{Max}[\Pi_C'^*, \hat{\Pi}_C^*]$. Note that $h(0) \geq g$ and $h'(0) = +\infty$ together imply $\text{Max}[\pi_C'^*, \hat{\pi}_C^*] > \pi_S'^*$ if f = 0, and that $\text{Max}[\pi_C'^*, \hat{\pi}_C^*]$ is decreasing in f whereas $\pi_S'^*$ is independent of f. Also, there exists f'' (> 0) such that $\text{Max}[\pi_C'^*, \hat{\pi}_C^*] < 0$ for all f > f''. Hence, for any given parameter values, there exists a value $\bar{\bar{f}}$ (> 0) such that, holding all parameter values except f fixed, $\text{Max}[\Pi_C'^*, \hat{\Pi}_C^*] > \Pi_S'^*$ if $f < \bar{\bar{f}}$ and $\text{Max}[\Pi_C'^*, \hat{\Pi}_C^*] < \Pi_S'^*$ if $f > \bar{\bar{f}}$. Through a similar procedure as in the proof of Proposition 1, it can be shown that $n_S \geq n_C$ holds. This completes the proof of (i).

To prove (ii), first note that $\Delta_f > 0 \Rightarrow \hat{\pi}_C^* < \pi_C'^*$ if $\theta = 1$, and that $\hat{\pi}_C^*$ is increasing in θ while $\pi_C'^*$ is independent of θ. Hence, there exists θ' (> 1) such that $\text{Max}[\Pi_C'^*, \hat{\Pi}_C^*] = \hat{\Pi}_C^*$ if and only if $\theta > \theta'$, which implies (a). Note also that $\hat{\Pi}_C^*$ is increasing in θ, and $\hat{\Pi}_C^* \to \infty$ as $\theta \to \infty$, while $\Pi_C'^*$ and $\Pi_S'^*$ are independent of θ. Hence, $\text{Max}[\Pi_C'^*, \hat{\Pi}_C^*]$ is increasing in (independent of) θ for all $\theta > \theta'$ ($\theta < \theta'$), which implies (b). Furthermore, $\hat{\Pi}_C^*$ is decreasing in Δ_f while $\Pi_C'^*$ is independent of Δ_f. Hence, $\text{Max}[\Pi_C'^*, \hat{\Pi}_C^*]$ is decreasing in (independent of) θ if $\theta > \theta'$ (if $\theta < \theta'$), which implies (c). *Q.E.D.*

Proof of Proposition 3: Propositions 1 and 2 together imply the following: pattern I emerges if $f > \text{Max}[\bar{f}, \bar{\bar{f}}]$, pattern III emerges if $\bar{f} < f < \bar{\bar{f}}$, and pattern IV emerges if $f < \text{Min}[\bar{f}, \bar{\bar{f}}]$. Note that $\hat{\Pi}_C^* \to \infty$ as $\theta \to \infty$ (see the previous proof) implies $\bar{\bar{f}} \to \infty$ as $\theta \to \infty$, while $\bar{f}$ is independent of θ. Hence, $\bar{f} < \bar{\bar{f}}$ holds if θ is sufficiently large. We show the possibility of pattern II by an example. Let $h(x) = 0.4x^{1/2} + 3.0$, g = 2.1, c = 1.5, f = 0.1, $\Delta_f = 0.02$, y = 0.005, $\Delta_y = 0.004$, and θ be sufficiently close to 1. We find, $\pi_S^* \approx 1.41 < \pi_C^* \approx 1.43$

and Max[$\pi_C'^*$, $\hat{\pi}_C^*$] ≈ 1.45 < $\pi_S'^*$ ≈ 1.51. Then, $\Pi_S^* < \Pi_C^*$ and Max[$\Pi_C'^*$, $\hat{\Pi}_C^*$] < $\Pi_S'^*$ hold when λ is sufficiently small, and so pattern II emerges in this example. *Q.E.D.*

Appendix B

In this appendix we present an example which exhibits pattern IV and the number of potential suppliers decreases after the IT revolution. We use the same notation as in Appendix A. Let $h(x) = 0.4x^{1/2} + 3.2$, $g = 2.1$, $c = 1.5$, $f = 0.08$, $\Delta_f = 0.02$, $y = 0.005$, $\Delta_y = 0.003$, $\theta = 1.3$. We find, $\pi_S^* \approx 1.41 < \pi_C^* \approx 1.65$, $\pi_S'^* \approx 1.48 < \pi_C'^* \approx 1.66 < \hat{\pi}_C^* \approx 1.70$, and so $\Pi_S^* < \Pi_C^*$ and $\Pi_S'^* < \Pi_C'^* < \hat{\Pi}_C^*$ hold. We also find that $n_C = 5$ in the *C-equilibrium* of the original model, while $n_C = 3$ in the *C-equilibrium* of the variant of the model. Hence, the example exhibits the desired property.

Appendix C

We have interviewed the following individuals in each firm (we cannot reveal the names of firms and individuals). The interviews have been conducted in Tokyo between 21 September and 29 September, 2000. Interviews took 1.5 – 3 hours, and many of them were followed by additional questions by e-mails and/or telephones.

Firm	Industry	Interviewed individuals
A	Automobile	Manager, Procurement Planning; Assistant Manager, Public Relations
B	Construction machinery	Executive Managing Director; General Manager, Computer System; Manager, Computer System
C	Heavy industry	Manager, Procurement; Manager, Corporate Strategy
D	Apparel	General Manager, Procurement; Manager, Computer System
E	Electric machinery/ Electronics	General Manager, Procurement System; Manager, Information System
F	Electric machinery/ Electronics	General Manager, Procurement Strategy
G	Electric machinery/ Electronics	Senior General Manager, Procurement Management
H	Electric machinery/ Electronics	General Manager, Information System; General Manager, Production Planning
I	Electric machinery/ Electronics	General Manager, Procurement; Manager, Procurement
J	Electric machinery/ Electronics	General Manager, Procurement Management

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