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, their long-term relationships with manufacturers and financial as well as personal ties between them, 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 several aspects of “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, suppliers’ willingness to make customized investments, and financial as well as personal ties 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.\(^1\) Also, Japanese manufacturers typically own partial shareholdings of their suppliers, and they tend to build close personal ties by transferring employees between manufacturers and suppliers (see, e.g., Dyer and Ouchi, 1993).

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, the Chrysler Corporation has made a substantial effort to establish Japanese-type relationships with its suppliers. Dyer (1996) observed that, as a result, suppliers increased their investment in

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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. Concerning long-term relationships, Aoki (1988) pointed out that 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).

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.
dedicated assets – plants, equipment, systems, processes, and people dedicated exclusively to serving Chrysler’s needs.

In contrast, a number of people recently asserted that recent advances in information technology (call it 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”).

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

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2 Asahi Newspaper on September 18, 2000.

3 Also, Steffensen (1998) pointed out that, because of the IT revolution, Japanese manufacturer-supplier relationships would switch from stable relationships under closed informational networks to flexible relationships under open networks. Araki and Makita (2002) pointed out that, due to the rapid prevalence of the internet since 1995, “vertical keiretsu” type relationships are about to disappear in Japan.

More broadly, the Information Economy Committee of Industrial Structure Council pointed out (in their report submitted to the Ministry of Economy, Trade and Industry) that the IT revolution reduces transaction costs between firms, which in turn reduces the advantage of closed corporate networks in which memberships are stable and limited, and increases the advantage of more open and flexible relationships. Note, this report was published as METI (2002). See also Noguchi (2002) for a similar argument.
standard parts. 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 can be substantially improved by taking advantage of the IT revolution such as the usage of 3D CAD (Three-dimensional Computer Aided Design) systems, which enhance the efficiency for engineers of manufacturers and suppliers to coordinate their design activities. The realization of such efficiency, however, often 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” type relationships 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, the IT revolution could strengthen several aspects of “vertical keiretsu” type relationships. The nature of the product development process, which differs across products, seems to be an important factor that determines which type of impact

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4 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.
will emerge. That is, the latter pattern is more likely if the importance of close coordination among engineers made possible by the IT revolution 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 the IT revolution will strengthen this aspect of “vertical keiretsu” type relationship (that is, purchase of customized parts from a limited number of suppliers) with their suppliers. 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 concerning impacts of the IT revolution on manufacturer-supplier relationships. Section 4 presents findings from our interviews with ten Japanese manufacturing firms, and discusses the consistency between our predictions and the interview results. 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 final product manufactured with the standard part is \( g (> 0) \) for the downstream firm. If the downstream firm chooses a customized interface, it announces the required level of quality of a customized part, which is denoted \( q (> 0) \), and the value of the final product manufactured with the customized part is \( q \) for the downstream firm.\(^5\)

In order to produce a customized part, in each period an upstream firm must make a given level of fixed customized investment (denoted \( f > 0 \)). In order to meet the quality requirement \( q \), it must also make a level of variable customized investment, denoted \( x \geq 0 \), which determines the quality of the customized part by \( h(x) + \mu = q \).\(^6\) 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 \( h(0) \geq g \). Also, \( \mu = \lambda (> 0) \) if the upstream firm made a customized investment in the previous period and \( \mu = 0 \) otherwise, where \( \lambda < g \). 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

\(^{5}\) This formulation is consistent with the following observation by Asanuma (1985a, b; 1989) who studied the Japanese automobile and electric machinery industries in detail: 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.

\(^{6}\) 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.
investments are verifiable, and that the downstream firm can subsidize the customized investment.\footnote{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. …”}

In order to procure a part from a supplier, the downstream firm must contact and communicate with the supplier by incurring communication costs of $y (~> 0)$ per upstream firm. Each upstream firm $i$’s production cost per part (whether a customized part or the standard part) in period $t$ is given by $c – \varepsilon_i$ per unit, where $c (~> 0)$ is a constant and $\varepsilon_i$ is a random variable. We assume that $\varepsilon_i$ is identically and independently distributed according to a uniform distribution between 0 and 1, and $c – 1 > 0$.

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. The choice becomes common knowledge.

[Stage 2] If the downstream firm chose the standard interface at Stage 1, it contacts and communicates with a set of upstream firms by incurring communication costs of $y (~> 0)$ per upstream firm. If contacted, an upstream firm becomes a potential supplier for the downstream firm.

If the downstream firm chose a customized interface at Stage 1, it contacts and communicates with a set of upstream firms by incurring communication costs of $y (~> 0)$ per upstream firm, and announces $(q, s)$ where $q (~> 0)$ denotes the required level of quality of the customized part and $s (~\geq 0)$ denotes subsidy. The subsidy will be paid to contacted upstream firms that make the sufficient level of customized investments for achieving the required level of quality $q$. Contacted upstream firms then sequentially determine whether or not to become a potential supplier for the downstream firm by making the required level of customized investments. The decision becomes common knowledge.
[Stage 3] The random variable \( \varepsilon_i \) is realized and observed only by upstream firm \( i \). The downstream firm can then purchase a part (either the standard part or a customized part, depending on its choice of interface at Stage 1) from a potential supplier through a procurement auction. The auction is designed by the downstream firm to maximize its expected profit.

3. Analyses

In this section, we first consider the Subgame Perfect Nash Equilibria (SPNE) of the model described above. We first outline the analysis of the model, and then 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.

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 \( n_C \) (\( \geq 1 \)) upstream firms, and all of them make the required level of customized investments. The downstream firm purchases one 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 comunicates with \( n_S \) (\( \geq 1 \)) upstream firms. It purchases one unit of the standard part from a potential supplier that has realized the lowest production cost.

Also, throughout the analysis we make the following assumptions:

**Assumption 1:** \( g > f + y + c + 1 \).

**Assumption 2:** \( y \leq 2/9 \).
Assumption 1 implies that the value of parts is large enough so that (i) the downstream firm can earn a strictly positive expected profit in each period regardless of its choice of interface (customized or standard), and (ii) the downstream firm purchases a part with probability one through procurement auction in equilibrium. Assumption 2 implies that the communication cost $y$ is small enough so that the downstream firm communicates with at least two upstream firms in S-equilibrium. These assumptions are not crucial for our results, but simplify the analysis and the statement of propositions. Note, all proofs are presented in Appendix A.

Consider a stage 3 subgame in period 1, where (i) the downstream firm chose a customized interface at Stage 1, and (ii) the downstream firm contacted and communicated with $n'$ ($\geq 1$) upstream firms and announced $(q, s)$ where $q \geq h(0)$ and $s \geq 0$, and $n$ ($1 \leq n \leq n'$) contacted upstream firms made the required level of customized investments at Stage 2. The standard result of auction theory indicates that, in an optimal procurement auction, the downstream firm procures a customized part from a supplier who realized the lowest production cost among $n$ potential suppliers, and that the expected price of the part is equal to the expected value of the second lowest realization of the production cost among $n$ potential suppliers if $n \geq 2$ and $c$ if $n = 1$ (see, e.g., Myerson, 1981). The expected price of the part is then $c - \frac{n-1}{n+1}$ (note, the expected value of jth order statistic from a uniform $(0, 1)$ is $k/(n+1)$), and hence the expected profit of the downstream firm is

$$\pi_C(x, s, n) = h(x) - n(s + y) - \left(c - \frac{n-1}{n+1}\right),$$

where $x \equiv h^{-1}(q)$.

Consider $n$ potential suppliers who made the required level of customized investments (that is, the fixed customized investment $f$ and the variable customized investment $x = h^{-1}(q)$) at Stage 2. Each of the $n$ potential suppliers wins the procurement auction with probability $1/n$, and the expected profit of the supplier conditional on winning the procurement auction is $1/(n+1)$. Noting each of the $n$ potential suppliers receives subsidy $s$ from the downstream

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8 More precisely, Assumption 1 guarantees that the downstream firm purchases a customized part with probability one through a procurement auction in equilibrium. See Appendix A for details.
firm, its expected overall profit at Stage 2 is $\frac{1}{n} \frac{1}{n+1} - (x + f - s)$. We then have that (2) holds in the C-equilibrium.

(2) $\frac{1}{n} \frac{1}{n+1} - (x + f - s) = 0$.

To see this, first note that $\frac{1}{n} \frac{1}{n+1} - (x + f - s) \geq 0$ must hold so that n potential suppliers make non-negative profits in equilibrium. Suppose $\frac{1}{n} \frac{1}{n+1} - (x + f - s) > 0$. Then the downstream firm can increase its expected profit by announcing $q' (> q)$ at Stage 2 such that $\frac{1}{n} \frac{1}{n+1} - (x' + f - s) = 0$ and $x' = h^{-1}(q')$. Hence (2) holds in the C-equilibrium. Also, $n' = n$ holds in the C-equilibrium, because the downstream firm has no incentive to contact more than n firms at Stage 2.

In what follows we proceed our analysis by treating the number of suppliers as a continuous variable. The analysis outlined above indicates that, in period 1 of the C-equilibrium, the downstream firm contacts $n_C$ upstream firms and announces $(q, s) = (q^*, s^*)$ at Stage 2 such that $(q, s, n) = (q^*, s^*, n_C)$ maximizes its expected profit $\pi_C(x, s, n)$ subject to condition (2) (recall $x = h^{-1}(q)$). Let $\pi_C(q^*, s^*, n_C) \equiv \pi_C^*$. Also, in period 2 the downstream firm contacts the same set of upstream firms and announces $(q, s) = (q^* + \lambda, s^*)$ at Stage 2, and earns $\pi_C^* + \lambda$ as its expected profit. Analogously, in the S-equilibrium, in each period the downstream firm contacts $n_S (\geq 1)$ upstream firms such that $n = n_S$ maximizes its expected profit $\pi_S(n)$ given by (3). Let $\pi_S(n_S) \equiv \pi_S^*$.

(3) $g - ny - (c - \frac{n-1}{n+1}) \equiv \pi_S(n)$.

This in turn implies that the downstream firm chooses a customized interface (the standard interface) in each period if $2\pi_C^* + \lambda > 2\pi_S^*$ ($2\pi_C^* + \lambda < 2\pi_S^*$), and that the model exhibits the C-equilibrium (the S-equilibrium) if $2\pi_C^* + \lambda > 2\pi_S^*$ ($2\pi_C^* + \lambda < 2\pi_S^*$). Proposition 1 characterizes the equilibria of the model.
**Proposition 1**: 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 \( n_S > n_C \geq 1 \) holds for all \( f > 0 \). Furthermore, \( n_C \) is strictly decreasing in \( f \) if \( n_C > 1 \) while \( n_S \) is independent of \( f \).

In the C-equilibrium, the downstream firm contacts \( n_C \) upstream firms and announces subsidy for customized investments and the required level of quality of a customized part such that all \( n_C \) potential suppliers make the required level of customized investments and earns zero expected profits. That is, the downstream firm announces \((q, s)\) such that

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\frac{1}{n_C} \cdot \frac{1}{n_C + 1} - (x + f - s) = 0
\]

holds, where \( x \) is the required level of variable customized investment to achieve the quality level \( q \). This means that the downstream firm captures the entire surplus due to customized investments made by potential suppliers, and hence the expected profit of the downstream firm in the C-equilibrium decreases as the production of a customized part becomes less cost effective. The model therefore exhibits the C-equilibrium if the level of the fixed customized investment \( f \) is sufficiently low, while the equilibrium switches to the S-equilibrium once \( f \) exceeds the threshold \( \overline{f} \).

The number of potential suppliers is endogenously determined in our model, and is smaller in the C-equilibrium than in the S-equilibrium. The logic here is as follows: As the number of potential suppliers increases, the downstream firm can choose one supplier from a larger number of candidates, which reduces its expected procurement costs. This is the downstream firm’s marginal benefit gained by increasing the number of potential suppliers, and this benefit is the same across the two equilibria. The marginal costs, however, are different. The downstream firm’s marginal cost to increase the number of potential suppliers is just the communication cost \( y \) in the S-equilibrium. In addition, the downstream firm must incur another marginal cost in the C-equilibrium. That is, the downstream firm must also increase subsidy and/or reduce the required level of quality in order to guarantee zero overall expected profit.
profits to the greater number of potential suppliers. In other words, in order to increase $n_C$, the downstream firm must increase $s$ and/or reduce $q$ in order to ensure that equation (4) holds. The marginal cost to increase the number of potential suppliers is therefore greater in the C-equilibrium, which in turn results in the smaller number of potential suppliers in the C-equilibrium. Similarly, the marginal cost is increasing in the level of the fixed customized investment $f$, which in turn implies that $n_C$ is decreasing in $f$.

In the C-equilibrium, a limited number of upstream firms 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 set of upstream firms make customized investments again in the next period due to learning-by-doing concerning customized investments. This equilibrium captures several key features of “vertical keiretsu” type relationships that had been identified in Japanese manufacturer-supplier relationships. That is, as discussed in the 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 to win 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. Transactions of customized parts have attracted much attention in Japanese manufacturer-supplier relationships. Consistent with this, all ten Japanese
manufacturing firms we interviewed told us that a majority (at least 70%) of parts they procure are customized parts. At the same time, many Japanese manufacturers also procure a non-trivial amount of standard parts. For example, out of the ten firms we interviewed, five told us that 10-30% of parts they procure are standard parts. See Section 4 for more details on our interview results.

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, Yates, and Benjamin (1987) argued 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.9

Second, the efficiency of designing customized parts can be substantially improved by taking advantage of the IT revolution such as the usage of 3D CAD (Three-dimensional Computer Aided Design) systems.10 Baba and Nobeoka (1998) argue that 3D CAD systems have significant impacts on the process and the efficiency of product development. They 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).11 The realization of such efficiency, however, requires suppliers to make substantial investments in information

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9 See also, e.g., Bakos (1997), Barua et al. (1997) and Lucking-Reiley and Spulber (2001) for similar arguments.
10 Information systems closely related to CAD include CAM (Computer Aided Manufacturing), CAE (Computer Aided Engineering), and PDM (Product Data Management).
11 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).
systems, and such investments are often customized to a particular manufacturer to a certain degree. For instance, suppliers need to introduce and maintain a 3D CAD system that is tailored to that of their purchaser.\textsuperscript{12,13}

In the variant of the model, everything is the same as in the original model except for the following: First, the downstream firm’s communication cost is given by $y' = y - \Delta y$ instead of $y$, where $\Delta y (\in (0, y))$ captures the reduction of the communication cost due to the prevalence of the internet. Second, in order to produce a customized part, each upstream firm has an option of introducing an advanced information system (for which the introduction of 3D CAD systems is an important example) by incurring a certain level of fixed customized investment $\Delta f > 0$ (call it “IT-customized investment”) in addition to $f$.\textsuperscript{14} Under this option,

\textsuperscript{12} 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 the Japanese automobile industry, Toyota uses CADCEUS, Nissan uses I-DEAS and Honda uses CATIA. A supplier’s investment in CATIA is not a completely customized investment because, among these six auto manufacturers, Honda and DaimlerChrysler use the same system, but it is a customized investment to a certain degree because the other four firms use different systems.

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.

\textsuperscript{13} Our focus on these two effects of the IT revolution is consistent with an influential work on electronic markets and hierarchies by Malone et al. (1987). They pointed out that, in addition to the reduction of communication costs, the “electronic integration effect” is another important impact that the innovations in information technologies have on the relationships between a supplier and a procurer. They wrote, “When a supplier and a procurer use information technology to create joint, interpenetrating processes at the interface between value-added stages, they are taking advantage of the electronic integration effect. This effect occurs when information technology is used not just to speed communication, but to change – and lead to tighter coupling of – the processes that create and use the information” (p. 488). They then pointed out that CAD/CAM technology often allows both design and manufacturing engineers to access and manipulate their respective data to test potential designs and create a product more acceptable to both sides. Note, Malone et al. (1987) also identified the “electronic brokerage effect” as the other important effect, which is similar to the reduction of communication costs.

\textsuperscript{14} The level of $\Delta f$ depends on the extent to which the investment in the advanced information system is customized. See footnote 12 for a related discussion.
the value of the customized part is determined by $\theta h(x) + \mu$ rather than $h(x) + \mu$, where $\theta > 1$. The parameter $\theta$ 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 this investment is increasing in $\theta$. Proposition 2 characterizes the equilibria of this variant of the model.

**Proposition 2:** (i) For any given parameter values, there exists a value $\overline{f}$ ($> 0$) such that, holding all parameter values except $f$ fixed, the variant of the model exhibits the C-equilibrium if $f < \overline{f}$ and the S-equilibrium if $f > \overline{f}$, where $n_S > n_C \geq 1$ holds for all $f > 0$. Furthermore, $n_C$ is strictly decreasing in $f$ if $n_C > 1$ while $n_S$ is independent of $f$.

(ii) For any given parameter values, there exist values $\theta'$ and $\theta''$ ($1 < \theta' < \theta''$) such that

(a) if $f < \overline{f}$, all potential suppliers make IT-customized investments in the C-equilibrium if and only if $\theta > \theta'$, and

(b) $\overline{f}$ is independent of $\theta$ for all $0 < \theta'$ while $\overline{f}$ is strictly increasing in $\theta$ for all $0 > \theta'$.

Also, $\overline{f} < \overline{f}$ if $0 < \theta''$ while $\overline{f} > \overline{f}$ if $0 > \theta''$.

The variant of the model exhibits the C-equilibrium if the level of the fixed customized investment $f$ is lower than $\overline{f}$. The threshold $\overline{f}$ is strictly less than the threshold $\overline{f}$ of the original model, if the efficiency of IT-customized investment (captured by $\theta$) is sufficiently low such that $\theta < \theta'$ holds. To see this, first note that, if $\theta < \theta'$, potential suppliers do not make IT-customized investments in the C-equilibrium, and hence the only relevant effect of the IT revolution is the reduction of the communication cost. In turn, since the number of potential suppliers is greater in the S-equilibrium than in the C-equilibrium, the IT revolution increases the downstream firm’s profitability more in the S-equilibrium than in the C-equilibrium. The result is that $\overline{f} < \overline{f}$ if $0 < \theta'$; that is, the interval of $f$ in which the model exhibits the C-equilibrium is narrower in the variant of the model than in the original model if $0 < \theta'$. If $0 > \theta'$, potential suppliers make IT-customized investment in the C-equilibrium,
and so $\bar{f}$ is strictly increasing in $\theta$. There exists $\theta'' (> \theta')$, such that $\bar{f} < \bar{f}$ continues to hold as long as $\theta < \theta''$, while $\bar{f}$ exceeds $\bar{f}$ once $\theta$ exceeds $\theta''$. 

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, where Pattern I (Pattern II) emerges if $f < \text{Min}[\bar{f}, \bar{f}]$ (if $\bar{f} < f < \bar{f}$), while Pattern III (Pattern IV) emerges if $\bar{f} < f < \bar{f}$ (if $f > \text{Max}[\bar{f}, \bar{f}]$):

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Original model</th>
<th>Variant of the model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern I</td>
<td>$C$-equilibrium</td>
<td>$C$-equilibrium</td>
</tr>
<tr>
<td>Pattern II</td>
<td>$C$-equilibrium</td>
<td>$S$-equilibrium</td>
</tr>
<tr>
<td>Pattern III</td>
<td>$S$-equilibrium</td>
<td>$C$-equilibrium</td>
</tr>
<tr>
<td>Pattern IV</td>
<td>$S$-equilibrium</td>
<td>$S$-equilibrium</td>
</tr>
</tbody>
</table>

As discussed in the 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 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. In our model, this pattern emerges if $\bar{f} < f < \bar{f}$, while if $f < \text{Min}[\bar{f}, \bar{f}]$ our analysis indicates Pattern I where the manufacturer continues to procure customized parts after the IT revolution. Noting that the threshold $\bar{f}$ is strictly increasing in $\theta$, we find that Pattern II becomes less likely to emerge as the efficiency of the IT customized investment (captured by $\theta$) increases, and it never emerges if $\theta > \theta''$.  

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Concerning the procurement of the standard parts, our analysis predicts Pattern III as well as Pattern IV, where Pattern III becomes more likely to occur as the efficiency of the IT customized investment increases because $f$ is strictly increasing in $\theta$.

In contrast to the recent popular argument, our analysis predicts that the IT revolution could strengthen several aspects (procurement of customized parts from a limited number of potential suppliers) of “vertical keiretsu” type relationships between manufacturer and suppliers. This prediction is captured by Patterns I and III. In Pattern I, the manufacturer continues to procure customized parts after the IT revolution, while in Pattern III the manufacturer switches from standard parts to customized parts. The number of potential suppliers decreases after the IT revolution in Pattern III, and it can also decrease in Pattern I.\(^\text{15}\) Since $f$ is strictly increasing in $\theta$, Pattern I and III become more likely to emerge as the efficiency of the IT-customized investment increases. That is, our analysis predicts that the IT revolution could strengthen several aspects of “vertical keiretsu” type relationships between manufacturer and suppliers in industries where the efficiency of designing customized parts can be substantially improved by taking advantage of the IT revolution.

The importance of close coordination among engineers made possible by the IT revolution (such as the usage of 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 is crucial for achieving product integrity. Automobiles are an example of such products. 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. In our framework, this suggests that the efficiency of the IT customized

\(^{15}\) We have worked out examples (see Appendix B) in which the number of potential suppliers decreases after the IT revolution in Pattern I.
investment is higher for “modular architecture” type products than for “integral architecture”
type products.

Our prediction can then be restated that Pattern I or III (Pattern II or IV) is more likely
to emerge in industries that produce “integral architecture” (“modular architecture”) type
products. In other words, we predict that “vertical keiretsu” type relationships between
manufacturer and suppliers would be more likely to become weaker or even disappear due to
the IT revolution for “modular architecture” type products, while the IT revolution could
strengthen several aspects of “vertical keiretsu” type relationships for “integral architecture”
type products. In the next section, we will discuss consistency between this prediction and
our interview results.

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 for 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 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. All ten firms told us that a majority (at least 70%) of parts they procure are customized parts, and for five of them almost all parts they procure are customized parts. Hence, among four patterns (Patterns I-IV) we discussed in the previous section, the most relevant are Patterns I and II. 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 IT revolution. For example, an interviewee of Firm F estimated that they would switch 20% of their customized parts to standard parts. These results are captured by Pattern II in our analysis, and consistent with the popular argument that Japanese manufacturers would change the nature of parts required for their products from customized parts to standard parts. All these three firms are in electronic machinery/ electronics industry, which produces “modular architecture” type products such as personal computer (Fujimoto, 2000; 2001). This is consistent with our theoretical prediction that Pattern II is more likely to emerge in industries that produce “modular architecture” type products.

At the same time, the remaining seven firms told us that they would not make this switch, as captured by Pattern I in our analysis. Also, in response to Questions (3-1) and (3-2), five firms told us that the level of the IT-customized investments that should be made by their suppliers in order to enhance the efficiency for designing customized parts is high, and this results in the reduction of the number of their potential suppliers. 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 12), 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, our interview results also suggest that the IT revolution can strengthen, rather than weaken, a certain aspect of “vertical keiretsu” type relationships between a manufacturer and suppliers.

Concerning standard parts, five firms told us that at least 10% of the parts they procure are standard parts. All these five firms utilize the internet to enhance the
Table 1  Interview Results from Ten Japanese Manufacturing Firms (September, 2000)

<table>
<thead>
<tr>
<th>Question</th>
<th>Firm A</th>
<th>Firm B</th>
<th>Firm C</th>
<th>Firm D</th>
<th>Firm E</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Percentage of standard parts.</td>
<td>Nearly 0%</td>
<td>10%</td>
<td>Nearly 0%</td>
<td>Small portion</td>
<td>30%</td>
</tr>
<tr>
<td>(2-1) Usage of the internet for procuring standard parts.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2-2) The internet procurement increases the number of potential suppliers.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3-1) The level of IT-customized investments by your suppliers is high.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3-2) The high IT-customized investments reduces the number of your potential suppliers.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(4) Switch from customized parts to standard parts.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5) Switch from standard parts to customized parts.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Question</th>
<th>Firm F</th>
<th>Firm G</th>
<th>Firm H</th>
<th>Firm I</th>
<th>Firm J</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Percentage of standard parts.</td>
<td>10%</td>
<td>25%</td>
<td>10%</td>
<td>Nearly 0%</td>
<td>Small portion</td>
</tr>
<tr>
<td>(2-1) Usage of the internet for procuring standard parts.</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>(5) Switch from standard parts to customized parts.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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).
effectiveness of procurement, and the internet procurement increases the number of potential suppliers. Out of the five firms, one firm (Firm G) told us that it would switch the nature of some parts from standard parts to customized parts in order to take advantage of the IT revolution.\textsuperscript{16}

In summary, broadly consistent with our theoretical predictions, we have identified two impacts of the IT revolution through our interviews. On one hand, consistent with the recent popular argument, 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 standard parts in order to take advantage of this. Consistent with our prediction that this switch is more likely to occur for “modular architecture” type products, in our interviews this switch was identified in three firms that are in the electronic machinery/electronics industry. 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 could purchase customized parts from a smaller number of potential suppliers. In other words, the IT revolution could strengthen, rather than weaken, a certain aspect of “vertical keiretsu” type relationships.

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

\textsuperscript{16} Firm G is in electronic machinery/electronics industry, which is not necessarily consistent with our prediction that Pattern III is more likely to emerge in industries that produce “integral architecture” type products. One possible reason for this is that, in our interviews, except for Firm C all other four firms that procure non-negligible amount of standard parts are in electronic machinery/electronics industry.
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; Budusky, 2000). In our preliminary interviews, some 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, suppliers’ willingness to make customized investments, and financial as well as personal ties, 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 such as the usage of 3D CAD systems, which enhance the efficiency for engineers of
manufacturers and suppliers to coordinate their design activities. The realization of such efficiency, however, often requires suppliers to make substantial investments in information systems, and such investments are often customized to a particular manufacturer to a certain degree. 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, the IT revolution could strengthen a certain aspect of “vertical keiretsu” type relationships.

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 the IT revolution would strengthen a certain aspect of “vertical keiretsu” type relationships with their suppliers.

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

We first present the proof of our results concerning an optimal procurement auction described in the third paragraph of Section 3. Consider a stage 3 subgame in period 1, where (i) the downstream firm chose a customized interface at Stage 1, and (ii) the downstream firm contacted and communicated with n’ (≥ 1) upstream firms and announced (q, s) where q ≥ h(0) and s ≥ 0, and n (1 ≤ n ≤ n’) contacted upstream firms made the required level of customized investments at Stage 2. 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, ..., 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 holds by Assumption 1. 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. Then, in an optimal auction,

(i) if n ≥ 2, the bidder with the highest valuation purchases the object. The expected amount of money the bidder pays to the seller is the expected value of 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 ≥ 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 expected value of 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

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

Note, c < g – 1 (by Assumption 1) and q ≥ h(0) imply c < q – 1, which in turn implies q – c > (q – c + 1)/2.
noting that the expected value of jth order statistic from a uniform distribution between 0 and 1 is \( j/(n+1) \).

Now we present the proofs of the propositions.

**Proof of Proposition 1:** We first 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 \( \pi_C^* + \phi \), where \( \phi = \lambda \) if \( t = 2 \) and \( \phi = 0 \) if \( t = 1 \), and \( \pi_C^* \) is the maximum value of the following maximization problem:

\[
\begin{align*}
\text{Max}_{(x, s, n)} & \quad h(x) - n(x + f + y) - (c - \frac{n}{n+1}) \equiv \pi_C(x, s, n) \\
\text{subject to} & \quad x + f - s = \frac{1}{n(n+1)}, \quad x \geq 0, s \geq 0, n \geq 1.
\end{align*}
\]

(Note that \( x + f - s = 1/[n(n+1)] \) \( \Rightarrow \pi_C(x, s, n) = h(x) - n(s + y) - [c - (n - 1)/(n + 1)] \).)

**Proof:** We first show that the solution exists to the maximization problem. Define \( \chi(z) \) by \( h'(\chi(z)) = z \), where \( z \geq 1 \). For any given \( n \), let \( x^*(n) \) and \( s^*(n) \) denote optimal values for \( x \) and \( s \), respectively. Noting that \( h(x) \) is increasing in \( x \), we have that \( x^*(n) = \chi(n) \) and \( s^*(n) = \chi(n) + f - 1/[n(n+1)] \) if \( \chi(n) + f - [1/n(n+1)] \geq 0 \), 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).

\[
\begin{align*}
\text{Max}_{n} & \quad h(x^*(n)) - n(x^*(n) + f + y) - (c - \frac{n}{n+1}) \\
\text{subject to} & \quad x^*(n) = \text{Max}[\chi(n), \frac{1}{n(n+1)} - f], n \geq 1.
\end{align*}
\]

Define \( \psi(n) = h(\chi(n)) - n[\chi(n) + f + y] - [c - n/(n + 1)] \), where \( n \geq 1 \). By definition of \( \chi(n) \), we have \( \psi'(n) = -[\chi(n) + f + y] + 1/(n + 1)^2 \). Hence, there exists a value \( n' (\geq 1) \) such that \( \psi(n) \) is monotone decreasing in \( z \) for all \( n \geq n' \). This implies that the modified problem has a solution, denoted \( n^* (\geq 1) \). Then, \( \pi_C^* = \pi_C(x^*(n^*), s^*(n^*), n^*) \). Note, Assumption 1 implies \( \pi_C^* > 0 \).

Now suppose that the downstream firm chooses a customized interface, 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 \( m (\geq 1) \) denote the number of potential suppliers that make the required level of customized investments in period \( t \). Above analysis of an optimal procurement auction implies that \( h^1(q - \phi) + f - s \leq 1/[m(m+1)] \) must hold for \( m (\geq 1) \) 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

\[
q - m(s + y) - [c - (m - 1)/(m + 1)] = q - m\{s + y + 1/[m(m + 1)]\} - [c - m/(m + 1)]
\]

\[
= h(x) + \phi - m(x + f + y) - [c - m/(m + 1)],
\]

where \( x = h^{-1}(q - \phi) \). This implies that the maximum expected profit the downstream firm can make in period \( t \) is \( \pi_c^* + \phi \).  \( Q.E.D. \)

Now suppose that, in period \( t \), the downstream firm chooses the standard interface and contacts and communicates with \( n (\geq 1) \) potential suppliers. Through an analogous procedure, we find that the downstream firm’s expected profit in period \( t \) is given by

\[
\pi_s(n) \equiv g - ny - [c - (n - 1)/(n + 1)].
\]

Since \( \pi_s(n) \) is strictly concave in \( n \), there exists a unique value \( n^{**} (\geq 1) \) such that \( n = n^{**} \) maximizes \( \pi_s(n) \). Given \( \pi_s'(n) = -y + 2/(n+1)^2 \), Assumption 2 implies that \( n^{**} \geq 2 \).

Let \( \pi_s(n^{**}) = \pi_s^* \). Assumption 1 implies \( \pi_s^* > 0 \).

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 \( \Pi_C^* = 2\pi_c^* + \lambda, \Pi_S^* = 2\pi_s^* \), \( n_C = n^* \), and \( n_S = n^{**} \).

**Proof:** Suppose that in equilibrium the downstream firm chooses a customized interface and contacts and communicates with \( n^* \) suppliers at Stage 2 in both periods, and announces \( q = h(x^*(n^*)) \) and \( s = s^*(n^*) \) at Stage 2 in period 1 and \( q = h(x^*(n^*)) + \lambda \) and \( s = s^*(n^*) \) at Stage 2 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, the downstream firm’s profit maximization implies that the downstream firm contacts the same set of \( n^* \) upstream firms in both periods, and all \( n^* \) upstream firms make the required level of customized investments in each period. The downstream firm’s expected profit is then \( \pi_c^* \) in period 1 and \( \pi_c^* + \lambda \) in period 2. Note that \( \pi_c^* \) 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 \( \pi_s^* \) 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 \( \pi_C^* \) is decreasing in \( f \) whereas \( \pi_S^* \) 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 Claims 3 and 4, which complete the proof of Proposition 1.

**Claim 3:** \( n^{**} > n^* \) holds.

**Proof:** First suppose \( n^{**} < n^* \). We have \( \pi_S(n^*) < \pi_S(n^{**}) \), which implies

\[
- n^* y + (n^* - 1)/(n^* + 1) < - n^{**} y + (n^{**} - 1)/(n^{**} + 1).
\]

Then, we have

\[
\pi_C(x^*(n^*), s^*(n^*), n^*) = h(x^*(n^*)) - n^*(s^*(n^*) + y) - \left[ c - (n^* - 1)/(n^* + 1) \right]
< h(x^*(n^*)) - n^{**}(s^*(n^{**}) + y) - \left[ c - (n^{**} - 1)/(n^{**} + 1) \right] = \pi_C^{**}.
\]

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

Next suppose \( n^{**} = n^* \). Since \( n = n^{**} = n^* \) maximizes \( \pi_S(n) \), by the first order condition we have that \(- y + 2/(n^*+1)^2 = 0 \). Consider period 1 in the C-equilibrium. Let \( x^*(n^*) \equiv x^* \) and \( s^*(n^*) \equiv s^* \). Suppose \( s^* > 0 \). We then have

\[
\frac{d}{d n} \pi_C(x^*, s^*, n^*) = -(s^* + y) + 2/(n^*+1)^2 < 0.
\]

This in turn implies that there exists \( n' \in [1, n^*] \) such that \( \pi_C(x^*, s^*, n') > \pi_C^* \).

Noting that \( x^* + f - s^* < 1/[n'(n'+1)] \), this implies that, in period 1 of the C-equilibrium, the downstream firm can make an expected profit strictly greater than \( \pi_C^* \). This contradicts Claim 1. Similarly, we reach a contradiction when \( s^* = 0 \). Hence, \( n^{**} > n^* \) holds. Q.E.D.

**Claim 4:** \( n^* \) is strictly decreasing in \( f \).

**Proof:** Suppose that the C-equilibrium is characterized by \((x, s, n) = (x', s', n') \) when \( f = f' \), and characterized by \((x, s, n) = (x'', s'', n'') \) when \( f = f' + \Delta \) where \( \Delta > 0 \). We prove \( n' > n'' \), which implies the desired result.

First suppose \( n' < n'' \). We have \( x' + f - s' = 1/[n'(n'+1)] \) and \( x'' + f + \Delta - s'' = 1/[n''(n''+1)] \). We also have \( \pi_C(x'', s'', n''; f' + \Delta) \geq \pi_C(x', s' + \Delta, n'; f' + \Delta) \). Suppose \( s'' \geq \Delta \). \( n' < n'' \) then
implies that $\pi_c(x'', s'' - \Delta, n''; f') > \pi_c(x', s', n'; f')$. Noting that $x'' + f' - (s'' - \Delta) = 1/[n''(n'' + 1)]$, this contradicts our supposition that the C-equilibrium is characterized by $(x, s, n) = (x', s', n')$ when $f = f'$. We reach a similar contradiction when $s'' < \Delta$. Hence, $n' < n''$ cannot hold.

Now let $h(x^*(n)) - n(x^* + f + y) - (c - n/n + 1) = \pi_c(n; f)$, and suppose $\chi(n*) \neq 1/[n^*(n^* + 1)] - f$. We then have that $d\pi_c(n^*; f) = 0$ and $d\pi_c(n^*; f + \Delta) \neq 0$ for all sufficiently small $\Delta > 0$. This implies that $n' = n''$ cannot hold, and hence we have $n'' > n''$. Q.E.D.

\textbf{Proof of Proposition 2:} We first establish the following claim.

\textbf{Claim 5:} 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 $\max[\pi_c(x^* + \phi, \pi_c^* + \phi)]$, 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 $\pi_c^*$ is the maximum value of the following maximization problem:

\begin{equation}
\max_{x, s, n} \theta h(x) - n(x + f + \Delta f + y') - (c - n/n + 1) = \hat{\pi}_c(x, s, n)
\end{equation}

subject to $x + f + \Delta f - s = \frac{1}{n(n+1)}$, $x \geq 0, s \geq 0, n \geq 1$.

\textbf{Proof:} Through the procedure analogous to the proof of Claim 1, we can show that the solution exists in the maximization problem. Also note that Assumption 1 implies $\pi_c^* > 0$.

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 $m (\geq 1)$ denote the number of upstream firms that make the required level of customized investments in period 2. Note that, if an upstream firm 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 $\min \left[ h^{-1}(q - \lambda), h^{-1}((q - \lambda)/\theta) + \Delta f \right] + f - s = 1/[m(m + 1)]$ 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

\begin{equation}
q - m(s + y') - [c - (m - 1)/(m + 1)]
\end{equation}

\begin{equation}
= q - m \{ \min \left[ h^{-1}(q - \lambda), h^{-1}((q - \lambda)/\theta) + \Delta f \right] + f + y' \} - [c - m/(m + 1)].
\end{equation}
Suppose \( h^{-1}(q - \lambda) \geq h^{-1}((q - \lambda)/\theta) + \Delta \), and let \( x = h^{-1}((q - \lambda)/\theta) \). Then, the downstream firm’s expected profit in period 2 is \( \hat{\pi}_C(x, s, m) + \lambda \), where \( x + f + \Delta - s = 1/[m(m+1)] \). The maximum possible expected profit in period \( t \) is then \( \hat{\pi}_C + \lambda \). Suppose \( h^{-1}(q - \lambda) < h^{-1}((q - \lambda)/\theta) + \Delta \), and let \( x = h^{-1}(q - \lambda) \). Then, the downstream firm’s expected profit in period 2 is \( \pi_C(x, s, m; y=y') + \lambda \), where \( x + f - s = 1/[m(m+1)] \). The maximum possible expected profit in period \( t \) is then \( \pi_C^* + \lambda \). This completes the proof for \( t = 2 \) case. The proof for \( t = 1 \) case is analogous. \( Q.E.D. \)

Define \( \Pi_C^* = 2\hat{\pi}_C^* + \lambda \), \( \Pi_C^* = 2\pi_C^* + \lambda \) and \( \Pi_S^* = 2\pi_S^* \), where \( \pi_S^* \) is same as \( \pi_S^* \) 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 \( \overline{f} (> 0) \) such that, holding all parameter values except \( f \) fixed, \( \text{Max}[\Pi_C^*, \hat{\Pi}_C^*] > \Pi_C^* \) if \( f < \overline{f} \) and \( \text{Max}[\Pi_C^*, \hat{\Pi}_C^*] < \Pi_S^* \) if \( f > \overline{f} \). Through a similar procedure as in the proof of Proposition 1, it can be shown that \( n_S > n_C \geq 1 \) holds for all \( f > 0 \), and that \( n_C \) is strictly increasing in \( f \) if \( n_C > 1 \). This completes the proof of (i).

We have that \( \Delta > 0 \Rightarrow \Pi_C^* > \hat{\Pi}_C^* \) if \( \theta = 1 \), and that \( \hat{\Pi}_C^* \) is strictly increasing in \( \theta \) with \( \hat{\Pi}_C^* \to \infty \) as \( \theta \to \infty \), while \( \Pi_C^* \) and \( \Pi_S^* \) are independent of \( \theta \). Hence, there exists \( 0' (> 1) \) such that \( \text{Max}[\Pi_C^*, \hat{\Pi}_C^*] = \hat{\Pi}_C^* \) if and only if \( \theta > 0' \), which implies (ii)-(a). This also implies that \( \overline{f} \) is strictly increasing in \( \theta \) for all \( \theta > 0' \) and \( \overline{f} \to \infty \) as \( \theta \to \infty \). Since \( \Pi_C^* = \Pi_S^* \) if \( f = \overline{f} \), \( n_S > n_C \) and \( y' < y \) together imply that \( \Pi_C^* < \Pi_S^* \) if \( f = \overline{f} \). This implies \( \overline{f} < \overline{f} \) for all \( \theta > 0' \), which in turn implies (ii)-(b). \( Q.E.D. \)

\textit{Proof of Proposition 3:} Propositions 1 and 2 together imply the result. \( Q.E.D. \)
Appendix B

In this appendix we present an example which exhibits Pattern I 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, 
\[ \pi_S^* \approx 1.41 < \pi_C^* \approx 1.65, \ \pi_S'^* \approx 1.48 < \pi_C'^* \approx 1.66 < \pi_C^* \approx 1.70, \]
and so \( \Pi_S^* < \Pi_C^* \) and \( \Pi_S'^* < \Pi_C'^* < \Pi_C^* \). 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.

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


