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Technological Innovation and Multiple- and Single-Sourcing Policies In the Automobile Parts Trade

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Abstract. The single sourcing policy, in which an automobile manufacturer purchases identical or similar parts from one supplier, has an advantage of scale economy. Meanwhile, multiple sourcing policy, which allows procuring similar parts from multiple suppliers, has benefits of dispersing risks and promoting competition among suppliers. This paper analyzes the procurement policies by presenting a model of the Japanese automobile parts trade. It concludes that maturity of technology involved should be taken into account besides above-mentioned factors which have traditionally been recognized. For parts produced using evolving technologies, the single sourcing enhances purchaser's benefits because of the scale economy in learning process. In the meantime, multiple sourcing is more beneficial to the purchaser if the parts are based on mature technologies. In either policy, if the technology involved is evolving, motivating suppliers by returning a great part of cost reduction as a reward to them may eventually increase profit for the purchaser. The conclusion supports the situation where the number of suppliers is being cut down as the trend of modularization and system deliveries of parts progresses in the auto parts industry, and suggests that returning part of benefits to parts suppliers may be encouraged from the viewpoint of auto manufacturers' own interest.

Keywords: Multiple-sourcing, Single-sourcing, Conditions of Transaction, Cost Reduction, Profit Sharing

1. INTRODUCTION

Recent developments in the automobile industry include cutdown in the number of part suppliers by automobile manufacturers and associated reorganization of part suppliers. It is important to understand what factors influence the change in part procurement practices.

In the Japanese automobile parts trade, multiple sourcing has been widely adopted where a purchaser buys same or similar parts from multiple part suppliers. As Asanuma (1990) suggests, multiple sourcing has advantages of dispersing risks associated with supply stoppages, as well as of promoting competition among suppliers. On the other hand, single sourcing, which involves ordering the same or similar parts from one supplier, has a benefit associated with economy of scale. A series of papers by Asanuma (1984a; 1984b; 1990) deal with multiple sourcing and associated trade practices. Itami (1988) discusses the purchaser's management of competition among suppliers and information to suppliers. Tanaka (1991) analyzes parts pricing by auto manufacturers from the viewpoint of cost planning. Fujimoto (1995) surveys literature on parts trade and company relationships. No model is found, however, which explicitly analyzes the market mechanism of competition.

This paper presents a trade model based on practices in the Japanese automobile parts market and analyzes a procurement policy of the purchaser. The procurement policy refers to whether the purchaser selects multiple or single sourcing, and how cost reduction by suppliers is reflected on conditions of transactions. The model proposed is a game by a purchaser and suppliers, in which each player maximizes its own profit.

The analysis of the model shows, in determining a procurement policy, maturity of technology should be taken into account besides above-mentioned factors recognized conventionally. In the trade of parts which use evolving technologies, single sourcing is beneficial to the purchaser, due to economy of scale for cost reduc-

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tion efforts. On the other hand, multiple sourcing brings benefits to the purchaser in the trade of parts based on mature technologies because multiple sourcing encourages competition among suppliers. Whichever form of sourcing may be adopted, the less mature technology is used, the greater part of benefits of cost reduction should be returned to suppliers in order to motivate suppliers, which in turn brings benefits to the purchaser.

The above conclusion supports the situation where the number of suppliers is cut down in the emergence of new technologies, such as modularization and system deliveries, in the automobile parts industry. The conclusion also suggests that returning greater part of benefits to parts suppliers may be encouraged for the profit of auto manufacturer.

2. STRUCTURE

Two sourcing policies are comparatively analyzed, using a model of automobile parts trade in Japan. The model is a game by three players, one purchaser and two suppliers. Timing of the players' action is shown in Figure 1. Following actual trade practices, the model has a structure that the purchaser selects single or multiple sourcing and sets the conditions of trade. And then, suppliers decide the amount of efforts to reduce production cost. The model allows one supplier in representing single sourcing and two suppliers in representing multiple sourcing. Profits from the trade, which is caused by the cost reduction by suppliers, are divided among the purchaser and suppliers, according to the conditions set by the purchaser. By analyzing equilibrium of the game, choices of the purchaser and suppliers are examined.

In the following Section 3 practices in the automobile parts trade are explained. Section 4 introduces the model, and Section 5 analyzes equilibrium of the model. Section 6 presents conclusion.

3. TRADE PRACTICES

Before introducing a model of automobile parts trade, it will be appropriate to explain practices of automobile parts trade in Japan since details of the practices embody incentives for parties concerned.

3.1 Procurement and Supply

Multiple sourcing here refers to practices of a purchaser dealing with multiple parts suppliers for a part group of similar kind, such as 'large stamped parts of medium level of technical difficulty'. Single sourcing refers to practices of a purchaser dealing with one supplier for a part group. In either sourcing, however, for individual parts identified by specific part codes, such as 'a metal fixture for the fuel injection unit for Primera', it is common for the purchaser to place orders on a specific supplier to minimize fixed costs such as cost of dies.

Rules for deciding prices and selecting suppliers are set by the purchaser (Itami, 1988). Orders are placed at the time of model changeover for service throughout the production period of the new model. In selecting

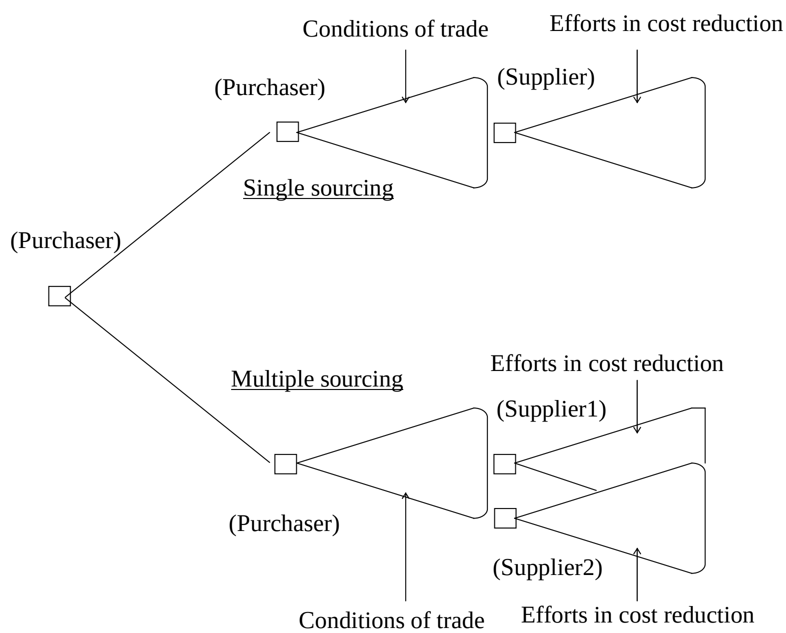

Figure 1. Timing of the Players' Actions

supplier of individual parts, the purchaser requests several part suppliers to estimate cost. In principle, a supplier with the lowest cost is selected for individual parts. However, other factors such as the supplier's product quality, delivery performance and cost reduction in the previous dealings, are also taken into account, and therefore, the winner of the order is not necessarily the one which offers the lowest cost. A given purchaser and a supplier have dealings of similar parts for different models, and the supplier's cost reduction for a part of a particular model is taken into account in selecting suppliers for other models. The purchaser evaluates continuous efforts of the supplier and rewards for it quickly with adjustment of the supplier's dealing share in entire parts group, by allocating orders to suppliers referring to their achievements.

The price is decided on a certain proportion between the target price set by the purchaser and the estimated cost presented by the supplier. The proportion is a part of the rules set by the purchaser and shares the fruit of cost reduction between the purchaser and supplier.

Thus, with multiple sourcing, the purchaser gives incentives to suppliers by returning part of cost reduction benefits as well as by allocating their shares in overall dealings of part group. In order to simplify the dual structure of single supplier system for individual parts and share allocation in part groups, the model proposed by this paper uses the dealing of a certain part to represent dealings of the entire part group. More specifically, in the model multiple suppliers receive orders of a particular part which represents the entire part group. If economy of scale at the level of individual part is neglected, the simplified model does not harm the representation of strategic issues concerning multiple sourcing.

3.2 Information

The purchaser knows the supplier's production cost highly precisely through technical guidance activities, past supply records, the supplier's financial postures and equipment planning. The information of each supplier's cost is also precisely provided to its competitors by the purchaser (Itami, 1988). Meanwhile, information on rules about determining prices and allocating order shares is communicated to suppliers through occasions of dealings and frequent negotiations. In fact, when suppliers are switched, there are few cases where suppliers are embarrassed by discrepancies in recognizing facts.

4. MODEL

There are three players in the model, which are: a purchaser (A), and two suppliers (B_1 and B_2). Subscripts of variables used in the model are: A to indicate the purchaser; 1 and 2 to represent suppliers B_1 and B_2; i to indicate any supplier. Actions and the timing are illustrated in Figure 1. First, the purchaser chooses between single sourcing and multiple sourcing, as well as the conditions of trade. And then, suppliers decide the amount of efforts to reduce cost. The number of suppliers is two if the purchaser selects multiple sourcing, and one if the purchaser selects single sourcing. Each player maximizes its own profit. The profits are the cost reduction, which is realized by the supplier's efforts and divided among the purchaser and supplier, according to the conditions of trade. The total dealing volume is one unit, and the volume does not change depending on the dealing price.

4.1 Multiple Sourcing

If the purchaser selects multiple sourcing, the purchaser sets conditions of trade for multiple sourcing, and then, two suppliers respectively decide the amount of efforts. The determinants of production cost, as well as the conditions of trade, are explained in the following subsections.

4.1.1 Supplier's Efforts and Production Cost

The supplier Bi makes efforts to reduce unit production cost C_i. The efforts are fixed costs, and the monetary value of the efforts is e_i. The larger the efforts, the larger the decrement of production cost becomes. As the efforts become larger, however, the efficiency of cost reduction diminishes. The supplier chooses an amount of effort which may maximize its profit. The cost function has the following characteristic.

$$\frac{dC_i}{de_i} < 0 \quad , \quad \frac{d^2C_i}{de_i^2} > 0 \tag{1}$$

The following equation is assumed as the cost function which has the above characteristic.

$$C_i = C_0 - De_i^{\alpha} \qquad (\mathrm{D} > 0,\quad 0 < a < 1) \tag{2}$$

C_0 is the target cost, which is set equal to the unit production cost achievable with efforts made in the past (i.e. $e_i = 0$). D is a parameter representing efficiency of cost reduction. D is determined by such factors as supplier's technical capability. a is a parameter which shows the rate of diminishing effects of effort. a is related to the degree of maturity of the production technology involved. Where a is small, initial efforts may promote cost reduction, but such efforts reach the peak relatively soon. Such is the case if the relevant technology is mature: although the cost reduction by known methods may be conducted with ease, it gets harder once such methods are exhausted. On the other hand, where a is large, the cost reduction progresses at a relatively constant rate along with efforts made. This applies to the case where the technology involved is new and has a large room for innovation.

4.1.2 Price

The purchaser determines the unit price P by using the smaller amount of the costs achievable by the two suppliers as shown below.

$$P = C_0 - y \cdot \max_i (C_0 - C_i) \tag{3}$$
$$(0 \leq y \leq 1,\ 0 < C_i \leq P \leq C_0)$$

The price P is determined at a certain proportion between C_0 and C_i. The result of cost reduction is shared between the purchaser and suppliers at the proportion. y is a parameter indicating the proportion acquired by the purchaser ($0 \leq y \leq 1$). The larger the value y, the greater the proportion the purchaser gets.

4.1.3 Dealing Share

The dealing share of the supplier Bi is shown as S_i. The purchaser allocates a greater share to the supplier which offers lower cost. Dealing share S_i is represented as in the equations below.

$$S_1 = \frac{1}{2} + k(C_2 - C_1) \quad (k \geq 0)$$
$$S_2 = 1 - S_1 \qquad (0 \leq S_i \leq 1) \tag{4}$$

k is a parameter indicating sensitivity of the share to the cost difference ($k \geq 0$). k also expresses the strength of incentive in the share-winning competition. The share is equally divided between the two suppliers if they achieve the same cost. In a case where the difference between C_1 and C_2 is large, so that S_1 in (4) is either smaller than 0 or greater than 1, it is inferred that S_1=0 and S_1 =1, respectively.

4.1.4 Profits of the Purchaser and the Supplier

The profit of the purchaser is obtained by multiplying the price reduction C_0 - P and the dealing volume 1. Therefore, profit of the purchaser π_A is shown by the following equation.

$$\pi_A = C_0 - P \tag{5}$$

Meanwhile, the profit of the supplier Bi is obtained by multiplying dealing volume S_i and the difference between the price P and the cost C_i, and then subtracted by the cost of effort e_i. Therefore, the supplier Bi's profit π_i is shown by the following equation.

$$\pi_i = S_i(P - C_i) - e_i \tag{6}$$

4.2 Single Sourcing

If the purchaser selects single sourcing, the purchaser sets conditions of trade for single sourcing, and then, one supplier (B1) decides the amount of efforts to reduce cost. Conceptually, a subgame following the purchaser's choice of single sourcing is obtained by dropping one supplier (B2) from the subgame following the choice of multiple sourcing. Therefore, the model specification for single sourcing is identical to that for multiple sourcing introduced in 4-1, except the followings. The price P is obtained by replacing $\max_i (C_0 - C_i)$ in the equation (3) by $C_0 - C_1$, to the following equation.

$$P = C_0 - y\,(C_0 - C_1) \tag{7}$$

Besides, the dealing share is S_1 = 1 to replace the equation (4). The cost function (2), the purchaser's profit (5) and the supplier's profit (6) remain the same.

4.3 List of Symbols

Table 1 lists the symbols used in the model and their representations. Among them the last two symbols in the list, π_{1w} and π_{1f}, are to be introduced in section 5.

Table 1. List of Symbols

Symbol	Representation
A	Purchaser
B_i	Supplier i (i = 1, 2)
C_0	Target cost
C_i	Unit production cost of supplier i (i = 1, 2)
D	Efficiency of cost reduction (D > 0)
e_i	Effort for cost reduction by supplier i (i = 1, 2)
k	Sensitivity of the share to the cost reduction ($k \geq 0$)
P	Price
S_i	Dealing share of supplier i (i = 1, 2)
Y	Proportion of cost reduction profiting purchaser ($0 \leq y \leq 1$)
α	Rate of diminishing effects of efforts (degree of immaturity of the technology involved, $0 < \alpha < 1$)
π_A	Profit of purchaser
π_i	Profit of supplier i (i = 1, 2)
π_{1w}	Profit of supplier 1 in the case of cost leader
π_{1f}	Profit of supplier 1 in the case of cost follower

5. ANALYSIS

Decisions of the players are inferred by deriving Nash equilibrium of the model. The equilibrium is obtained by inducting the player's decisions backward on the tree exhibited in Figure 1. Specifically, the first step is to infer the supplier's decision, given the sourcing policy and conditions of trades. The second step is to infer the purchaser's decision on conditions of trade (namely, parameter k and y), given sourcing policy, referring to the estimated decision of supplier obtained at the first step. Conducting the first and second steps for each of single and multiple sourcings, profits to the purchaser in both sourcings are obtained. Then, the last step of analysis, the purchaser's choice of single or multiple sourcing, is to choose a policy with larger profit to the purchaser.

Since the conditions of trade are set by the purchaser, the profit of the purchaser in this game will be larger than that in the case where the supplier sets the conditions. On the other hand the profit of the supplier will be smaller in this game than in the case where the supplier sets the conditions to maximize its profit.

5.1 Analysis of Single Sourcing

The paper first analyzes the relatively simple case of single sourcing.

5.1.1 Supplier's Action in Single Sourcing

The profit of the supplier B_1 is obtained by the following equation, by substituting the equation (7) for P, (2) for C_1, and $S_1 = 1$ for S_i in the equation (6).

$$\pi_1 = (1-y)De_1^{\alpha} - e_1 \tag{8}$$

In order to find conditions of effort e_1 which maximizes the supplier's profit, the equation (8) is partially differentiated by e_1, to obtain

$$\frac{\partial \pi_1}{\partial e_1} = (1-y)\alpha D \cdot e_1^{\alpha-1} - 1 = 0$$

therefore,

$$e_1 = \left[(1-y)\alpha D\right]^{\frac{1}{1-\alpha}} \tag{9}$$

5.1.2 Purchaser's Action in Single Sourcing

Since the supplier is expected to charge the amount of effort shown by the equation (9), the profit of the purchaser is obtained by substituting the equation (7) for P in the equation (5), replacing C_1 after substitution by the equation (2), then replacing e_1 by the equation (9) to obtain the following equation.

$$\pi_A = yD\left[(1-y)\alpha D\right]^{\frac{\alpha}{1-\alpha}} \tag{10}$$

In order to find the conditions of parameter y that maximizes the profit of the purchaser, the equation (10) is partially differentiated by y and the following equation is arrived at.

$$\frac{\partial \pi_A}{\partial y} = D\left[\left\{(1-y)\alpha D\right\}^{\frac{\alpha}{1-\alpha}} + y\frac{\alpha}{1-\alpha}\left\{(1-y)\alpha D\right\}^{\frac{2\alpha-1}{1-\alpha}} \cdot (-\alpha D)\right] = 0$$

therefore,

$$y = 1-\alpha \tag{11}$$

The profit of the purchaser when y is optimized is obtained by substituting the equation (11) into the equation (10).

$$\pi_A = (1-\alpha)\alpha^{\frac{2\alpha}{1-\alpha}} D^{\frac{1}{1-\alpha}} \tag{12}$$

The profit of the purchaser in single sourcing shown in the equation (12) is compared with the profit of the purchaser in multiple sourcing, which is derived hereafter. To examine the characteristic of the equation (12), π_A increases as D increases, and π_A first increases and then decreases as α increases from $0+\varepsilon$ to $1-\varepsilon$, since the equation (12) has the factors of $(1-\alpha)$ and α.

5.2 Analysis of Multiple Sourcing

5.2.1 Supplier's Action in Multiple Sourcing

Supplier's choice of e_i responsive to given k and y is estimated. With two suppliers, the optimum response of a supplier changes depending on if it achieves a lower cost than the competing supplier. Accordingly, an analysis is conducted in the following three cases.

① Case where the supplier under analysis achieves cost lower than the other party
(where the supplier under analysis becomes the cost leader)
② Case where the supplier under analysis achieves cost equivalent to the other party
③ Case where the supplier under analysis achieves cost higher than the other party
(where the supplier under analysis becomes a follower)

The abscissa in Figure 2 expresses the amount of effort e_2, while the ordinate expresses the amount of effort e_1 chosen by the supplier B_1 for e_2. The thick line in Figure 2 shows the optimum response curve of B_1 for the amount of e_2. This line traces e_1 which maximizes the profit of B_1 for a given e_2. The broken line in the figure indicates combinations of e_1 and e_2 which make $C_1 = C_2$ (case ②). In the upper left region of the broken line, $C_1 < C_2$ (case ①) holds, while in the lower right region, $C_1 > C_2$ (case ③) holds. Hereafter, * is used as a subscript to represent an optimum response in the case ①, and ** to represent an optimum response in the case ③.

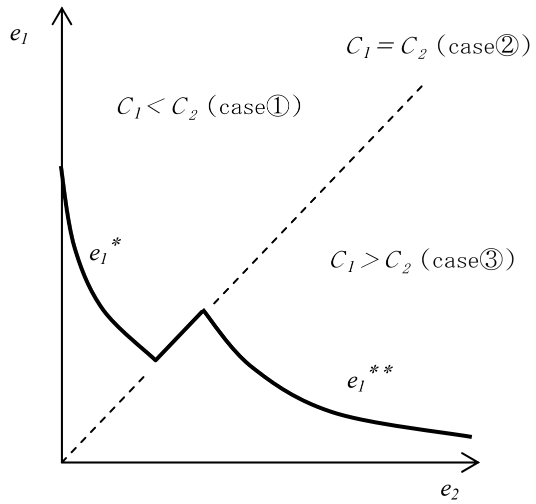

Figure 2. Optimum Response Curve of B_1

The characteristic of the optimum response curve is examined in the rest of this subsection 5.2.1. The profit of B_1 in the case ①, π_{1w}, is found by the following equation by substituting equations (3) and (4) into the equation (6). Here, the equation (3) is equivalent to $P = C_0 - y(C_0 - C_1)$ as B_1 is the cost leader.

$$\pi_{1w} = \left[\frac{1}{2} + k(C_2 - C_1)\right](1-y)(C_0 - C_1) - e_1 \qquad (13)$$
$$(C_1 < C_2)$$

Below is an equation for finding conditions of e1 which mazimizes π_{1w}. Such conditions make the result of partial differentiation of the equation (13) by e_1 equal to zero:

$$\frac{\partial \pi_{1w}}{\partial e_1} = \frac{\partial C_1}{\partial e_1}\left[\begin{array}{l}\left\{\frac{1}{2} + k(C_2 - C_1)\right\}(1-y)(-1) \\ \qquad + (-k)(1-y)(C_0 - C_1)\end{array}\right] - 1 = 0$$

therefore,

$$\frac{\partial C_1}{\partial e_1} = \frac{1}{(1-y)\left[-k(C_0 - 2C_1 + C_2) - \frac{1}{2}\right]} \qquad (14)$$

Since the cost function C_1 satisfies conditions of the equation (1), $\partial C_1 / \partial e_1$ is an increasing function in e_1. Therefore, the optimum amount of e_1 decreases as the right-hand members of equation (14) decreases. Since $1- y \geq 0$ and $k \geq 0$, when e_2 increases and C_2 decreases, right-hand members of equation (14) becomes smaller, and the optimum e_1 decreases. It means the optimum response curve is descending in the case ①. The descending curve corresponds to the fact that an increase in e_2 reduces the cost C_2, which decreases the profit share for the supplier B_1. Because of the diminishing effect of cost reduction efforts, a decrease in profit share lowers the optimal amount of effort e_1.

In the case ③ where B_1 is the follower, the price is determined based on the cost of the leader B_2 and so if B_1 reduces its cost, holding the cost of B_2 constant, B_1's share and profit increase accordingly. On the other hand, in the case ① where B_1 is the cost leader, as the cost of B_1 is reduced, the price decreases, and therefore, B_1's profit does not increase as in the case ③. Because of this reason, the incentive for B_1 to reduce its cost is weaker in the case ①. This corresponds to the fact that as e_1* is followed towards lower right, its value would be smaller than e_1**.

The profit of B_1 in case ③, π_{1f}, is found by the following equation obtained by substituting equations (3) and (4) into (6). Here, the equation (3) is equivalent to $P = C_0 - y(C_0 - C_2)$ as B_2 is the cost leader.

$$\pi_{1f} = \left[\frac{1}{2} + k(C_2 - C_1)\right]\left[(1-y)C_0 - C_1 + yC_2\right] - e_1 \qquad (15)$$
$$(C_1 > C_2)$$

Conditions of e_1 which maximizes π_{1f} is found by making the result of partial differentiation of the equation (15) by e_1 equal to zero:

$$\frac{\partial \pi_{1f}}{\partial e_1} = \frac{\partial C_1}{\partial e_1}\left[\begin{array}{l}\left\{\frac{1}{2} + k(C_2 - C_1)\right\}(-1) \\ \qquad + (-k)\left\{(1-y)C_0 - C_1 + yC_2\right\}\end{array}\right] - 1 = 0$$

therefore,

$$\frac{\partial C_1}{\partial e_1} = \frac{1}{-k\left[(1-y)C_0 - 2C_1 + (1+y)C_2\right] - \frac{1}{2}} \qquad (16)$$

Since $\partial C_1 / \partial e_1$ is an increasing function in e_1, the optimum amount of e_1 decreases as the right-hand members of equation (16) decreases. When e_2 increases and C_2 decreases, right-hand members of equation (16) becomes smaller, and optimum e_1 decreases. It means the optimum response curve is descending in the case ③.

Plots on the line of $C_1 = C_2$ (i.e. case ②) represent optimum response where the incentive is not so strong as to reduce the cost below the other party but strong enough to maintain the same level of cost as the other party. The optimum response curve is continuous but kinks at two points.

The optimum response curve moves up and down depending on k and y set by the purchaser. The larger the value k (that is, the harsher the competition for share between the suppliers) and the smaller the value y (that is, the greater part of the profit obtained by the supplier), the larger the right-hand members of the equations (14) and (16), and the larger e_1* and e_1** become. That is to say, the larger the value k and the smaller the value y

become, the optimum response curve in Figure 2 will shift upward.

5.2.2 Optimum Responses of the Two Suppliers

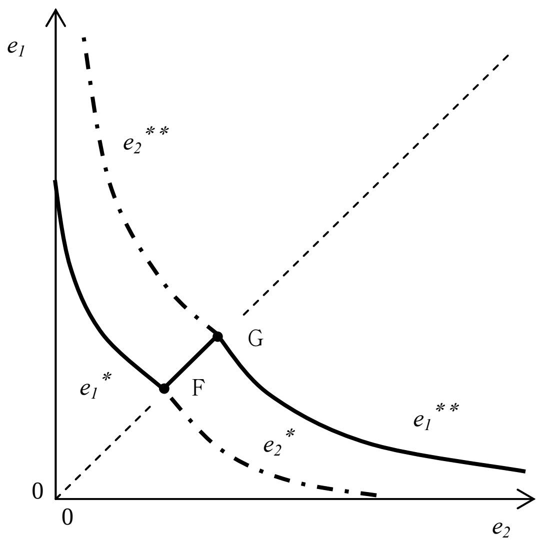

Figure 3. Optimum Response Curves of the Two Suppliers

Figure 3 shows optimum response curves of both suppliers together. The solid line indicates the optimum response curve of the supplier B_1, while the line shown by dash and dots indicates that of B_2. The cost achieved by the two suppliers becomes equal on the broken line. Where the two optimum response curves intersect, choices of both suppliers are subgame equilibrium actions for given values of k and y. The subgame equilibrium referred here is a situation where the amount of effort chosen by one supplier is the best response for the amount of effort chosen by the other, for given values of k and y in multiple sourcing. Neither of them is motivated to change its amount of effort.

Subgame equilibrium is found on all the points on the line segment FG in Figure 3. Of those points, profit of each supplier is maximized at the point F. Since both suppliers have sufficient information about each other, and therefore, about the subgame equilibrium, they are supposed to choose the point F.

Since both suppliers have an identical cost function and $C_1 = C_2$ at the point F, the amounts of effort of both suppliers at the point F are equal. The amount of e_1 at the point F should satisfy the equation (14) as well as $C_1 = C_2$. Therefore, e_1 at the point F satisfies the following equation obtained by substituting $C_1 = C_2$ and the equation (2) into the equation (14).

$$-\alpha D e_1^{\alpha-1} = \frac{1}{(1-y)\left(-kDe_1^{\alpha} - 1/2\right)} \tag{17}$$

The equation (17) is rearranged around e1 to become the following equation.

$$(1-y)k\alpha D^2 e_1^{2\alpha-1} + \frac{1}{2}(1-y)\alpha D e_1^{\alpha-1} - 1 = 0 \tag{18}$$

The equation (18) is used in deriving the purchaser's action in the next subsection.

5.2.3 Purchaser's Action in Multiple Sourcing

The purchaser maximizes its profit by optimizing k and y. The purchaser's profit is maximized when the purchaser sets k and y at the values in the equations (19) and (20). (19) and (20) represent a real number solution, and satisfy continuity against a. Since unique solution exists because of the nature of the model, (19) and (20) provide the unique solution.

$$k = \frac{1}{4}(1-\alpha)\left(\frac{\alpha D}{2}\right)^{\frac{1}{\alpha-1}} \tag{19}$$

$$y = 1-\alpha \tag{20}$$

When the purchaser sets k in the equation (19) and y in the equation (20), the amount of supplier's effort e_1 at the subgame equilibrium should satisfy the following equation obtained by substituting equations (19) and (20) into equation (18).

$$\left(\frac{\alpha D}{2}\right) e_1^{\alpha-1}\left[(1-\alpha)\left(\frac{\alpha D}{2}\right)^{\frac{\alpha}{\alpha-1}} e_1^{\alpha} + \alpha\right] - 1 = 0 \tag{21}$$

In the equation (21), e_1 has a solution shown by the following equation.

$$e_1 = \left(\frac{\alpha D}{2}\right)^{\frac{1}{1-\alpha}} \tag{22}$$

And then, the purchaser gains the profit shown by the following equation.

$$\pi_A = (1-\alpha)\left(\frac{\alpha}{2}\right)^{\frac{\alpha}{1-\alpha}} D^{\frac{1}{1-\alpha}} \tag{23}$$

The purchaser's profit in multiple sourcing shown in (23) increases as D increases, but changes in non-monotonous manner as a increases.

5.3 Equilibrium of the Game

The purchaser compares the profit arising from the single sourcing, which is shown in the equation (12), and that from multiple sourcing, which is shown in the equation (23), to maximize its profit. Comparing the equations, the purchaser obtains a larger profit from multiple sourcing if α is smaller than 1/2 (corresponding to the case where the technology involved is relatively mature). On the other hand, single sourcing is more beneficial to the purchaser, if α is greater than 1/2 (corresponding to the case where the technology is relatively immature). Where α is equal to 1/2, there is no difference in the profit whichever sourcing may be adopted.

This result is explained as follows. Where the technology is immature, cost may be reduced at relatively a constant rate even after the amount of effort is increased. Therefore, the incentive for increasing the amount of effort may diminish slowly, and competition is not essential for motivating suppliers. In this case, it is more desirable to strengthen self-helping incentive by concentrating dealings on one supplier and increasing the dealing volume. As the technology matures, however, cost reduction effort may hit the peak and the supplier may stop making further efforts unless an incentive by competition is at work, so it is more beneficial to employ multiple sourcing.

Equations (11) and (20), which finds an optimum y in single sourcing and multiple sourcing, respectively, correspond to each other at $y = 1-\alpha$. The condition of $y = 1-\alpha$ can be interpreted as follows. Where a is large, such as when technology is in the process of development, it is desirable for the purchaser to motivate the supplier to promote cost reduction by choosing a small y value to set the price at relatively high level. As the technology becomes more mature and a gets smaller, it is more favorable for the purchaser to set the price at a relatively low level to secure a larger share in the profit for the purchaser.

An optimum k in multiple sourcing, which is found in the equation (19), is not a monotonous function of a. Maturation of the technology used in parts changes the optimum value of k in a non-monotonous way. On the other hand, optimum k is an increasing function of D. The more effectively the supplier's efforts are transformed into cost reduction, the stronger an optimum degree of competitive incentive becomes.

Profit of the supplier in single sourcing π_1 is positive in the equilibrium. On the other hand, the profit of the supplier in multiple sourcing π_1 becomes zero in the equilibrium, by substituting equations (2), (3), (4) and (22) into (6). Zero profit in multiple sourcing is attributable to the assumption that both suppliers have the same cost reduction efficiency D. If their cost reduction efficiencies differ, the profit of the supplier with lower efficiency is zero, while the supplier with higher efficiency gains non-negative profit. The assumption of equal D for both suppliers is adopted for simplicity, but relaxing the assumption does not change fundamental properties of the purchaser's procurement policy.

6. CONCLUSION

This paper presents a model of market transaction of automobile parts and analyzes multiple and single sourcings. The analysis shows that maturity of the technology used in parts is another factor in selecting multiple or single sourcing, besides traditionally recognized factors of dispersing risks and promoting competition.

Where benefits of cost reduction efforts slowly diminish, as in cases where immature technologies are used, single sourcing, in which dealing volume per supplier is large, is more advantageous to the purchaser. On the contrary, where the cost reduction hits the ceiling soon, as in cases where mature technologies are utilized, it is more beneficial for the purchaser to rely on multiple sourcing, which takes the advantage of competition among suppliers. In either type of sourcing, the more evolving the technology involved, the more desirable it is for the purchaser to enhance the motivation of the supplier by increasing its profit share from cost reduction, while it is better for the purchaser to increase its own profit share as the technology involved matures.

Modularization and system delivery of parts require suppliers to use new technologies to manufacture assemblage of parts. The new technologies provide new room of reducing production cost to suppliers. With a recent trend of modularization, a conclusion of the paper tells us that it is desirable for the purchaser to decrease the number of suppliers and increase the volume of dealing per supplier. Cutdown of suppliers accompanying modularization is supported not just by the economy of scale, but by evolution of the technology involved. On the part of the purchaser, it is advisable to return a greater share of cost reduction benefits to its suppliers to enhance their incentives for cost reduction for the sake of the purchaser.

The specification of the model does not include factors such as dispersing risks and the scale economy in manufacturing, if not the scale economy in learning. Those conventionally recognized factors are desirably analyzed together with the degree of technological maturity. It is a limit of this paper and a candidate of future research topic.

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