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Why Are Firms' R＆D Investment Behaviors Different?*

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Abstract: This paper studies R&D investments in a successive duopoly market. This paper shows that market size and investment efficiency parameter may play a significant role on firms' heterogeneous R&D investment behaviors. When market size is large and R&D investment is in favorable economic environment, firms are liable to make different R&D investments. This paper also figures out two interesting comparative statics under asymmetric equilibrium in which firms make different R&D investment behaviors. One is that when the market demand increases, the large market-shared downstream firm decreases its output, while the small market-shared one increases its output. The other is that when the input cost increases, the former increases its output, while the latter decreases its output.

Key words: R&D investment; market size; below-cost pricing; heterogeneous firms' behaviors

JEL codes: D43, L13, L25, L60

1. Introduction

Heterogeneous phenomena are widely spread in our real world. Therefore, these phenomena have paid considerable attention by many scholars as an important research arena. Empirical studies have also suggested that these phenomena have led to different technologies, sizes, capacities, strategies, and so on. The phenomena frequently arise in the same industry as well as within a firm. However, theoretical economics have mainly taken the phenomena as exogenous rather than endogenous variables. Therefore, this paper studies the logical gap with a successive duopoly model.

Previous literature on asymmetric equilibrium has been conducted in an oligopoly market. For instance, Mills (1990) demonstrates that heterogeneous plant sizes are easy to emerge in equilibrium capacity expansion of a growing industry, even though scale economies give larger plants a unit cost advantage. Salop and Stiglitz (1977) examine the consequences of imperfectly informed consumers in a "tourists and natives" model, where some firms choose high prices and small scale by catering to the poorly informed consumer segment, while other firms choose low prices and large scale as they attract well-informed consumers. Hermalin (1994) studies asymmetric equilibrium in a principal-agent model. He considers a case in which two firms offer an incentive contract to their own agents. In equilibrium, one firm provides strong incentive with its agent. As a best response, the other firm provides weak incentive with its agent. Mills and Smith (1996), analyze, under the cost trade-off between the fixed cost and the

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variable cost, if the technology set is insufficiently convex, heterogeneous equilibrium may exist. The model is similar to our model in such a way that both may produce asymmetric equilibrium. On the other hand, there are two main differences between them. One is that the former has a two-technology set, while the latter has a continuous-technology set. The other is that, in the first model, asymmetric equilibrium is caused by the investment cost, while, in the second model, it is produced by the condition of non-negative input price. Gal-Or (1999) considers an oligopoly market in which two firms compete with two differentiated products. If the demand between two products is moderately correlated, asymmetric equilibrium exists: one firm establishes its own sales-force, while the other has its independent sales-force. She also shows that vertical separation is more likely than vertical integration when two products are highly substitutable. Another significant contribution to this research is related to that of Marx and Shaffer (1999). The model is also similar to ours. The main difference between them is that we analyze an oligopoly model with investment, while they examine a monopoly model with no investment. Our result depends on investment environment, whereas their result depends on substitute products as well as sequential timing of the game. They demonstrate that below-cost pricing can arise in input market when a monopolist negotiates with two suppliers of substitute intermediate goods. One monopolist negotiates in sequence with two suppliers. In their model, the main result depends deeply on sequential negotiation and substitute goods. However, in our model, technological environment and market size play important roles in asymmetric equilibrium. They also stress that if two goods are complements, the optimal pricing calls for above-cost pricing. O'brien and Shaffer (1997) also show that if a monopolist contracts with two suppliers simultaneously, one of the suppliers can be excluded in equilibrium even though the production of both goods is efficient.

This paper is summarized as follows. When market size is large and investment efficiency is in good condition, firms are liable to make different R&D investments. This paper also figures out two interesting comparative statics under the asymmetric equilibrium in which firms make different R&D investment behaviors. This paper also figures out two interesting comparative statics under the asymmetric equilibrium with firms' different R&D investments. One is that when the market demand increases, the large market-shared downstream firm decreases its output, while the small market-shared one increases its output. The other is that when the input cost increases, the former increases its output, while the latter decreases its output.

This paper is organized as follows: Section 2 describes the model; Section 3 analyzes and characterizes the equilibria; Section 4 provides some implications; and Section 5 states the conclusion.

2. The Model

Consider two downstream firms that each contracts with an exclusive upstream supplier, respectively. Each downstream firm purchases a key input from its own upstream supplier and then transforms it into a final product.

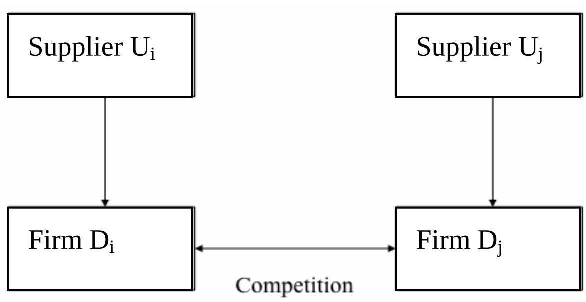

Figure 1 Market

The inverse demand function for the downstream firms is specified as follows:

$$p = a - b(q_i + q_j) \tag{1}$$

where p is the price, q_i and q_j are the output produced by firm i and firm j, respectively, while a and b are positive parameters.

A distinctive characteristic in input market is typically nonlinear pricing.[1] Thus, each downstream firm, D_k, $k = i, j$, proposes a take-it-or-leave-it offer to its own exclusive supplier, U_k, $k = i,j$, respectively. The simplest contract consists of two elements; input price, w_k, and lump-sum transfer, F_k.[2]

Each upstream supplier, U_k, $k = i,j$, makes its decision about a cost reduction investment, x_k, $k = i, j$, simultaneously before the input is produced. The cost reduction investment decreases the marginal cost of the input. For simplicity, suppose that if each supplier makes an investment of x_k in the cost reduction, the marginal cost becomes c-x_k. The investment cost is assumed to $\frac{tx_k^2}{2}$ where t is a strictly positive constant.[3]

We assume that each downstream firm, D_k, and upstream supplier, U_k, are fully committed to these contracts and renegotiations do not occur after each supplier, U_k, makes the cost reduction investment. For simplicity, the cost of transforming the input into the final product is normalized to zero. We also assume that each unit of the final product requires exactly one unit of the input.

Specifically, this paper analyzes a three-stage game as follows:

(1) Each downstream firm, D_k, proposes a take-it-or-leave-it offer, ($w_k \geq 0$, F_k), to its own supplier, U_k.

(2) Each supplier, U_k, makes the decision on cost reduction investment, x_k, simultaneously.

(3) Each downstream firm, D_k, chooses its output, q_k, simultaneously a la Cournot.

We focus on a sub-game perfect equilibrium for this game.

3. The Analysis

At stage three, each downstream firm chooses its output to maximize its profit given the rival firm's output. Then, downstream firm D_i's maximization problem is:

$$\max_{q_i} \ \pi_{D_i} = \left(a - b(q_i + q_j) - w_i\right)q_i - F_i$$

From the F. O. C.,[4] the reaction functions are given by:

$$q_i(q_j) = \frac{(a - bq_j - w_i)}{2b} \quad and \quad q_j(q_i) = \frac{(a - bq_i - w_j)}{2b}$$

The above two reaction functions yield the equilibrium outputs as solutions to the third-stage game:

$$q_i(w_i, w_j) = \frac{(a - 2w_i + w_j)}{3} \tag{2-1}$$

$$q_j(w_i, w_j) = \frac{(a - 2w_j + w_i)}{3} \tag{2-2}$$

Substituting Equation (2-1) and Equation (2-2) into Equation (1) and the above maximand, we obtain the

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[1] See Mark and Shaffer (1999) and O'Brien and Shaffer (1997) for details.

[2] Our main results will not change in a bargaining model instead of using take-it-or-leave-it offer. See Mark and Shaffer (1999) for details.

[3] Note that the parameter t is an investment efficiency parameter. Increases in parameter t mean an inefficient environment in R&D investment and vice versa.

[4] We can easily check the S. O. C. that $\frac{\partial^2 \pi_{D_i}}{\partial q_i^2} = -2b < 0$ is satisfied.

equilibrium price and downstream firm D_i's profit as follows:

$$p = \frac{(a + w_i + w_j)}{3} \tag{3-1}$$

$$\pi_{D_i} = \frac{(a - 2w_i + w_j)^2}{9b} - F_i \tag{3-2}$$

From Equation (3-1) and Equation (3-2), what is important to note is that

$$q_i \geq q_j \ \text{ if } \ w_j \geq w_i \ \text{ and } \ q_i \leq q_j \ \text{ if } \ w_j \leq w_i \tag{4}$$

The above equations show the relationship between the input price, w_k, and the output level, q_k. Concisely speaking, the higher downstream firm D_i's input price, w_i, is, the larger downstream firm D_j's output level, q_j, is, and vice versa.

We restrict our attention to the duopoly market. In equilibrium, therefore, each firm maximizes its profit with respect to its output given the rival firm's output. As a result, it holds that $q_i > 0$ and $p > w_i$, (or $q_j > 0$ and $p > w_j$), simultaneously, when both input prices satisfy the following inequalities, and zero otherwise:

$$0 \leq w_i < \frac{a + w_j}{2} \ \text{ and } \ 0 \leq w_j < \frac{a + w_i}{2}$$

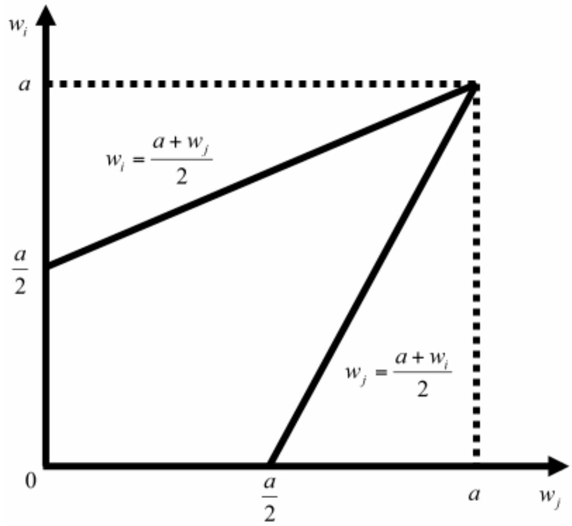

Figure 2 Equilibrium Area at Stage Three

Figure 2 shows the region that the above inequalities hold.

At stage two, each upstream supplier, U_k, makes a decision about the cost reduction investment, x_k, simultaneously. Supplier U_i's maximization problem is:

$$\max_{x_i} \pi_{U_i} = \frac{(w_i - c + x_i)(a - 2w_i + w_j)}{3b} - \frac{tx_i^2}{2} + F_i$$

From the F. O. C.,[5] the Cournot-Nash equilibrium investment level as solutions to the second-stage game is given by:

$$x_i(w_i, w_j) = \frac{(a - 2w_i + w_j)}{3bt} \tag{5-1}$$

[5] We can easily check the S. O.C that $\frac{\partial^2 \pi_{U_i}}{\partial x_i^2} = -t < 0$ is satisfied.

$$x_j(w_i, w_j) = \frac{(a - 2w_j + w_i)}{3bt} \tag{5-2}$$

Substituting Equation (5-1) and Equation (5-2) into supplier U_i's marginal cost function and the above maximand, we obtain supplier U_i's marginal cost and profit:

$$c_i(w_i, w_j) = c - \frac{(a + 2w_i - w_j)}{3bt} \tag{6-1}$$

$$\pi_{iS}(w_i, w_j) = \frac{(a - 2w_i + w_j)(a - 2w_i + w_j + 6bt(w_i - c))}{18b^2 t} + F_i \tag{6-2}$$

From Equation (5-1) and Equation (5-2), we focus on two things. One is the relationship between the investment levels and the input prices. Concisely speaking, Equation (5-1) and Equation (5-2) imply that the higher the input price w_i is, the larger supplier U_j's investment level x_j is, and vice verse. The other is that upstream supplier U_i's investment level, x_i, is independent of supplier U_j's investment level, x_j, and vice versa.

It is assumed that a is sufficiently too large so that all possible variables are positive in equilibrium. Specifically, this assumption takes a following form:

Assumption 1: $2c < a$.

Assumption 1 and the condition $c_k \geq 0$, $k = i, j$ imply that the pair (c_i, c_j) must fall into the region inside the square in Figure 3.

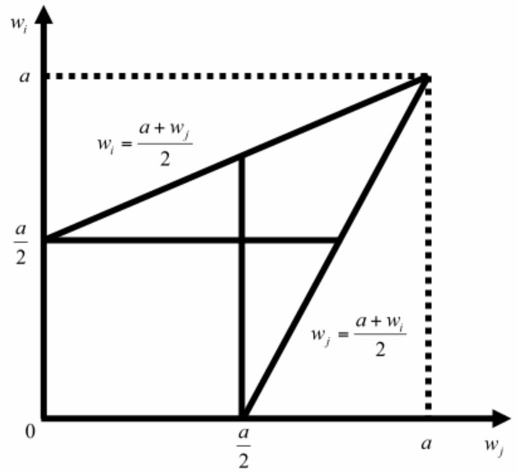

Figure 3 Equilibrium Area at Stage Two

We now turn to the first stage. Each downstream firm, D_k, $k = i, j$, chooses its input price, w_k, and the lump-sum transfer, F_k, to maximize its own profit given two constraint conditions that its supplier U_k's profit and the input price, w_k, are nonnegative. Downstream firm D_i's maximization problem is:

$$\max_{w_i,\, F_i} \ \pi_{D_i} = \frac{(a - 2w_i + w_j)^2}{9b} - F_i$$

$$s.t.\ \pi_{U_i} = \frac{(a - 2w_i - w_j)(a - 2w_i + w_j + 6bt(w_i - c))}{18b^2 t} + F_i \geq 0,\ and\ w_i \geq 0$$

Note that the first constraint condition is binding. Therefore, the above maximization problem can be reduced as follows:

$$\max_{w_i} \ \pi_{D_i} = \frac{(a - 2w_i + w_j)^2}{9b} + \frac{(a - 2w_i + w_j)(a - 2w_i + w_j + 6bt(w_i - c))}{18b^2 t}$$

$$s.t.\ w_i \geq 0$$

The F. O. C.[6] is given by:

$$\frac{\partial \pi_{D_i}}{\partial w_i} = \frac{\left(6bct\text{ - }a(bt+2) - 4(bt\text{ - }1)w_i - (bt+2)w_j\right)}{9b^2t} \le 0,$$
$$\left(\frac{\partial \pi_{D_i}}{\partial w_i}\right)w_i = 0,\ and\ w_i \ge 0 \tag{7}$$

We set an assumption to satisfy the S. O. C. Specifically, the assumption takes the following form:

Assumption 2: $1 < bt$.

This assumption is closely related to technological environment and market size. Suppose that parameter *b* keeps constant. In this case, if *t* approaches to zero, it means that the technological environment becomes more efficient and vice versa. On the other hand, suppose that parameter *t* keeps constant. In the case, if *b* approaches to zero, it means that the market size becomes larger and vice versa.

Let us see the first equation in Equation (7). It is worth considering that if w_i = 0, the equation can be changed as $\frac{\partial \pi_{D_i}}{\partial w_i} = \frac{\left(6bct\text{ - }a(bt+2) - (bt+2)w_j\right)}{9b^2t}$. Therefore, the best-response function can be rewritten as:

$$w_i(w_j) = \frac{\left(6bct - a(bt+2) - (bt+2)w_j\right)}{4(bt\text{ - }1)} \quad \text{if} \quad 6bct - a(bt+2) \ge (bt+2)w_j \tag{8-1}$$

$$w_i(w_j) = 0 \quad \text{if} \quad 6bct - a(bt+2) < (bt+2)w_j \tag{8-2}$$

It is also worth noting that if $6bct - a(bt+2) < 0$, Equation (8-2) should be satisfied for given $w_j \ge 0$. The case corresponds to a corner solution:

$$w_i^O = w_j^O = 0 \tag{9}$$

where the superscript o denotes the corner solution.

Let see Equation (8-1). If $6bct - a(bt+2) \ge 0$, the intercept and the slope of the response function can be easily obtained, respectively.

(1) $w_i(w_j = 0) = \frac{6bct\text{ - }a(bt+2)}{4(bt\text{ - }1)} > 0$ and

(2) $\frac{dw_i}{dw_j} = -\frac{(bt+2)}{4(bt\text{ - }1)} < 0$.

Let us note Cournot stability condition. The sufficient condition for Cournot stability is that the slope of the best-response function in the neighborhood of equilibrium be less than 1 in absolute value:

$$\left|\frac{dw_i\,*}{dw_j\,*}\right| < 1$$

where the superscript * indicates that the expression is evaluated at the equilibrium input price. By the slope of the best-response function and Cournot stability condition, we can easily obtain the following result.

$$\left|\frac{dw_i}{dw_j}\right| \le 1 \ \text{ if } \ bt \ge 2 \ \text{ and } \ \left|\frac{dw_i}{dw_j}\right| > 1 \ \text{ if } \ 1 < bt < 2$$

If the condition is *bt* > *2*, the equilibrium input price is, therefore, the intersection of two best-response curves as follows:

[6] Under **Assumption 2**, we can easily check the S. O. C. that $\frac{\partial^2 \pi_{D_i}}{\partial w_i^2} = -\frac{4(bt\text{ - }1)w_i}{9b^2t}$ is satisfied.

$$w_i^* = w_j^* = \frac{6bct - a(bt+2)}{5bt - 2}$$

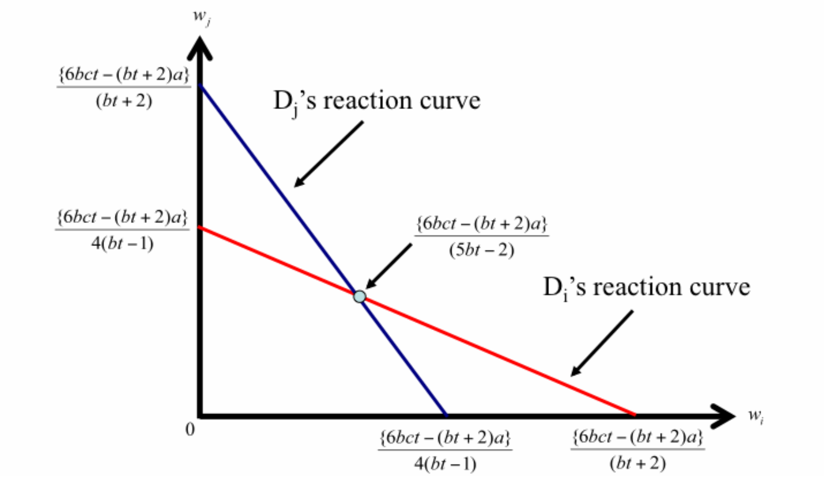

Figure 4 Symmetric Equilibrium (bt > 2)

Under the condition that $bt > 2$, Figure 4 shows both firms' best-response curves.[7]

On the other hand, if $bt = 2$, we have multiple equilibria. Note that the two best-response curves are completely identical.

Finally, consider the case that $1 < bt < 2$.[8] From Equation (8-2), if downstream firm D_i sets the input price to be higher than $\frac{6bct - a(bt+2)}{bt+2}$, downstream firm D_j sets the input price to be zero.[9] Downstream firm D_i's best-response curve, $w_i(w_j)$, is made up of two segments: one part is given by the Equation (8-1); and the other part is given by the non-negative constraint of input price.

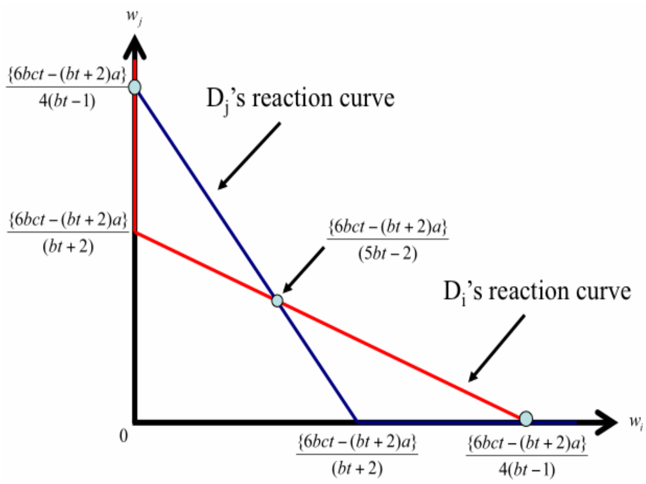

Figure 5 Asymmetric Equilibria (1 < bt < 2)

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[7] Note that the symmetric equilibrium is stable.

[8] See ***Assumption 2*** for the condition that $1 < bt < 2$.

[9] When $1 < bt < 2$, the conditions that $\frac{6bct - a(bt+2)}{4(bt-1)} > \frac{6bct - a(bt+2)}{bt+2} > \frac{6bct - a(bt+2)}{5bt-2}$ are satisfied.

Figure 5 shows the best-response curves under the condition that $1 < bt < 2$. Therefore, we focus on two asymmetric equilibria.[10] Specifically, the asymmetric equilibria are shown as follows:

$$\begin{cases} w_i ** = 0 \\ w_j ** = \dfrac{6bct - a(bt+2)}{4(bt-1)} \end{cases} \text{ and } \begin{cases} w_i ** = \dfrac{6bct - a(bt+2)}{4(bt-1)} \\ w_j ** = 0 \end{cases}$$

Furthermore, we obtain another equilibrium that refers to the intersection of the two best-response curves, $w_i* = w_j* = \dfrac{6bct - a(bt+2)}{5bt - 2}$. However, it is worth noting that the symmetric equilibrium is unstable. To sum up, given the condition that $1 < bt < 2$, there exist three Cournot-Nash equilibria.

$$\begin{cases} w_i^* = w_j^* = \dfrac{6bct - a(bt+2)}{(5bt-2)} & (10\text{-}1) \\ (w_i^{**}, w_j **) = (0, \dfrac{6bct - a(bt+2)}{4(bt-1)}) & (10\text{-}2) \\ (w_i^{**}, w_j^{**} = (\dfrac{6bct - a(bt+2)}{4(bt-1)}, 0) & (10\text{-}3) \end{cases}$$

***Proposition 1**:* Under Equation (1), **Assumption** 1, and 2, when $\dfrac{a}{c} < \dfrac{6bt}{bt+2}$ and $bt < 2$, there exist two stable asymmetric equilibria.

Figure 6 shows the regions of the Cournot equilibria.[11] Specifically, we focus on the two asymmetric equilibria regions. The regions have two specific characteristics. First, holding other factors constant, the asymmetric equilibria regions indicate that the investment efficiency parameter (t) is small. In other words, it is favorable economic condition for firms to make an R&D investment. Second, ceteris paribus, the asymmetric equilibria regions mean the market size (b) is large.[12]

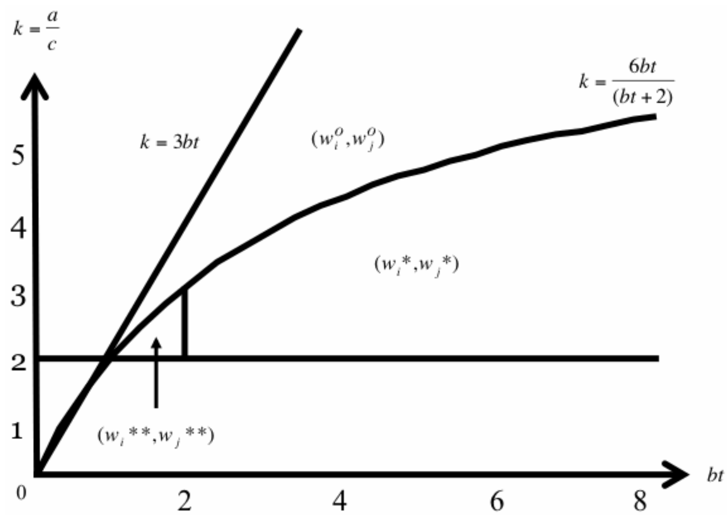

Figure 6 Equilibria Region

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[10] In this case, even if the two best-response curves have an intersection, the symmetric equilibrium is unstable. Therefore, we focus on two asymmetric equilibria.

[11] Note the condition that $\dfrac{a}{c} < 3bt$ in the corner solution. If the condition is violated, the marginal cost becomes negative.

[12] Note that, keeping other factors constant, the value of b is related to the market size. The smaller the value of b is, the larger the market size is.

4. Comparative Analysis

4.1 Corner Solution

Under Equation (1), **Assumption 1**, and **Assumption 2**, if $\frac{6bt}{bt+2} < \frac{a}{c} < 3bt$, the Cournot equilibrium input price is:

$$w_i^O = w_j^O = 0 \tag{12}$$

The Cournot equilibrium is shown in Table 1.

Table 1　Equilibrium for Corner Solution

	i	j
Investment Amount $\left(x_i^O, x_j^O\right)$	$\frac{a}{3bt}$	
Marginal Production Cost $\left(c_i^O, c_j^O\right)$	$\frac{(3bct-a)}{3bt}$	
Output $\left(q_i^O, q_j^O\right)$	$\frac{a}{3b}$	
Price (p^O)	$\frac{a}{3b}$	
Profit $\left(\pi_{Di}^O, \pi_{Dj}^O\right)$	$\frac{a\{(2bt+1)a - 6bct\}}{18b^2t}$	
Lump-sum Transfer $\left(F_i^O, F_j^O\right)$	$\frac{a(6bct-a)}{18b^2t}$	

Now, we easily check that the optimal values shown in Table 1 are non-negative under **Assumption 1**, **Assumption 2**, andthe condition that $\frac{6bt}{bt+2} < \frac{a}{c} < 3bt$. From the condition that $\frac{6bt}{bt+2} < \frac{a}{c} < 3bt$, in fact, it can be proved to be $c_i^O = c_j^O > 0$. Note the fact that $(bt+2) < (2bt+1)$ under **Assumption 2**. Therefore, it is obvious that $\pi_{D_i}^O = \pi_{D_j}^O > 0$ from the condition that $6bct < a(bt+2)$.

We now turn to the comparative statics. Note that a is a parameter that shifts the profit functions of both firms. In order to examine how each firm optimally changes its investment and output as the parameter *a* changes, we differentiate the Cournot Equilibrium shown in Table 1. Increase in the parameter *a* induces each supplier to increase its investment level. As a result, the marginal input cost decreases. However, it also causes the final product price to increase. More aggressive investment will induce downstream firms to sell more outputs and to gain more payoffs. Suppose that the cost parameter *c* shifts upward. The rise in the cost parameter *c* will reduce downstream firms' profit owing to increments of the lump-sum transfer. However, note that it does not directly affect theequilibrium investment level, output level, and final product price.

4.2 Symmetric Equilibrium

Under Equation (1), Assumption 1, and $bt > 2$, if $6bct > a(bt+2)$, the Cournot equilibrium input price is:

$$w_i{*} = w_j{*} = \frac{6bct - a(bt+2)}{5bt-2} \tag{12}$$

The Cournot equilibrium is shown in Table 2.

Table 2 Symmetric Equilibrium

	i	j
Investment Amount (x_i^*, x_j^*)	$\frac{2(a-2c)}{5bt-2}$	
Marginal Production Cost (c_i^*, c_j^*)	$\frac{5bct-2a}{5bt-2}$	
Output (q_i^*, q_j^*)	$\frac{2t(a-2c)}{5bt-2}$	
Price (p^*)	$\frac{\{(bt-2)a+4bct\}}{5bt-2}$	
Profit $(\pi_{D_i}^*, \pi_{D_j}^*)$	$\frac{2t(bt-1)(a-c)^2}{(5bt-2)^2}$	
Lump-sum Transfer (F_i^*, F_j^*)	$\frac{2t(bt+1)(a-c)^2}{(5bt-2)^2}$	

Now, we can easily check that the optimal values shown in Table 2 are non-negative under **Assumption 1**, $bt > 2$, and $6bct > a(bt+2)$. Let us examine the effect of the parameter *a* on all variables. Increase in the parameter *a* will increase its Cournot equilibrium output. As a result, each supplier will increase its Cournot equilibrium investment. The investment increment will decrease its marginal cost and input price. Note that each downstream firm sets the input price to be lower than the marginal cost of its own supplier.

Next, we examine how change in the parameter *c* affects the Cournot equilibrium. Increase in the parameter *c* will decrease the Cournot equilibrium output, investment, and profit. Furthermore, note that the final product price is positively influenced by the parameter *a* and the parameter *c*.

4.3 Asymmetric Equilibrium

Under Equation (1), ***Assumption 1*** and $1 < bt < 2$, if $6bct > a(bt+2)$, two stable asymmetric equilibria are:

$$w_i^{**} = \frac{6bct - a(bt+2)}{4(bt-1)} \text{ and } w_j^{**} = 0 \tag{13-1}$$

$$w_i^{**} = 0 \text{ and } w_j^{**} = \frac{6bct - a(bt+2)}{4(bt-1)} \tag{13-2}$$

The Cournot equilibrium is shown in Table 3.

Table 3 Asymmetric Equilibrium

	i	*j*
Input price (w_i^{**}, w_j^{**})	$\frac{6bct-a(bt+2)}{4(bt-1)}$	0
Investment Amount (x_i^{**}, x_j^{**})	$\frac{a-2c}{2(bt-1)}$	$\frac{2bct-a(2-bt)}{4bt(bt-1)}$
Marginal Production Cost (c_i^{**}, c_j^{**})	$\frac{2bct-a}{2(bt-1)}$	$\frac{a(2-bt)-2bct(3-2bt)}{4bt(bt-1)}$
Output (q_i^{**}, q_j^{**})	$\frac{t(a-2c)}{2(bt-1)}$	$\frac{2bct-a(2-bt)}{4b(bt-1)}$
Price (p^{**})	$\frac{2bct-a(2-bt)}{4(bt-1)}$	
Profit $(\pi_{D_i}^{**}, \pi_{D_j}^{**})$	$\frac{t(a-2c)^2}{8(bt-1)}$	$\frac{\{2bct-(2-bt)a\}\{2bt(5-2bt)c-(2-bt)(2bt+1)a\}}{32b^2t(bt-1)^2}$
Lump-sum Transfer (F_i^{**}, F_j^{**})	$\frac{t(bt+1)(a-2c)^2}{8(bt-1)^2}$	$\frac{\{2bct-(2-bt)a\}\{2bt(4bt-5)+(2-bt)a\}}{32b^2t(bt-1)^2}$

Now, we can easily check that all optimal variables shown in Table 3 are non-negative under **Assumption 1**, $1 < bt < 2$, and 6bct > a(bt+2).[13] In this case, firm D_j sets the input price to be zero, while firm D_i sets it to be positive. The characteristics of the asymmetric equilibrium can be described as follows.

Proposition 2: Under Equation (1), $bt < 2$, 6bct > a(bt+2) and **Assumption 1**, the Cournot asymmetric equilibria are characterized as follows:

(1) Each downstream firm sets its input price to be lower than the marginal input cost of its own supplier.

$$c_i ** > w_i ** > 0 \quad \text{and} \quad c_j ** > w_j ** = 0$$

(2) The firm with zero-input price enjoys more profit, output, and investment than those of the firm with positive input price.

See **Appendix B** for the proof.

Let us examine the effect of some parameters on firms' profits under asymmetric equilibria. Suppose that the parameter of demand (a) shifts upward. Demand increase leads to two downstream firms to increase their outputs. This is the direct effect of demand increase. Output increases induce suppliers to make more aggressively in cost reduction investment. More aggressive investment makes downstream firms set the input price to be lower than before. Note that firm D_j already set the input price at zero. Therefore, firm D_j cannot set the input price to be lower than before. On the other hand, firm D_i with a positive input price will increase its output through setting the input price down. Increasing the output amount induces its supplier U_i to make more aggressively in cost reduction investment. More investment not only will result in the marginal production cost to come down but also that firm D_i's payoff to increase. Unlike firm D_i's positive response to demand increase, firm D_j with a zero input price reduces its Cournot equilibrium output amount. Note that firm D_i and firm D_j are in Cournot competition by changing their input prices. When demand increases, firm D_j cannot decrease its input price down because it already set a zero. Another important thing is that increase in demand parameter (a) decreases the price for final goods.

Secondly, let us see the effect of cost condition (c) on all variables. Suppose that cost condition (c) shifts upward. It will increase the input price for firm D_i. Therefore, it will decrease Cournot equilibrium output amount for firm D_i. It will induce its supplier U_i not only to decrease investment level but also to increase marginal production cost. In the end, the payoff for firm D_i will decrease. Unlike decreasing Cournot equilibrium output as firm D_i's response to worse cost condition, firm D_j with a zero input price will increase its Cournot equilibrium output level because it takes advantage position in Cournot competition with the rival firm D_i. Increasing the output amount induces its supplier U_j to make more aggressively in cost reduction investment. More investment will result in not only that the marginal production cost will come down but also that firm D_j's payoff will increase. It is also interesting to have the positive effect of cost condition (c) on output of firm D_j. However, note that increasing the cost condition (c) will reduce the total output amounts and will increase the final goods price.

Hybrid cars have various advantages over conventional vehicles, such as fuel efficiency, low cost per a mile, and environmental benefits. However, the hybrid cars also have disadvantage over the conventional automobiles. From the firm's point of view, it takes high cost for firm to produce the hybrid cars. The same can be said for the luxury cars, such as *Lexus* which is the most expensive among the Japanese automobiles. In this case, our model proposes that the advantageous firm produces more hybrid cars and more luxury cars than the disadvantageous firm produces.

[13] See **Appendix A** for a detail.

5. Conclusions

This paper examined a successive duopoly model in which each firm purchased input from its own supplier. When market size is large and R&D investment is in favorable economic environment, firms are liable to make different R&D investments. We also illustrated two interesting comparative results under asymmetric equilibria. One was that the larger the demand became, the less output the large market-shared firm produced, while the more output the small market-shared firm produced. The other was that the worse the cost condition became, the more output the former produced, while the less output the latter produced.

It had been illustrated that the existence of asymmetric equilibrium by using trade-off relationship between fixed cost and variable cost (Mills & Smith, 1996). Their technology choice is selected one of the alternatives. However, our asymmetric equilibrium is generated in the continuous technology set. They obtained this result with insufficiently convex technology set and random variable, while we achieved it with sufficiently convex component price set and continuous variable.

We discussed some limitations of our model. There was a key assumption in our model: the restriction to two-part tariffs. The assumption of two-part tariffs played an important role in our main results, but our below-cost pricing result holds for $\Re \to \Re$.

Our model used a take-it-or-leave-it offer. Marx and Shaffer (1999) made a bargaining model between a monopoly retailer and two suppliers instead of using a take-it-leave-it offer. Our model could be easily extended in a bargaining model. Intuitionally explaining, suppose a bargaining game in our model, with proposition $\lambda \in [0,1]$ going to supplier U_k. We made a minimal assumption about the bargaining outcomes that corresponded to maximize two firms' joint profit. Our model corresponded to $\lambda = 0$. If supplier U_k proposed a take-it-or-leave-it offer to firm D_k, then $\lambda = 1$.

References:

Baker G. P., Gibbons R. and Murphy K. J. (2002). "Relational contracts and the theory of the firm", *Quarterly Journal of Economics*, Vol. 117, No. 1, pp. 39-84.

Bettignies J. (2006). "Product market competition and boundaries of the firm", *Canadian Journal of Economics*, Vol. 39, No. 3, pp. 948-970.

Bonanno G. and Vickers J. (1988). "Vertical separation", *Journal of Industrial Economics*, Vol. 36, No. 3, pp. 257-265.

Brander J. and Spencer B. (1983). "Strategic commitment with R & D: The symmetric case", *Bell Journal of Economics*, Vol. 14, No. 1, pp. 225-235

Chen YongMin (2001). "On the vertical mergers and their competitive effects", *RAND Journal of Economics*, Vol. 32, No. 4, pp. 667-685.

Chen YongMin (2005). "Vertical disintegration", *Journal of Economics & Management Strategy*, Vol. 14, No. 1, pp. 209-229.

Economides Nicholas and Steven C. Salop (1992). "Competition and integration among complements, and network market", *Journal of Industrial Economics*, Vol. 40, No. 1, pp. 105-123.

Erin Anderson (1985). "The salesperson as outside agent or employee: A transaction cost analysis", *Marketing Science*, Vol. 4, No. 3, pp. 234-254.

Gal-Or Esther (1999). "Vertical integration and separation of the sales function as implied by competitive forces", *International Journal of Industrial Organization*, Vol. 17, No. 5, pp. 641-662.

Hermalin Benjamin E. (1994). "Heterogeneity in organizational form: Why otherwise identical firms choose different incentives for their managers", *RAND Journal of Economics*, Vol. 25, No. 4, pp. 518-537.

Lin Ping (2006). "Strategic spin-offs of input divisions", *European Economic Review*, Vol. 50, No. 4, pp. 977-993.

Marx Leslie M. and Greg Shaffer (1999). "Predatory accommodation: below-cost pricing without exclusion in intermediate goods market", *RAND Journal of Economics*, Vol. 30, No. 1, pp. 22-43.

McLean Richard P. and Michael H. Riordan (1989). "Industry structure with sequential technology choice", *Journal of Economic Theory*, Vol. 47, No. 1, pp. 1-21.

Mills David E. (1990). "Capacity expansion and the size of plants", *RAND Journal of Economics*, Vol. 21, No. 4, pp. 555-566.

Mills David E. and Smith William (1996). "It pays to be different: Endogenous heterogeneity of firms in an oligopoly", *International Journal of Industrial Organization*, Vol. 14, No. 3, pp. 317-329.

O'Brien D. P. and Greg Shaffer (1997). "Nonlinear supply contracts, exclusive dealing, and equilibrium market foreclosure", *Journal of Economics and Management Strategy*, Vol. 6, No. 4, pp. 755-785.

SalopS. C. and Stiglitz J. E. (1977). "Bargains and ripoffs: A model of monopolistically competitive price dispersion", *Review of Economic Studies*, Vol. 44, No. 3, pp. 493-510.

Vives Xavier (1989). "Technological competition, uncertainty, and oligopoly", *Journal of Economic Theory*, Vol. 48, No. 2, pp. 386-415.

Appendix A

We show that all parameters of the Cournot asymmetric equilibrium are non-negative, hereinafter, under ***Assumption 1***, ***Assumption 2***, (bt+2) $a < 6bct$, $b\,t< 2$. Firstly, it will be proved that $\frac{a}{c} < 2bt$, to begin with, under ***Assumption 2*** and (bt+2)a < 6bct. The condition 0 < $2bt$ ($bt-1$) is satisfied under ***Assumption 2***. Let's add $6bt$ to both sides of the above equation and divide it by $bt+2$. Rearranging it, we obtain $\frac{6bt}{(bt+2)} < 2bt$. Under (bt+2)a < 6bct, therefore, this leads

$$\frac{a}{c} < \frac{6bct}{(bt+2)} < 2bt \tag{A-1}$$

Secondly, it will be proved that $\frac{a}{c} < \frac{2bt}{(2-bt)}$ is satisfied, under ***Assumption 2***, bt < 2, and (A-1). ***Assumption 1*** and bt < 2 lead to the condition (2-bt) < 1. Rearranging and multiplying it by $2bt$, we obtain $2bt < \frac{2bt}{(2-bt)}$. From ***Assumption 1*** and $2bt < \frac{2bt}{(2-bt)}$, it is proved to be

$$\frac{a}{c} < 2bct < \frac{2bt}{(2-bt)} \tag{A-2}$$

Thirdly, it will be proved that the condition $\frac{2bt(3-2bt)}{(2-bt)} < \frac{a}{c}$ is satisfied under ***Assumption 1*** and ***Assumption 2***. Suppose that $x = bt$ and $f(x) = \frac{a}{c}$. Then, this leads to $f(x) = \frac{2bt(3-2bt)}{(2-bt)}$. Differentiating $f(x)$ with respect to x, this is easily seen to be

$$\frac{\partial f(x)}{\partial x} = \frac{4(x-1)(x-3)}{(2-x)^2}$$

The function $f(x)$ is decreasing function in the interval between 1 < x < 2. Therefore, the value of $f(x)$ has 2, when x = 1. From ***Assumption 1***, therefore, it is obvious

$$\frac{2bt(3-2bt)}{(2-bt)} < \frac{a}{c} \tag{A-3}$$

Lastly, it will be proved that all parameters of asymmetric equilibria are non-negative. It is manifested that the input prices $\left(w_i **, w_j **; w_i ** > w_j ** = 0\right)$ are non-negative from $(bt+2)a < 6bct$. Investment levels $\left(x_i **, x_j **;\ x_j ** > x_i ** > 0\right)$ are non-negative from ***Assumption 1*** and ***Assumption 2***, and **Eq. (13-1)**. Marginal input costs are non-negative from the conditions **Eq. (A-1)** and **Eq. (A-2)**. Quantities $\left(q_i **, q_j **;\ q_j ** > q_i ** > 0\right)$ are apparent from ***Assumption 1*** and ***Assumption 2***, and **Eq. (13-2)**. The final product price is non-negative under the condition **Eq. (A-2)**. Firms' profits $\pi_{jA} ** > \pi_{iA} ** > 0$ are non-negative from ***Assumption 1*** and ***Assumption 2***, and **Eq. (13-1)**. It is obviously proved that all variables are non-negative.

Appendix B

Under ***Assumption 1***, ***Assumption 2***, $1 < bt < 2$, and $\dfrac{a}{c} < \dfrac{6bt}{bt+2}$, we have

$$x_j ** - x_i ** = \frac{6bct - (bt+2)a}{4bt(bt-1)} > 0 \tag{B-1}$$

$$q_j ** - q_i ** = \frac{6bct - (bt+2)a}{4bt(bt-1)} > 0 \tag{B-2}$$

$$c_i ** - w_i ** = \frac{bt(a-2c) + a}{4bt(bt-1)} > 0 \tag{B-3}$$ [14]

Furthermore, note that

$$2bt(3-2bt)c - \left(2 + bt - 2(bt)^2\right)a = \left(6bct - (bt+2)a\right) + 2(bt)^2(a - 2c) > 0\,.$$

Then, we have

$$\pi_j ** - \pi_i ** = \frac{\left(6btc - (bt+2)a\right)\left(6bct - (bt+2)a + 2b^2t^2(a-2c)\right)}{32b^2t(bt-1)^2} > 0 \tag{B-4}$$

Q.E.D.

[14] It is obvious that $c_j ** > w_j ** = 0$.