Procurement of Advanced Technology and Welfare-Reducing Vertical Integration

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This article presents a model in which two downstream firms compete in a differentiated product market and choose whether to adopt new advanced inputs supplied by the monopolist, while standard inputs are competitively supplied. When the monopoly supplier is independent, from the welfare viewpoint, the incentive to adopt the new inputs is insufficient (can be excessive) given that the rival does not adopt (adopts). When the monopoly supplier and one downstream firm merge, such integration increases the unintegrated downstream firm's incentive to adopt the new input supplied by the rival and thus helps the spread of new inputs in the industry. However, because of the collusive effect of increasing the prices of the final products, vertical integration can be harmful for welfare despite the reduction in the welfare loss due to double marginalization and the increase in product quality.

JEL Classification Codes: D43, L13, L41

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I. Introduction

Adopting new advanced inputs and announcing this fact broadly improves consumers' awareness of final products, allowing firms to expand their demand. However, such new inputs are often provided by a limited number of input suppliers or even by monopolists, which supply them at less competitive prices. Considering the hold-up problem in which suppliers may name high prices in the future, committing to the adoption of a new input is thus risky for manufacturing firms. Therefore, they may hesitate to adopt such an input unless its demand-enhancing effect is sufficiently large.

The following example highlights the type of situation on which this study focuses. In the early stage of development, Sharp was the only supplier of liquid crystal display panels made with IGZO (indium-gallium-zinc-oxide) and TFT (thin film transistor) that provided high energy-saving performance. Introducing such displays substantially improves the quality of mobile phones, tablets, and laptops, and downstream producers can advertise their product quality by announcing the introduction of this new advanced input. However, the commitment to procure this input may be risky because no other input suppliers can supply this product, and thus Sharp may require a higher input price in the future. In fact, major downstream firms such as Apple have recognized the advantage of this input but not adopted it. We also observe a similar situation for the adoption of organic electroluminescent displays for TV sets, where LG Electronics is the only supplier of large panels at a reasonable cost.

In this study, we investigate the adoption of new inputs embodying advanced technology and analyze firms' incentives to adopt a specific input that enhances their demand. In the presented vertical model, downstream firms first choose whether they purchase the high quality input that enhances demand from the monopolist or the standard input from the competitive market[1] and then the input suppliers name their prices. We next examine the role of the demand-enhancing effect and provide the conditions under which firms adopt specific inputs.

[1] Instead, we can interpret our model as one with a make-or-buy decision. Each firm chooses whether it procures the high quality inputs that enhance its demand from outside and saves the maintenance cost of production technology or maintains its production ability and continues to makes low quality inputs inside. For a discussion on make-or-buy decisions under price competition, see Sappington (2005).

We compare two cases. The first is the non-integration case in which the specific inputs are produced by an independent supplier. The second is the integration case under which one of the two downstream firms produces the specific inputs in house and the other downstream firm chooses whether to purchase these inputs from its rival or from the competitive market.

In the first case (non-integration case), we analyze the equilibria in three subgames (i.e., no firm adopts the specific input, only one firm adopts it, and both firms adopt it). We show that if no firm adopts the specific input, the private incentive to adopt the specific input by a firm is insufficient from the welfare viewpoint, while if only one firm has adopted it already, the private incentive for the additional adoption of the new input by another firm may be insufficient or excessive. Thus, the private incentive to adopt the high quality input as a pioneer is always insufficient for social welfare, but that of the second adopter can be excessive.

In the second case (integration case), we analyze the equilibria in two subgames (i.e., only the integrated firm adopts the specific input and both firms adopt it). We show that the decision to adopt by the rival firm depends on the size of the demand-enhancing effect. Only when the market-enhancing effect is strong does the rival firm also adopt it; however, this might be harmful for welfare.

Finally, we compare the results in the non-integration case with those in the integration case. Counterintuitively, integration stimulates the unintegrated downstream firm to adopt the specific input. In other words, a downstream firm has a stronger incentive to adopt the new input when the rival firm supplies it than when the independent firm supplies it. Moreover, we show that integration can be harmful for welfare, although it partially eliminates the distortion from double marginalization, which by itself improves welfare. This is because it induces the unintegrated downstream firm to adopt the input supplied by the integrated rival. The adoption of the new input by the rival induces weaker pricing by the integrated downstream firm. That is, there exists an implicit collusion effect in deciding higher prices. Thus, procuring new inputs from the rival increases downstream firms' profits and reduces welfare. Our analysis therefore highlights a new aspect of the possible anti-competitive effect of new technology adoption and vertical integration.

Our analysis may also highlight the welfare implications of Yahoo's search engine strategy that invokes intensive discussions in the anti-trust context (Harbour and Koslov , 2010). Yahoo tried to introduce Google's advanced search engine technology to improve its search quality and save the investment and maintenance costs of its own search engine. The anti-trust departments of the United States and EU were against this strategy because it stagnates innovation in the search engine market, and finally Yahoo gave up introducing it. Our results suggest that Yahoo's search engine strategy has more direct anti-competitive effects, which supports the judgment of the anti-trust departments of the United States and EU. Our results also imply that the adoption of the rival's input may have a direct price-raising effect in downstream markets such as advertising markets, although a firm has an incentive to introduce the rival's technology of the input.

Our analysis can apply to other broad contexts such as Corporate Social Responsibility (CSR) procurement and biological inputs in the food industry. For example, firms often commit to purchase CSR-oriented inputs (e.g., child labor-free, CO_2-free, fair trade products). Announcing the adoption of these inputs as CSR is appealing for consumers and may enhance demand.[2] However, few suppliers of these specialized inputs exist and firms adopting such CSR-oriented inputs may face a similar hold-up problem in our analysis. In particular, once firms obtain certification, it is difficult for them to switch from a CSR-oriented input to a non-CSR-oriented input even when the input price of the former rises

Adopting non-genetically modified (GM) agricultural inputs is another example. Products made from non-GM soybeans are highly evaluated and can be sold at higher prices than standard products. However, non-GM soybeans are not popular globally, and few suppliers provide this input. Once a downstream firm advertises its products as GM bean-free, it is difficult to switch from the monopolistic supplier to competitive suppliers that do not offer non-GM soybeans. Our result can thus apply to these situations.

[2] Manasakis et al. (2013, 2014) and Liu et al. (2015) explicitly considered the market-expanding effect of CSR and examined CSR certificates and market structure. For intensive discussions of qualitative and empirical works on CSR, see Schreck (2011) and Kitzmueller and Shimshack (2012) for excellent reviews.

Finally, we discuss the difference between our analysis and the literature on vertical foreclosure. As the seminal papers of Salinger (1988) and Ordover et al. (1990) demonstrated, the possible anti-competitive effect of vertical integration enables the integrated firm to raise its rival's costs. In their model, the input market is competitive in the sense that vertically unintegrated firms have the option to purchase inputs from outsiders. In our model, however, downstream firms first choose whether to abandon the outside option and commit to purchase the input from a specific firm.[3] In the short run, this may be unrealistic because downstream firms will choose the supplier after observing the prices of other suppliers. However, it is difficult to pre-commit to a future price level in the long run, while firms often commit to a specific quality of the final product, which makes it difficult for firms to switch suppliers flexibly. Under such circumstances, it is risky to commit to the monopoly supplier. Surprisingly, in such a situation, vertical integration with the monopoly supplier of advanced technology enhances the adoption of the new technology by the unintegrated downstream firm. Moreover, we incorporate the demand-enhancing effect of the adoption of the high quality input that is not discussed in these works. Thus, we can emphasize that the adoption of the high quality input may be motivated by improving product quality. Nevertheless, under vertical integration, this may reduce welfare because of the collusion effect.[4]

In addition to vertical foreclosure, this study is different from the discussion in the literature on entry deterrence by using exclusive contracts.[5] In our model, each downstream firm has the option to deal with competitive input suppliers; if a downstream firm expects to be excluded, it never commits to adopt the input supplied by the monopolistic supplier in equilibrium. Instead, its reliance upon input procurement provides

[3] For the same reason, our model formulation is different from those in the standard works on licensing such as Kamien and Tauman (1986) and Katz and Shapiro (1986), in which a royalty or fixed fee payment is determined before firms become licensees.

[4] Allain et al. (2016) suggested that vertical integration creates a hold-up problem. Our discussion is different from theirs because in our analysis a hold-up problem exists with and without integration and vertical integration mitigates, rather than accelerates, this problem.

[5] See Rasmusen et al. (1991). For recent developments of exclusion by adopting exclusive contracts, see Wright (2009), Kitamura (2010), and Kitamura et al. (2017). For other discussions of anti-competitive vertical integration, see Matsushima and Pan (2016) and the works cited therein.

a cost-increasing effect, which might push up the price of competitive products. Thus, the entry deterrence effect does not matter in our analysis.

The remainder of this paper is organized as follows. Section 2 constructs the duopoly model of a vertical structure. We analyze the non-integration case and integration case in Sections 3 and 4, respectively. Section 5 compares these two cases and examines the welfare consequences. Section 6 concludes the paper.

2. The Model

We consider a vertical model in which two downstream firms compete in a differentiated product market. Each downstream firm chooses whether to purchase advanced inputs from specific input suppliers or standard products from the competitive market.[6] We normalize the standard (non-advanced) input price to zero. Let r be the price of the advanced input. For tractability, we assume that the advanced input is supplied by the monopolist, firm U.

Two downstream firms choose whether to commit to purchase advanced inputs. We assume that these advanced inputs increase the value of the final product. Therefore, consumers' willingness to pay for firm *i*'s product depends on whether firm *i* adopts the advanced input. The utility function of the representative consumer is

$$U(q_i, q_j) = A_i q_i + A_j q_j - \frac{1}{2}\left({q_i}^2 + 2\beta q_i q_j + {q_j}^2\right) \quad (1)$$

where $\beta \in (0,1)$ represents the degree of product differentiation and q_i and P_i are the output and price of downstream firm *i* (i = 1,2), respectively. We assume that $A_i = A^*$ $(A_i = A)$ if firm *i* adopts (does not adopt) the advanced input and $A < A^* < \bar{A} = A\left(\frac{2-\beta^2}{\beta}\right)$ in order to ensure all the games discussed below have interior solutions.

The inverse demand function and demand function of each firm i $(i = 1,2.\, i \neq j)$ are, respectively,

$$P_i = A_i - q_i - \beta q_j, \qquad q_i = \frac{A_i - \beta A_j - P_i + \beta P_j}{1-\beta^2} \quad (2)$$

The profit of firm i $(i = 1,2.\, i \neq j)$ is

[6] Instead, we can interpret our model as a model with a make-or buy-decision. See footnote 1.

$$\pi_i = (P_i - c_i)q_i \tag{3}$$

where c_i is zero if firm *i* adopts the standard input and *r* otherwise. We assume that the marginal costs of all upstream firms are constant, which are normalized to zero.[7]

The game runs as follows. In the first stage, each downstream firm simultaneously chooses whether to commit to adopt the high quality input. In the second stage, after observing downstream firms' decisions in the first stage, firm U sets *r*. In the third stage, downstream firms choose their prices simultaneously.

3. The Equilibrium without Integration

3-1 Third-stage competition

We discuss the third stage in which each downstream firm faces price competition. From the first-order condition of each firm i $(i = 1,2.\, i \neq j)$, we obtain the following equilibrium price:

$$P_i = \frac{(2-\beta^2)A_i - \beta A_j + 2c_i - \beta c_j}{4-\beta^2} \tag{4}$$

3-2 Second-stage choice

We discuss the second stage in which firm U chooses input price *r*. We now discuss the following three subgames.

3-2-1. The subgame in which both firms adopt the standard input

Suppose that both downstream firms adopt the standard input. In this subgame, the upstream monopolist, firm U, does nothing. By substituting $A_i = A_j = A$ and $c_i = c_j = 0$ into (4), we obtain the second-stage equilibrium outcomes shown in Table 1.[8]

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[7] It may be natural to assume that the production cost for the advanced input is higher than that for the standard one. Suppose that the cost difference between them is *c*. All of our lemmas and propositions hold if we replace A* with A** =A* - c. In other words, we can interpret A* as the net benefit (i.e., the demand-expanding effect minus the additional production cost of the input) of adopting the high quality input.

[8] The first digit in the bracket indicates the decision of firm i on high quality procurement and the second digit indicates the decision of firm j on high quality procurement. For example, $\pi_i(0,0)$ denotes the profit of firm i when neither firm i nor firm j adopts the high quality input.

Table 1. Equilibrium outcomes without integration when no firm adopts

$P_i(0,0) = \frac{A(1-\beta)}{2-\beta}$	$q_i(0,0) = \frac{A}{2+\beta-\beta^2}$
$\pi_i(0,0) = \frac{A^2(1-\beta)}{(2-\beta)^2(1+\beta)}$	$CS(0,0) = \frac{A^2}{(2-\beta)^2(1+\beta)}$
$W(0,0) = \frac{A^2(3-2\beta)}{(2-\beta)^2(1+\beta)}$	

3-2-2 The subgame in which only one firm adopts the high quality input

Suppose that only firm *i* adopts the high quality input. By substituting $A_i = A^*, A_j = A, c_i = r$ and $c_j = 0$ into (4), we obtain the following profit of firm U:

$$\pi_U = rq_i = \frac{r((2-\beta^2)A^* - A\beta - r(2-\beta^2))}{4-5\beta^2+\beta^4} \quad (5)$$

The first-order condition provides the equilibrium outcomes shown in Table 2.

Table 2. Equilibrium outcomes without integration when only one firm adopts

$r(1,0) = \frac{(2-\beta^2)A^* - A\beta}{2(2-\beta^2)}$	$\pi_U(1,0) = \frac{((2-\beta^2)A^* - A\beta)^2}{4(2-\beta)(1-\beta)(1+\beta)(2+\beta)(2-\beta^2)}$
$P_i(1,0) = \frac{(3-\beta^2)((2-\beta^2)A^* - A\beta)}{(2-\beta)(2+\beta)(2-\beta^2)}$	$P_j(1,0) = \frac{A(8-9\beta^2+2\beta^4) - \beta(2-\beta^2)A^*}{2(2-\beta)(2+\beta)(2-\beta^2)}$
$q_i(1,0) = \frac{(2-\beta^2)A^* - A\beta}{2(2-\beta)(1-\beta)(1+\beta)(2+\beta)}$	$q_j(1,0) = \frac{A(8-9\beta^2+2\beta^4) - \beta(2-\beta^2)A^*}{2(2-\beta)(1-\beta)(1+\beta)(2+\beta)(2-\beta^2)}$
$\pi_i(1,0) = \frac{((2-\beta^2)A^* - A\beta)^2}{4(4-\beta^2)^2(1-\beta^2)}$	$\pi_j(1,0) = \frac{(\beta(2-\beta^2)A^* - A(8-9\beta^2+2\beta^4))^2}{4(1-\beta^2)(2-\beta)^2(2+\beta)^2(2-\beta^2)^2}$
$CS(1,0) = \frac{A^2(64-108\beta^2+53\beta^4-8\beta^6)+2A\beta(8-18\beta^2+11\beta^4-2\beta^6)A^* + (2-\beta^2)^2(4-3\beta^2)(A^*)^2}{8(1-\beta^2)(8-6\beta^2+\beta^4)^2}$	
$W(1,0) = \frac{A^2(192-372\beta^2+259\beta^4-76\beta^6+8\beta^8)-2\beta(2-\beta^2)(36-31\beta^2+6\beta^4)AA^* + (2-\beta^2)^2(28-21\beta^2+4\beta^4)(A^*)^2}{8(1-\beta^2)(8-6\beta^2+\beta^4)^2}$	

3-2-3 The subgame in which both firms adopt the high quality input

Suppose that both firms adopt the high quality input. By substituting $A_i = A_j = A^*$ and $c_i = c_j = r$ into (4), we obtain the following profit of firm U:

$$\pi_U = r(q_i + q_j) = \frac{2r(A^* - r)}{(2-\beta)(1+\beta)} \quad (6)$$

The first-order condition provides the equilibrium input price. We obtain the equilibrium outcomes shown in Table 3.

Table 3. Equilibrium outcomes without integration when both firms adopt

$r(1,1)=\frac{A^*}{2}$	$\pi_U(1,1)=\frac{(A^*)^2}{2(2-\beta)(1+\beta)}$
$P_i(1,1)=\frac{(3-2\beta)A^*}{2(2-\beta)}$	$q_i(1,1)=\frac{A^*}{2(2-\beta)(1+\beta)}$
$\pi_i(1,1)=\frac{(1-\beta)(A^*)^2}{4(2-\beta)^2(1+\beta)}$	$CS(1,1)=\frac{(A^*)^2}{4(2-\beta)^2(1+\beta)}$
$W(1,1)=\frac{(7-4\beta)(A^*)^2}{4(2-\beta)^2(1+\beta)}$	

3-3 First-stage choice

We discuss the first stage in which downstream firms simultaneously choose whether to commit to adopt the high quality input. We have the following lemma.

Lemma 1. Define $A_\pi(1,0)=\frac{A(4-\beta-2\beta^2)}{2-\beta^2}$ and $A_\pi(1,1)=\frac{A(8-9\beta^2+2\beta^4)}{(2-\beta^2)^2}$. Then, $A_\pi(1,0)<A_\pi(1,1)$. In equilibrium, (i) no firm adopts the high quality input if $A^* \leqq A_\pi(1,0)$, (ii) only one firm adopts the high quality input if $A_\pi(1,0) \leqq A^* \leqq A_\pi(1,1)$, and (iii) both firms adopt the high quality input if $A_\pi(1,1) \leqq A^*$.

Proof. Suppose that firm j does not adopt the high quality input.

$\pi_i(1,0)-\pi_i(0,0)=\frac{\left((2-\beta^2)A^*-A(4-\beta-2\beta^2)\right)\left(A(4-\beta(3+2\beta))+(2-\beta^2)A^*\right)}{4(4-\beta^2)^2(1-\beta^2)}>0$ if and only if $A^*>A_\pi(1,0)=\frac{A(4-\beta-2\beta^2)}{2-\beta^2}$. This implies (i).

Suppose that firm j adopts the high quality input.

$\pi_i(1,1)-\pi_i(0,1)=\frac{(2-\beta^2)^3(2-\beta(2+\beta))(A^*)^2+2\beta(2-\beta^2)(8-9\beta^2+2\beta^4)AA^*-(8-9\beta^2+2\beta^4)^2A^2}{4(1-\beta^2)(8-6\beta^2+\beta^4)^2}>0$ if and only if $A^*>A_\pi(1,1)=\frac{A(8-9\beta^2+2\beta^4)}{(2-\beta^2)^2}$. This implies (iii).

Finally, $A_\pi(1,1)-A_\pi(1,0)=\frac{A\beta(1-\beta)(2+\beta)}{(2-\beta^2)^2}>0$. This implies (ii). **Q.E.D.**

Lemma 1 is intuitive. If the demand-enhancing effect is sufficiently large, both firms adopt the high quality input. If it is sufficiently small, no firm chooses the high quality input. If it is intermediate, only one firm adopts the high quality input.

Next, we compare the profit of each downstream firm when only one firm adopts the high quality input.

Lemma 2. $\pi_i(1,0) > \pi_j(1,0)$ if $A^* > A_\pi(1,0)$.

Proof. $\pi_i(1,0) - \pi_j(1,0) = \frac{(2-\beta^2)^2(A^*)^2+2\beta(2-\beta^2)AA^*-(4+\beta-2\beta^2)(4-\beta-2\beta^2)A^2}{4(4-\beta^2)(2-\beta^2)^2} > 0$ if and only if $A^* > \frac{A(4-\beta-2\beta^2)}{2-\beta^2} = A_\pi(1,0)$. **Q.E.D.**

Lemma 2 states that if only one firm adopts the high quality input in equilibrium, the firm adopting it obtains greater profits than its rival. The adoption of the high quality input increases the firm's profit directly by expanding demand. The change in the demand parameter directly reduces the rival's demand and thus reduces its profit. However, the adoption of the high quality input raises the price of the firm and this increases the profit of its rival indirectly. The former direct effect dominates the latter effect and the adoption of the high quality input thus reduces the rival's profit. This leads to Lemma 2. Note that given that the rival does not adopt the high quality input, a firm adopts the high quality input only if it increases its own profit.

This result has another implication. Instead of simultaneous choice in the model, if firms sequentially choose whether to adopt the high quality input, the leader chooses the high quality input when $A_\pi(1,0) \leqq A^* \leqq A_\pi(1,1)$. Thus, there is a first-mover advantage in adopting the high quality input.

We now discuss welfare. The welfare gain of the high quality input is caused by the increase in consumer value. However, because the market of the high quality input is less competitive than the perfectively competitive standard input market, adopting the high quality input raises the price. This yields a welfare loss.

Define

$$A_W(1,0) = A\frac{\beta(36-31\beta^2+6\beta^4)+2(1-\beta)(2+\beta)\sqrt{(2+\beta)(2-\beta^2)(84-\beta(70+\beta(62-\beta(53+8(1-\beta)\beta))))}}{(2-\beta^2)(28-21\beta^2+4\beta^4)}$$

and $A_W(1,1) =$

$$A\frac{(2+\beta)\sqrt{2(1-\beta)(672-\beta(768+\beta(1140-\beta(1320+\beta(653-2\beta(398+\beta(69-\beta(97+4\beta-8\beta^2))))))))}-\beta(36-31\beta^2+6\beta^4)}{(2-\beta^2)(28-\beta(32+\beta(21-2\beta(5+2\beta))))}$$

Then, $A_W(1,0) < A_W(1,1)$. We obtain the following lemma.

Lemma 3.

$$\max\{W(0,0),W(1,0),W(1,1)\} = \begin{cases} W(0,0) & \text{if } A^* < A_W(1,0) \\ W(1,0) & \text{if } A_W(1,0) < A^* < A_W(1,1) \\ W(1,1) & \text{if } A_W(1,1) < A^* \end{cases}.$$

Proof. $W(1,0) \gtreqless W(0,0) \Leftrightarrow A^* \gtreqless A_W(1,0)$ and $W(1,1) \gtreqless W(1,0) \Leftrightarrow A^* \gtreqless A_W(1,1)$. These yield $A < A_W(1,0) < A_W(1,1)$. **Q.E.D.**

Lemma 3 is intuitive. When the value-added effect of the high quality input is sufficiently small (large), adopting the high quality input is harmful (beneficial) for social welfare because the higher prices (quality) induced by the less competitive (more valuable) procurement reduces (increases) the consumer surplus. If this effect is intermediate, the welfare-enhancing effect of the high quality input exists but it is weak. Therefore, one firm's adoption of the high quality input improves (reduces) welfare given that the rival does not (does) adopt the high quality input.

We now discuss whether the private incentive to adopt the high quality input is excessive or insufficient from the welfare viewpoint.

Proposition 1. (i) $A_W(1,0) < A_\pi(1,0)$. (ii) Both $A_W(1,1) > A_\pi(1,1)$ and $A_W(1,1) < A_\pi(1,1)$ are possible.

Proof

(i) $A_\pi(1,0) - A_W(1,0) = \frac{2A}{(2-\beta^2)^2(28-21\beta^2+4\beta^4)}(B - \sqrt{C})$,

where $B = (7-11\beta+4\beta^2)(4+2\beta-2\beta^2-\beta^3)^2 > 0$ and

$C = (1-\beta)^2(4+2\beta-2\beta^2-\beta^3)^3(84-70\beta-62\beta^2+53\beta^3+8\beta^4-8\beta^5) > 0$. Because $B^2 - C = 2(1-\beta)^2(2+\beta)^3(2-\beta^2)^3\big((2-\beta)(28-21\beta^2+4\beta^4)\big) > 0$, we obtain (i).

(ii) Fig. 1 shows that $A_W(1,1) > A_\pi(1,1)$ and $A_W(1,1) < A_\pi(1,1)$ are possible.

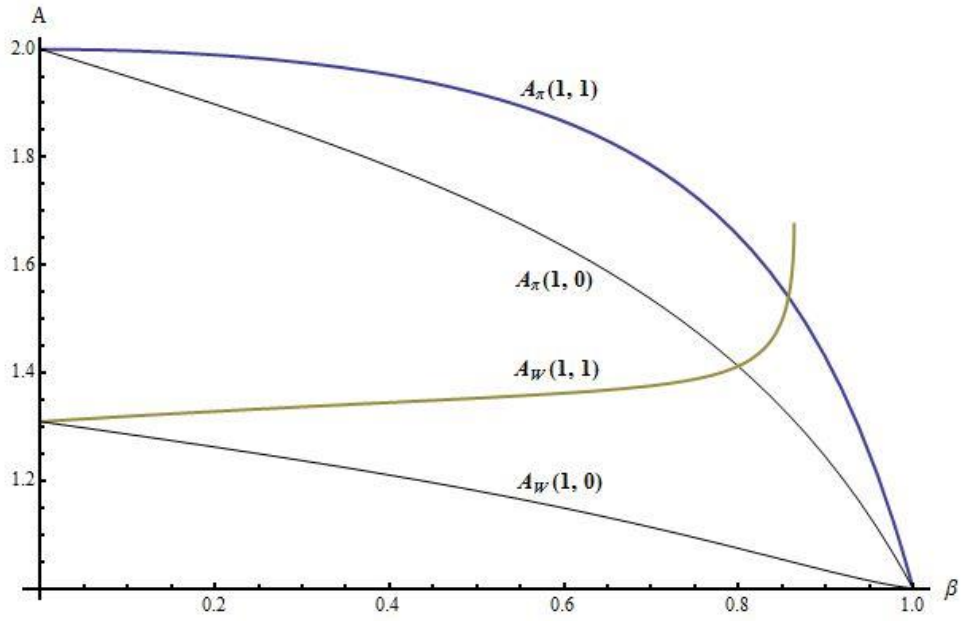

Fig. 1. Comparisons of the thresholds without integration

Q.E.D.

Lemmas 1–3 and Proposition 1(i) imply that, starting from the situation in which no firm adopts the high quality input, the private incentive to adopt the high quality input by a downstream firm is insufficient from the welfare viewpoint. Adopting the high quality input increases product value, which raises the consumer surplus as well as the profit of the upstream firm. However, a downstream firm does not take account of these effects when it chooses the high quality input. This yields the insufficient adoption of the high quality input.

Lemmas 1–3 and Proposition 1(ii) imply that, starting from the situation in which only one firm adopts the high quality input, the private incentive for the additional adoption of the high quality input by another firm may be insufficient or excessive from the welfare viewpoint. The adoption of the high quality input by firm 2 reduces firm 1's profit. Because of this business-stealing effect, the incentive can be excessive.[9]

We have thus far examined the case in which the superior input is supplied by the independent firm. However, such an input may be produced in house by downstream firms. In the next section, we discuss the case in which one downstream firm produces

[9] For a discussion of the business-stealing effect, see Mankiw and Whinston (1986).

such an input and the other downstream firm chooses whether to purchase the input from the rival.

4. The Equilibrium with Integration

In this section, we consider the case in which one of the downstream firms, rather than an independent input supplier, produces the high quality input in house. This corresponds to the situation in which firm 1 merges with firm U.

The game runs as follows. In the first stage, firm 1 chooses whether it sells the high quality input to firm 2. In the second stage, firm 2 chooses whether to adopt the high quality input. In the third stage, firm 1 chooses the price of high quality input *r*. In the fourth stage, firms face price competition.

It is obvious that firm 1 adopts the high quality input because $A^* > A$. It is also obvious that in the first stage, firm 1 offers the high quality input to firm 2.[10] Thus, it is sufficient to discuss the following two situations. One is the case in which firm 2 does not adopt the high quality input (and thus only firm 1 adopts the high quality input) and the other is the case in which firm 2 adopts the high quality input (and thus both firms adopt the high quality input). Let the superscript M represent the integration case (i.e., firms U and 1 merge).

4-1 The subgame in which only firm 1 adopts the high quality input

By substituting $A_1 = A^*,\ A_2 = A,\ c_1 = \ c_2 = 0$ into (4), we obtain the equilibrium prices and quantities including profits and social welfare shown in Table 4.[11]

Table 4. Equilibrium outcomes with integration when only firm 1 adopts

${P_1}^M(1,0) = \frac{(2-\beta^2)A^*-A\beta}{4-\beta^2}$	${P_2}^M(1,0) = \frac{A(2-\beta^2)-\beta A^*}{4-\beta^2}$
${q_1}^M(1,0) = \frac{(2-\beta^2)A^*-A\beta}{(2-\beta)(1-\beta)(1+\beta)(2+\beta)}$	${q_2}^M(1,0) = \frac{A(2-\beta^2)-\beta A^*}{(2-\beta)(1-\beta)(1+\beta)(2+\beta)}$

[10] This is because firm 1 can offer a sufficiently high price in the third stage. If firm 2 expects firm 1 to set such a high price, it never chooses to adopt the high quality input.

[11] The first digit in the bracket indicates the decision of firm 1 on the adoption of the high quality input and the second digit indicates the decision of firm 2 on the adoption of the high quality input. That is, ${\pi_1}^M(1,0)$ denotes the profit of firm 1 when it is the only firm to adopt the high quality input.

$\pi_1{}^M(1,0) = \frac{((2-\beta^2)A^*-A\beta)^2}{(4-\beta^2)^2(1-\beta^2)}$	$\pi_2{}^M(1,0) = \frac{(A(2-\beta^2)-\beta A^*)^2}{(4-\beta^2)^2(1-\beta^2)}$
$CS^M(1,0) = \frac{A^2(4-3\beta^2)-2A\beta^3A^*+(4-3\beta^2)(A^*)^2}{2(4-\beta^2)^2(1-\beta^2)}$	
$W^M(1,0) = \frac{(12-9\beta^2+2\beta^4)(A^*)^2-2\beta(8-3\beta^2)AA^*+(12-9\beta^2+2\beta^4)A^2}{2(4-\beta^2)^2(1-\beta^2)}$	

4-2. The subgame in which both firms adopt the high quality input

In this case, $A_1 = A_2 = A^*$. The profit functions of both firms are as follows:

$$\pi_1{}^M = P_1q_1 + rq_2 = \frac{r((1-\beta)A^*-P_2)+P_1(r\beta+\beta P_2+A^*(1-\beta))-P_1^2}{1-\beta^2} \quad (7)$$

$$\pi_2{}^M = (P_2 - r)q_2 = \frac{(P_2-r)(\beta P_1-P_2+A^*(1-\beta))}{1-\beta^2} \quad (8)$$

The first-order conditions provide the following equilibrium outcomes in the fourth stage:

$$P_1{}^M(1,1) = \frac{(1-\beta)(2+\beta)A^*+3r\beta}{4-\beta^2} \quad (9)$$

$$P_2{}^M(1,1) = \frac{(1-\beta)(2+\beta)A^*+r(2+\beta^2)}{4-\beta^2} \quad (10)$$

$$q_1{}^M(1,1) = \frac{(2+\beta)A^*-r\beta(1+\beta)}{(1+\beta)(4-\beta^2)} \quad (11)$$

$$q_2{}^M(1,1) = \frac{(2+\beta)A^*-2r(1+\beta)}{(1+\beta)(4-\beta^2)} \quad (12)$$

In the third stage, firm 1 chooses the high quality input price *r*. Its profit is

$$\pi_1 = \frac{(1-\beta)(2+\beta)^2(A^*)^2-r^2(1+\beta)(8+\beta^2)+r(1+\beta)(2+\beta)(4-2\beta+\beta^2)A^*}{(1+\beta)(4-\beta^2)^2} \quad (13)$$

The first-order condition provides the equilibrium input price. Thus, we obtain the equilibrium outcomes in the third stage shown in Table 5.

Table 5. Equilibrium outcomes with integration when both firms adopt

$r^M(1,1) = \frac{(8+\beta^3)A^*}{2(8+\beta^2)}$	
$P_1{}^M(1,1) = \frac{(4-\beta)(2+\beta)A^*}{2(8+\beta^2)}$	$P_2{}^M(1,1) = \frac{(12-\beta(4-(2-\beta)\beta))A^*}{2(8+\beta^2)}$

$q_1{}^M(1,1) = \frac{(8+\beta(2+\beta+\beta^2))A^*}{2(1+\beta)(8+\beta^2)}$	$q_2{}^M(1,1) = \frac{(2+\beta^2)A^*}{(1+\beta)(8+\beta^2)}$
$\pi_1{}^M(1,1) = \frac{(12+\beta(4+\beta+\beta^2))(A^*)^2}{4(1+\beta)(8+\beta^2)}$	$\pi_2{}^M(1,1) = \frac{(1-\beta)(2+\beta^2)^2(A^*)^2}{(1+\beta)(8+\beta^2)^2}$
$CS^M(1,1) = \frac{(80+16\beta+36\beta^2+24\beta^3+\beta^4+5\beta^5)(A^*)^2}{8(1+\beta)(8+\beta^2)^2}$	
$W^M(1,1) = \frac{(304+\beta(48+\beta(108+\beta(16+(11-\beta)\beta))))(A^*)^2}{8(1+\beta)(8+\beta^2)^2}$	

4-3 Firm 2's decisions on the adoption of the high quality input

We now discuss whether firm 2 adopts the high quality input in the second stage. We obtain the following lemma.

Lemma 4. Firm 2 adopts the high quality input if and only if $A^* > A_\pi{}^M(1,1)$, where $A_\pi{}^M(1,1) = \frac{A(2-\beta^2)(8+\beta^2)}{8+\beta^2(2-\beta(1+(1-\beta)\beta))}$.

Proof. We obtain $\pi_2{}^M(1,1) - \pi_2{}^M(1,0) = \frac{DE}{(1-\beta^2)(32-4\beta^2-\beta^4)^2}$ where $D = (8+\beta^2(2-\beta(1+(1-\beta)\beta)))A^* - A(2-\beta^2)(8+\beta^2)$ and $E = A(2-\beta^2)(8+\beta^2) - (\beta(16+(2-\beta)\beta(\beta+\beta^2-1)) - 8)A^*$.

$D > 0$ if and only if $A^* > \frac{A(2-\beta^2)(8+\beta^2)}{8+\beta^2(2-\beta(1+(1-\beta)\beta))} = A_\pi{}^M(1,1)$ and $E > 0$ if and only if $A^* < \frac{A(2-\beta^2)(8+\beta^2)}{\beta(16+(2-\beta)\beta(\beta+\beta^2-1))-8}$. Note that $\bar{A} < \frac{A(2-\beta^2)(8+\beta^2)}{\beta(16+(2-\beta)\beta(\beta+\beta^2-1))-8}$, which is sufficient to prove the result. **Q.E.D.**

Lemma 4 is again intuitive. When the market expansion effect of the high quality input is strong, firm 2 also adopts the high quality input.

We obtain a similar result on the welfare consequences of firm 2's adoption of the high quality input under integration. This is beneficial (harmful) for welfare if A^* is sufficiently large (small).

Lemma 5. There exists $A_W{}^M(1,0) > A_W{}^M(0,0) > 0$ such that (i) if $A^* \gtrless A_W{}^M(0,0)$, then $W^M(1,1) \gtrless W(0,0)$ and (ii) if $A^* \gtrless A_W{}^M(1,0)$, then $W^M(1,1) \gtrless W^M(1,0)$.

Proof. Fig. 2 shows that $A_W{}^M(1,0) > A_W{}^M(0,0) > 0$ for $\beta \in (0,1)$, in which $A_W{}^M(1,0)$ denotes the threshold between $W^M(1,1)$ and $W^M(1,0)$ and $A_W{}^M(0,0)$ denotes the threshold between $W^M(1,1)$ and $W(0,0)$.

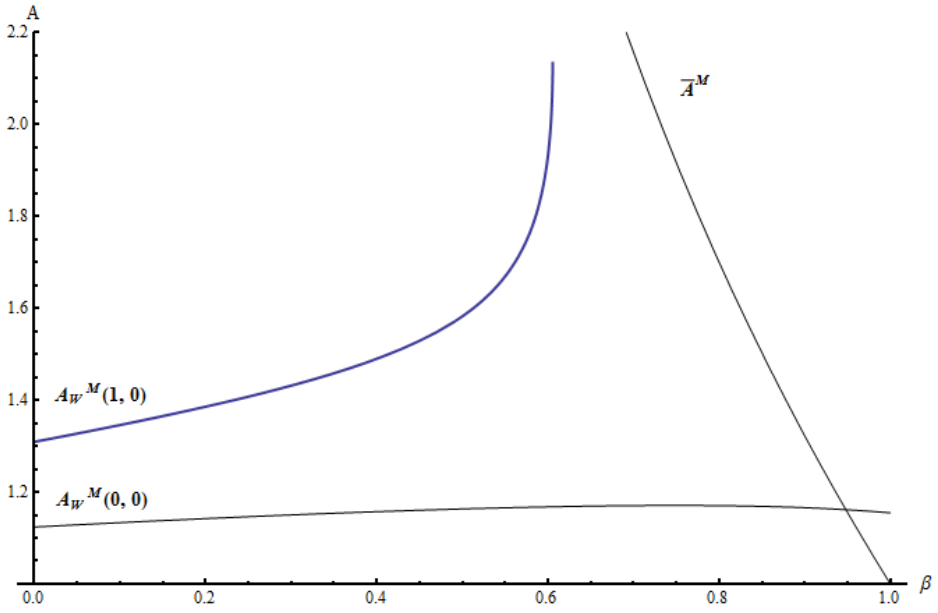

Fig. 2. Comparisons between $\boldsymbol{A_W{}^M(1,0)}$ and $\boldsymbol{A_W{}^M(0,0)}$

Q.E.D.

5. Comparisons

We now discuss whether vertical integration enhances the unintegrated firm's adoption of the high quality input. Counterintuitively, Proposition 2 states that integration accelerates the rival's adoption of the high quality input.

Proposition 2. $A_\pi(1,1) > A_\pi{}^M(1,1)$.

Proof. $A_\pi(1,1) - A_\pi{}^M(1,1) = \frac{\beta^2(1-\beta)(1+\beta)(2+\beta)(16-12\beta-\beta^2+5\beta^3-2\beta^4)}{(2-\beta^2)^2(8+2\beta^2-\beta^3-\beta^4+\beta^5)} > 0$. **Q.E.D.**

Proposition 2 implies that if both firms adopt the high quality input in the non-integration case, they also adopt the high quality input in the integration case; however, the inverse is not true. In other words, both integrated and unintegrated firms are more likely to adopt the high quality input under integration. The result that the unintegrated

downstream firm has a stronger incentive to adopt the high quality input under integration may thus be counterintuitive. We therefore explain the intuition behind this result.

Under integration, when firm 2 adopts the high quality input, firm 1 obtains the revenue from firm 2 that is proportional to firm 2's output given *r*. A higher final product price set by firm 1 raises the output of firm 2, resulting in an increase in firm 1's revenue from inputs. Therefore, firm 1 has a stronger incentive to raise its final product price when firm 2 adopts the high quality input. In other words, the adoption of the high quality input by firm 2 mitigates competition in the downstream market. Thus, the weaker competition caused by firm 2's adoption of the high quality input increases its profit. Therefore, firm 2 has a stronger incentive to adopt the high quality input under integration.

However, this does not imply that vertical integration is beneficial for firm 2. Integration reduces the marginal cost of firm 1 because it eliminates the double marginalization problem between firms U and 1. This induces stronger pricing by firm 1, which reduces firm 2's profit. Proposition 3 states that firm 2 obtains smaller profits under integration.

Proposition 3. Firm 2 always obtains smaller profits under integration compared with non-integration.

Proof. We have to consider the eight adoption combinations between the integration and non-integration cases.

(i) Suppose that both firms adopt the high quality input without integration. Then, from Proposition 2, both adopt the high quality input with integration, too. Therefore, we obtain

$$\pi_2(1,1) - {\pi_2}^M(1,1) = \frac{(1-\beta)\beta(4-3\beta+2\beta^2)(16-4\beta+5\beta^2-2\beta^3)(A^*)^2}{4(2-\beta)^2(1+\beta)(8+\beta^2)^2} > 0$$

(ii) Suppose that only firm 1 adopts the high quality input with and without integration. This happens only when $A^* < {A_\pi}^M(1,1)$. Then, we have ${\pi_2}^M(1,0) > \pi_2(1,0)$ if and only if $A^* > \frac{A(16-17\beta^2+4\beta^4)}{6\beta-3\beta^3}$. Because $\frac{A(16-17\beta^2+4\beta^4)}{6\beta-3\beta^3} > {A_\pi}^M(1,1)$, we can show that ${\pi_2}^M(1,0) > \pi_2(1,0)$ never holds in this case.

(iii) Suppose that only firm 1 adopts the high quality input with integration and both adopt the high quality input without integration. This contradicts Proposition 2 and thus it never takes place.

(iv) Suppose that both firms adopt the high quality input with integration but only firm 1 adopts the high quality input without integration. This happens only when $A^* > A_\pi(1,1)$. We obtain ${\pi_2}^M(1,1) > \pi_2(1,0)$ if and only if $A^* > \frac{A(8+\beta^2)(8-9\beta^2+2\beta^4)}{(2-\beta^2)(16-\beta(8-\beta(4-\beta(3+2(1-\beta)\beta))))}$. Because $\frac{A(8+\beta^2)(8-9\beta^2+2\beta^4)}{(2-\beta^2)(16-\beta(8-\beta(4-\beta(3+2(1-\beta)\beta))))} > A_\pi(1,1)$, ${\pi_2}^M(1,1) > \pi_2(1,0)$ never holds in this case.

(v) Suppose that only firm 2 adopts the high quality input without integration and only firm 1 adopts the high quality input with integration. As we showed in Lemma 2, in the non-integration case, the firm that does not adopt the high quality input obtains smaller profits. In addition, firm 1's marginal cost is lower under integration. Both effects reduce firm 2's profit, while there is no effect of increasing firm 2's profit. Therefore, firm 2's profit is smaller with integration.

(vi) Suppose that only firm 2 adopts the high quality input without integration and both firms adopt the high quality input with integration. Then, firm 2 earns a larger profit than that when only firm 1 adopts the high quality input without integration from Lemma 2. We also showed in (iv) that integration reduces firm 2's profit even when only firm 1 adopts the high quality input without integration. These two facts imply that integration reduces firm 2's profit in this case, too.

(vii) Suppose that no firm adopts the high quality input without integration and only firm 1 adopts the high quality input with integration. The adoption of the high quality input by firm 1 reduces firm 2's profit and vertical integration reduces firm 1's cost, which makes firm 1 stronger. Both effects reduce firm 2's profit, while there is no effect of increasing firm 2's profit. Therefore, firm 2's profit is smaller with integration.

(viii) Suppose that no firm adopts the high quality input without integration and both firms adopt the high quality input with integration. This happens only when $A^* < A_\pi(1,0)$. ${\pi_2}^M(1,1) > \pi_2(0,0)$ if and only if $A^* > \frac{A(8+\beta^2)}{4-2\beta+2\beta^2-\beta^3}$. Because $\frac{A(8+\beta^2)}{4-2\beta+2\beta^2-\beta^3} > A_\pi(1,0)$, ${\pi_2}^M(1,1) > \pi_2(0,0)$ never holds in this case. **Q.E.D.**

Integration increases the joint profits of firms U and 1. The merged firm's profit can increase through two channels. First, the merged firm internalizes the problem of double marginalization between the upstream and downstream firms (firm U and firm 1). Second, as shown in Proposition 2, vertical integration induces the rival to adopt the new inputs, and integration induces weaker price competition when both firms adopt the new inputs. This collusive effect increases the profit of firm 1.[12]

Because this collusive effect harms consumer welfare, integration involves a trade-off in welfare. On one hand, it mitigates the double marginalization problem between firm U and 1. On the other hand, it enhances the adoption of the new input by firm 2 and this makes the market less competitive. It is ambiguous whether the former welfare-enhancing effect dominates the latter welfare-reducing effect.

Proposition 4 (i) Suppose that the pattern of the high quality input adoption does not change with and without integration; then, integration always improves welfare. (ii) When integration encourages firm 2's adoption of the high quality input, integration may harm welfare.

Proof (i) First, suppose that both firms adopt the high quality input with and without integration. Then, we obtain

$$W^M(1,1) - W(1,1) = \frac{(1-\beta)(320 - 192\beta + 128\beta^2 - 64\beta^3 + 10\beta^4 - 14\beta^5 + \beta^6)(A^*)^2}{8(2-\beta)^2(1+\beta)(8+\beta^2)^2} > 0$$

Second, suppose that only firm 1 adopts the high quality input with and without integration. This happens only when $A_\pi(1,0) \leqq A^*$. Then, we have $W^M(1,0) > W(1,0)$ if and only if $A^* > \frac{A\beta(36-35\beta^2+8\beta^4)}{(2-\beta^2)(20-15\beta^2+4\beta^4)}$. Because $A_\pi(1,0) > \frac{A\beta(36-35\beta^2+8\beta^4)}{(2-\beta^2)(20-15\beta^2+4\beta^4)}$, we can show that this always holds.

[12] This anti-competitive effect appears even under passive vertical integration in which downstream firms acquire financial interests in the supplier without controlling right. See Hunold and Stahl (2016). See also Flath (1989) and Greenlee and Raskovich (2006).

(ii) Fig. 3 shows that ${A_W}^M(1,0) > {A_\pi}^M(1,0)(= A)$ and ${A_W}^M(0,0) > {A_\pi}^M(1,1)$ are possible.

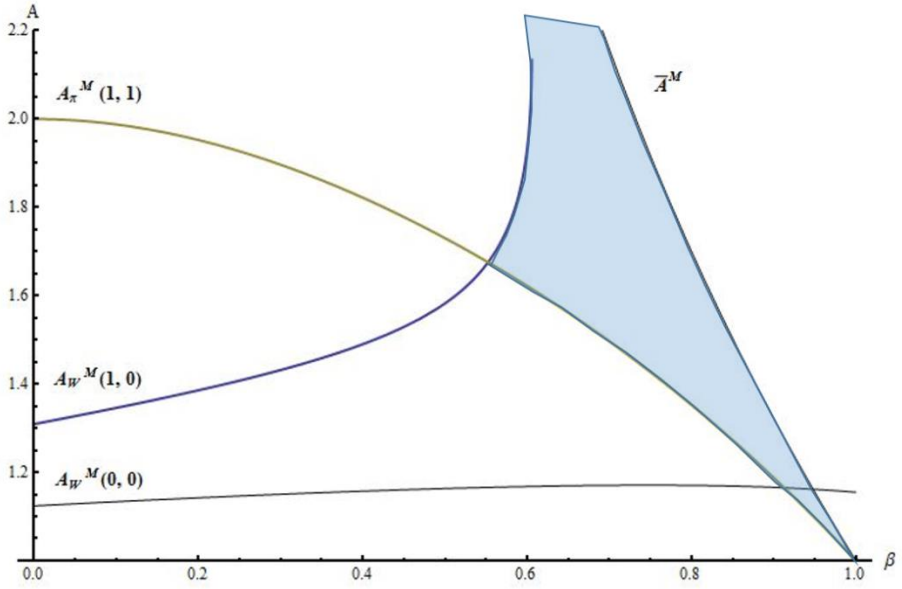

Fig. 3. Comparisons of the thresholds with integration

Q.E.D.

Proposition 4(i) states that under the same pattern of the high quality input adoption, the welfare-improving effect (from eliminating double marginalization) dominates the welfare-reducing effect (inducing implicit collusion). Thus, although both firms' adoption of the high quality input induces weaker price competition, it is socially desirable.

However, Proposition 4(ii) states that if integration changes the pattern of the high quality input adoption, this might reduce welfare. In particular, Fig. 3 shows that if vertical integration induces firm 2 to newly adopt the high quality input, it will be harmful to welfare when both A and β are high (the shaded area in Fig. 3).

6. Conclusion

We formulate a model in which two downstream firms choose whether they commit to adopt the high quality input before observing the input prices. We find that given that the rival does not adopt the high quality input, the private incentive to adopt the high quality input of the other firm is too small from the welfare viewpoint. By contrast, given that the rival adopts the high quality input, the private incentive to adopt the high

quality input is ambiguous. These results suggest that the first adopter of a new high quality input should be promoted, whereas the second adopter might not be.

Next, we investigate the case in which one downstream firm and the high quality input supplier merge. We find that integration enhances the adoption of the high quality input by the rival. This is because a firm's adoption of the inputs produced by the rival firm induces the rival's higher price in the downstream market, which increases its profit. Although integration enhances the adoption of the high quality input, it may be harmful for welfare because of the weaker competition in the final product market.

Finally, we discuss future research directions. A simplified model with a monopolistic high quality input provider and duopolistic competition in the downstream market should be further examined. For example, incorporating the competition effect into the input market with different production technologies would be an interesting topic for future research. We also assumed that the high quality input increases product value in a perfectly asymmetric way. If another channel can induce consumers' preferences to change, however, this imperfection of asymmetric effects among firms may yield different implications. Finally, we need to generalize the hold-up problem with high quality procurement into a multi-period or dynamic model. Nevertheless, this study provides a platform from which future works can address these important issues.

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