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Procurement of advanced inputs and welfare-reducing vertical integration

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Abstract

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 or competitively supplied standard inputs. When the downstream firms are independent of the monopolistic supplier, from the welfare viewpoint, the incentive to adopt the new inputs is insufficient (can be excessive) given that the rival firm does not (does) adopt. 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, spreading new inputs in the industry. We emphasize the price-increasing effect under the commitment to procure advanced inputs and show that vertical integration can be harmful to welfare despite the increase in product quality and the reduction in the welfare loss due to double marginalization.

Keywords Demand-enhancing inputs · Commitment to procure · Make-or-buy decision · CSR procurement

JEL Classification D43 · L13 · L41

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1 Introduction

Adopting new advanced inputs and announcing this fact broadly enhance consumers' awareness of final products, allowing firms to expand their demand. New inputs are often provided by a limited number of input suppliers or even by monopolists, which supply them at less competitive prices. The commitment to procure advanced inputs may be risky if rival firms do not adopt them and other competitive input suppliers do not supply them.[1] Thus, the firms may hesitate to adopt advanced inputs, unless their demand-enhancing effects are sufficiently large.

The following example highlights the type of situation that this study focuses on. 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 improves the quality of mobile phones, tablets, and laptops substantially, and downstream producers can advertise their product quality by announcing the introduction of this new advanced input. However, major downstream firms such as Apple had recognized the advantage of this input but have not adopted it. Additionally, we observed the adoption of organic electroluminescent displays for TV sets, where LG Electronics was the only large panel supplier at a reasonable cost.

In this study, we investigate the adoption of new inputs embodying advanced benefits 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 and then the input suppliers choose their prices.[2] We then examine the role of the demand-enhancing effect and provide the conditions under which firms adopt specific inputs.

We first analyze non-integration and integration cases. In the non-integration case, the specific inputs are produced by an independent supplier. However, in the integration case, 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 the standard input from the competitive market.

In the case of non-integration, we analyze the equilibria in three subgames: 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 is insufficient from the welfare viewpoint. In contrast, if only one firm

[1] It may be risky because there might be cannibalization effect between its own products and hold-up problem in which outsourcing suppliers may name high-input prices in the future after the firms have already invested and locked in this input. See Jungbauer et al. (2021) for empirical discussions on the organization of innovation.

[2] We can interpret our model as one with a make-or-buy decision in which 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 make low quality inputs inside. For a discussion on the make-or-buy decisions, see Sappington (2005), Arya et al. (2008), and Loertscher and Riordan (2019). In Sect. 6, we examine the hold-up problem wherein input suppliers name their prices first before downstream firms choose whether to purchase the specific input, and then they might change their prices later.

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 integration, we analyze the equilibria in two subgames: only the integrated firm adopts the specific input, and both firms adopt it. We show that the decision of the rival firm to adopt the input depends on the size of the demand-enhancing effect. Only when the market-enhancing effect is strong, the rival firm also adopts the input. However, this might be harmful to welfare.

We then compare the results in the non-integration case with those in the integration case and show that integration stimulates the unintegrated downstream firm to adopt the specific input. That is, 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. The intuition is that the adoption of input from the rival firm can mitigate price competition because the firm's decisions on prices are strategic complements.

We also show that integration can be harmful to welfare, although it partially eliminates the distortion from double marginalization, improving welfare. The merger encourages the unintegrated downstream firm to adopt the new input supplied by the integrated rival. The adoption of the new input by the rival induces higher pricing by the integrated downstream firm. That is, there exists an implicit collusion effect in deciding higher prices under vertical integration. Thus, procuring new inputs from the rival increases downstream firms' profits and reduces welfare. Our analysis highlights a new aspect of the possible anti-competitive effect of new technology adoption and vertical integration.[3]

Our analysis may also explain 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 the European Union were against this strategy because it stagnates innovation in the search engine market. As a result, Yahoo gave up on introducing Google's search engine technology. Our results suggest that Yahoo's search engine strategy has more direct anti-competitive effects, supporting the judgment of the anti-trust departments of the United States and the European Union. Our results also imply that the adoption of the rival's input may have a direct price-raising effect in downstream markets such as internet advertising markets.

Our analysis can also be applied to other broad contexts where commitment is influential in business strategies such as procurement with corporate social responsibility (CSR) and biological food with non-genetically modified organisms (non-GMO). For example, firms often commit to purchasing CSR-oriented inputs (e.g., child-labor-free, CO_2-free, fair trade products). Announcing the adoption of

[3] The literature suggests how vertical integration alters pricing incentives in relevant upstream and downstream markets. It emphasizes the efficiencies of the elimination of double marginalization but features trade-off between efficiencies and anticompetitive effects. We discuss the differences between our analysis and that of the previous literature later.

these inputs as CSR is appealing for consumers and may enhance demand.[4] Thus, the commitment to CSR activities is popular even though few suppliers of these specialized inputs exist, meaning that firms adopting such CSR-oriented inputs may face a hold-up problem in the future. That is, once firms obtain certification under commitment, it is difficult for them to switch from a CSR-oriented input to a non-CSR-oriented input. Adopting non-GMO agricultural inputs in the food industry is another example. Products made from non-GMO soybeans are highly valued and can be sold at higher prices than standard products. However, non-GMO soybeans are not popular globally, and it is difficult to prevent the contamination of non-GMO soybeans. Consequently, few suppliers can stably provide this input. Once a downstream firm advertises its products as GMO bean-free, it is difficult to switch from the monopolistic supplier to competitive suppliers that do not offer non-GMO soybeans. Our result can thus apply to these situations.

We discuss some relations with a strategic approach mentioned in the previous literature on vertical integration. Similar to Ordover et al. (1990), we demonstrate that the anti-competitive effect of vertical integration enables the integrated firm to raise its rival's costs. In our model, however, we identify a specific supplier providing a specific (new) input that can enhance its demand even though the input market is competitive, in the sense that vertically unintegrated firms have the option to purchase inputs from outsiders.

Chen (2001) also considered a vertical model in which two differentiated downstream firms use homogeneous input produced by two or more upstream firms where one firm may be more efficient than others in the upstream market while it can choose its supplier before the downstream prices are determined. He demonstrated that a vertical integration induces both efficiency gains and collusion effects. The competitive effects depend on both the cost of switching suppliers and the degree of product differentiation in downstream. In our model, however, we considered the commitment power where downstream firms first choose whether to abandon the outside option and commit to purchasing the input from a specific firm. Since the downstream firms can choose specific quality of the final product, it is seldom for them to switch suppliers flexibly. This happens when it is difficult for input suppliers to pre-commit to a future price level in the long run. In such circumstances, it is risky to commit to the monopoly supplier, but 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 adopting the high-quality input and examine welfare consequences, which are not discussed in Chen's (2001) study. We can also emphasize that the adoption of high-quality input may be motivated by improving product quality. Nevertheless, under vertical integration, this adoption of the high-quality input may reduce welfare because of the implicit collusion effect.

[4] Manasakis et al. (2013, 2014) and Liu et al. (2015) explicitly considered the market-expanding effect of CSR and examined certificates and market structure. Lee and Park (2019) and Hirose et al. (2017, 2020) also included the welfare effects of environmental CSR. For intensive discussions of qualitative and empirical works on CSR, see Schreck (2011) and Kitzmueller and Shimshack (2012) for excellent reviews.

This study is different from the previous literature on 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 the equilibrium. Instead, its reliance upon input procurement provides a cost-increasing effect, which might push up the price of competitive products. Thus, the entry deterrence effect from the exclusive contracts does not matter in our analysis.

The present study is different from the existing literature on strategic outsourcing, where the production of key inputs is outsourced to a vertically integrated retail competitor.[6] The standard outsourcing approach takes the reversed timing sequence: the vertically integrated firm sets its input price, and then downstream firms choose the supplier. This timeline may be more realistic in the short run, where the vertically integrated input supplier commits to its price. However, from the viewpoint of outsourcing decisions by downstream firms, this approach could not consider the anti-competitive effect of our analysis. In addition, our timeline captures a possible hold-up problem, namely, the risk that suppliers raise their prices after downstream firms commit to adopting their new inputs.[7] In this sense, our timeline may be realistic in the long run.[8] We believe that our analysis suggests new policy implications on the welfare consequences of the vertical model and provides an insight into the strategic choice of vertical integration by the input supplier, which is also ignored in the literature on outsourcing.

The remainder of this article is organized as follows. Section 2 constructs a product differentiated duopoly model of a vertical structure. We analyze the non-integration and integration cases under commitment in Sects. 3 and 4, respectively. Section 5 compares these two cases and examines the welfare consequences. Section 6 examines the extended game with a hold-up problem by incorporating a standard timing sequence. Finally, Sect. 7 concludes the article.

[5] The analysis of vertical integration and exclusive contracts yield important insights on the anti-competitive effects. Since Rasmusen et al. (1991), recent developments of exclusion by adopting exclusive contracts include Chen and Riordan (2007), Wright (2009), Kitamura (2010), Allain et al. (2016), Kitamura et al. (2017), and so on. For more discussions on anti-competitive vertical integration, see Matsushima and Pan (2016) and the studies cited therein.

[6] Arya et al. (2008), Chen (2010), Moresi and Schwartz (2017), and Loertscher and Riordan (2019) examined strategic outsourcing and showed that the vertically integrated firm generates a higher profit but lower welfare under price competition.

[7] In Sect. 6, we examine a hold-up problem by incorporating a standard timing sequence and show that the input supplier might commit to its price to induce the adoption of the new input and vertical integration might still affect the adoption pattern of the unintegrated firm in the equilibrium.

[8] Note that the commitment to procure high quality inputs has recently been influential given the popularity of CSR activities and non-GMO concerns.

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 input from the competitive market.[9] 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.

We assume that the advanced inputs increase the value of the final product. Thus, consumers' willingness to pay for firm i's product depends on whether firm i adopts the advanced input. In particular, we consider the following quasi-linear utility function of the representative consumer:

$$U(q_i, q_j) = A_i q_i + A_j q_j - \frac{1}{2}\left(q_i^2 + 2\beta q_i q_j + q_j^2\right) + \varepsilon_0, \tag{1}$$

where $\beta \in (0, 1)$ represents the product substitutability, which is the inverse degree of product differentiation; q_i and P_i are the output and price of downstream firm i (i = 1,2), respectively, and ε_0 denotes the other (numeraire) goods. We denote $A_i = A^*$ $(A_i = A)$ if firm i adopts (does not adopt) the advanced input where $A < A^* < \overline{A} = A\left(\frac{2-\beta^2}{\beta}\right)$, which ensures that all the games discussed below have interior solutions.

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

$$P_i = A_i - q_i - \beta q_j \quad \text{and} \quad q_i = \frac{A_i - \beta A_j - P_i + \beta P_j}{1 - \beta^2}. \tag{2}$$

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

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

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 zero.[10] Welfare is calculated as the aggregated sum of consumer's and producer's surplus.

We analyze the non-integration and integration cases under commitment in Sects. 3 and 4, respectively.

[9] Instead, we can interpret our model as a model with a make-or buy-decision. See footnote 2.

[10] It may be natural to assume that the production cost for the advanced input is higher than that for the standard input. Suppose that the cost difference between them is c. All of 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.

3 The equilibrium without integration

The game without integration runs as follows. In the first stage, downstream firms simultaneously choose whether to commit to adopting 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.

3.1 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 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. This second stage includes the following three subgames.

3.2.1 If 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.

3.2.2 If 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 upstream firm U:

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

The first-order condition provides the equilibrium outcomes shown in Table 2.[11]

3.2.3 If 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:

[11] 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, $\pi_i(1,0)$ denotes the profit of firm i when only firm i adopts the high-quality input.

Table 1 Equilibrium outcomes without integration when no firm adopts

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

Table 2 Equilibrium outcomes without integration when only one firm adopts

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

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

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

3.3 Adoption decision

We discuss the first stage in which downstream firms simultaneously choose whether to commit to adopting the high-quality input.[12] We have the following lemma[13]:

Lemma 1 *Define* $A_\pi(1,0)=(A(4-\beta-2\beta^2))/(2-\beta^2)$ *and* $A_\pi(1,1)=(A(8-9\beta^2+2\beta^4))/(2-\beta^2)^2$. *We have* $A_\pi(1,0)<A_\pi(1,1)$. *In the equilibrium,* (1) *no firm adopts the high-quality input if* $A^*\leqq A_\pi(1,0)$, (2) *only one firm adopts the high-quality input if* $A_\pi(1,0)\leqq A^*\leqq A_\pi(1,1)$, *and* (3) *both firms adopt the high-quality input if* $A_\pi(1,1)\leqq A^*$.

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

[12] We can show that the upstream firm always provides the specific input to the downstream firms when they commit to adopting, i.e., $\pi_U(1,1)>\pi_U(1,0)$ for $A<A^*<\bar{A}$ and $\beta\in(0,1)$. Thus, the upstream firm has no incentive to restrict the input provisions under the exclusive contracts.

[13] All the proofs of lemmas and propositions are provided in the Appendix.

Table 3 Equilibrium outcomes without integration when both firms adopt

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

high-quality input. If it is intermediate, only one firm adopts the high-quality input. Furthermore, both thresholds of firms' new inputs adoption are decreasing as β increases, $\frac{\partial A_\pi(1,0)}{\partial\beta}=-\frac{A\left(2+\beta^2\right)}{\left(2-\beta^2\right)^2}<0$ and $\frac{\partial A_\pi(1,1)}{\partial\beta}=-\frac{2A\beta\left(2+\beta^2\right)}{\left(2-\beta^2\right)^3}<0$. It means that as market competition is more aggressive, firms have more incentive to adopt new inputs.

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* $A^*>A_\pi(1,0)$.

Lemma 2 states that if only one firm adopts the high-quality input in the 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 firm's price, which 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. 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 choices 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.[14]

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, which might yield a welfare loss.[15]

[14] Hirose et al. (2017) and Lee and Park (2019) examined the commitment effects of ECSR (Environmental corporate social responsibility) and showed how sequential movement in a Stackelberg competition can yield the first-mover or second-mover advantage under price competition.

[15] Note that there exist threshold values of market enhancing effect, A^*, which satisfy $W(0,0)<W(1,0)<W(1,1)$. For more details, see the proofs in Appendix.

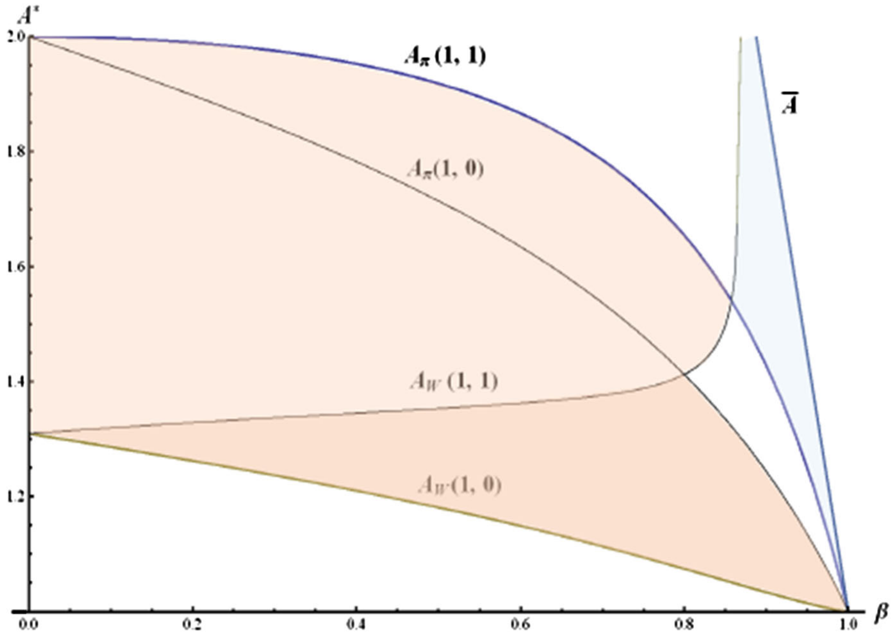

Fig. 1 Comparisons of the thresholds without integration (A = 1)

Lemma 3

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

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) to 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.

From Lemmas 1 and 3, we obtain Lemma 4, which compares the threshold values of private and social incentives for adopting the high-quality input in the non-integration case.

Lemma 4 (1) $A_W(1,0) < A_\pi(1,0)$. (2) *Both* $A_W(1,1) > A_\pi(1,1)$ *and* $A_W(1,1) < A_\pi(1,1)$ *are possible.*

Lemmas 1, 3, and 4 (1) imply that when the status quo is the situation in which no firm adopts the high-quality input, the private incentive to adopt the high-quality input for a downstream firm is insufficient for welfare. The difference between private and social incentives increases as the degree of product substitutability decreases (see Fig. 1). The intuition is as follows. Adopting the high-quality input by the firm may reduce its profit because it raises the cost. This increases the input supplier's profit and may also increase downstream rival's profit in price competition where the prices are strategic complements. Although adopting the high-quality input increases product value and raises the others' surplus, the downstream firm does not consider these effects when it chooses the high-quality input. This yields the insufficient adoption of the high-quality input. This missing effect is strengthened when the degree of product substitutability decreases.

Lemmas 1, 3, and 4 (2) imply that when the status quo is the situation in which only one firm adopts the high-quality input, the private incentive for the additional adoption of the high-quality input can be insufficient and excessive for welfare. When the degree of product substitutability is not high, the private incentive for the additional adoption of the high-quality input is insufficient. It is excessive when the product substitutability is high (see Fig. 1). The adoption of the high-quality input by firm 2 may reduce firm 1's profit, depending on the product substitutability, which is known as the business-stealing effect.[16] Thus, the follower's incentive for adopting new input can be excessive for welfare.

We summarize the results under the non-integration whether the private incentive to adopt the high-quality input is excessive or insufficient in Proposition 1.

Proposition 1 (1) *Suppose that no firm adopts the high-quality input in equilibrium. Then one firm's adoption of the high-quality input may improve welfare.* (2) *Suppose that only one firm adopts the high-quality input in equilibrium. Then the switch from this situation to the situation in which no firm adopts the high-quality input always harms welfare, whereas the switch to the situation in which both firms adopt the high-quality input may or may not improve welfare.* (3) *Suppose that both firms adopt the high-quality input in equilibrium. Then the switch from this situation to the situation in which one firm adopts the high-quality input may or may not improve welfare. However, a further reduction of the number of high-quality input adopters harms welfare.*

We have examined the case in which the superior input is supplied by the independent firm. However, such an input may be produced in-house by a downstream firm, as addressed in the next section.

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 with integration 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

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

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 evident that firm 1 adopts the high-quality input because $A^* > A$. It is also apparent that in the first stage, firm 1 offers the high-quality input to firm 2.[17] Thus, it is sufficient to discuss the following two situations. Firm 2 does not adopt the high-quality input; only firm 1 does, or firm 2 adopts it as well as firm 1. Then, the profit of the merged firm (upstream firm U and downstream firm 1) becomes $\pi_1^M = \pi_1 + \pi_U$, where superscript M represents the integration case.

4.1 If only firm 1 adopts the high-quality input

Given the profit of firm U in (5), by substituting $A_1 = A^*, A_2 = A, c_1 = r$, and $c_2 = 0$ into the profits of downstream firms in (3), the profit functions of the firms become $\pi_i^M = P_i q_i$ $(i = 1, 2. i \neq j)$. The equilibrium prices and quantities, including profits and welfare, are shown in Table 4.

4.2 If both firms adopt the high-quality input

Given the profit of firm U in (5), by substituting $A_1 = A_2 = A^*, c_1 = c_2 = r$ into (3), we obtain the following profit functions of the firms:

$$\pi_1^M = P_1 q_1 + r q_2 = \frac{r((1-\beta)A^* - P_2) + P_1(r\beta + \beta P_2 + A^*(1-\beta)) - P_1^2}{1-\beta^2}, \quad (7)$$

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

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

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

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

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

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

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

[17] 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.

Table 4 Equilibrium outcomes with integration when only firm 1 adopts

$P_1^M(1,0)=\frac{(2-\beta^2)A^*-A\beta}{4-\beta^2}$	$P_2^M(1,0)=\frac{A(2-\beta^2)-\beta A^*}{4-\beta^2}$
$q_1^M(1,0)=\frac{(2-\beta^2)A^*-A\beta}{(2-\beta)(1-\beta)(1+\beta)(2+\beta)}$	$q_2^M(1,0)=\frac{A(2-\beta^2)-\beta A^*}{(2-\beta)(1-\beta)(1+\beta)(2+\beta)}$
$\pi_1^M(1,0)=\frac{((2-\beta^2)A^*-A\beta)^2}{(4-\beta^2)^2(1-\beta^2)}$	$\pi_2^M(1,0)=\frac{(A(2-\beta^2)-\beta A^*)^2}{(4-\beta^2)^2(1-\beta^2)}$
$CS^M(1,0)=\frac{A^2(4-3\beta^2)-2A\beta^3A^*+(4-3\beta^2)(A^*)^2}{2(4-\beta^2)^2(1-\beta^2)}$	
$W^M(1,0)=\frac{(12-9\beta^2+2\beta^4)(A^*)^2-2\beta(8-3\beta^2)AA^*+(12-9\beta^2+2\beta^4)A^2}{2(4-\beta^2)^2(1-\beta^2)}$	

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

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

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

Lemma 5 is intuitive. When the market expansion effect of the high-quality input is strong, firm 2 also adopts the high-quality input. It is noteworthy that the integrated firm always provides the specific input to firm 2 when it commits to adopt.[18]

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).

There exist threshold values for A^*, $A_W^M(1,0)>A_W^M(0,0)$; each of them is a function only of A and β. Then, we obtain the following lemma.

Lemma 6 *There exists* $A_W^M(1,0)>A_W^M(0,0)>0$ *such that* (1) *if* $A^*\gtreqless A_W^M(0,0)$, *then* $W^M(1,1)\gtreqless W(0,0)$ *and* (2) *if* $A^*\gtreqless A_W^M(1,0)$, *then* $W^M(1,1)\gtreqless W^M(1,0)$.

From Lemmas 5 and 6, we can compare the threshold values indicating private and social incentives to adopt the high-quality input under the integration.

[18] ${\pi_1}^M(1,1)>{\pi_1}^M(1,0)$ for $A<A^*<\overline{A}$ and $\beta\in(0,1)$. Thus, the integrated firm has no incentive to restrict the input provisions under the exclusive contracts.

Table 5 Equilibrium outcomes with integration when both firms adopt

$r^M(1,1) = \frac{(8+\beta^3)A^*}{2(8+\beta^2)}$	
$P_1^M(1,1) = \frac{(4-\beta)(2+\beta)A^*}{2(8+\beta^2)}$	$P_2^M(1,1) = \frac{(12-\beta(4-(2-\beta)\beta))A^*}{2(8+\beta^2)}$
$q_1^M(1,1) = \frac{(8+\beta(2+\beta+\beta^2))A^*}{2(1+\beta)(8+\beta^2)}$	$q_2^M(1,1) = \frac{(2+\beta^2)A^*}{(1+\beta)(8+\beta^2)}$
$\pi_1^M(1,1) = \frac{(12+\beta(4+\beta+\beta^2))(A^*)^2}{4(1+\beta)(8+\beta^2)}$	$\pi_2^M(1,1) = \frac{(1-\beta)(2+\beta^2)^2(A^*)^2}{(1+\beta)(8+\beta^2)^2}$
$CS^M(1,1) = \frac{(80+16\beta+36\beta^2+24\beta^3+\beta^4+5\beta^5)(A^*)^2}{8(1+\beta)(8+\beta^2)^2}$	
$W^M(1,1) = \frac{(304+\beta(48+\beta(108+\beta(16+(11-\beta)\beta))))(A^*)^2}{8(1+\beta)(8+\beta^2)^2}$	

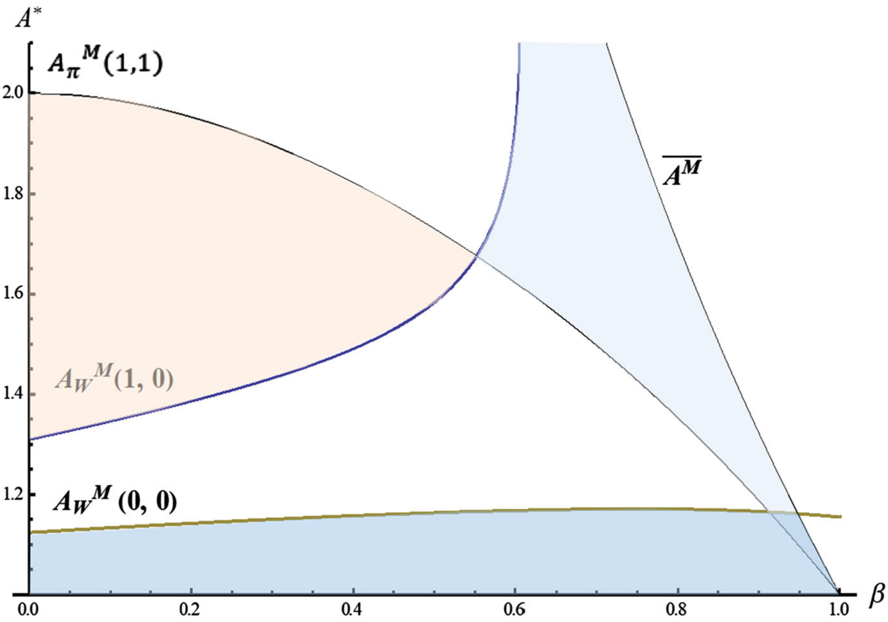

Fig. 2 Comparisons of the thresholds with integration (A = 1)

Lemma 7 (1) *Both* $A_W^M(1,0) < A_\pi^M(1,1)$ *and* $A_W^M(1,0) > A_\pi^M(1,1)$ *are possible*. (2) *Both* $A_W^M(0,0) > A_\pi^M(1,1)$ *and* $A_W^M(0,0) < A_\pi^M(1,1)$ *are possible.*

Lemmas 5, 6, and 7 (1) imply that the private incentive for the additional adoption of the high-quality input by the unintegrated firm may be insufficient or excessive from the welfare viewpoint (see Fig. 2). As the product substitutability decreases, the adoption of the high-quality input by the unintegrated firm may reduce its profit but increase rival's profit in price competition where the prices are strategic complements. Although adopting the high-quality input increases the integrated firm's profit, the unintegrated firm does not consider this effect when it chooses the high-quality input, yielding the insufficient adoption of the high-quality input.

Lemmas 5, 6, and 7 (2) imply that it is even possible that both firms adopt the high-quality input in equilibrium but it is socially desirable that no firm adopts it. This result holds when the degree of product substitutability is high enough (see Fig. 2). This is because the adoption of the high-quality input by the unintegrated firm may extensively increase prices under price competition and substantially reduce consumer surplus, which may be stronger than the profit-enhancing effect under price competition.

We summarize the results under the integration whether the private incentive to adopt the high-quality input is excessive or insufficient.

Proposition 2 (1) *Suppose that the independent firm does not adopt the high-quality input in equilibrium. Then the independent firm's adoption of the high-quality input may or may not improve welfare*. (2) *Suppose that both firms adopt the high-quality input in equilibrium. Then the switch from this situation to the situation in which only the integrated firm adopts the high-quality input may or may not improve welfare.* (3) *It is even possible that the situation in which no firm adopts the high-quality input is best for welfare but both firms adopt the high-quality input in equilibrium.*

5 Comparisons

We now discuss whether vertical integration enhances the unintegrated firm's adoption of high-quality input. Counterintuitively, Lemma 7 states that integration accelerates the rival's adoption of the high-quality input.

Lemma 8 $A_\pi(1,1) > A_\pi^M(1,1)$.

Lemma 8 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 firms are more likely to adopt the high-quality input under integration. Thus, the downstream firm has a stronger incentive (or is more likely) to adopt the advanced input when its rival firm (or the vertically integrated firm) supplies it than when the independent upstream firm does. This result 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 proportional to firm 2's output given r. A higher final product price set by firm 1 raises the output of firm 2, increasing firm 1's revenue from inputs. As firm's decisions on prices are strategic complements while the products are substitutes, the increase in firm 1's price induces the increase in firm 2's price, which can be favorable to firm 2. That is, firm 2's adoption of the new input results in increasing both prices. Therefore, firm 1 has a stronger incentive to raise its final product price when firm 2 adopts the high-quality input.[19] In other words, the

[19] It is easy to see that ${P_1}^M(1,0) < {P_1}^M(1,1)$ and ${P_2}^M(1,0) < {P_2}^M(1,1)$.

adoption of the high-quality input by firm 2 can result in implicit collusion on increasing prices while mitigating 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.

Proposition 3 *Merge encourages unintegrated firms to adopt the new input.*

However, Proposition 3 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 4 states that firm 2 obtains smaller profits under integration.

Proposition 4 *Firm 2 always obtains smaller profits under integration compared with non-integration.*

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 double marginalization between the upstream and downstream firms (firm U and firm 1). Second, as shown in Lemma 8, vertical integration induces the rival to adopt the new inputs, and integration induces weaker price competition when both firms adopt the new inputs. This price-increasing effect increases the profit of firm 1.[20]

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

We compare the choices of the adoption of high-quality input with and without integration (i.e., whether one or both downstream firms adopt the new inputs).

Proposition 5 (1) *Suppose that the choices of the high-quality input adoption do not change with and without integration; then, integration always improves welfare.* (2) *When integration encourages firm* 2*'s adoption of the high-quality input, integration may harm welfare.*

Proposition 5 (1) states that under the same choices 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 weakens price competition, it is socially desirable.

However, Proposition 5 (2) states that if integration changes the choices 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 β is high (blue shaded area in Fig. 3).

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

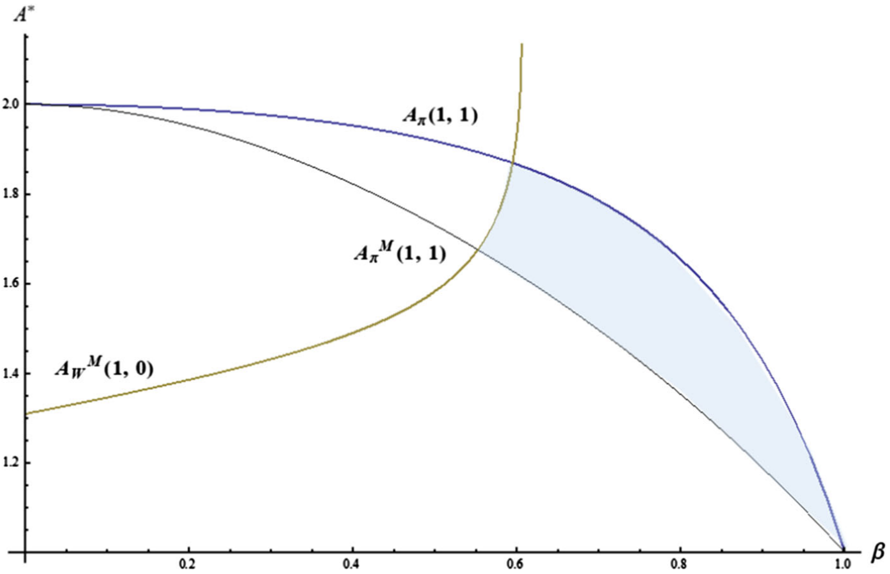

Fig. 3 Welfare distortion induced by integration ($A = 1$)

6 Discussions: hold-up problem

In the previous section, we assumed that downstream firms choose whether to adopt new inputs and then input suppliers set their prices. However, it may generate a hold-up problem in which input suppliers might set high input prices in the future after the firms have already invested in the input, which could cause a lock-in effect. This section considers a possibility of hold-up by examining an alternative timeline in which input suppliers set their prices first, and then downstream firms decide whether to adopt new inputs after observing the input price. We then examine an extensive game with the hold-up problem where the upstream firm might change its input prices after observing the commitment of the downstream firm to the adoption of new inputs. This model formulation corresponds to the case where the switching cost of input suppliers is small, but that of downstream firms is large.[21]

[21] It is also practical if the downstream firm has to invest in the capacities of producing the input materials after adopting the new inputs under the contract agreed. In the following analysis, we do not consider the other case of a hold-up problem that once downstream firm committed to adopting new inputs it can break up its agreement after the upstream firm changes the input price. This case also corresponds to the case where the switching cost of downstream firms is small. Thus, after the downstream firm announces to adopt the new inputs, it can negotiate the input prices or may give up the adoption when the input prices are changed. For example, Chen (2001) showed that the anti-competitive effects of an integration depend on the cost of switching suppliers and the degree of downstream product differentiation.

Table 6 Equilibrium outcomes without integration when only one firm adopts

$\pi_U(1,0) = \frac{w\left(\left(2-\beta^2\right)A^* - A\beta - w\left(2-\beta^2\right)\right)}{(2-\beta)(1-\beta)(1+\beta)(2+\beta)}$	
$P_i(1,0) = \frac{\left(2-\beta^2\right)A^* + 2w - A\beta}{4-\beta^2}$	$P_j(1,0) = \frac{w\beta + A\left(2-\beta^2\right) - \beta A^*}{4-\beta^2}$
$q_i(1,0) = \frac{\left(2-\beta^2\right)A^* - A\beta - w\left(2-\beta^2\right)}{(2-\beta)(1-\beta)(1+\beta)(2+\beta)}$	$q_j(1,0) = \frac{A\left(2-\beta^2\right) + r\beta - \beta A^*}{4-5\beta^2+\beta^4}$
$\pi_i(1,0) = \frac{\left(\left(2-\beta^2\right)A^* - A\beta - w\left(2-\beta^2\right)\right)^2}{\left(4-\beta^2\right)^2\left(1-\beta^2\right)}$	$\pi_j(1,0) = \frac{\left(\beta A^* - A\left(2-\beta^2\right) - w\beta\right)^2}{\left(4-\beta^2\right)^2\left(1-\beta^2\right)}$
$CS(1,0) = \frac{\left(4-3\beta^2\right)\left(A^2+(A^*-w)^2\right) - 2A\beta^3(A^*-w)}{2\left(4-\beta^2\right)^2\left(1-\beta^2\right)}$	
$W(1,0) = \frac{\left(12-9\beta^2+2\beta^4\right)(A^*)^2 - w^2\left(4-3\beta^2\right) + 4Aw\beta\left(2-\beta^2\right) + A^2\left(12-9\beta^2+2\beta^4\right) - 2\left(A\beta\left(8-3\beta^2\right) + w\left(4-3\beta^2+\beta^4\right)\right)A^*}{2\left(1-\beta^2\right)\left(4-\beta^2\right)^2}$	

Table 7 Equilibrium outcomes without integration when both firms adopt

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

6.1 The equilibrium without integration

The extended game without integration runs as follows. In the first stage, the upstream monopolist announces the intended input price w. After observing this price, the downstream firm simultaneously chooses whether to adopt the high-quality input in the second stage. In the third stage, the upstream monopolist might change its input price to r once the downstream firm committed its choice of adoption. After observing this input price, the downstream firms simultaneously choose their prices in the last stage. All the other assumptions with no integration are the same as those in the previous sections.

6.1.1 Alternative timeline without integration

We first examine an alternative timeline to understand the possibility of a hold-up problem in the extended game. That is, we see the time-consistence of the upstream firm in determining its profit-maximizing input prices (i.e., whether $w = r$ or not). Temporarily, the alternative game runs without the third stage where the upstream monopolist might change its input price to r once the downstream firm commits its choice of adoption.

In the last stage, there are three cases. First, if both firms adopt the standard input, by substituting $A_i = A_j = A$ and $c_i = c_j = 0$ into (4), we obtain the same equilibrium outcomes shown in Table 1. Second, if only firm i adopts the high-

Table 8 Profit payoffs of downstream firms without integration

Firm i\Firm j	Standard input	High quality input
Standard input	$\pi_i(0,0)$, $\pi_j(0,0)$	$\pi_i(0,1)$, $\pi_j(0,1)$
High quality input	$\pi_i(1,0)$, $\pi_j(1,0)$	$\pi_i(1,1)$, $\pi_j(1,1)$

quality input, whereas firm j adopts the standard input by substituting $A_i = A^*, A_j = A, c_i = w$, and $c_j = 0$ into (4), we obtain the equilibrium outcomes shown in Table 6. Finally, if both firms adopt the high-quality input, by substituting $A_i = A_j = A^*$ and $c_i = c_j = w$ into (4), we obtain the equilibrium outcomes shown in Table 7.

In the second stage, both downstream firms face the following profit table depending on the price of the high-quality input (Table 8).

Lemma 9 *Both firms adopt the high-quality input if and only if* $r \leq A^* - A$.

Lemma 9 implies that both downstream firms adopt the new input if the new input supplier sets the price as less than the increased market-enhancing effect where $A^* > A$.

In the first stage, given the input price constraint in Lemma 9, the profit of the upstream firm is $\pi_U(1,1) = \frac{2r(A^*-r)}{(2-\beta)(1+\beta)}$. Then, the first-order condition of maximizing profit yields the following optimal prices of the high-quality input[22]:

(a) If $A^* \geq 2A$, then $r = \frac{A^*}{2}$.
(b) Otherwise, $r = A^* - A$.

There are two cases. Case (a) implies that the upstream firm can set an interior solution without the input price constraint when the demand-enhancing effect is sufficiently high. However, Case (b) implies that the upstream firm should name the constrained price in Lemma 9 when the demand-enhancing effect is not sufficiently high.

6.1.2 Hold-up problem without integration

We now consider an extended game with the third stage where the upstream firm might change its input prices after observing the commitment of the downstream firm to the adoption of the new inputs. From Lemmas 1 and 9, we see that $A_\pi(1,1) < 2A$. It implies that Case (a) is time-consistent for the upstream firm if $A^* \geq 2A$ since the monopolist can keep the monopoly input price (i.e., $r = w = \frac{A^*}{2}$). However, if $A^* < 2A$, Case (b) is not time-consistent. Thus, a hold-up problem might occur since the monopolist might increase its input price after both firms adopt the new inputs (i.e., $w = A^* - A < r = \frac{A^*}{2}$).

[22] Note that we have the profits of the firms under case (a), i.e., $\pi_U(1,1) = \frac{A^{*2}}{2(2-\beta)(1+\beta)}$, $\pi_i(1,1) = \frac{(1-\beta)A^{*2}}{4(2-\beta)^2(1+\beta)}$, and under case (b), i.e., $\pi_U(1,1) = \frac{2A(A^*-A)}{(2-\beta)(1+\beta)}$, $\pi_i(1,1) = \frac{A^2(1-\beta)}{(2-\beta)^2(1+\beta)}$, respectively.

By expecting this time-inconsistent decision of the upstream firm, downstream firms can simultaneously choose whether to adopt the high-quality input in the second stage of an extended game. Then, Lemma 1 will be the equilibrium outcome of the adoption decision in the second stage. First, if $A_{\pi}(1,1) \leq A^{*} \leq 2A$, both downstream firms still adopt the high-quality input even though the hold-up problem occurs. The equilibrium outcome is presented in Table 3. Second, if $A_{\pi}(1,0) \leq A^{*} \leq A_{\pi}(1,1)$, only one firm adopts the high-quality input if the upstream firm cannot credibly commit the input price in the first stage. The input price in the first stage will be the same in the equilibrium outcome in Table 2. Finally, if $A^{*} \leq A_{\pi}(1,0)$, no firm adopts the high-quality input without credible commitment to the input price in the first stage. Accordingly, the upstream firm will not announce the input price since there exists a high risk of a hold-up to the downstream firm. The equilibrium outcome is presented in Table 1.

In sum, even if we incorporate the possibility of a hold-up problem in an extended game without integration, our findings in Proposition 1 still hold.

6.2 The equilibrium with integration

The extended game with integration runs as follows. In the first stage, one of the two downstream firms (firm 1) produces the high-quality input in-house and announces the intended input price w. After observing this price, an unintegrated firm (firm 2) decides whether to adopt the high-quality input in the second stage. In the third stage, firm 1 might change its input price to r once firm 2 has committed its choice of adoption. After observing this input price, both firms choose their prices simultaneously in the last stage. Again, all the other assumptions with integration are the same as those in the previous sections.

6.2.1 Alternative timeline with integration

We also examine alternative timeline to understand the hold-up problem in the extended game. Temporarily, the alternative game runs without the third stage where firm 1 might change its input price once firm 2 has committed its choice of adoption.

In the last stage, there are two cases. First, if firm 2 does not adopt the high-quality input, by substituting $A_1 = A^{*}, A_2 = A, c_1 = w$, and $c_2 = 0$ into the profits of the downstream firms in (3), the profit functions of the firms become $\pi_i^M = P_i q_i$. Table 9 shows the equilibrium outcomes. Second, if firm 2 adopts the high-quality input, by substituting $A_1 = A_2 = A^{*}$ and $c_1 = c_2 = w$ into (3) and using the profit functions of the firms, we obtain the equilibrium outcomes shown in Table 10.

In the second stage, the downstream firm decides whether to adopt the high-quality input by observing the input prices.

Lemma 10 *Under vertical integration, an unintegrated firm adopts the high-quality input if and only if* $r \leq \frac{\left(2-\beta^{2}\right)(A^{*}-A)}{\left(2-2\beta^{2}\right)}$.

Table 9 Equilibrium outcomes with integration when only firm 1 adopts

$P_1^M(1,0) = \frac{\left(2-\beta^2\right)A^* - A\beta}{4-\beta^2}$	$P_2^M(1,0) = \frac{A\left(2-\beta^2\right)-\beta A^*}{4-\beta^2}$
$q_1^M(1,0) = \frac{\left(2-\beta^2\right)A^* - A\beta}{4-5\beta^2+\beta^4}$	$q_2^M(1,0) = \frac{A\left(2-\beta^2\right)-\beta A^*}{4-5\beta^2+\beta^4}$
$\pi_1^M(1,0) = \frac{\left(\left(2-\beta^2\right)A^* - A\beta\right)^2}{\left(4-\beta^2\right)^2\left(1-\beta^2\right)}$	$\pi_2^M(1,0) = \frac{\left(\beta A^* - A\left(2-\beta^2\right)\right)^2}{\left(4-\beta^2\right)^2\left(1-\beta^2\right)}$
$CS^M(1,0) = \frac{\left(4-3\beta^2\right)\left(A^2+(A^*)^2\right)-2A\beta^3A^*}{2\left(1-\beta^2\right)\left(4-\beta^2\right)^2}$	
$W^M(1,0) = \frac{\left(A^2+A^{*2}\right)\left(12-9\beta^2+2\beta^4\right)-2A\beta\left(8-3\beta^2\right)A^*}{2\left(1-\beta^2\right)\left(4-\beta^2\right)^2}$	

Table 10 Equilibrium outcomes with integration when both firms adopt

$P_1^M(1,1) = \frac{3w\beta+\left(2-\beta-\beta^2\right)A^*}{4-\beta^2}$	$P_2^M(1,1) = \frac{w\left(2+\beta^2\right)+\left(2-\beta-\beta^2\right)A^*}{4-\beta^2}$
$q_1^M(1,1) = \frac{(2+\beta)A^*-w\beta(1+\beta)}{(1+\beta)\left(4-\beta^2\right)}$	$q_2^M(1,1) = \frac{(2+\beta)A^*-2w(1+\beta)}{(1+\beta)\left(4-\beta^2\right)}$
$\pi_1^M(1,1) = \frac{(2+\beta)A^*\left(w(1+\beta)(4-(2-\beta)\beta)+\left(2-\beta-\beta^2\right)A^*\right)-w^2(1+\beta)\left(8+\beta^2\right)}{(1+\beta)\left(4-\beta^2\right)^2}$	
$\pi_2^M(1,1) = \frac{(1-\beta)((2+\beta)A^*-2w(1+\beta))^2}{(1+\beta)\left(4-\beta^2\right)^2}$	
$CS^M(1,1) = \frac{w^2\left(4+4\beta+5\beta^2+5\beta^3\right)-2w(1+\beta)(2+\beta)^2A^*+2(2+\beta)^2(A^*)^2}{2(1+\beta)\left(4-\beta^2\right)^2}$	
$W^M(1,1) = \frac{2(3-2\beta)(2+\beta)^2(A^*)^2-w^2\left(4+4\beta+5\beta^2+5\beta^3\right)-2w(2+\beta)^2\left(1-\beta^2\right)A^*}{2(1+\beta)\left(4-\beta^2\right)^2}$	

Lemma 10 implies that an unintegrated firm adopts the new input because an integrated firm can set the price to induce the adoption of its input since $A^* > A$.

In the first stage, given the input price constraint in Lemma 10, the integrated firm chooses the following optimal prices of the high-quality input[23]:

(a) If $A^* > A_\pi^M(1,1)$, then $r = \frac{\left(8+\beta^3\right)A^*}{2\left(8+\beta^2\right)}$

(b) Otherwise, $r = \frac{\left(2-\beta^2\right)(A^*-A)}{\left(2-2\beta^2\right)}$.

There are two cases. Case (a) implies that the integrated firm can set an interior solution without the input price constraint when the demand-enhancing effect is sufficiently high. However, Case (b) implies that the integrated firm should name the constrained price in Lemma 10 when the demand-enhancing effect is not sufficiently high.

[23] Note thatwe have the profits of the firms under case (a), i.e., ${\pi_1}^M(1,1) = \frac{(12+\beta(4+\beta+\beta^2))(A^*)^2}{4(1+\beta)(8+\beta^2)}$ and ${\pi_2}^M(1,1) = \frac{(1-\beta)\left(2+\beta^2\right)^2(A^*)^2}{(1+\beta)\left(8+\beta^2\right)^2}$, and under case (b), i.e., $\pi_1(1,1) = \frac{(16-16\beta-48\beta^2+28\beta^3+28\beta^4-14\beta^5-5\beta^6+2\beta^7)(A^*)^2+A(2-\beta^2)(2(8+\beta^2(2-\beta(1+(1-\beta)\beta)))A^*-A(2-\beta^2)(8+\beta^2))}{4(4-5\beta^2+\beta^4)^2}$ and $\pi_2(1,1) = \frac{(A(2-\beta^2)-\beta A^*)^2}{(1-\beta^2)(4-\beta^2)^2}$, respectively.

6.2.2 Hold-up problem with integration

We now consider an extended game with the third stage where firm 1 might change its input prices after observing the commitment of firm 2 on whether to adopt new inputs. From Lemmas 5 and 10, we have the same threshold as $A_{\pi}^{M}(1,1)$. Thus, both Case (a) and (b) are coincident. It implies that Case (a) is time-consistent to the integrated firm if $A^* > A_{\pi}^{M}(1,1)$ since firm 1 can keep the input price (i.e., $r = w = \frac{(8+\beta^3)A^*}{2(8+\beta^2)}$). However, if $A^* < A_{\pi}^{M}(1,1)$, Case (b) is not time-consistent since firm 1 might increase its input price after firm 2 adopts new input (i.e., $w = \frac{(2-\beta^2)(A^*-A)}{(2-2\beta^2)} < r = \frac{(8+\beta^3)A^*}{2(8+\beta^2)}$). In other words, the hold-up problem does not occur.

By expecting this time-inconsistent decision of the integrated firm, firm 2 chooses whether to adopt the high-quality input in the second stage of an extended game. Then, Lemma 5 is the equilibrium outcome of the adoption decision in the second stage. First, if $A^* > A_{\pi}^{M}(1,1)$, firm 2 still adopts the high-quality input (see Tables 5 and 10). Table 5 presents the equilibrium outcome. Second, if $A^* \le A_{\pi}^{M}(1,1)$, firm 2 does not adopt the high-quality input unless the integrated firm can credibly commit to the input price in the first stage. Firm 1 will not announce the input price since there is a high risk of holding up to firm 2. Table 4 illustrates the equilibrium outcome. Therefore, the input supplier might commit to its price to induce the adoption of the new input, but vertical integration does not affect the adoption pattern of the unintegrated firm in the equilibrium.

In sum, even if we incorporate the possibility of a hold-up problem in an extended game with integration, our findings in Proposition 2 still hold.

6.3 Comparison

In the above analysis, our extended timeline captures a possible hold-up problem, namely, the risk that suppliers raise their prices after downstream firms commit to adopting their new inputs, and indicates that a hold-up problem exists with and without integration. However, we can see that Propositions 3, 4, and 5 still hold. It confirms that the adoption of the new input by the unintegrated firm mitigates price competition under vertical integration. Thus, the integrated input supplier has a stronger incentive to induce the adoption of the new input.[24] Therefore, with or without hold-up problems, vertical integration mitigates, rather than accelerates, the pattern of adoption of the new inputs.

[24] Note that under the alternative time line, vertical integration cannot affect social welfare if the new input supplier with or without merge can credibly commit to its price before the decision on the adoption of new input. Note also that from Lemmas 9 and 10, vertical integration increases the threshold of price discount (i.e., $\frac{(2-\beta^2)(A^*-A)}{2-2\beta^2} > A^* - A$).

7 Conclusion

The commitment to procure high-quality inputs has recently been influential given the popularity of CSR activities and non-GMO concerns. We formulate a model in which two downstream firms choose whether they commit to adopting 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 should not be promoted.

We also 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 to welfare because of the weaker competition in the final product market. Our findings can suggest new policy implications on the welfare consequences of the vertical model by providing an insight into the strategic choice of vertical integration by the downstream firms.

We discuss future research directions. First, a simplified model with a monopolistic high-quality input provider and duopolistic competition in the downstream market should be further examined. Second, incorporating the competition effect into the input market with different production technologies and spillovers such as asymmetric demand-enhancing effects would be interesting. Furthermore, for a general analysis, considering the hold-up problem with high-quality procurement into a multi-period or dynamic model is important. Nevertheless, this study guides future works to address these important issues.

Appendix: Proofs of Propositions and Lemmas

Proof of Lemma 1

Suppose that firm j does not adopt the high-quality input. Then, we obtain $\pi_i(1,0) - \pi_i(0,0) = \frac{\left(\left(2-\beta^2\right)A^* - A\left(4-\beta-2\beta^2\right)\right)\left(A(4-\beta(3+2\beta)) + \left(2-\beta^2\right)A^*\right)}{4\left(4-\beta^2\right)^2\left(1-\beta^2\right)} > 0$ if and only if $A^* > A_\pi(1,0) = \frac{A\left(4-\beta-2\beta^2\right)}{2-\beta^2}$. This implies (1).

Suppose that firm j adopts the high-quality input. Then, we obtain $\pi_i(1,1) - \pi_i(0,1) = \frac{\left(2-\beta^2\right)^3(2-\beta(2+\beta))(A^*)^2 + 2\beta\left(2-\beta^2\right)\left(8-9\beta^2+2\beta^4\right)AA^* - \left(8-9\beta^2+2\beta^4\right)^2 A^2}{4\left(1-\beta^2\right)\left(8-6\beta^2+\beta^4\right)^2} > 0$ if and only if $A^* > A_\pi(1,1) = \frac{A\left(8-9\beta^2+2\beta^4\right)}{\left(2-\beta^2\right)^2}$. This implies (3).

Finally, $A_\pi(1,1) - A_\pi(1,0) = \frac{A\beta(1-\beta)(2+\beta)}{\left(2-\beta^2\right)^2} > 0$. This implies (2).

Proof of Lemma 2

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

Proof of Lemma 3

Define $A_W(1,0)$ and $A_W(1,1)$, which satisfy $W(1,0) \gtreqless W(0,0) \Leftrightarrow A^* \gtreqless A_W(1,0)$ and $W(1,1) \gtreqless W(1,0) \Leftrightarrow A^* \gtreqless A_W(1,1)$. We have $A_W(1,0) = A\frac{\beta\left(36-31\beta^2+6\beta^4\right)+2(1-\beta)(2+\beta)\sqrt{\sigma(1,0)}}{\left(2-\beta^2\right)\left(28-21\beta^2+4\beta^4\right)}$ and $A_W(1,1) = A\frac{(2+\beta)\sqrt{\sigma(1,1)}-\beta\left(36-31\beta^2+6\beta^4\right)}{\left(2-\beta^2\right)(28-\beta(32+\beta(21-2\beta(5+2\beta))))}$ where $\sigma(1,0) = (2+\beta)\left(2-\beta^2\right)(84-\beta(70+\beta(62-\beta(53+8(1-\beta)\beta)))) > 0$ and $\sigma(1,1) = 2(1-\beta)(672-\beta(768+\beta(1140-\beta(1320+\beta\left(653-2\beta\left(398+\beta\left(69-\beta\left(97+4\beta-8\beta^2\right)\right)\right)\right)))) > 0$. We also have $A_W(1,0)|_{\beta=0} = A_W(1,1)|_{\beta=0} = 2A\sqrt{\frac{3}{7}} \approx 1.31$, and $\frac{\partial A_W(1,0)}{\partial\beta} < 0$, $\frac{\partial A_W(1,1)}{\partial\beta} > 0$ for $\beta \in (0,1)$. Then, $A < A_W(1,0) < A_W(1,1)$ for $\beta \in (0,1)$.

Proof of Lemma 4

We have $A_\pi(1,0) - A_W(1,0) = \frac{2A}{\left(2-\beta^2\right)^2\left(28-21\beta^2+4\beta^4\right)}\left(B - \sqrt{C}\right)$, where $B = \left(7-11\beta+4\beta^2\right)\left(4+2\beta-2\beta^2-\beta^3\right)^2 > 0$ and $C = (1-\beta)^2\left(4+2\beta-2\beta^2-\beta^3\right)^3\left(84-70\beta-62\beta^2+53\beta^3+8\beta^4-8\beta^5\right) > 0$. Because $B^2 - C = 2(1-\beta)^2(2+\beta)^3\left(2-\beta^2\right)^3\left((2-\beta)\left(28-21\beta^2+4\beta^4\right)\right) > 0$. This implies (1).

We have $A_W(1,1)|_{\beta=0} = 2A\sqrt{\frac{3}{7}} \approx 1.31A < A_\pi(1,1)|_{\beta=0} = 2A$, $\frac{\partial A_W(1,1)}{\partial\beta} > 0$, $\frac{\partial A_\pi(1,1)}{\partial\beta} < 0$ for $\beta \in (0,1)$ and $A_\pi(1,1)|_{\beta=1} = A$. Then, $A_W(1,1)$ and $A_\pi(1,1)$ are crossed at $(\beta, A^*) = (0.85, 1.54A)$. This implies (2). Figure 1 shows an example that $A_W(1,1) > A_\pi(1,1)$ and $A_W(1,1) < A_\pi(1,1)$ are possible.

Proof of Lemma 5

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

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 $\overline{A} < \frac{A(2-\beta^2)(8+\beta^2)}{\beta(16+(2-\beta)\beta(\beta+\beta^2-1))-8}$, which is sufficient to prove the result.

Proof of Lemma 6

Define $A_W^M(0,0)$ and $A_W^M(1,0)$, which satisfy $W^M(1,1) \gtreqless W(0,0) \Leftrightarrow A^* \gtreqless A_W^M(0,0)$ and $W^M(1,1) \gtreqless W^M(1,0) \Leftrightarrow A^* \gtreqless A_W^M(1,0)$. We have $A_W^M(0,0) = A\frac{2(8+\beta^2)\sqrt{6-4\beta}}{(2-\beta)\sqrt{304+48\beta+108\beta^2+16\beta^3+11\beta^4-\beta^5}}$ and $A_W^M(1,0) = A\frac{2(8+\beta^2)\left((4-\beta^2)\sqrt{\sigma^M(1,0)}-2\beta(8+\beta^2)(8-3\beta^2)\right)}{4(448-1024\beta+16\beta^2+144\beta^3-60\beta^4+72\beta^5+6\beta^6+\beta^7-3\beta^9)-\beta^8(21-\beta^2)}$ where $\sigma^M(1,0) = (1-\beta)\big(2(672-864\beta-496\beta^2+104\beta^3-6\beta^4+80\beta^5+11\beta^8-\beta^9)$ $+19\beta^6(7+3\beta)\big) > 0$.

We have $\frac{\partial A_W^M(1,0)}{\partial \beta} > 0$, $\frac{\partial^2 A_W^M(1,0)}{\partial \beta^2} > 0$, $A_W^M(1,0)\big|_{\beta=0} = 2A\sqrt{\frac{3}{7}} \approx 1.31A$, $\frac{\partial A_W^M(0,0)}{\partial \beta} \gtrless 0$ and $\frac{\partial^2 A_W^M(0,0)}{\partial \beta^2} < 0$ for $\beta \in (0,1)$. Moreover, we have $A_W^M(0,0)\big|_{\beta=0} = 2A\sqrt{\frac{6}{19}} \approx 1.12A$ and $A_W^M(0,0)\big|_{\beta=1} = \frac{2A}{\sqrt{3}} \approx 1.15A$, meaning $A_W^M(0,0)$ has the maximum value, $1.17A$ at $\beta \approx 0.74$. Then, $A_W^M(0,0) < A_W^M(1,0)$. Figure 2 shows that $A_W^M(0,0) < A_W^M(1,0)$ for $\beta \in (0,1)$.

Proof of Lemma 7

We have $\frac{\partial A_\pi^M(1,1)}{\partial \beta} < 0$ for $\beta \in (0,1)$, $A_\pi^M(1,1)\big|_{\beta=0} = 2A$ and $A_\pi^M(1,1)\big|_{\beta=1} = A$, meaning that $A_\pi^M(1,1)$ is a monotonically decreasing function with respect to β, from A to $2A$. From Lemma 6, the intersection between $A_W^M(1,0)$ and $A_\pi^M(1,1)$ is $(\beta, A^*) = (0.55, 1.67A)$ and that of between $A_W^M(0,0)$ and $A_\pi^M(1,1)$ is $(\beta, A^*) = (0.77, 1.39A)$. Figure 2 shows an example that (1) and (2) are possible.

Proof of Lemma 8

$A_\pi(1,1) - A_\pi^M(1,1) = \frac{\beta^2(1-\beta)(1+\beta)(2+\beta)(16-12\beta-\beta^2+5\beta^3-2\beta^4)}{(2-\beta^2)^2(8+2\beta^2-\beta^3-\beta^4+\beta^5)} > 0$ for $\beta \in (0,1)$.

Proof of Proposition 4

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

(1) 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

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

(2) 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 $A^* > \frac{A\left(16-17\beta^2+4\beta^4\right)}{6\beta-3\beta^3}$. Because $\frac{A\left(16-17\beta^2+4\beta^4\right)}{6\beta-3\beta^3} > A_\pi^M(1,1)$, we can show that $\pi_2^M(1,0) > \pi_2(1,0)$ never holds in this case.

(3) 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.

(4) 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 $A^* > \frac{A\left(8+\beta^2\right)\left(8-9\beta^2+2\beta^4\right)}{\left(2-\beta^2\right)(16-\beta(8-\beta(4-\beta(3+2(1-\beta)\beta))))}$. Because $\frac{A\left(8+\beta^2\right)\left(8-9\beta^2+2\beta^4\right)}{\left(2-\beta^2\right)(16-\beta(8-\beta(4-\beta(3+2(1-\beta)\beta))))} > A_\pi(1,1)$, $\pi_2^M(1,1) > \pi_2(1,0)$ never holds in this case.

(5) Suppose that only firm 2 adopts the high-quality input without integration and only firm 1 adopts the high-quality input with integration. Then, we have $\pi_2(0,1) - \pi_2^M(1,0) = \frac{6AA^*\beta\left(2-\beta^2\right)+(A^*)^2\left(4-8\beta^2+\beta^4\right)-A^2\left(16-17\beta^2+4\beta^4\right)}{4\left(4-\beta^2\right)^2\left(1-\beta^2\right)}$. Then, $\pi_2(0,1) < \pi_2^M(1,0)$ if $A^* < \frac{\left(4+\beta-2\beta^2\right)}{2+2\beta-\beta^2}$ or $A^* > \frac{\left(4-\beta-2\beta^2\right)}{-2+2\beta+\beta^2}$. Because $\frac{\left(4+\beta-2\beta^2\right)}{2+2\beta-\beta^2} < A_\pi(1,0)$ and $\frac{\left(4-\beta-2\beta^2\right)}{-2+2\beta+\beta^2} > \overline{A}$ for $\beta \in (0,1)$, $\pi_2(0,1) < \pi_2^M(1,0)$ never holds in this case. Furthermore, 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, whereas there is no effect of increasing firm 2's profit. Therefore, firm 2's profit is smaller with integration.

(6) 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 when only firm 1 adopts the high-quality input without integration from Lemma 2. We also showed in (4) 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.

(7) Suppose that no firm adopts the high-quality input without integration and only firm 1 adopts the high-quality input with integration. We have

$\pi_2(0,0) - \pi_2^M(1,0) = \frac{(A^*-A)\beta\left(A\left(4-\beta-2\beta^2\right)-\beta A^*\right)}{\left(4-\beta^2\right)^2\left(1-\beta^2\right)}$. Then, $\pi_2(0,0) < \pi_2^M(1,0)$ if and only if $A^* > A\frac{4-\beta-2\beta^2}{\beta}$. Because $A\frac{4-\beta-2\beta^2}{\beta} > \overline{A}$ for $\beta \in (0,1)$, $\pi_2(0,0) < \pi_2^M(1,0)$ never holds in this case. Furthermore, the adoption of the high-quality input by firm 1 reduces firm 2's profit, and vertical integration reduces firm 1's cost, making firm 1 stronger. Both effects reduce firm 2's profit, whereas there is no effect of increasing firm 2's profit. Therefore, firm 2's profit is smaller with integration.

(8) 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 $A^* > \frac{A\left(8+\beta^2\right)}{4-2\beta+2\beta^2-\beta^3}$. Because $\frac{A\left(8+\beta^2\right)}{4-2\beta+2\beta^2-\beta^3} > A_\pi(1,0)$, $\pi_2^M(1,1) > \pi_2(0,0)$ never holds in this case.

Proof of Proposition 5

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

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

Second, suppose that only firm 1 adopts the high-quality input with and without integration. This happens only when $A_\pi(1,0) \leqq A^*$. We obtain

$$\begin{aligned} &W^M(1,0) - W(1,0) \\ &\quad = \frac{\left(A^*\left(2-\beta^2\right) - A\beta\right)\left(A^*\left(2-\beta^2\right)\left(20 - 15\beta^2 + 4\beta^4\right) - A\beta\left(36 - 35\beta^2 + 8\beta^4\right)\right)}{8\left(1-\beta^2\right)\left(8 - 6\beta^2 + \beta^4\right)^2} \end{aligned}$$

Thus, we have $W^M(1,0) > W(1,0)$ if and only if $A^* > A\frac{\beta\left(36-35\beta^2+8\beta^4\right)}{\left(2-\beta^2\right)\left(20-15\beta^2+4\beta^4\right)}$. Because $A_\pi(1,0) - A\frac{\beta\left(36-35\beta^2+8\beta^4\right)}{\left(2-\beta^2\right)\left(20-15\beta^2+4\beta^4\right)} = \frac{2A(1-\beta)(2+\beta)\left(20-4\beta-17\beta^2+2\beta^3+4\beta^4\right)}{\left(2-\beta^2\right)\left(20-15\beta^2+4\beta^4\right)} > 0$, we can show that this always holds.

(2) Fig. 3 shows that $A_\pi(1,1) > A_\pi^M(1,1)$, but both $A_\pi^M(1,1) > A_W^M(1,0)$ and $A_\pi^M(1,1) < A_W^M(1,0)$ are possible.

Proof of Lemma 9

First, when firm j adopts the standard input, firm i adopts the high-quality input if and only if $\pi_i(1,0) \geq \pi_i(0,0)$, which requires $r \leq A^* - A$. Second, when firm j adopts the high-quality input, firm i also adopts the high-quality input if and only if

$\pi_i(1,1) \geq \pi_i(0,1)$, which requires $r \leq A^* - A$. Hence, both firms adopt the high-quality input in the equilibrium if and only if $r \leq A^* - A$.

Proof of Lemma 10

In the second stage, after observing r, firm 2 adopts the high-quality input if and only if $\pi_2^M(1,1) > \pi_2^M(1,0)$, which requires $A^* < \overline{A} = A\left(\frac{2-\beta^2}{\beta}\right)$. Thus, we have the input price constraint that $r \leq \frac{\left(2-\beta^2\right)(A^*-A)}{\left(2-2\beta^2\right)}$. Otherwise, firm 2 adopts the standard input.

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