The impacts of suppliers and mutual outsourcing on organizational forms*

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May 8, 2022

Abstract

We consider a downstream duopoly model with a monopolistic common supplier and mutual outsourcing between the two symmetric downstream firms. The market structure captures the recent procurement environment in the smartphone industry. We also incorporate managerial delegation into the duopoly model because deciding on organizational forms within a firm is critical to achieving better performance in almost all industries. There is an equilibrium in which only one of the firms delegates its downstream production to its sales manager. A delegating firm becomes less aggressive. The profits when both firms delegate can be higher than those when no firm delegates. Social welfare when both firms delegate can be smaller than that when no firm delegates.

Keywords: Mutual outsourcing, Supplier, Delegation, Asymmetric managerial forms.
JEL Codes: L13, D43.

*We have benefited from many constructive comments from the Co-Editor, Dan Bernhardt, and anonymous referees. We are thankful to Michael Kopel for his invaluable comments and suggestions. We gratefully acknowledge the financial support from the Japan Society for the Promotion of Science (JSPS), KAKENHI Grant Numbers JP15H03349, JP15H05728, JP17H00984, JP18H00847, JP18K01593, JP19H01483, JP20H05631, JP21H00702, JP21K01452, and JP21K01541. Although Matsushima serves as a member of the Competition Policy Research Center (CPRC) at the Japan Fair Trade Commission (JFTC), the views expressed in this paper are solely ours and should not be attributed to the JFTC. The usual disclaimer applies.

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1 Introduction

Mutual outsourcing has become a common business practice in technology-intensive industries, typically the smartphone industry.[1] For instance, Google and Samsung mutually outsource their key components to each other.[2] Google manages the Android operating system, which is a critical component for smartphone operation. Samsung embeds the Android operating system into its Galaxy smartphone and sells the smartphone to final consumers. On the other hand, Samsung produces the Nexus smartphone for Google as an original equipment manufacturer (OEM). Along with such mutual outsourcing, in the input market for smartphones, Qualcomm plays an indispensable role and exerts strong monopoly power over the smartphone makers including Apple, Google, and Samsung in various ways in the modem chip market.[3] In fact, Qualcomm held more than half the market share in the modem chip industry in 2017 (Ai and Lu, 2019, p.645).[4]

Given the current technological environment mentioned above, we consider a downstream duopoly model with a monopolistic common supplier and mutual outsourcing between the two downstream firms.[5] We also incorporate managerial delegation into the

[1] Pun (2015) and Milliou and Serfes (2020) provide some real-world examples of mutual outsourcing in some industries.

[2] We borrowed this example from Pun (2015, p.2092).

[3] Although Samsung is also a modem chip maker, it has depended on Qualcomm to produce its *high-end* smartphones (see, for instance, Srivastava (2016) and Leswing (2019)).

[4] Qualcomm demanded that Apple's OEMs pay royalty fees that are higher than the standard-essential patent (SEP) royalty fees (see Ai and Lu, 2019, p.647), although the royalty rates of Qualcomm's SEPs for 4G cellular technologies are *nominally* inflexible under the committed terms based on the FRAND (fair, reasonable, and nondiscriminatory) licenses. Any refusal to this demand would lead to Qualcomm's refusal to supply its modem chip to the refusing OEM. See the discussions on antitrust concerns in Hovenkamp (2017) and Hovenkamp and Simcoe (2020).

[5] Our analytical framework would also apply to the automobile industry because mutual outsourcing is a common practice. For instance, competitors Nissan and Daimler mutually traded their car components (Pun, 2015). On the one hand, Nissan produced its luxury car, Infinity, by purchasing the front-wheel-drive architecture platform used in Daimler's Mercedes. On the other hand, Nissan supplied diesel and gas engines to Daimler. Automobile manufacturers depend on suppliers in oligopolistic

duopoly model, as in Fershtman and Judd (1987), Sklivas (1987), and Basu (1995), and derive the equilibrium managerial structure because deciding on organizational forms within a firm is critical to achieving better performance in almost all industries (Foss and Klein, 2014).[6]

The details of the model are as follows. The downstream firms compete in quantity, which is suitable for investigating competition in the manufacturing industries (see, e.g., Sundaram et al., 1996; Plehn-Dujowich and Serfes, 2010).[7] The downstream firms mutually outsource their inputs from the rivals under linear input prices, where the per-unit payment is constant with respect to the quantity demanded for input. The monopolistic input supplier sells its key input to the two downstream firms under a common linear input price.[8] Each downstream firm produces one unit of the final product by combining each one unit of those three inputs.

We consider the following four stage game.[9] In the first stage, each downstream firm's owner determines whether to delegate its decision regarding the downstream production to a manager. If the owner delegates, the firm needs to incur costs of delegation, as in Basu (1995). Those costs come from hiring a manager. In the second stage, the monopoly supplier and the owners set the contract terms in the input market regardless of the managerial forms determined in the first stage. In the third stage, each owner offers an incentive contract to the manager if she/he delegates in the first stage. The incentive contract in each firm consists of a linear combination of its profit

industries, including tires, glass, and so on.

[6] See excellent surveys on strategic delegation by Sengul et al. (2012), Lambertiti (2017), and Kopel and Pezzino (2018); empirical analysis of delegation, Colombo et al. (2007) and Bloomfield (2021).

[7] For instance, in the smartphone industry, capacity constraints on production in input markets (e.g., modem chip production) can be a bottleneck to producing enough smartphones (see, for instance, Sohn, 2021, a recent article about the global chip shortage).

[8] We obtain a qualitatively similar result even when the supplier can price discriminate against the downstream firms.

[9] We explain the plausibility of the timing structure in Section 3.

and revenue (Fershtman and Judd, 1987). In the fourth stage, the decision-makers in the downstream market simultaneously set their quantities.

We obatin the following two main results. First, we show that the delegating owner places a negative weight on the revenue in the linear combination of the incentive contract to its manager, inducing the manager to be less aggressive than an owner-managed firm. Second, we also show that there are three types of equilibrium managerial structures depending on costs of delegation: (i) no owner delegates; (ii) only one owner delegates; (iii) both owners delegate. Moreover, the first and the second results imply that the sum of the quantities supplied in case (i) is the largest. This comparison means that the consumer surplus in case (i) is the largest.

We explain the intuition behind the first result. The objective of each decision-maker in the downstream market consists of two parts: (i) a linear combination of profits and revenues in the downstream market, and (ii) revenue from the input market, which is independent of the decision-maker's strategic variable (its downstream quantity). Because the input market revenue and its downstream quantity are independent, the decision-maker sets its quantity without considering the input market revenue. If an owner delegates, it can internalize the input market revenue by offering an incentive contract that induces its manager to produce less than an owner-managed firm. Specifically, the owner who delegates sets a negative weight on the revenue in the linear combination of the incentive contract. Note that the monopolistic supplier does not play an important role in establishing the first main result, in contrast to the related papers whose timing structures differ from ours (Szymanski, 1994; Liao, 2010).

We illustrate the intuition behind the second main result. The owner who delegates enjoys a lower input price offered by the competing owner than if it does not delegate. This is because the competing owner anticipates that the delegating owner induces its manager to produce less than if it does not delegate, meaning that the demand for input produced by the competing owner is smaller. The competing owner's lower input price allows the monopolistic supplier to offer a higher input price because of the strategic substitution in the complementary input market. Thus, delegation strengthens the monopolistic supplier's market power, offsetting the delegating owner's gain from the lower input price offered by the competing owner. The effect of such an offset is strong under an asymmetric managerial structure, making the asymmetric structure attainable.

The logic behind the second result is new in the context of strategic delegation.[10] The second result implies that mimicking the well-performed rival's organizational form can be an inconsiderate decision. Related to the result, the well-known facts are that Samsung is more likely to employ centralized management (Joseph et al., 2016) and that Google is more likely to employ delegated management (Steiber, 2014). Following our second result, we can conclude that the coexistence of asymmetric managerial forms is a considerable consequence. Note that the interaction of the two essential forces (the monopolistic supplier and mutual outsourcing) is the key to obtaining the result because the negative weight in the incentive contract stems from the first force mentioned above.

The remainder of this paper is organized as follows. Section 2 surveys the related papers. Section 3 constructs the model. Section 4 analyzes the three subgames and shows the main result. Section 5 offers concluding remarks.

2 Related papers

Several papers show the possibility of making managers less aggressive than owner-managed firms (e.g., vertical relations (e.g., Szymanski, 1994; Liao, 2010; Habiger and

[10] Several papers also show asymmetric managerial structures in different contexts (Vroom, 2006; Mujumdar and Pal, 2007; Kopel and Löffler, 2008, 2012; Pan et al., 2020). We explain the difference between those papers and ours in Section 2.

Kopel, 2020), network externalities (e.g., Hoernig, 2012; Lee and Choi, 2018)).[11] Szymanski (1994) incorporates firm-specific labor unions into the standard duopoly model with delegation. His numerical analysis shows that delegating firms are less aggressive than profit-maximizing firms because these delegating firms anticipate that the labor unions extract rents after the determination of incentive contracts.[12] The timing structure in the related papers (e.g., Liao, 2010; Claude, 2018) is different from ours. Those related papers consider the following sequence: incentive contracts, input prices, and strategic variables in the downstream market. The different timing structure in those papers is the key to deriving such less aggressive behavior.

Although most of those papers with vertical relations do not investigate the equilibrium managerial structure, Choi et al. (2020) is the exception. They investigate endogenous managerial forms in duopoly models with two exclusive vertical relations. They show that employing managerial delegation is a dominant strategy, which contrasts with our result. Even if they would also assume that a delegating firm incurs costs of delegation, as in Basu (1995) and our paper, an asymmetric managerial structure does not appear.[13]

Some theoretical studies have investigated how strategic organizational design affects firm asymmetry (Vroom, 2006; Mujumdar and Pal, 2007; Kopel and Löffler, 2008, 2012; Pan et al., 2020).[14] The stream of this research interprets the organizational design as

[11] Liao (2014) and Claude (2018) extend Liao (2010). Fanti and Scrimitore (2019) consider a duopoly model where a vertically integrated firm and an independent downstream firm that procures inputs from the integrated firm compete in quantity. Vertical integration is the key in their model to obtaining the negative weight on the sales volume in equilibrium.

[12] Fanti and Meccheri (2013) and Chatterjee and Saha (2017) further investigate the model framework in Szymanski (1994).

[13] We check it by comparing $\pi_i^{ddC} - \pi_i^{ndC}$ (the gross gain from delegation given that the rival delegates) and $\pi_i^{dnC} - \pi_i^{nnC}$ (the gross gain from delegation given that the rival does not delegate) in their paper, and find that $(\pi_i^{ddC} - \pi_i^{ndC}) > (\pi_i^{dnC} - \pi_i^{nnC})$, implying that an asymmetric managerial structure does not appear.

[14] Recently, Macho-Stadler et al. (2021) discuss a downstream duopoly with technological spillovers

a commitment device for firms' output decisions. Specifically, when a firm's owner hires a manager with an incentive contract, the owner can make the manager more/less aggressive through the contract terms than an owner-managed firm.

Vroom (2006) discusses a duopoly market where a firm's owner offers a relative-performance-based incentive contract to the (downstream) marketing manager. He shows the possibility that one owner chooses decentralization and the other chooses centralization. In this asymmetric case, the decentralized firm acquires an advantage (the relative aggressiveness in the downstream market) and a disadvantage (the double mark-up problem). The two contrasting effects make the asymmetric organizational forms attainable. External sourcing is beyond the scope of analysis in Vroom (2006).

Several papers consider duopoly models with sequential choice of production volumes to obtain asymmetric managerial forms.

Mujumdar and Pal (2007) consider a symmetric duopoly with twice the production opportunities. They show that the first mover delegates to a manager with a profit-based incentive contract, while the second mover delegates with a sales-based contract. The first mover does not have an incentive to change the owner's best response because she/he chooses her/his quantity based on the second mover's best response, although the second mover can benefit from making it more aggressive.

Kopel and Löffler (2008) consider the interaction of two commitment devices: process-innovation R&D and delegation to a manager in a Stackelberg duopoly model. They show that both firms invest in process innovation and that only the follower delegates to a manager because (i) a Stackelberg leader cannot benefit from the strategic delegation, and (ii) the leader's cost-reducing investment does not directly affect the follower's quantity choice. They also show that the follower can overcome the disadvantage of its

and show an equilibrium asymmetric managerial structure. The key factor is the interaction between the modes of downstream competition and the strategic nature of R&D investments.

second-mover position.

Kopel and Löffler (2012) consider a duopoly model in which firms can choose their organizational governance and leader–follower roles. They consider the delegation cost and show that a firm chooses to be the market leader and does not delegate, whereas the other firm hires a manager. The key factor in the three papers is sequential choices of quantities.

Recent work by Pan et al. (2020) also shows the possibility that an asymmetric managerial structure emerges in a duopoly with quantity competition. The key factor in their paper is equilibrium multiplicity under the convex inverse demand function proposed by Ishibashi and Matsushima (2009).[15] Under some parameter sets, one of the firms does not delegate to a manager in order to avoid the worse equilibrium. That is, the demand system is the key factor in obtaining an asymmetric managerial structure.

3 Model

We consider a Cournot duopoly market with a monopolistic supplier. The inverse demand in the downstream market is

$$p = a - q_i - q_j,$$

where p is the price, a is a positive constant, and q_i is the quantity supplied by firm i ($i, j = 1, 2$; $j \neq i$).

Each of the profit-maximizing downstream firms needs three types of inputs produced by the downstream firms and the monopolistic supplier (hereinafter we refer to the latter as "the supplier"). To produce one unit of the final product, each downstream firm uses one unit of each of the three inputs, respectively. We assume that the

[15] Pan (2018, 2020) are applications of the inverse demand function in Ishibashi and Matsushima (2009) to the problems of endogenous timing and firm entry, respectively.

three firms do not incur any production cost in producing their inputs for notational simplicity. The total marginal cost of firm i, c_i ($i = 1, 2$), is the sum of the input prices imposed by the rival firm j ($j = 1, 2,\ j \neq i$) and the supplier, r_j and w; that is, $c_i = r_j + w$. Here, the supplier offers a common input price w to firms 1 and 2. Figure 1 summarizes the trading structure in the industry.

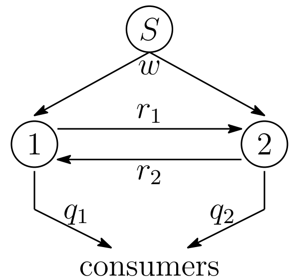

Figure 1: The market structure

The profits of firm i and the supplier, Π_i and Π_S, are

$$\Pi_i = (R_i - (r_j + w)q_i) + r_i q_j, \quad \text{where } R_i = (a - q_i - q_j)q_i, \quad (i, j = 1, 2,\ j \neq i),$$

$$\Pi_S = w(q_1 + q_2).$$

Π_i ($i = 1, 2$) is the sum of the profits from the downstream and upstream/input markets.

In the duopoly market, each downstream firm (owner) determines whether to delegate the downstream production to its manager. Following the tradition in the context of strategic delegation (Fershtman and Judd, 1987; Basu, 1995), we assume that the managerial compensation contracts are of the form $A_i + B_i g_i$, where A_i and B_i are a fixed wage and a weight on the performance measure g_i:

$$g_i = \alpha_i \Pi_i + (1 - \alpha_i) R_i,$$

where α_i is the weight imposed by the owner of firm i.[16] The reservation utilities of the

[16] Several articles explored cases where a manager's compensation is determined by the combination of various parameters (profits and sales quantities (Vickers, 1985), own profits and rival's profits (Salas-Fumás, 1992; Miller and Pazgal 2002), profits and market share (Ritz, 2008)). In this paper, we use the traditional compensation scheme to highlight the new sources of asymmetric managerial structures.

managers are assumed to be Y. We assume that the owner can earn profits X by hiring a manager, where $X < Y$. Examples of X include money from time saved by the owner and profit generated from the manager's expertise.[17] We define F as the difference between Y and X, that is, $F \equiv Y - X$, which becomes a fixed cost of delegation to hire a manager.[18]

The linear formulation of g_i is consistent with the real-world practices summarized in Murphy (1999) and Kelly and Matthews (2020). Murphy (1999, p.2500) points out that companies generally use multiple performance measures, which are essentially additive and separable, in their incentive plans. Recently, in the Willis Towers Watson 2020 Annual Incentive Design Survey, Kelly and Matthews (2020) also mention that the multiple measures used by about 80% of companies are additive and independent of each other.

In reality, for instance, the executive officer compensation in Apple consists of three primary components (Apple Inc., 2021): annual base salary (fixed element); annual cash incentive, which depends on an equal weight for net sales and operating income; and long-term equity awards (stock prices).[19] Because those compensation components are calculated independently, we can say that the remuneration system in Apple is a linear combination of profits and other indicators.[20]

[17] Given the inherent nature of delegation, the gain assumed here is plausible (see, Kopel and Löffler, 2012).

[18] The compensation $E_i = A_i + B_i g_i$ should be larger than or equal to Y; that is, $A_i + B_i g_i \geq Y$. When the owner offers the contract term, it needs to consider the maximization problem: max $\Pi_i - E_i$ such that $E_i = A_i + B_i g_i \geq Y$. As a result, the owner's net payment to the manager is $E_i = Y$ and the owner gains X. In total, the owner's net profit is $\Pi_i - Y + X = \Pi_i - F$ when it hires a manager. We thank an anonymous referee for providing us with this formulation.

[19] It is difficult to determine precisely how equity awards influence managers' incentives. If managers think that collusive conduct contributes to long-term profits, they behave less aggressively. This scenario seems plausible if they face equal footing rivals and the market is stable. However, if managers think that excluding rivals contributes to long-term profits, they behave aggressively. This scenario seems plausible if they are in progressive or growing markets.

[20] We also pick up Siemens as another example. Siemens uses linear managerial contracts as well.

The assumption on strategic delegation means that the owners of firms in our model can delegate managerial decisions to their managers for saving time and strategic motives. Such a strategic motive of delegation is consistent with the empirical finding in Bloomfield (2021) that shows that many firms add revenue-based pay to their CEO's pay packages immediately after the requirement to disclose compensation plans for their executives, which facilitates the strategic commitment to executives' objectives as in the scenario of Fershtman and Judd (1987).[21]

We consider the following four-stage game:[22]

1. Each downstream firm's owner determines whether to delegate overall downstream production to its manager. If the owner delegates, the firm needs to incur a fixed cost, F, to delegate. This assumption follows Basu (1995). We denote the decisions of delegation and no delegation as D and N, respectively.

   Firms are often reluctant to change their organizational forms, so-called "organizational inertia," because of routines (e.g., Yi et al., 2016). Changing the forms can be a long-term decision because of such inertia. Therefore, we assume that the firms decide whether to delegate in the first stage.

The compensation of Managing Boardmembers in Siemens also consists of three components: Fixed compensation (approx. 40%); Short-term variable compensation (bonus) (approx. 25%); and Long-term variable compensation (stock award) (approx. 35%) (note that the report (Siemens, 2021, p.9) explicitly mentions those percentages). The company's profits and profitability are reflected in the short-term variable. The long-term variable depends on the total shareholder return and the Environmental, Social, and Governance (ESG) index. Because those components are independent, we can say that the remuneration system in Siemens is a linear combination of profits and another indicator (long-term incentive).

[21] Gipper (2021) shows the changes in incentive pay packages after the revision of the Compensation Discussion and Analysis statement.

[22] The timing structure is different from those in the related papers (e.g., Liao, 2010; Claude, 2018) and suitable for the motivating example in the introduction. Those related papers consider the following sequence: incentive contracts, input prices, and strategic variables in the downstream market. The timing structure in those related papers appears to be plausible in other contexts. We believe that the timing structure in a game-theoretical model should depend on the context that researchers consider.

2. The supplier and the owners of firms 1 and 2 simultaneously determine the linear input prices, w, r_1, and r_2. As explained in the introduction, even if we assume that the supplier can offer different input prices for the downstream firms, the qualitative nature of the main results does not change (see Section 4.5).

   The duration of alliances in input markets is longer than that of the incentive contracts. For instance, Qualcomm announced a multi-year strategic relationship agreement with Samsung in 2018 (e.g., Qualcomm Technologies Inc., 2018). We could expect that the signed trading terms are valid for longer periods.

3. Each downstream firm's owner determines the incentive scheme for its manager, α_i, if it delegates the production in the first stage.

   We treat the proposal of an incentive scheme for managers as a yearly based decision, which is shorter than those in the input market.

4. The agents with the right to control the downstream production determine the quantities in the downstream market.

We derive the subgame perfect Nash equilibrium by backward induction.

4 Analysis

We consider three subgames: (i) both firms delegate, case (D, D); (ii) one of the firms delegates, case (N, D); (iii) no firm delegates, case (N, N). Finally, we use the outcomes in the three subgames and obtain the main result.

4.1 Both firms delegate, case (D, D)

We consider the case in which both firms delegate.

The fourth stage The objective of the manager in firm i is

$$\begin{aligned} g_i &= \alpha_i \Pi_i + (1-\alpha_i) R_i \\ &= \alpha_i \{(a - q_i - q_j - r_j - w) q_i + r_i q_j\} + (1-\alpha_i)(a - q_i - q_j) q_i. \end{aligned}$$

In this stage, both firms' managers simultaneously set the quantities. We can obtain the best response function of firm i's manager as follows:

$$q_i = \frac{a - q_j - \alpha_i (r_j + w)}{2}, \quad (i, j = 1, 2, \ j \neq i). \tag{1}$$

This best response function is a decreasing function of α_i. As α_i becomes smaller, in other words, as the manager's attention to the cost $(r_j + w)$ is weaker, the quantity of firm i increases. The best response function does not include the input price imposed by firm i, r_i, that is, the manager does not take into account the revenue from the input market, as in the standard quantity competition with internal market licensing (e.g., Faulí-Oller and Sandonís, 2002, p.195).[23] This manager's ignorance regarding the revenue from selling input influences the choice of firm i's owner on α_i in the third stage. Solving the simultaneous equations mentioned in (1), we obtain the quantity of firm i:

$$q_i(\boldsymbol{\alpha}, \boldsymbol{r}, w) = \frac{a - 2\alpha_i (r_j + w) + \alpha_j (r_i + w)}{3}. \tag{2}$$

When α_j is small, manager i knows that the rival firm commits to set a higher q_j, inducing manager i to set a small output because of the strategic substitution of downstream outputs. Using the result in (2), we have the profit in the fourth stage:

$$\Pi_i (\boldsymbol{\alpha}, \boldsymbol{r}, w) = (q_i(\boldsymbol{\alpha}, \boldsymbol{r}, w) - (1-\alpha_i)(r_j + w)) q_i(\boldsymbol{\alpha}, \boldsymbol{r}, w) + r_i q_j(\boldsymbol{\alpha}, \boldsymbol{r}, w). \tag{3}$$

The first term is the profit from the downstream market and the second term is the profit from the input market.

[23] Faulí-Oller and Sandonís (2002) discuss the Cournot duopoly with a licenser (firm 1) and a licensee (firm 2). The licenser (firm 1)'s maximization problem $\max_{x_1}\ p_1(x_1, x_2)x_1 + r x_2$ leads to the first-order condition: $p_1 + x_1(\partial p_1/\partial x_1) = 0$, where $p_1(x_1, x_2)$ is the inverse demand for the licenser, x_i is the quantity of firm i $(i = 1, 2)$, and r is the per unit fee on the licensee. This condition does not include r, as in our paper. This property is common in the context of licensing under quantity competition.

The third stage The owner of firm i sets the parameter α_i to maximize profit $\Pi_i(\boldsymbol{\alpha}, \boldsymbol{r}, w)$. Using (3), we solve the maximization problem and then obtain the owner's best response function:

$$\alpha_i(\alpha_j, \boldsymbol{r}, w) = \frac{6(r_j + w) - a}{4(r_j + w)} - \frac{\alpha_j(r_i + w)}{4(r_j + w)} + \frac{3r_i}{4(r_j + w)}, \quad (i, j = 1, 2, \ j \neq i). \tag{4}$$

The first and second terms in (4) are the standard best response in the delegation game, and the last term in (4) is the element, which reflects firm i's revenue from the input market.

To maximize profit, firm i must consider the trade-off between the downstream profit and the profit from firm j. However, the Cournot best response function (1) shows that the manager of firm i does not consider the revenue in the input market.

In the third stage, each firm can use the degree of delegation α_i as a commitment device to decrease the quantity in the fourth stage to balance the profits from the downstream and input markets (Macho-Stadler and Verdier, 1991).[24] Solving the simultaneous equations in (4), we obtain $\alpha_i(\boldsymbol{r}, w)$

$$\alpha_i(\boldsymbol{r}, w) = \frac{-a + 8(r_j + w) - 2(r_i + w)}{5(r_j + w)} + \frac{4r_i - r_j}{5(r_j + w)}. \tag{5}$$

The first term in (5) captures the degree of delegation in the standard delegation game without the last term in (4), and the second term in (5) captures the impact of their revenues from inputs on α_i. As explained before, the input revenue makes the firm less aggressive (a high α_i) in the fourth-stage competition.

By substituting (5) into (2), we can rewrite the output as a function of $(\boldsymbol{r}, w)$:

$$q_i(\boldsymbol{r}, w) = \frac{2(a - 3(r_j + w) + 2(r_i + w))}{5} + \frac{2r_j - 3r_i}{5}. \tag{6}$$

[24] Macho-Stadler and Verdier (1991) also show such delegation incentives to lower quantities in a duopoly market with cross-shareholding. Because of the cross-shareholding by one of the firms, the holding firm weighs heavily on the profit in the delegation stage to mitigate competition (Proposition 1 in their paper).

The second term in (6) reflects the impact of their revenues from inputs on the quantity through the delegation levels. An increase in its input price, r_j, leads to a larger quantity because the rival becomes less aggressive by offering a higher α_j. The converse holds, that is, an increase in its rival's input price, r_i, induces a smaller quantity.

The second stage The supplier and firms 1 and 2 set w, r_1, and r_2 to maximize their own profits. The supplier's profit function is

$$\Pi_S(\boldsymbol{r}, w) = wq_1((\boldsymbol{r}, w) + q_2(\boldsymbol{r}, w)). \tag{7}$$

Solving the first-order condition, we obtain the best response function of the supplier:

$$w = \frac{4a - 3(r_i + r_j)}{8}. \tag{8}$$

The negative coefficient of r_j (resp., r_i) comes from the strategic substitution between the prices of firm i's (resp. firm j's) complementary inputs, w and r_j (resp., r_i), which is a key factor for deriving the asymmetric outcome. The strategic substitution resembles that in the standard Cournot complementary input market. Therefore, as r_j or r_i increases, the monopoly power of the supplier weakens.

Firm i's profit function is $(i, j = 1, 2,\ j \neq i)$:

$$\Pi_i(\boldsymbol{r}, w) = (q_i(\boldsymbol{r}, w) - (1 - \alpha_i)(r_j + w))q_i(\boldsymbol{r}, w) + r_i q_j(\boldsymbol{r}, w). \tag{9}$$

Solving the first-order conditions, we have the best response functions:

$$\begin{aligned} r_i &= \frac{7(a - (2r_j + 3w) + 2w)}{34} + \frac{5(2a + (r_j + 4w) - 6w)}{34} \\ &= \frac{17a - 17w - 9r_j}{34}, \quad (i, j = 1, 2,\ j \neq i). \end{aligned} \tag{10}$$

The first fraction in the first line comes from the gain from the downstream competition. The marginal gain from weakening the rival through r_i is larger as firm i's efficiency increases. The second fraction in the first line comes from the direct gain from the input market.

Solving the simultaneous equations in (8) and (10) and substituting the derived outcome into (7) and (9), we obtain the proposition:

Proposition 1 *If both firms delegate, the equilibrium input prices, output levels, and* α_i *are*

$$w^* = \frac{35a}{121}, \quad r_i^* = \frac{34a}{121}, \quad q_i^* = \frac{14a}{121}, \quad \alpha_i^* = \frac{79}{69}, \quad (i, j = 1, 2, \; j \neq i).$$

The resulting overall profits under (D, D) *are*

$$\pi_i = \frac{812a^2}{14641} - F \simeq 0.0555a^2 - F, \quad \pi_S = \frac{980a^2}{14641} \simeq 0.0669a^2.$$

To clarify the role of mutual outsourcing, we also solve the simultaneous equations in (10) and $w = 0$. Then, we obtain the result:

Result 1 *We hypothetically suppose that the supplier does not have any bargaining power, that is,* $w = 0$*, which equals to its marginal cost. If both firms delegate, the equilibrium input prices, output levels, and* α_i *are*

$$r_i^* = \frac{17a}{43}, \; q_i^* = \frac{7a}{43}, \; \alpha_i^* = \frac{22}{17} \quad (i, j = 1, 2, \; j \neq i).$$

The profits under (D, D) *are*

$$\pi_i = \frac{203a^2}{1849} - F \simeq 0.1098a^2 - F.$$

Note that α_i $(i = 1, 2)$ is strictly larger than 1 in Proposition 1 and Result 1. Contrary to the standard delegation game in Cournot competition, each owner places weights on its profit rather than its revenue, leading to less aggressive behavior in the downstream market. Proposition 1 and Result 1 clarify that the existence of mutual outsourcing is sufficient to induce less aggressive behavior in the downstream market.

4.2 Only one firm delegates, case (N, D)

Now suppose that only firm j delegates. Because the mathematical procedures are similar to those in Section 4.1, we directly mention the proposition in this case.

Proposition 2 *If only firm j delegates, the equilibrium input prices, output levels, and α_j are*

$$w^* = \frac{4a}{13},\ r_i^* = \frac{3a}{13},\ r_j^* = \frac{9a}{26},\ q_i^* = \frac{3a}{26},\ q_j^* = \frac{3a}{26},\ \alpha_j^* = \frac{17}{14} \quad (i, j = 1, 2,\ j \neq i).$$

The resulting overall profits under (N, D) are

$$\pi_i = \frac{27a^2}{676} \simeq 0.0399a^2,\ \pi_j = \frac{45a^2}{676} - F \simeq 0.0666a^2 - F,\ \pi_S = \frac{12a^2}{169} \simeq 0.0710a^2.$$

We have a remark on the input price w.

Remark 1 *The input price w in case (N, D), $w = 4a/13 \simeq 0.308a$, is higher than that in case (D, D), $w = 35a/121 \simeq 0.289a$.*

We explain the intuition behind Remark 1. Firm i without delegation anticipates a lower quantity supplied by firm j, which delegates, and sets an input price lower than that in case (D, D). Because of the mechanism of the complementary input pricing, the supplier in case (N, D) sets a higher input price than in case (D, D). The supplier's higher input price implies that abolishing delegation causes a reduction of the actual market size for the downstream firms.

To clarify the role of the strategic interaction in the input market, we also solve the simultaneous equations in (12) and (13) and $w = 0$. Then, we obtain the result:

Result 2 *We hypothetically suppose that the supplier does not have any bargaining power, that is, $w = 0$. If only firm j delegates, the equilibrium input prices, output levels, and α_j are*

$$r_i^* = \frac{a}{3},\ r_j^* = \frac{a}{2},\ q_i^* = \frac{a}{6},\ q_j^* = \frac{a}{6},\ \alpha_j^* = \frac{3}{2} \quad (i, j = 1, 2,\ j \neq i).$$

The profits under (N, D) are

$$\pi_i = \frac{a^2}{12} \simeq 0.0833a^2, \ \pi_j = \frac{5a^2}{36} - F \simeq 0.139a^2 - F.$$

As in Proposition 1 and Result 1, the delegating owner places a negative weight on its revenue in the manager's objective function in Proposition 2 and Result 2. This delegation decision balances the profits from the downstream and input markets.

Firm j's better procurement condition (the lower r_i) offsets the less aggressive behavior caused by the higher α_j. Then, the quantities of the two firms are the same.

4.3 No firm delegates, case (N, N)

Next, we consider the case in which no firm delegates to managers. As in the previous subsection, because the mathematical procedures are similar to those in Section 4.1, we directly mention the proposition in this case:

Proposition 3 *If no firm delegates, the equilibrium input prices and output levels are*

$$w^* = \frac{6a}{17}, \quad r_i^* = \frac{5a}{17}, \quad q_i^* = \frac{2a}{17} \quad (i, j = 1, 2, \ j \neq i).$$

The resulting profits under (N, N) are

$$\pi_i = \frac{14a^2}{289} \simeq 0.0484a^2, \quad \pi_S = \frac{24a^2}{289} \simeq 0.0830a^2.$$

We have a remark on the supplier's input price w.

Remark 2 *Similar to Remark 1, the supplier's input price in case (N, N), $w = 6a/17 \simeq 0.353a$, is higher than that in case (N, D), $w = 4a/13 \simeq 0.308a$. The incremental amount of the supplier's input price in Remark 2, $0.045a$, is significantly higher than that in Remark 1, $0.018a$.*

The quantities in case (N, N) are larger than those in case (D, D). The increase in downstream competition through no delegation dominates the supplier's monopoly power in response to the reduction of r_i $(i = 1, 2)$.

4.4 The first stage

From Sections 4.1, 4.2, and 4.3, we obtain the payoff matrix in the first stage (see Table 1). Using the outcomes, we obtain Proposition 4.

1/2	D	N
D	$0.0555a^2 - F$ $0.0555a^2 - F$	$0.0399a^2$ $0.0666a^2 - F$
N	$0.0666a^2 - F$ $0.0399a^2$	$0.0484a^2$ $0.0484a^2$

D: Delegation; N: No delegation.

Table 1: The first-stage decision

Proposition 4 *The profits under* (D, D) *are higher than those under* (N, N) *if* $F < 0.0071a^2$.

As we check in Remarks 1 and 2, the larger the number of delegating firms, the lower the supplier's input price. Furthermore, as we show in Propositions 1 and 2, employing delegation induces the firm to be less aggressive than an owner-managed firm, which mitigates downstream competition. From the two effects, the profits under (D, D) can be higher than those under (N, N). Proposition 4 implies that mutual outsourcing can facilitate collusive conduct.[25] We discuss the welfare properties of the subgames in Section 4.5.

The profit ranking in Proposition 4 is not common but resembles those in Liao (2010) and Meccheri and Fanti (2014) whose mechanisms differ from ours.[26]

From the payoff matrix, we obtain the following proposition (see also Figure 2):

[25] Of course, mutual outsourcing saves fixed costs to produce additional complementary inputs, although such costs are beyond the scope of this paper.

[26] Bhattacharjee and Pal (2014) show a similar result in a duopoly model with network externality.

Proposition 5 *Both owners delegate if and only if* $F \leq 0.0156a^2$*; Only one of the owners delegates if and only if* $0.0156a^2 \leq F \leq 0.0182a^2$*; No owner delegates if and only if* $0.0182a^2 \leq F$.

In the symmetric downstream duopoly, there is a possibility that asymmetry of the delegation decisions occurs. In many previous related papers, decisions on strategic delegation are strategic complements, that is, the outcomes of (D, D) and (N, N) can coexist (e.g., Colombo and Scrimitore, 2018), which is in contrast to Proposition 5.

Here, we explain the mechanism behind Proposition 5. First, if delegation is costless, both firms employ delegation. Setting the costless situation as a starting point, as the fixed cost of delegation F increases, delegation becomes less profitable. One of the firms stops employing delegation at the threshold value of F ($F = 0.0156a^2$). At the fixed cost of delegation slightly higher than the threshold value of F, $F = 0.0156a^2$, the rival downstream firm does not change its managerial form, anticipating the substantial increase of the supplier's input price (Remark 2). The substantial increase comes from the strategic interaction in the input market. Therefore, when F is moderate, the asymmetric managerial forms occur in equilibrium.

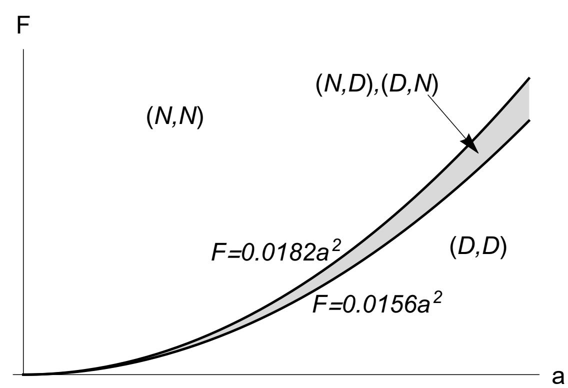

Figure 2: The parameter range in Proposition 5

Proposition 5 implies that mimicking the well-performed rival's organizational form can be an inconsiderate decision. Actually, Samsung is more likely to employ centralized management (Joseph et al., 2016), and Google is more likely to employ delegated management (Steiber, 2014). Following Proposition 5, we can conclude that the co-existence of asymmetric managerial forms is a considerable consequence.[27]

Finally, we restate the logic behind the asymmetric outcome in Vroom (2006) and compare it with ours. In his asymmetric outcome, the decentralized firm acquires an advantage from aggressiveness in the downstream market and the disadvantage of the double mark-up problem. We provide a different source to balance the two firms' competitive advantages. The delegating/decentralized firm acquires the advantage of the lower input price and the disadvantage of less aggressive behavior in the downstream market.

4.5 Welfare analysis

We briefly check the welfare ranking between the three cases.

The consumer surplus in our model with the linear demand is $(q_1 + q_2)^2/2$. That is, the consumer surplus monotonically increases in the total quantity supplied by the downstream firms. From Propositions 1, 2, and 3, we find that the total quantity in Proposition 3 is the highest and that in Proposition 2 is the lowest.

Furthermore, social welfare in our model is the sum of the firms' profits including benefits from delegation, X, and the consumer surplus. We denote it in each case by SW_k ($k \in \{(D,D),(N,D),(N,N)\}$).[28] From the assumption that no firm incurs production costs except for input prices, social welfare minus the delegation benefits monotonically increases in the total quantity supplied by the downstream firms. In addition to this argument, a delegating firm obtains the delegation benefit X. The total delegation benefit in the case of Proposition 3 is the lowest (no firm delegating),

[27] We implicitly assume that the firms properly coordinate the delegation choices in multiple equilibria. We can not predict which firm delegates from our theoretical result.

[28] The payments for the managers are cancelled out when we evaluate social welfare.

and that in the case of Proposition 1 is the highest (two firms delegating). From the discussions, we have the following proposition:

Proposition 6 *The consumer surplus in case (N, N) is the highest and that in case (N, D) is the lowest. The ranking of social welfare in the three cases is in the following order:*

$$\begin{cases} SW_{(N,N)} > SW_{(D,D)} > SW_{(N,D)} & \text{if } 0 \leq X < \dfrac{6308a^2}{4231249} \simeq 0.00149a^2, \\ SW_{(D,D)} \geq SW_{(N,N)} > SW_{(N,D)} & \text{if } 0.00149a^2 \leq X < \dfrac{339a^2}{97682} \simeq 0.00347a^2, \\ SW_{(D,D)} > SW_{(N,D)} \geq SW_{(N,N)} & \text{if } 0.00347a^2 \leq X. \end{cases}$$

4.6 Robustness check

We have incorporated the two key elements in the smartphone industry: the supplier and the mutual outsourcing. We further investigate several scenarios to clarify that the key elements are crucial. First, we derive the two results with only one of the two elements in the model, respectively, to clarify that the existence of multiple inputs is essential for obtaining the asymmetric organizational forms. Second, we show that input price discrimination by the supplier does not bear on the main result (Proposition 5). The detail is available in an earlier version (Arai and Matsushima, 2021).

5 Conclusion

We consider a downstream duopoly model with a monopolistic common supplier and mutual outsourcing between the two downstream firms. The recent procurement environment in the smartphone industry motivates us to formulate the market structure. We also incorporate managerial delegation into the duopoly model, as in Fershtman and Judd (1987), because deciding on organizational forms within a firm is critical to achieving better performance in almost all industries (Foss and Klein, 2014).

Section 4 shows that depending on the fixed cost of delegating to a manager, we obtain three types of managerial forms in equilibrium: (i) both owners delegate if and only if the fixed cost is low; (ii) only one of the owners delegates if and only if the fixed cost is medium; (iii) no owner delegates if and only if the fixed cost is high. Section 4.6 shows that the two key elements in our model are necessary for obtaining the asymmetric managerial forms in the main results.

Following the literature of strategic delegation, we assume the standard linear combination of profit and revenue as an incentive contract to a manager. The linear formulation is consistent with the real-world practices (Murphy, 1999).[29] Contrary to the formulation, recently, Fanti et al. (2017) and Dickson et al. (2021) propose interesting incentive structures. They show nonstandard effects of the incentive structure.

We briefly discuss nonlinear incentive contracts in our main model, as in Dickson et al. (2021). Following their formulation, we set the nonlinear performance measure as follows: $g_i = \alpha_i \Pi_i + (1 - \alpha_i) v(R_i)$, where $v(R_i)$ is a concave function of the revenue R_i. Incorporating the concave function differs from the performance measure in the main model. Because of the concavity, each firm is less aggressive than when $v(R_i)$ is linear in R_i, $v(R_i) = R_i$. Even in this modified formulation, each firm needs to internalize the licensing revenue by offering an incentive contract that makes its manager less aggressive. We guess that each delegating firm sets α_i to be greater than 1 unless the concavity of $v(R_i)$ is strong. If this logic holds, the relationship between the decisions to employ delegation and the supplier's monopoly power remains in the modified formulation. Therefore, we guess that the main results hold even in the modified formulation. However, because the modified model requires us to solve complex problems, we leave these problems to future research.

[29] This is also consistent with the previous studies finding the plausibility of linear contracts (Bhattacharyya and Lafontaine, 1995; Chu and Sappington, 2007; Bose, Pal, and Sappington, 2011).

Besides, it may be interesting to investigate oligopoly competition with nonprofit maximizing firms in our model framework (for instance, socially concerned firms (e.g., Kopel and Putz, 2021, and the references therein)). This possibility is also left for future research. Furthermore, considering the endogenous choice of outsourcing in our model framework is an interesting topic (e.g., Colombo and Scrimitore, 2018) for future research.

Appendix

The stage games in Section 4.2

Suppose that only firm j delegates. We can use the derived outcome on the quantities in the fourth stage in the previous subsection. Thus, first, we consider the third stage.

The third stage In this subgame, firm i does not delegate, which is equivalent to the case in which firm i sets $\alpha_i = 1$ in this stage. From (4), we can obtain $\alpha_j(1, \boldsymbol{r}, w)$ as

$$\alpha_j = (1, \boldsymbol{r}, w) = \frac{-a + 6\,(r_i + w) - (r_j + w)}{4\,(r_i + w)} + \frac{3r_j}{4\,(r_i + w)}.$$

By using this equation and (2), we can rewrite the outputs as a function of $(\boldsymbol{r}, w)$:

$$q_i(\boldsymbol{r}, w) = \frac{a + 2\,(r_i + w) - 3(r_j + w)}{4} + \frac{r_j}{4},$$
$$q_j(\boldsymbol{r}, w) = \frac{a + (r_j + w) - 2\,(r_i + w)}{2} - \frac{r_j}{2}.$$

The second stage Using the quantities derived immediately prior to equation (7), we can obtain the supplier's best response function as:

$$w = \frac{3a - 2(r_i + r_j)}{6} \tag{11}$$

The best response functions of the downstream firms are:

$$r_i = \frac{a - (2r_j + 3w) + 2w}{6} + \frac{2(a + w - 2w)}{6} = \frac{3a - 3w - 2r_j}{6}, \tag{12}$$

$$r_j = \frac{a - 2(r_i + w) + w}{4} + \frac{a + 2r_i - 3w}{4} = \frac{a - w}{2}. \tag{13}$$

Solving the simultaneous equations in (11), (12), and (13), we obtain Proposition 2.

The stage games in Section 4.3

We consider the case in which no firm delegates to managers. This case is equivalent to the case in which $\alpha_i = \alpha_j = 1$.

The fourth stage From equation (2), the equilibrium output of firm i is equal to

$$q_i(\boldsymbol{r}, w) = \frac{a + (r_i + w) - 2\,(r_j + w)}{3}. \tag{14}$$

The second stage Anticipating the quantities in (14), the supplier maximizes the profit in (7). Solving the first-order conditions of the maximization problem, the supplier's best response function is:

$$w = \frac{2a - r_i - r_j}{4}, \quad (i, j = 1, 2,\ j \neq i). \tag{15}$$

Anticipating the quantities in (14), each downstream firm maximizes the profit in (9). Solving the first-order condition of the maximization problems, we obtain the best response function of each downstream firm:

$$r_i = \frac{5a - 5w - r_j}{10}, \quad (i, j = 1, 2,\ j \neq i). \tag{16}$$

Using the best response functions in (15) and (16), we can obtain Proposition 3.

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The impacts of suppliers and mutual outsourcing on organizational forms

Yasuhiro Arai and Noriaki Matsushima

Supplementary Appendix

We explain the mathematical procedures to derive the results in Section 5.

A Without mutual outsourcing

We remove mutual outsourcing from the model. In other words, we consider the case in which $r_i = r_j = 0$.

A.1 Both firms delegate

The objective of the manager in firm i is

$$\begin{aligned} g_i &= \alpha_i \Pi_i + (1-\alpha_i) R_i \\ &= \alpha_i \{(a - q_i - q_j - w) q_i\} + (1-\alpha_i)(a - q_i - q_j) q_i \end{aligned}$$

We can obtain the best response function of firm i's manager as follows:

$$q_i = \frac{a - q_j - \alpha_i w}{2}, \quad (i, j = 1, 2, \ j \neq i).$$

Solving the simultaneous equations mentioned above, we obtain the quantity of firm i:

$$q_i(\boldsymbol{\alpha}, w) = \frac{a - 2\alpha_i w + \alpha_j w}{3}.$$

The third stage The owner of downstream firm i sets the parameter α_i to maximize profit $\Pi_i(\boldsymbol{\alpha}, w)$. We solve the maximization problem and then obtain the owner's best response function:

$$\alpha_i(\alpha_j, w) = \frac{6w - a}{4w} - \frac{\alpha_j w}{4w} \quad (i, j = 1, 2,\ j \neq i).$$

Solving the simultaneous equations, we obtain $\alpha_i(w)$

$$\alpha_i(\boldsymbol{w}) = \frac{-a + 8w - 2w}{5w}.$$

We can rewrite output as a function of w:

$$q_i\,(w) = \frac{2(a - 3w + 2w)}{5}.$$

The second stage The supplier sets w to maximize its own profits. From the supplier's profit function, we obtain the equilibrium parameters:

$$w^* = \frac{a}{2},\ r_i^* = 0,\ q_i^* = \frac{a}{5},\ \alpha_i^* = \frac{4}{5}.$$

The profits under (D, D) are

$$\pi_i = \pi_j = \frac{a^2}{50} - F, \quad \pi_S = \frac{a^2}{5}.$$

A.2 Only one firm delegates

Now suppose that only firm j delegates. Thus, first, we consider the third stage.

The third stage In this subgame, firm i does not delegate; in other words, firm i sets $\alpha_i = 1$ in this stage. We can obtain $\alpha_j(1, w)$ as

$$\alpha_j = (1, w) = \frac{-a + 6w - w}{4w}.$$

By using this equation, we can rewrite the outputs as a function of w:

$$q_i(w) = \frac{a + 2w - 3w}{4},\ q_j(w) = \frac{a + w - 2w}{2}.$$

The second stage Solving the first-order condition of the supplier, we obtain

$$w^* = \frac{a}{2},\ r_i^* = r_j^* = 0,\ q_i^* = \frac{a}{8},\ q_j^* = \frac{a}{4},\ \alpha_i^* = 1,\ \alpha_j^* = \frac{3}{4}.$$

The profits under (N, D) are

$$\pi_i = \frac{a^2}{64},\ \pi_j = \frac{a^2}{32} - F,\quad \pi_S = \frac{3a^2}{16}.$$

A.3 No firm delegates

Next, we consider the case in which no firm delegates to managers, that is, $\alpha_i = \alpha_j = 1$.

The fourth stage The quantity of firm i is equal to

$$q_i(w) = \frac{a + w - 2w}{3}.$$

The second stage Anticipating the quantities, the supplier maximizes its profit. Solving the first-order conditions of the maximization problem, we can obtain the equilibrium outcome under the case in which no firm delegates as follows.

$$w^* = \frac{a}{2},\ r_i^* = 0,\ q_i^* = \frac{a}{6}.$$

The profits under (N, N) are

$$\pi_i = \pi_j = \frac{a^2}{36},\quad \pi_S = \frac{a^2}{6}.$$

A.4 First stage

We can derive the payoff matrix in the first stage (see Table 2).

The equilibrium organizational forms are as follows: *The outcome that both owners delegate is sustainable in equilibrium if and only if $F \leq 7a^2/1600$. The outcome that no owner delegates is sustainable in equilibrium if and only if $a^2/288 \leq F$. The two*

1/2	D	N
D	$a^2/50-F$ (firm 2); $a^2/50-F$ (firm 1)	$a^2/64$ (firm 2); $a^2/32-F$ (firm 1)
N	$a^2/32-F$ (firm 2); $a^2/64$ (firm 1)	$a^2/36$ (firm 2); $a^2/36$ (firm 1)

D: Delegation; N: No delegation.

Table 2: The first-stage decision: without mutual outsourcing

outcomes can be simultaneously sustainable in equilibrium if and only if $a^2/288 \leq F \leq 7a^2/1600$.

B Without the monopolistic supplier

We remove the monopolistic supplier from the main model. In other words, we consider the case in which $w_i = w_j = 0$.

B.1 Both firms delegate

The fourth stage The objective of the manager in firm i is

$$\begin{aligned} g_i &= \alpha_i \Pi_i + (1-\alpha_i) R_i \\ &= \alpha_i \{(a - q_i - q_j - r_j)q_i + r_i q_j\} + (1-\alpha_i)(a - q_i - q_j)q_i \end{aligned}$$

We can obtain the best response function of firm i's manager as follows:

$$q_i = \frac{a - q_j - \alpha_i r_j}{2}, \quad (i, j = 1, 2,\ j \neq i).$$

Solving the simultaneous equations, we obtain the quantity of firm i:

$$q_i(\boldsymbol{\alpha}, \boldsymbol{r}) = \frac{a - 2\alpha_i r_j + \alpha_j r_i}{3}.$$

Using $q_i(\boldsymbol{\alpha}, \boldsymbol{r})$, we can obtain the profit in the fourth stage.

The third stage The owner of downstream firm i sets the parameter α_i to maximize its profit. From the profit in the fourth stage, we solve the maximization problem and then obtain the owner's best response function:

$$\alpha_i(\alpha_j, \boldsymbol{r}) = \frac{6r_j - a}{4r_j} - \frac{\alpha_j r_i}{4r_j} + \frac{3r_i}{4r_j}, \quad (i, j = 1, 2, \ j \neq i).$$

Solving the simultaneous equations above, we obtain $\alpha_i(\boldsymbol{r})$

$$\alpha_i(\boldsymbol{r}) = \frac{-a + 7r_j + 2r_i}{5r_j}.$$

By using $\alpha_i(\boldsymbol{r})$, we can rewrite the output as a function of r:

$$q_i\left(\boldsymbol{r}\right) = \frac{2a - 4r_j + r_i}{5}.$$

The second stage Firms 1 and 2 set r_1, and r_2 to maximize their own profits. Solving the first-order conditions, we have the best response functions:

$$r_i = \frac{17a - 9r_j}{34}, \quad (i, j = 1, 2, \ j \neq i).$$

From the best response functions, the equilibrium wholesale prices, output levels, and α_i $(i = 1, 2)$ are

$$w_i^* = w_j^* = 0, \ r_i^* = \frac{17a}{43}, \ q_i^* = \frac{7a}{43}, \ \alpha_i^* = \frac{22}{17}.$$

The profits under (D, D) are

$$\pi_i = \pi_j = \frac{203a^2}{1849} - F \simeq 0.1098a^2 - F, \quad \pi_S = 0.$$

B.2 Only one firm delegates

Now suppose that only firm j delegates. We can use the derived outcome on the quantities in the fourth stage in the previous subsection. Thus, first, we consider the third stage.

The third stage In this subgame, firm i does not delegate, which is equivalent to the case in which firm i sets $\alpha_i = 1$ in this stage. We can obtain $\alpha_j(1, \boldsymbol{r})$ as

$$\alpha_j = (1, \boldsymbol{r}) = \frac{-a + 6r_i - r_j}{4r_i} + \frac{3r_j}{4r_i}.$$

We can rewrite the outputs as a function of r:

$$q_i(\boldsymbol{r}) = \frac{a + 2r_i - 2r_j}{4},\ q_j(\boldsymbol{r}) = \frac{a - 2r_i}{2}.$$

The second stage The best response functions of the downstream firms are:

$$r_i = \frac{3a - 2r_j}{6},\ r_j = \frac{a}{2}.$$

From these equations, and $w_i = w_j = 0$, we can obtain the equilibrium output levels, and α_i $(i = 1, 2)$ as follows.

$$w_i^* = w_j^* = 0,\ r_i^* = \frac{a}{3},\ r_j^* = \frac{a}{2},\ q_i^* = \frac{a}{6},\ q_j^* = \frac{a}{6},\ \alpha_i^* = 1,\ \alpha_j^* = \frac{3}{2}.$$

The profits under (N, D) are

$$\pi_i = \frac{a^2}{12},\ \pi_j = \frac{5a^2}{36} - F, \quad \pi_S = 0.$$

B.3 No firm delegates

Next, we consider the case in which no firm delegates to managers, which is equivalent to the case in which $\alpha_i = \alpha_j = 1$.

The fourth stage In this case, the quantity of firm i is equal to

$$q_i(\boldsymbol{r}) = \frac{a + r_i - 2r_j}{3}.$$

The second stage We obtain the best response function of each downstream firm:

$$r_i = \frac{5a - r_j}{10}, \quad (i, j = 1, 2, \ j \neq i).$$

From these best response functions, we can obtain the equilibrium outcomes under the case that no firm delegates:

$$w_i^* = w_j^* = 0, \ r_i^* = \frac{5a}{11}, \ q_i^* = \frac{2a}{11}.$$

The profits under (N, N) are

$$\pi_i = \pi_j = \frac{14a^2}{121} \simeq 0.1157a^2, \quad \pi_S = 0.$$

B.4 First stage

We can derive the payoff matrix in the first stage (see Table 3).

1/2	D	N
D	$203a^2/1849 - F$ $203a^2/1849 - F$	$a^2/12$ $5a^2/36 - F$
N	$5a^2/36 - F$ $a^2/12$	$14a^2/121$ $14a^2/121$

D: Delegation; N: No delegation.

Table 3: The first-stage decision: without the supplier

The equilibrium organizational forms are as follows: *The outcome that both owners delegate is sustainable in equilibrium if and only if* $F \leq 587a^2/22188$. *The outcome that no owner delegates is sustainable in equilibrium if and only if* $101a^2/4356 \leq F$. *The two outcomes can be simultaneously sustainable in equilibrium if and only if* $101a^2/4356 \leq F \leq 587a^2/22188$.

C Wholesale price discrimination by the monopolistic supplier

We suppose that the monopolistic supplier can price discriminate to the downstream firms.

C.1 Both firms delegate

The fourth stage The objective of the manager in firm i is

$$\begin{aligned} g_i &= \alpha_i \Pi_i + (1-\alpha_i) R_i \\ &= \alpha_i \left\{ (a - q_i - q_j - r_j - w_i) q_i + r_i q_j \right\} + (1-\alpha_i)(a - q_i - q_j) q_i \end{aligned}$$

We can obtain the best response function of firm i's manager as follows:

$$q_i = \frac{a - q_j - \alpha_i (r_j + w_i)}{2}, \quad (i, j = 1, 2,\ j \neq i).$$

Solving the simultaneous equations mentioned above, we obtain the quantity of firm i:

$$q_i(\boldsymbol{\alpha}, \boldsymbol{r}, \boldsymbol{w}) = \frac{a - 2\alpha_i (r_j + w_i) + \alpha_j (r_i + w_j)}{3}.$$

The third stage We solve the owner's maximization problem and then obtain its best response function:

$$\alpha_i(\alpha_j, \boldsymbol{r}, \boldsymbol{w}) = \frac{6(r_j + w_i) - a}{4(r_j + w_i)} - \frac{\alpha_j (r_i + w_j)}{4(r_j + w_i)} + \frac{3r_i}{4(r_j + w_i)}, \quad (i, j = 1, 2,\ j \neq i).$$

Solving the simultaneous equations above, we obtain $\alpha_i(\boldsymbol{r}, \boldsymbol{w})$

$$\alpha_i(\boldsymbol{r}, \boldsymbol{w}) = \frac{-a + 8(r_j + w_i) - 2(r_i + w_j)}{5(r_j + w_i)} + \frac{4r_i - r_j}{5(r_j + w_i)}.$$

By substituting $\alpha_i(\boldsymbol{r}, \boldsymbol{w})$ into $q_i(\boldsymbol{\alpha}, \boldsymbol{r}, \boldsymbol{w})$, we can rewrite output as a function of $(\boldsymbol{r}, \boldsymbol{w})$:

$$q_i(\boldsymbol{r}, \boldsymbol{w}) = \frac{2(a - 3(r_j + w_i) + 2(r_i + w_j))}{5} + \frac{2r_j - 3r_i}{5}.$$

The second stage The supplier and firms 1 and 2 set w, r_1, and r_2 to maximize their own profits. Solving the first-order conditions, we have the best response functions:

$$
\begin{aligned}
w_i &= \frac{2a - 4r_j + (r_i + 4w_j)}{12} + \frac{4w_j}{12} \\
&= \frac{2a - 4r_j + r_i + 8w_j}{12}, \quad (i, j = 1, 2,\ j \neq i), \\
r_i &= \frac{7(a - (2r_j + 3w_i) + 2w_j)}{34} + \frac{5(2a + (r_j + 4w_i) - 6w_j)}{34} \\
&= \frac{17a - (w_i + 16w_j + 9r_j)}{34}, \quad (i, j = 1, 2,\ j \neq i).
\end{aligned}
$$

In this case, the equilibrium parameters are

$$
w_i^* = \frac{35a}{121},\ r_i^* = \frac{34a}{121},\ q_i^* = \frac{14a}{121},\ \alpha_i^* = \frac{79}{69}.
$$

The profits under (D, D) are

$$
\pi_i = \pi_j = \frac{812a^2}{14641} - F \simeq 0.0555a^2 - F, \quad \pi_S = \frac{980a^2}{14641} \simeq 0.0669a^2.
$$

C.2 Only one firm delegates

Now suppose that only firm j delegates. We consider the third stage.

The third stage In this subgame, firm i does not degelate, which is equivalent to the case in which firm i sets $\alpha_i = 1$. We can obtain $\alpha_j(1, \boldsymbol{r}, \boldsymbol{w})$ as

$$
\alpha_j = (1, \boldsymbol{r}, \boldsymbol{w}) = \frac{-a + 6\left(r_i + w_j\right) - (r_j + w_i)}{4\left(r_i + w_j\right)} + \frac{3r_j}{4\left(r_i + w_j\right)}.
$$

We can rewrite the outputs as a function of

$$
\begin{aligned}
q_i(\boldsymbol{r}, \boldsymbol{w}) &= \frac{a + 2\left(r_i + w_j\right) - 3(r_j + w_i)}{4} + \frac{r_j}{4}, \\
q_j(\boldsymbol{r}, \boldsymbol{w}) &= \frac{a + (r_j + w_i) - 2\left(r_i + w_j\right)}{2} - \frac{r_j}{2}.
\end{aligned}
$$

The second stage Using the quantities derived immediately above, we can obtain the supplier's best response functions as:

$$w_i = \frac{a - 2r_j + 2\left(r_i + w_j\right)}{6} + \frac{2w_j}{6} = \frac{a - 2r_j + 2r_i + 4w_j}{6},$$
$$w_j = \frac{a - 2r_i + w_i}{4} + \frac{w_i}{4} = \frac{a - 2r_i + 2w_i}{4}.$$

The best response functions of the downstream firms are:

$$r_i = \frac{a - (2r_j + 3w_i) + 2w_j}{6} + \frac{2(a + w_i - 2w_j)}{6} = \frac{3a - 2w_j - w_i - 2r_j}{6},$$
$$r_j = \frac{a - 2(r_i + w_j) + w_i}{4} + \frac{a + 2(r_i + w_j) - 3w_i}{4} = \frac{a - w_i}{2}.$$

We can obtain

$$w_i^* = \frac{a}{3},\ w_j^* = \frac{3a}{10},\ r_i^* = \frac{7a}{30},\ r_j^* = \frac{a}{3},\ q_i^* = \frac{a}{10},\ q_j^* = \frac{2a}{15},\ \alpha_i^* = 1,\ \alpha_j^* = \frac{19}{16}.$$

The profits under (N, D) are

$$\pi_i = \frac{37a^2}{900} \simeq 0.0411a^2,\ \pi_j = \frac{29a^2}{450} - F \simeq 0.0644a^2 - F,\ \pi_S = \frac{11a^2}{150} \simeq 0.0733a^2.$$

C.3 No firm delegates

Next, we consider the case in which no firm delegates to managers, which is equivalent to the case in which $\alpha_i = \alpha_j = 1$.

The fourth stage The quantity of firm i is equal to

$$q_i(\boldsymbol{r}, \boldsymbol{w}) = \frac{a + (r_i + w_j) - 2\left(r_j + w_i\right)}{3}.$$

The second stage Solving the first-order conditions of the maximization problem, we can obtain the supplier's best response functions as:

$$w_i = \frac{a + (r_i + w_j) - 2r_j}{4} + \frac{w_j}{4}, \quad (i, j = 1, 2,\ j \neq i).$$

Similarly, we obtain the best response function of each downstream firm:

$$r_i = \frac{5a - 4w_j - w_i - r_j}{10}, \quad (i, j = 1, 2, \ j \neq i).$$

Using those best response functions, we can obtain the equilibrium wholesale prices and output levels as follows.

$$w_i^* = \frac{6a}{17}, \ r_i^* = \frac{5a}{17}, \ q_i^* = \frac{2a}{17}.$$

The profits under (N, N) are

$$\pi_i = \pi_j = \frac{14a^2}{289} \simeq 0.0484a^2, \quad \pi_S = \frac{24a^2}{289} \simeq 0.0830a^2.$$

C.4 First stage

We can derive the payoff matrix in the first stage (see Table 4).

1/2	D	N
D	$0.0555a^2 - F$ $0.0555a^2 - F$	$0.0411a^2$ $0.0644a^2 - F$
N	$0.0644a^2 - F$ $0.0411a^2$	$0.0484a^2$ $0.0484a^2$

D: Delegation; N: No delegation.

Table 4: The first-stage decision: different input prices by the supplier

The equilibrium organizational forms are as follows: *The outcome that both owners delegate if and only if* $F < 0.0144a^2$*; Only one of the owners delegates if and only if* $0.0144a^2 < F < 0.016a^2$*; No owner delegates if and only if* $0.016a^2 < F$.