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Delegation vs. Control in Supply Chain Procurement under Competition

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This paper studies the optimal component procurement strategies of two competing OEMs selling substitutable products. The OEMs outsource their production to a common contract manufacturer, who in turn needs an input from a component supplier. Each OEM may either directly procure the input from the component supplier, or delegate the procurement task to the contract manufacturer. We first analyze the OEMs' procurement game under a non-strategic supplier whose component price is exogenously given. It is found that symmetric equilibria arise for most situations, that is, both OEMs either control or delegate their component procurement in equilibrium. Interestingly, despite the commonly-held belief that the contract manufacturer would be worse off as OEMs gain component procurement control, we show that the contract manufacturer may enjoy a higher profit. Then we study the OEMs' procurement game under a strategic supplier who can set its component price. We find that the supplier's strategic pricing behavior plays a critical role in the equilibrium procurement structure. In particular, in the equilibrium under strategic supplier, the larger OEM always uses delegation while the smaller OEM may use either delegation or control. By identifying the driving forces behind the OEMs' procurement choices, this research helps explain observed industry practices and offer useful guidelines for firms' component sourcing decisions.

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1. Introduction

Fierce competition in the global marketplace has driven many original equipment manufacturers (OEMs) to outsource their production processes to external suppliers. By doing so, the OEMs can reduce production costs while focusing on core competencies such as product design and marketing (Kakabadse and Kakabadse 2005). It has been widely believed that the trend of outsourcing will continue in the near future (Stevens 2009). A prevailing practice in production outsourcing is the so-called contract manufacturing, that is, instead of making the products themselves, the OEMs depend on contract manufacturers to produce their products. In order to fulfill the production function, the contract manufacturer may need to procure certain parts and components on behalf of the OEM. This gives rise to a fundamental question: should the OEM control the procurement of components or delegate this task to the contract manufacturer?

This question has received an increasing amount of attention in the business media in recent years. Industry evidence shows that both the "delegation" and the "control" strategies have been adopted by OEMs. For instance, Sun Microsystems imposes a tight control on component procurement whereas Cisco prefers to delegate the responsibility to its contract manufacturers (Kayiş et al. 2013). Even the same firm may customize the strategies for different parts and components. Dell delegates the procurement of some components for its notebooks, including cases and circuit boards, to its contract manufacturers, but controls the procurement of CPUs, hard disk drives, and memory chips (CENS 2007). Similarly, Hewlett-Packard (HP) delegates commodity-like components to suppliers, but controls the procurement of strategic components (Carbone 2004). A more recent industry trend indicates that more and more OEMs are switching from the "delegation" strategy to the "control" strategy. Motorola has changed its long-standing strategy of delegating component procurement to its contract manufacturers to controlling their component procurement (Jorgensen 2004). Boeing has launched a procurement program to negotiate contracts directly with fastener suppliers instead of decentralized procurement via its first-tier manufacturing partners (Anupindi and Lee 2009). Such a trend has also been observed in the service industries. For example, rather than asking Boeing and Airbus to manage engine parts procurement, airline carriers have increasingly used direct contracts with aircraft engine manufacturers (Kayiş et al. 2013).

An OEM's decision to delegate or control its component procurement is critical when it intends to use outsourcing as a competitive weapon in the marketplace. The management at Motorola has explicitly emphasized that controlling component procurement would help restore the company's competitive advantage (Jorgensen 2004). Interestingly, it is quite common that competing OEMs share common contract manufacturers and depend on the same supplier for critical components or parts. For example, Dell and HP compete in the laptop computer market. They use a common contract manufacturer, Wistron, to produce their products (Shen 2011). In addition, both Dell and HP use the same components, such as Intel's processors. Similarly, a number of OEMs (e.g., Apple, Motorola Mobility, and Nokia) depend on Foxconn for the manufacturing of their smartphones, and they all use the chips supplied by Qualcomm, a dominant chip maker for smartphones and other electronics products (Troianovski and Clark 2012). Clearly, competition plays an important role in firms' procurement strategy decisions. In particular, when selecting its own procurement structure (i.e., delegation or control), a firm must take its competitors' strategies into consideration.

Our study aims at better understanding how firms should manage component procurement in a supply chain with competition. A game-theoretic model is proposed for this purpose. We consider two competing OEMs that outsource their production to a common contract manufacturer; both of the OEMs' products require a key component provided by a third-party supplier. The OEMs may either procure the component directly from the supplier or delegate the procurement function to the contract manufacturer. For concision, hereafter we will use D to stand for the *direct* procurement strategy (i.e., the control strategy) and I for the *indirect* procurement strategy (i.e., the delegation strategy), respectively. For instance, if both OEMs delegate their component procurement to the contract manufacturer, the procurement structure is called II. As typical, procurement contracts reflect economies of scale via the use of quantity discount terms, that is, volume increases are rewarded by lower unit prices. We divide the analysis in this study into two parts. In the first part, the supplier's price is exogenously given, that is, the supplier is non-strategic. This corresponds to market conditions where the supplier has little pricing flexibility for various reasons. In the second part, the supplier can adjust its component price in response to the OEMs' procurement choice, that is, the supplier is strategic. This fits well with situations where the supplier possesses more pricing power in the market. With this model setup, we attempt to address the following research questions: *What is the equilibrium outcome of the procurement game? How does the procurement structure affect supply chain members' profits? What is the impact of the supplier's pricing behavior on the OEMs' procurement choices?* There are several major findings from this study:

First, under a non-strategic supplier, either II or DD may arise as equilibrium for most parameter ranges. The II equilibrium is not surprising because it allows the contract manufacturer to aggregate the orders and thus achieve a deeper quantity discount from the supplier. However, the DD equilibrium is less intuitive. Under the DD equilibrium, no OEM will unilaterally switch from direct to indirect procurement. We examine the firms' incentives and identify an interesting trade-off behind an OEM's potential deviation from DD. If an OEM deviates from DD, then a differentiated sourcing strategy (either ID or DI) will soften the market competition, that is, both OEMs' prices will go up. This competition dampening effect benefits both OEMs. However, deviating from D to I will increase the component price of the OEM, due to the so-called discount-sharing effect. That is, under delegation, the discount from large order quantity must be shared between the contract manufacturer and the OEM, so these downstream firms have less incentive to order more components, which increases the component price. Such a discount-sharing effect is similar to double marginalization but occurs in a different setting. Under reasonable conditions, no OEM will deviate from DD because the positive competition dampening effect is dominated by the negative discount-sharing effect, making DD an equilibrium.

Second, we find that the contract manufacturer may prefer that the OEMs control their component procurement under non-strategic supplier, that is, the contract manufacturer's profit is higher under DD than under II. This is contrary to a widely held belief in practice that the contract manufacturer's profit will be squeezed when OEMs switch from delegation to controlling their component procurement (see, e.g., the discussion in Pick 2004). It can be shown that the margins charged by the contract manufacturer do not change across the II and DD structures, but the margin for the larger OEM is higher than that for the smaller OEM; in addition, the larger OEM will order more (while the smaller OEM will order less) under DD than under II. Therefore, the contract manufacturer earns a higher profit under DD because a larger portion of demand will come from the more profitable customer. This result implies that contract manufacturers may not be worse off if both OEMs change their procurement strategy from delegation to direct control.

Third, our analysis shows that the supplier's strategic pricing behavior plays a critical role in the OEMs' equilibrium procurement strategies. In the strategic supplier case, either II or DI may arise as equilibrium outcome in the procurement game; however, unlike in the non-strategic case, DD is not an equilibrium any more. It is noteworthy that DI can never be an equilibrium under a non-strategic supplier. This change is caused by a new driving force associated with the supplier's pricing behavior. Specifically, when the supplier is able to customize the price, it tends to charge a higher (lower) price to the larger (smaller) OEM due to its higher (lower) market potential. By deviating from II, the smaller OEM will enjoy a more advantageous component price than the larger OEM. As a result, under a strategic supplier, the smaller OEM may have incentives to choose direct control while the larger OEM always prefers delegation. Therefore, II and DI are the only possible equilibria of the procurement game.

The rest of the study is organized as follows. Section 2 reviews the related literature. Section 3 describes the model setting. The game analyses for the non-strategic and strategic supplier cases are presented in sections 4 and 5, respectively. Section 6 compares the equilibrium procurement structures in the two cases and section 7 concludes the study. All proofs are given in the Appendix.

2. Literature Review

Recently, there has been an increasing interest in studying firms' component procurement strategies when outsourcing to contract manufacturers. Our study is mostly related to this growing body of literature. Guo et al. (2010) consider a three-tier supply chain where an OEM may choose from three outsourcing structures. These structures may involve either controlling or delegating the component procurement function. It has been assumed that both the contract manufacturer's and the component supplier's production costs are private information. They characterize each firm's optimal decision and compare their profits in different outsourcing structures. Kayiş et al. (2013) study a contracting problem where an OEM chooses between delegating component procurement to the contract manufacturer and contracting directly with the component supplier. They examine how asymmetric cost information and contract complexity influence the optimal component procurement decision. They show that if complex contracts can be used, then the OEM would be indifferent between delegation and control of component procurement; but under price-only contracts, either of these procurement structures could be optimal. Similarly, Niu et al. (2014) examine the interaction between the OEM's delegation decision and the contract format (e.g., push or pull). They find that the contract formats have different impacts on the OEM's delegation decision. They also characterize the conditions under which the OEM may prefer a specific contract format. Deshpande et al. (2011) study the component procurement problem from a distinct perspective. In particular, they aim to develop secure price-masking mechanisms that possess some useful properties, such as preserving the private component prices of all parties in the supply chain.

When studying the component procurement problem, most studies consider a monopolist OEM in the market. One of the exceptions is Chen et al. (2012) in which two competing OEMs outsource to a common contract manufacturer. It has been assumed that only the larger OEM can choose its component procurement structure, and the smaller OEM must delegate its procurement function to the contract manufacturer. This is different from our study where both OEMs can choose their component procurement structures. In addition, we study two different scenarios to shed some light on the effect of competition in the supply market on the OEMs' optimal component procurement strategies.

Our study is also related to the extensive literature on quantity discounts that have been mostly studied from the perspectives of channel coordination (Chen and Roma 2011, Ingene and Parry 1995) and operational efficiency (Dada and Srikanth 1987, Erhun et al. 2008). Interested readers are referred to Weng (1995) and Chen and Roma (2011) for a review of this literature. In particular, Chen and Roma (2011) study two retailers' decision to form a group buying unit to take advantage of the quantity discounts. This is similar to the OEMs' delegation or control decision in our study because the firms will get common sourcing terms if they both delegate, which is essentially group buying. However, Chen and Roma (2011) are not concerned about contract manufacturing, while we consider a three-tier supply chain where the supplier's component needs to be processed further by a contract manufacturer before it can be delivered to the OEMs. In addition, we also study the case where the component supplier is strategic by customizing the prices for different downstream firms.

There are papers in the economics literature that study similar problems where firms transact in a multi-tier network (see, e.g., Baron and Basenko 1992, McAfee and McMillan 1995, Melumad et al. 1997, Mookherjee 2006). These studies adopt the principal-agent framework to investigate the firms' optimal transaction strategies in a network. In this study, we focus on studying the impact of competition at the supplier's and the OEMs' levels on the OEMs' component procurement strategies. So both the model setting and the insights are different from those in the above mentioned economics literature.

3. Model Setting

We consider a three-tier supply chain consisting of a component supplier, a contract manufacturer, and two OEMs. The downstream OEMs, denoted by M1 and M2, produce and sell partially differentiated products in the same market. Both OEMs use the contract manufacturer to perform significant manufacturing tasks or customized processing services. For instance, they depend on the contract manufacturer for the assembly of a portion or the whole product. We use C to stand for the contract manufacturer. Like the OEMs, the contract manufacturer does not manufacture its product from scratch; instead, it needs a key component (e.g., a computer chip) from the upstream supplier. Let S denote the component supplier. Such a supply chain structure is quite common in the industry. For instance, the two OEMs may refer to Dell and HP, while the contract manufacturer and chip supplier can be viewed as Wistron and Intel, respectively.

We are interested in the OEMs' procurement strategies in such a model setting. Specifically, an important question for the OEMs is: should they control or delegate their component procurement to their contract manufacturer and when? To address this question, we study a two-stage game among the above four players: the OEMs (M1 and M2), the contract manufacturer (C), and the component supplier (S).

In the first stage of the game, the OEMs choose their procurement strategy simultaneously. In particular, an OEM may choose to either control procurement of the key component or delegate it to the contract manufacturer. The former case is referred to as "direct procurement," or *D* for short, since the OEM directly contracts with the component supplier, while the latter case is called "indirect procurement," or *I* for short, since the OEM outsources procurement to the contract manufacturer. Clearly, depending on the OEMs' decisions in the first stage, there are four possible procurement structures: {*II*, *DD*, *DI*, *ID*}, where the letters stand for the procurement strategies of the two OEMs, respectively. For illustration, Figure 1 depicts two of the procurement structures. Figure 1a corresponds to the *II* structure (indirect procurement for both M1 and M2), where C is responsible for procurement of the key component from S. Figure 1b represents the *DD* structure (direct procurement for both M1 and M2), where both OEMs contract directly with S to supply the key component to C. For brevity, we omit the pictures for procurement structures *DI* and *ID* as self-evident by-products of our discussion so far.

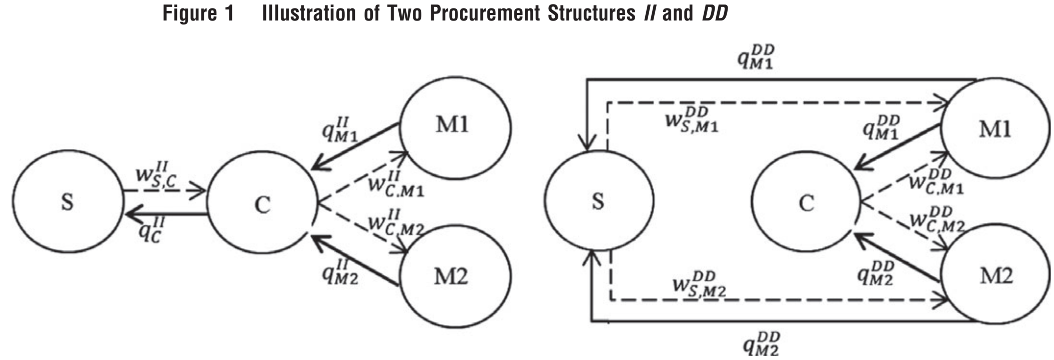
After the procurement structure has been determined, players set their prices and place their orders in the second stage of the game. The detailed sequence of events in the second stage will be introduced in the next two sections, but first we need to introduce some notations. Let $i \in \{M1, M2\}$ index the OEMs and $j \in \{II, DD, DI, ID\}$ index the procurement structures. Further, let p_i^j and q_i^j denote the price and demand for OEM i in the market under procurement structure j. We consider a linear duopoly demand model as follows.

$$q^j_{M_1} = 1 - p^j_{M_1} + \gamma p^j_{M_2}, \tag{1}$$

$$q^j_{M_2} = \alpha - p^j_{M_2} + \gamma p^j_{M_1}. \tag{2}$$

This model has been widely used to model price competition in the market (see, e.g., Feng and Lu 2013, McGuire and Staelin 1983, Trivedi 1998). In this model, α denotes M2's market depth while M1's market depth is normalized to 1. Without loss of generality we assume that $\alpha \geq 1$. The parameter γ captures the demand interdependence for the products and satisfies $0 \leq \gamma \leq 1$. When γ is equal to zero, the OEMs' product demands are independent and there is no market competition. As γ increases, the

Figure 1 Illustration of Two Procurement Structures *II* and *DD*



(a) *II* procurement structure **(b)** *DD* procurement structure market becomes more competitive, and one firm's price decision has a greater impact on the other firm's demand. Thus γ reflects the intensity of competition between the OEMs. Market demand for many electronics products, such as cell phones, computers, and game consoles, can be modeled as above where each OEM's market depth is a proxy of its market power, brand image, and leadership position in the market. Thus $\alpha > 1$ implies that M2 has a stronger position than M1 in the market, that is, M2 enjoys a higher demand if the firms charge the same market price. Also M2's demand would be less price-sensitive due to its larger α, that is, M1's demand has a greater price-elasticity than M2's. It is straightforward to show that price elasticity of M2 decreases in α. All firms' production costs are normalized to zero to simplify the analysis and exposition. Each firm's objective is to maximize its own profit.

Throughout the study, we assume that the supplier offers a quantity discount price schedule to buyers: The unit price for supplier's component is $w(q) = w_0 - \beta q$ if a buyer orders a quantity q, where w_0 is the base price and β is the discount rate. The quantity discount schedule is commonly observed in practice and captures two important facts from our problem setting: First, the supplier may enjoy more efficient production due to economies of scale; second, by aggregating the order quantities from OEMs, the contract manufacturer may achieve higher bargaining power and obtain a lower unit price. Later we will see that the quantity discount rate plays an important role in the firms' procurement strategies. To simplify the analysis and focus on most practical situations, we assume $0 < \beta \leq \frac{1}{2}$ (i.e., the discount rate is no greater than 50%; see Hu et al. 2012 for more discussion of this assumption). For simplicity, we assume that C offers a wholesale price rather than a quantity discount schedule to customers. This is because the effect of scale economies at C should be less significant than that at the supplier. For example, the supplier may produce a common component for all customers while C's operations can be tailored to different customers. In addition, relaxing this assumption will not affect the qualitative results as long as C's discount rate is not too large.

We separate the analysis of the procurement game into two cases. In the first case, the supplier's price is exogenously given. This corresponds to market conditions where the supplier has little pricing flexibility for various reasons. Call this the non-strategic supplier case. In the second case, the component supplier has more pricing power and can choose the pricing scheme based on the procurement structure. Call this the strategic supplier case. Next we analyze these two cases and show that the supplier's pricing power plays a critical role in the equilibrium outcome of the procurement game.

4. Non-Strategic Supplier

In this section, we study the case where the component supplier is non-strategic, that is, the supplier offers a fixed pricing schedule regardless of the procurement structure. The case of strategic supplier will be studied in section 5. Specifically, the unit price charged by the supplier is given by a quantity discount schedule $w_{S,k}(q) = w_0 - \beta q$, $k \in \{C, M1, M2\}$, where w_0 and β are fixed parameters and q is the order quantity. We assume $w_0 \leq 1$ since the market size has been normalized to 1. Such a linear discount schedule has been widely adopted in the literature to maintain tractability (e.g., Chen and Roma 2011, Ingene and Parry 1995). However, a limitation is that the price $w_{S,k}$ may become negative when β or q is too large. Following the literature, in the subsequent analysis we will restrict our attention to scenarios where firms' prices and order quantities are positive in equilibrium. Since the supplier's pricing schedule is fixed, the contract manufacturer is the Stackelberg leader in the second, pricing stage of the game. For any chosen procurement structure $j \in \{II, DD, DI, ID\}$ in the first stage, the sequence of events in the second stage is as follows: First, the contract manufacturer sets its prices for each of the OEMs; second, the OEMs set their market prices and place orders at the contract manufacturer (when they use delegation) or at the supplier (when they control their component procurement); and, finally, the contract manufacturer, if necessary (for the II, DI, and ID structures), places its order at the component supplier. We denote these prices by $w^j_{l,k}$ with $l \in \{S, C\}$, which represents a price offered by l to k under procurement structure j. Given the contract manufacturer's and supplier's prices, each OEM chooses the market price p^j_i and associated order quantity q^j_i to maximize its own profit. OEM i's profit under procurement structure j can be written as:

$$\Pi^j_i = \left(p^j_i - w^j_{S,i} - w^j_{C,i}\right)q^j_i, \tag{3}$$

where $w^j_{S,i}(q^j_i) = w_0 - \beta q^j_i$ denotes the OEMs' unit procurement costs from the supplier and q^j_i, $i \in \{M1, M2\}$ are given by the linear demand functions in (1) and (2). For the profit function in (3) to hold in all procurement structures, we set the non-existing prices to zero, that is, $w^{II}_{S,M1} = w^{II}_{S,M2} = w^{ID}_{S,M1} = w^{DI}_{S,M2} = w^{DD}_{S,C} = 0$; this is for notational convenience and will not affect the analysis and results.

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Table 1 Equilibrium Outcomes of the Second-Stage Game (non-strategic supplier)

	$j = II$	$j = DD$
p^j_{M1}	$\frac{1}{2(2+\gamma)(\gamma^2-1)(2-\gamma+2\beta(\gamma-1))}(-6-2w_0 + \gamma(-w_0+\gamma(3+w_0(\gamma+2)-5\beta)-2\beta)+7\beta + \alpha(\beta+\gamma(-5+\gamma^2(2-4\beta)+6\beta-3\gamma\beta)))$	$\frac{1}{4}\left(\frac{-4(1+\alpha\gamma)}{\gamma^2-1}+\frac{1+\alpha+2w_0(\gamma-1)}{(\gamma-1)(2-\gamma+2\beta(\gamma-1))} - \frac{1-\alpha}{(\gamma+1)(2+\gamma-2\beta(1+\gamma))}\right)$
p^j_{M2}	$\frac{1}{2(2+\gamma)(\gamma^2-1)(2-\gamma+2\beta(\gamma-1))}(-2w_0+\beta + \gamma(-5-w_0+\gamma(2w_0+\gamma(2+w_0-4\beta)-3\beta)+6\beta) + \alpha(-6+\gamma^2(3-5\beta)+7\beta-2\gamma\beta))$	$\frac{1}{4}\left(\frac{-4(\alpha+\gamma)}{\gamma^2-1}+\frac{1+\alpha+2w_0(\gamma-1)}{(\gamma-1)(2-\gamma+2\beta(\gamma-1))} - \frac{\alpha-1}{(1+\gamma)(2+\gamma-2\beta(1+\gamma))}\right)$
q^j_{M1}	$\frac{1}{4}\left(\frac{1-\alpha}{2+\gamma}+\frac{1+\alpha+2w_0(\gamma-1)}{2-\gamma+2\beta(\gamma-1)}\right)$	$\frac{1}{4}\left(\frac{1+\alpha+2w_0(\gamma-1)}{2-\gamma+2\beta(\gamma-1)}-\frac{\alpha-1}{2+\gamma-2\beta(\gamma+1)}\right)$
q^j_{M2}	$\frac{1}{4}\left(\frac{\alpha-1}{2+\gamma}+\frac{1+\alpha+2w_0(\gamma-1)}{2-\gamma+2\beta(\gamma-1)}\right)$	$\frac{1}{4}\left(\frac{1+\alpha+2w_0(\gamma-1)}{2-\gamma+2\beta(\gamma-1)}-\frac{1-\alpha}{2+\gamma-2\beta(\gamma+1)}\right)$
Π^j_{M1}	$\frac{(2+w_0(\gamma^2+\gamma-2)+(\gamma-1)\beta+\alpha(\gamma+\beta-\gamma\beta))^2}{4(2+\gamma^2)(\gamma-2+2\beta-2\beta\gamma)^2}$	$\frac{(1-\beta)(\gamma(\alpha+w_0+w_0\gamma)-2\beta(\alpha\gamma+w_0(\gamma^2-1))-2(\beta+w_0-1))^2}{4(\gamma^2(1-2\beta)^2-4(\beta-1)^2)^2}$
Π^j_{M2}	$\frac{(2\alpha+w_0(\gamma^2+\gamma-2)+\beta(\alpha-1)(\gamma-1))^2}{4(2+\gamma^2)(\gamma-2+2\beta-2\beta\gamma)^2}$	$\frac{(1-\beta)(2\alpha+\gamma+w_0(\gamma^2+\gamma-2)-2\beta(\alpha+\gamma+w_0(\gamma^2-1)))^2}{4(\gamma^2(1-2\beta)^2-4(\beta-1)^2)^2}$
Π^j_{C}	$\frac{1}{4(\gamma+2)(\gamma^2-1)(2-\gamma+2\beta(\gamma-1))}(-2-4w_0(w_0-1) -2w_0^2\gamma^4-2w_0\gamma^3(w_0+1)+2\gamma(w_0^2+w_0-\beta)+\beta +\gamma^2(-1-4w_0+6w_0^2+\beta)+\alpha^2(-2+\gamma^2(\beta-1) +\beta-2\beta\gamma)-2\alpha(-2w_0+\beta+\gamma(3+(-1+\gamma(2+\gamma))w_0 +\beta(\gamma-2))))$	$\frac{1}{8}\left(\frac{(1+\alpha+2w_0(\gamma-1))^2}{(1-\gamma)(2-\gamma+2\beta(\gamma-1))}+\frac{(\alpha-1)^2}{(1+\gamma)(2+\gamma-2\beta(1+\gamma))}\right)$
Π^j_{S}	$\frac{-1+\alpha+2w_0(\gamma-1))(\beta(1+\alpha)+2w_0(-2+\gamma+\beta-\gamma\beta))}{4(2-2\beta+\gamma(2\beta-1))^2}$	$\frac{1}{4(\gamma^2(1-2\beta)^2-4(\beta-1)^2)^2}(2w_0(1+\alpha)(2+\gamma(\beta-1)-\beta) \times(2+\gamma-2\beta-2\gamma\beta)^2+2(\gamma-1)w_0^2(2+\gamma-2\beta-2\beta\gamma)^2 \times(4-3\beta+\gamma(-2+3\beta))-\beta(\alpha^2(\gamma^2(1-2\beta)^2+4(\beta-1)^2) +\gamma^2(1-2\beta)^2+4(\beta-1)^2+8\alpha\gamma(1-3\beta+2\beta^2)))$

The contract manufacturer's objective is to maximize its profit by quoting input prices for the OEMs. The contract manufacturer's profit under procurement structure j can be written as:

$$\Pi^j_C = w^j_{C,M1}q^j_{M1} + w^j_{C,M2}q^j_{M2} - w^j_{S,C}q^j_C, \tag{4}$$

where $w^j_{S,C}(q^j_C) = w_0 - \beta q^j_C$ denotes the contract manufacturer's unit procurement cost when it orders q^j_C from the supplier.

We first solves the second-stage game using backward induction. As an illustration, we analyze the equilibrium outcome under the II procurement structure as follows (the analysis for the other structures is similar). First, for a given set of component prices $\{w^j_{C,M1}, w^j_{C,M2}\}$ from the contract manufacturer, we find the optimal market prices and order quantities p^j_i and q^j_i for the OEMs. Their optimal order quantities are functions of $w^j_{C,M1}$ and $w^j_{C,M2}$, therefore we can write the contract manufacturer's profit as a function of $w^j_{C,M1}$ and $w^j_{C,M2}$. Since the contract manufacturer's profit is just a function of these prices, we can maximize the profit to find the contract manufacturer's optimal prices and thus order quantities. Table 1 summarizes the equilibrium outcomes under the II and DD procurement structures.

4.1. Equilibrium Outcome

In this subsection, we characterize the equilibrium outcome for the two-stage procurement game. As preparation, we first present two lemmas. These lemmas introduce several important effects that help explain the equilibrium outcome of the game. Lemma 1 compares the three procurement structures DD, ID and DI in the second stage of the game.

LEMMA 1. *Under a non-strategic supplier, the following relationships hold for DD, ID and DI procurement structures:*

(i) $p^{DD}_{M1} \le p^{ID}_{M1}$ *and* $p^{DD}_{M2} \le p^{ID}_{M2}$, $q^{DD}_{M1} \ge q^{ID}_{M1}$ *and* $q^{DD}_{M2} \le q^{ID}_{M2}$;

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(ii) $p_{M1}^{DD} \leq p_{M1}^{DI}$ and $p_{M2}^{DD} \leq p_{M2}^{DI}$, $q_{M1}^{DD} \leq q_{M1}^{DI}$ and $q_{M2}^{DD} \geq q_{M2}^{DI}$;

(iii) $\Pi_{M1}^{DI} \geq \Pi_{M1}^{DD}$, $\Pi_{M2}^{ID} \geq \Pi_{M2}^{DD}$.

Parts (i) and (ii) show how the OEMs' market prices and demands change when one of them deviates from DD. We can see that a deviation by any firm will soften market competition because it will lead to higher market prices for both firms. In fact, Part (iii) indicates that each OEM will be better off if the other OEM moves from direct to indirect procurement. We may call this the *competition softening* effect. What will happen to the profit of the deviating firm? The answer is ambiguous. Take M1 for example (the observation for M2 is similar), it has been found that after deviating from DD to ID, M1 will procure a lower quantity and thus pay a higher total procurement price (component price plus processing fee). Close scrutiny reveals an interesting driving force behind this observation. Under direct procurement, M1 determines the order quantity and has stronger incentives to place a large order quantity (M1 is the sole-beneficiary from a large discount). In contrast, under indirect procurement, we add an intermediary contract manufacturer who sets a price that will determine M1's order quantity. Since the contract manufacturer will share the benefit of a large discount with M1, these two downstream firms have less incentives to increase order quantity. The contract manufacturer anticipates such an incentive change, and therefore will charge a higher total procurement price to compensate for the loss of volume. Such under-ordering behavior under indirect procurement is analogous to the classic under-ordering behavior caused by double marginalization. It is well known that in a two-stage supply chain governed by wholesale price contract, the downstream firm will order less than in the centralized supply chain due to sharing the profit margin with the upstream firm. Here, the downstream firms will order less due to sharing the component quantity discount with each other. The difference is that in our setting, the split of discount hinges upon the quantity discount schedule offered by the supplier, while the classic double marginalization does not require a quantity discount schedule and the split of unit profit margin is independent of volume. For easy reference, we call this the *discount-sharing* effect. The next lemma introduces another effect in the procurement game.

Lemma 2. *Under a non-strategic supplier, the procurement structure DI is never an equilibrium.*

The DI structure can never be sustained in equilibrium because M1 (the smaller OEM) will always have incentives to deviate from direct to indirect procurement (from DI to II). The deviation allows the contract manufacturer to aggregate the two OEMs' orders and thus obtain a better quantity discount from the supplier. This will benefit both OEMs. We may call this the *order aggregation* effect. Due to its smaller order quantity, M1 will benefit more from the order aggregation relative to M2. Therefore, DI will never arise in equilibrium.

Next, we characterize the equilibrium outcome for the two-stage procurement game. Define

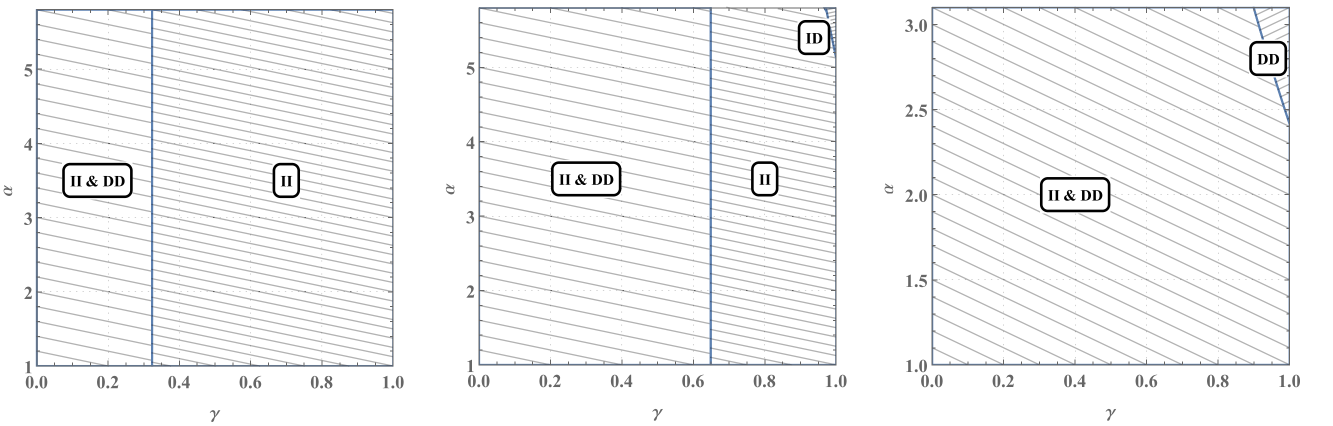
$$\begin{aligned}\Delta_1 \equiv & -4(1-\beta)(-4+\gamma^2-2\beta(\gamma^2-1))\\ & \times(\beta+\alpha(2+\beta(\gamma-1))-\gamma(\beta-1)\\ & +w_0(\gamma^2+\gamma-2))^2+4(\gamma+2)^2(-2-2\beta(\gamma-1)+\gamma)^2\\ & \times(\alpha(\beta-2)+\gamma(\beta-1)+w_0(\gamma-1)\\ & \times(\beta-2+\gamma(\beta-1)))^2,\\ \Delta_2 \equiv & -4\beta(-1+\beta)^3+4(\beta-1)^2(-1+\beta+2\beta^2)\gamma^2-\\ & \times(1-2\beta)^2(\beta^2+\beta-1)\gamma^4.\end{aligned}$$

Proposition 1. *Under a non-strategic supplier, the sub-game perfect equilibrium of the procurement game can be characterized as follows:*

(i) *If $\Delta_1 \leq 0$ and $\Delta_2 \leq 0$, then both II and DD are equilibria.*
(ii) *If $\Delta_1 \leq 0$ and $\Delta_2 > 0$, then II is the unique equilibrium.*
(iii) *If $\Delta_1 > 0$ and $\Delta_2 \leq 0$, then DD is the unique equilibrium.*
(iv) *If $\Delta_1 > 0$ and $\Delta_2 > 0$, then ID is the unique equilibrium.*

Proposition 1 indicates that else than DI, all procurement structures may arise in equilibrium. First, II will arise as an equilibrium as long as $\Delta_1 \leq 0$. From the discussion of Lemma 2, we know M1 will not deviate from II; thus II will be an equilibrium as long as M2 does not deviate from II. If M2 deviates from II to ID, then the contract manufacturer can no longer aggregate the OEMs' orders, which will increase the component price for M2. However, the component price for M1 would increase even more due to its lower order quantity. So although the deviation from II to ID will increase M2's component price, it will also give it a more advantageous position in market competition. M2 will find it profitable to deviate when β is large (i.e., the negative impact of procurement economies of scale on M1 is large) and γ is large (i.e., market competition is intense). In other words, M2 is less likely to deviate when either β or γ is relatively small. As an illustration, Figure 2 shows the equilibrium outcome for the procurement game under three different β values and $w_0 = 1$ (the outcome is not

Figure 2 Equilibrium Outcome under Different β Values (non-strategic supplier)



(a) $\beta = 0.1$ **(b)** $\beta = 0.3$ **(c)** $\beta = 0.5$

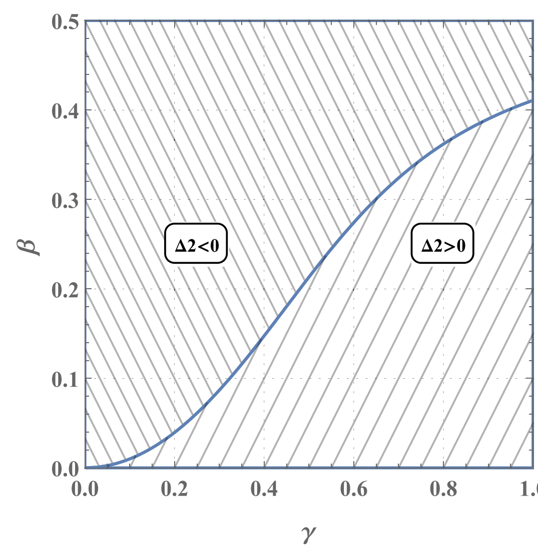
sensitive to the value of w_0). When β is small (e.g., Figure 2a), II will always be an equilibrium. When β and γ are both large (e.g., Figures 2b and c), ID and DD may arise as unique equilibrium (these two equilibria also require α to be large; note a large α means a large difference in the OEMs' order quantities, which will incentivize M2 to deviate from II to ID). It is worth mentioning that DD may also arise as equilibrium under other parameter ranges (see more discussion below). These observations are consistent with the equilibrium condition $\Delta_1 > 0$,which tends to hold when all three parameters α, β, and γ are large.

The II equilibrium is not surprising because the OEMs can enjoy a deeper discount by both delegating procurement to the contract manufacturer. However, Proposition 1 indicates that DD may also arise as an equilibrium, which is less intuitive. Under DD, both OEMs will receive a higher component price compared to II; nevertheless, no firm would deviate when $\Delta_2 \leq 0$. Next we provide an explanation of this equilibrium using the effects introduced by Lemma 1.

It can be shown that whenever M1 prefers not to unilaterally deviate from DD, M2 prefers not to deviate either. Thus to ensure the DD equilibrium, we only need to check the conditions under which M1 will not deviate. From the discussion after Lemma 1, M1 will not deviate if the negative discount-sharing effect, as it drives up the procurement cost, dominates the positive effect of softening competition. This corresponds to the condition $\Delta_2 \leq 0$. Note Δ_2 is a function of only β and γ and Figure 3 characterizes their relationship. For any β, $\Delta_2 \leq 0$ holds when the products are sufficiently differentiated, that is, when γ is smaller than a threshold. We can see that the threshold for γ increases in β since a large β strengthens the discount-sharing effect.

Proposition 1(iv) states that ID and DD may arise as the unique equilibrium when $\Delta_1 > 0$.

Figure 3 The Sign of Δ_2 as a Function of β and γ



Under this condition, II cannot be an equilibrium because M2 will choose to deviate from indirect to direct procurement. To obtain a better understanding of the odds for different equilibrium structures to happen, we conduct extensive numerical experiments as follows. The range of each parameter is evenly divided into 20 intervals (so each parameter can take 20 values), where $\alpha \in [1, 10]$, $\gamma \in [0, 1]$, $\beta \in [0, \frac{1}{2}]$, and $w_0 \in [0, 1]$. For each parameter combination, we derive the equilibrium outcome (again we restrict our attention to scenarios with positive equilibrium prices and order quantities). It has been found that II is the unique equilibrium among 48.6% of the scenarios, II and DD coexist among 51.1% of the scenarios, and DD or ID may arise as the unique equilibrium under only 0.3% of the scenarios. Thus, the condition of $\Delta_1 > 0$ is rather restrictive, as is also shown by the small regions for ID and DD in Figure 2. Since

ID is an equilibrium only under extreme conditions, we will focus our analysis and discussion on the equilibria II and DD in the rest of the section.

4.2. Comparison of II and DD

We have characterized the equilibrium outcome for the procurement game. Now we may compare these different equilibria and examine supply chain members' preferences. We focus on II and DD since they are the equilibria for most parameter ranges. In addition, these two equilibria may coexist under certain conditions. First, the following proposition shows that when both II and DD are equilibria, then II Pareto dominates DD.

Proposition 2. *Under a non-strategic supplier, if II and DD are both sub-game perfect equilibria of the procurement game, then II Pareto dominates DD, that is, both OEMs' profits are higher in II than in DD.*

The Pareto dominance implies that both OEMs would prefer the II equilibrium to the DD equilibrium. However, it does not mean the DD equilibrium will not happen in practice at all. Many research studies demonstrate that Pareto dominated equilibrium may happen in experimental settings (see, e.g., Van Huyck et al. 1991, and the references therein). Also DD may happen in the following sequential entry setting: Suppose at the beginning there is only one OEM in the market, and it can be shown that the single OEM will choose control; and then the second OEM enters, and it would also choose control if $\Delta_2 \leq 0$. Although the Pareto dominance cannot rule out the DD equilibrium, it does indicate that the II equilibrium might be more likely to happen in practice.

The next proposition sheds some light on the preferences of different supply chain members.

Proposition 3. *Under a non-strategic supplier, the following holds for the II and DD procurement structures:*

(i) $p^{II}_{M1} \leq p^{DD}_{M1}, p^{II}_{M2} \geq p^{DD}_{M2}, q^{II}_{M1} \geq q^{DD}_{M1}, q^{II}_{M2} \leq q^{DD}_{M2}$;

(ii) $\Pi^{DD}_{C} \geq \Pi^{II}_{C}$;

(iii) $\Pi^{DD}_{S} \geq \Pi^{II}_{S}$;

(iv) $\Pi^{DD}_{S} + \Pi^{DD}_{C} + \Pi^{DD}_{M1} + \Pi^{DD}_{M2} \geq \Pi^{II}_{S} + \Pi^{II}_{C} + \Pi^{II}_{M1} + \Pi^{II}_{M2}$.

We know that both OEMs' procurement costs would be higher under DD than under II because of the lost quantity discounts. Interestingly, Proposition 3(i) shows that the OEMs adopt different strategies to absorb the heightened costs. The smaller OEM would increase its market price; in contrast, the larger OEM would decrease its market price, which would result in higher market demand and therefore larger quantity discounts. The OEMs' different strategies are due to their different price elasticities. Knowing that its smaller competitor has greater price elasticity (which would make it increase market price when its input cost increases), the larger OEM with less price elasticity prefers to reduce its market price and take advantage of the supplier's quantity discounts. Part (ii) of the above proposition shows that the contract manufacturer prefers DD over II, which is unexpected. One may intuit that the contract manufacturer's profit will be squeezed as the OEMs gain more control of their component procurement. For example, Pick (2004) mentions that electronics manufacturing services (EMS) providers (i.e., the contract manufacturers in the electronics industry) can generate significant profits from the acquisition and sale of components; thus, as OEMs are implementing component procurement control, the EMS providers are losing significant portion of their value-added from procurement. However, our model analysis suggests that contract manufacturers might actually benefit from the OEMs' control on component procurement. We offer the following explanation of this interesting finding in Part (ii). First, it can be shown that the margins charged by the contract manufacturer do not change across the II and DD procurement structures. Specifically, the margin set for the larger OEM is higher (again, because of the lower price elasticity of the larger OEM). Second, as Part (i) indicates, when switching from II to DD, M1's order quantity decreases while M2's order quantity increases. This implies a bigger portion of the contract manufacturer's demand comes from the larger firm, thus higher overall margins for the contract manufacturer. Therefore, based on the given model setting, direct control of component procurement by the OEMs may benefit the contract manufacturer. An immediate implication is that if the contract manufacturer has the power to impose the component procurement structure in a competitive supply market, he would choose DD over II and require the OEMs to procure their own components.

The rest of Proposition 3 implies the supplier and the entire supply chain earn a higher profit under DD. Note that the OEMs' component costs would be lower under II (due to the aggregated order discounts). Since the contract manufacturer charges the same margins under both II and DD, the supplier receives a greater profit margin under DD and therefore prefers DD to II. Similarly, the supply chain also prefers DD to II, using the same explanation for part (ii): Under DD, the larger OEM with a higher market price will sell more, which increases the overall supply chain profit; under II, the competition drives down the larger firms' demand and hence reduces the supply chain profit.

Finally, we finish this section by presenting the equilibrium outcome for two special cases, that is, symmetric OEMs and no market competition.

PROPOSITION 4. *Consider the non-strategic supplier case.*

(i) *For symmetric OEMs (i.e., $\alpha = 1$), both II and DD are equilibria of the procurement game if $\Delta_2 \le 0$, and II is the unique equilibrium otherwise.*
(ii) *If there is no market competition (i.e., $\gamma = 0$), then both II and DD are equilibria of the procurement game.*

Proposition 4(i) indicates that even for symmetric OEMs, DD can arise in equilibrium. That is, if one of the OEMs controls its component procurement, then the other one may also prefer to do the same, even though both of them prefer II to DD. Chen and Roma (2011) study two competing retailers' procurement strategies under non-strategic supplier. They find that group buying is always preferable for symmetric retailers. However, as shown by Proposition 4(i), both II (which is similar to group buying) and DD may arise in equilibrium in our problem. This is mainly due to the intermediary contract manufacturer who can set a price and grab a share of the profit in the supply chain. Specifically, the strategic role of this new player in our model gives rise to the discount-sharing effect that is absent in Chen and Roma (2011). Such an effect reduces the incentives for an OEM to deviate from D (direct procurement) to I (indirect procurement), which makes DD a possible equilibrium in our model.

Proposition 4(ii) indicates that when there is no market competition, DD always arises as an equilibrium. Without competition, the competition softening effect from procurement delegation disappears. As a result, any OEM that deviates from DD would decrease the competitor's procurement cost while increasing its own. This implies that DD is an equilibrium for any value of the discount parameter β in the absence of product competition. These findings are consistent with our discussion above for more general cases.

5. Strategic Supplier

In this section, we study the case of a strategic component supplier, that is, the supplier can adjust the component price based on the procurement structure. Again let $w^j_{S,k}(q) = w^j_k - \beta q^j_k$ be the supplier's pricing schedule offered to firm k under procurement structure j, where $k \in \{C, M1, M2\}$ and $j \in \{II, DD, ID, DI\}$. For ease of exposition, we assume the quantity discount β is fixed; this might hold for situations where the supplier has a limited flexibility in adjusting the discount rate. Given this assumption, we may discuss what will happen for different values of β. Allowing both β and w^j_k to vary will significantly complicate the analysis. Although β is fixed, the supplier may charge different base prices w^j_k to different customers, which is not uncommon in practice. According to an iSuppli survey, various pricing programs (e.g., rebate, consignment, buy/sell agreement) have been used to disguise suppliers' component prices (Pick 2004). How to effectively implement confidential price agreement with different customers has also been studied in the literature (see Deshpande et al. 2011).

The strategic supplier is the Stackelberg leader in the second stage of the game. For any procurement structure $j \in \{II, DD, DI, ID\}$ chosen in the first stage, the sequence of events is as follows: First, the supplier sets the component price schedules for its customers (either the contract manufacturer or the OEMs); second, the contract manufacturer sets its prices for the OEMs; finally, the OEMs set their market prices and place their orders at the upstream firm (either the supplier or the contract manufacturer).

In the second-stage game, the supplier's objective is to maximize the profit by choosing the base prices w^j_k for its customers:

$$\Pi^j_S = w^j_{S,M1} q^j_{M1} + w^j_{S,M2} q^j_{M2} + w^j_{S,C}\, q^j_C. \qquad (5)$$

Similar to the non-strategic supplier case, the prices that do not exist under certain procurement structures are set to zero. We may solve the second-stage game using backward induction. Table 2 presents the equilibrium solutions for the II and DI procurement structures, which may arise as the equilibrium outcome in the first-stage game.

Define the following threshold value for later use:

$$\begin{aligned}\Delta_3 \equiv\ & 16(\gamma+2)^2(2+\gamma(\beta-1)-\beta)^2(\beta-1)(-4 \\ & +\alpha\gamma(\beta-2)+\beta)^2 + (-6+2\alpha+\gamma-3\alpha\gamma \\ & +2(\alpha-1)(\gamma-1)\beta)^2((\beta-4)(3\beta-4) \\ & +\gamma^2(\beta(8-3\beta)-4))^2.\end{aligned}$$

Then we can characterize the sub-game perfect equilibrium for the procurement game under a strategic supplier.

PROPOSITION 5. *Under a strategic supplier, II is the unique equilibrium if $\Delta_3 \ge 0$, and DI is the unique equilibrium otherwise.*

According to Proposition 5, both II and DI may arise as the equilibrium outcome under a strategic

Table 2 Equilibrium outcomes of the second-stage game (strategic supplier)

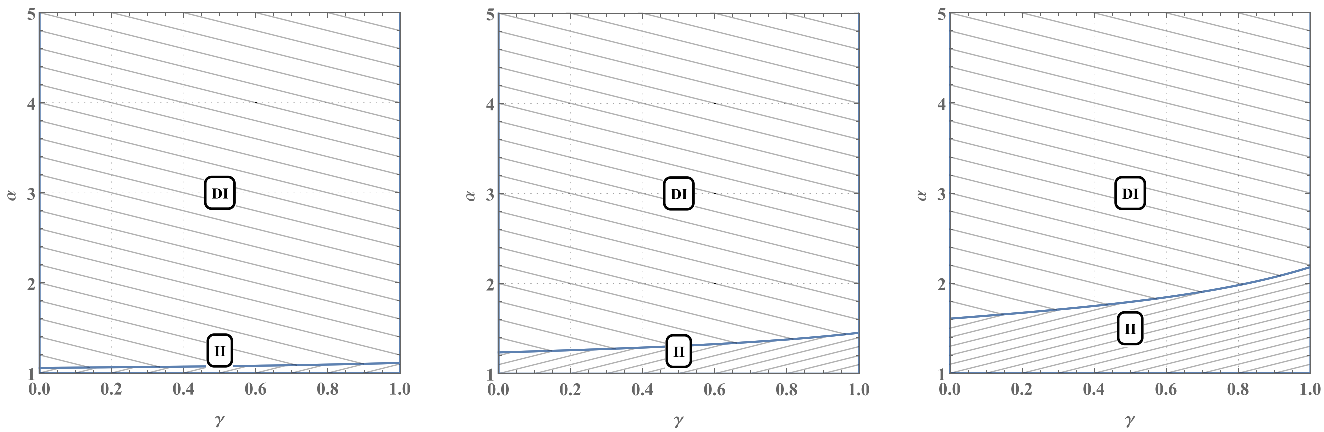
	$j = II$	$j = DI$
p^j_{M1}	$\frac{1}{8}\left(\frac{2-2\alpha}{2+\gamma}+\frac{1+\alpha}{2+\gamma(\beta-1)-\beta}\right)$	$\frac{1+\alpha\gamma}{1-\gamma^2}+\frac{-4+\beta+\gamma(\gamma(3\beta-2)+\alpha(4\beta-6))}{2(\gamma^2-1)((4-\beta)(3\beta-4)+\gamma^2(\beta-2)(3\beta-2))}$
p^j_{M2}	$\frac{1}{8}\left(\frac{2\alpha-2}{2}+\gamma+\frac{1+\alpha}{2+\gamma(\beta-1)-\beta}\right)$	$\frac{\alpha+\gamma}{1-\gamma^2}+\frac{-6\gamma-2\alpha(\gamma^2+2)+4\alpha\gamma+\alpha\beta(\gamma^2+3)}{2(\gamma^2-1)((4-\beta)(3\beta-4)+\gamma^2(\beta-2)(3\beta-2))}$
q^j_{M1}	$\frac{1}{8(\gamma-1)}\left(-8\alpha+\frac{4(\alpha-1)}{1+\gamma}+\frac{6(\alpha-1)}{2+\gamma}+\frac{1+\alpha}{2+\gamma(\beta-1)-\beta}\right)$	$\frac{\alpha\gamma(\beta-2)+\beta-4}{-2(\beta-4)(3\beta-4)+2\gamma^2(\beta-2)(3\beta-2)}$
q^j_{M2}	$\frac{1}{8(\gamma-1)}\left(-8+\frac{4(1-\alpha)}{1+\gamma}+\frac{6(1-\alpha)}{2+\gamma}+\frac{1+\alpha}{2+\gamma(\beta-1)-\beta}\right)$	$\frac{3\beta(\gamma+\alpha)-2(\gamma+2\alpha)}{-2(\beta-4)(3\beta-4)+2\gamma^2(\beta-2)(3\beta-2)}$
Π^j_{M1}	$\frac{(-6+2\alpha+\gamma-3\alpha\gamma+2(\alpha-1)(\gamma-1)\beta)^2}{64(2+\gamma)^2(-2+\gamma+\beta-\beta\gamma)^2}$	$\frac{(\beta-1)(\alpha\gamma(\beta-2)+\beta-4)^2}{4((\beta-4)(3\beta-4)+\gamma^2(+(8-3\beta)\beta-4))^2}$
Π^j_{M2}	$\frac{(2-6\alpha-3\gamma+\alpha\gamma-2\beta(\alpha-1)(\gamma-1))^2}{64(2+\gamma)^2(-2+\gamma+\beta-\beta\gamma)^2}$	$\frac{(3\beta(\gamma+\alpha)-2(\gamma+2\alpha))^2}{4((\beta-4)(3\beta-4)+\gamma^2(+(8-3\beta)\beta-4))^2}$
Π^j_{C}	$\frac{1}{32}\left(\frac{4(1-\alpha)^2}{(1+\gamma)(2+\gamma)}-\frac{2(1+\alpha)^2}{(\gamma-1)(2+\gamma(\beta-1)-\beta)}-\frac{(-2+\gamma)(1+\alpha)^2}{(\gamma-1)(-2+\gamma(1-\beta)+\beta)}\right)$	$\frac{1}{4(\gamma^2-1)((\beta-4)(3\beta-4)+\gamma^2(-4+\beta(8-3\beta))^2}$ $(\gamma^4(1-\beta)(3\beta-2)^2+2(\beta-4)^2(\beta-1)+\gamma^2(\beta(16+\beta(7\beta-19))-8)+2\alpha\gamma(\beta(88+\beta(11\beta-53)-48)+\gamma^2(\beta(-40+\beta(37-11\beta))+12))+\alpha^2((4-3\beta)^2(\beta-2)-\gamma^4(\beta-2)^2(2\beta-1)-\gamma^2(8+\gamma(\beta(7\beta-17)+4))))$
Π^j_{S}	$\frac{(1+\alpha)^2}{16(1-\gamma)(2+\gamma(\beta-1)-\beta)}$	$\frac{2(2+6\alpha\gamma+\gamma^2+\alpha^2(\gamma^2+2))-\beta(1+8\alpha\gamma+3\gamma^2+\alpha^2(\gamma^2+3))}{4(\gamma^2-1)((4-\beta)(3\beta-4)+\gamma^2(\beta-2)(3\beta-2))}$

supplier. Recall under a non-strategic supplier, DI cannot be an equilibrium because M1 always prefers II to DI due to the higher quantity discount benefit. Let us now examine M1's preference between II and DI under the strategic supplier. If M1 deviates from II to DI, it receives a lower quantity discount, for the same reason as before. However, now the deviation allows the supplier to charge different prices for the components going to different OEMs. In particular, the supplier will decrease its component price for M1 while increasing its price for M2 since the price elasticity of demand for M1 is higher than that for M2. That is, the deviation will reduce M1's own component cost, while increasing its competitor's component cost. Clearly, this will benefit M1 when setting prices for the competitive market. We may call this new driving force the *price discrimination* effect. So M1's choice depends on the trade-off between the negative quantity discount effect and the positive price discrimination effect. The equilibrium outcome depends on three key parameters. First, since a large α implies a greater difference in the OEMs' price elasticities, the discrimination effect would be more significant when α is large. It can be shown that there is a threshold value $\hat{\alpha} > 1$ such that DI is the equilibrium if and only if $\alpha > \hat{\alpha}$. Second, the quantity discount effect would be stronger if there is a large β, so the DI equilibrium will be less likely to happen as β increases. Third, the quantity discount effect would be stronger if the market is more competitive (i.e., γ is large). In that case both firms' demands would be higher, which means they will lose more if they do not aggregate their demands. On the other hand, the price discrimination effect weakens as γ increases since the OEMs' order quantity increases and the supplier has less incentive to decrease its base prices for the OEMs. Hence the chance for II to happen increases in γ. For illustration, Figure 4 demonstrates the equilibrium procurement structures for three discount rates, $\beta = 0.1$, $\beta = 0.3$ and $\beta = 0.5$. We can see that the region for II equilibrium (i.e., $\Delta_3 \geq 0$) is more likely to happen for large β and γ but small α, which is consistent with the above discussion.

Since DD may arise as an equilibrium under a non-strategic supplier, it would be interesting to investigate why it cannot be an equilibrium under a strategic supplier. We find that this is because the larger OEM always prefers DI to DD under a strategic supplier. To explain this result, we need to compare the procurement structures DI and DD. It can be shown that under a strategic supplier, the following relationships hold for the procurement structures DI and DD: (i) $p^{DD}_{M1} \leq p^{DI}_{M1}$ and $p^{DD}_{M2} \leq p^{DI}_{M2}$; (ii) $q^{DD}_{M1} \leq q^{DI}_{M1}$ and $q^{DD}_{M2} \geq q^{DI}_{M2}$; (iii) $\Pi^{DD}_{M1} \geq \Pi^{DI}_{M1}$ and $\Pi^{DD}_{M1} \geq \Pi^{DI}_{M1}$.

Similar to the findings in Lemma 1, under a strategic supplier, when M2 deviates from DD to DI (i.e., M2 delegates its procurement to the contract manufacturer), both OEMs increase their prices in the market, that is, the deviation softens competition and benefits both firms. At the same

Figure 4 Equilibrium Characterization for Different Discount Rates with Strategic Supplier



(a) $\beta = 0.1$ (b) $\beta = 0.3$ (c) $\beta = 0.5$

time, due to the discount-sharing effect, M2 will face a higher component price under indirect than under direct procurement. Unlike Lemma 1, we find that the positive softened competition effect always dominates the negative effect of heightened component price for M2, so M2 always prefers DI to DD under a strategic supplier. This is because when the supplier can adjust its component price, it will take the discount-sharing effect into account and induce M2 to order more by reducing its base price. At the same time, the supplier will increase the base price for M1, who controls its procurement. This strategic move by the supplier is intended to minimize the negative effect of discount sharing on its profit. It is straightforward to show that the supplier charges a higher margin to the larger OEM, so it prefers to increase M2's order due to the higher margin. Such a strategic behavior would mitigate the discount-sharing effect, and thus make the softened competition the dominant effect. As a result, DD is always dominated by DI from M2's perspective and can never be an equilibrium under a strategic supplier. Notice that in a non-strategic supplier setting, the supplier could not change its base price to mitigate the discount-sharing effect. Hence the discount-sharing effect may dominate the softened competition effect, leading to the DD equilibrium structure.

In summary, the strategic supplier is able to price discriminate the OEMs for certain procurement structures, which offers incentives for the smaller OEM to choose control. By directly procuring from the strategic supplier, the smaller OEM may enjoy a lower component price due to its larger price elasticity of demand. Further, the supplier's strategic pricing behavior may also change the larger OEM's incentives as well. In particular, it will reduce the negative effect of discount sharing caused by delegation (i.e., the OEM would receive a higher component price when switching from direct control to delegation) and, as a result, the larger OEM will always prefer delegation to direct control under a strategic supplier.

6. Discussion

The previous two sections study the non-strategic supplier and strategic supplier cases, respectively. In each section, it has been shown that the equilibrium of the procurement game depends on several key factors, including the difference in market potential (α), the intensity of market competition (γ), and the supplier's discount rate (β). This section summarizes and compares the results from these two cases. The purpose is to highlight the critical role of the component supplier's pricing behavior in the equilibrium outcome of the procurement game.

We may start the discussion with II, which could be an equilibrium in both cases. The reason behind this equilibrium is that under II, both OEMs can receive a large quantity discount by allowing the contract manufacturer to aggregate the orders. Interestingly, the OEMs' incentives to deviate from II depends on the supplier's pricing power. Under a non-strategic supplier, it is the larger OEM who may choose to deviate from the II structure. Deviating from II will increase the larger OEM's component price due to the loss of discount; at the same time, it will help the OEM achieve a competitive advantage because the smaller OEM's component price will increase more significantly. When the discount rate is small (β is small) or the market competition is not very intense (γ is small), the larger OEM will not deviate from II because the loss of discount dominates the benefits of competitive advantage. In contrast, under a strategic supplier, it is the smaller OEM who may choose to deviate from II,

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while the larger OEM will never do so. The strategic supplier price discriminates and tends to charge a lower price to the smaller OEM due to its smaller market potential. This is enough of an incentive for the smaller OEM to deviate from II. The smaller OEM will not choose to deviate only if the loss of discount is significant enough to outweigh the benefit from price discrimination, which happens when α is small (the discrimination effect is small) and β is large (the loss of discount is more significant). We can see that the conditions for II to be an equilibrium are quite different depending on the supplier's pricing power.

The nature of the other equilibrium of the procurement game also depends on whether the supplier is strategic or not. Specifically, DD could be an equilibrium under a non-strategic supplier but never under a strategic one; by contrast, DI could be an equilibrium under a strategic supplier but never under a non-strategic one. The supplier's strategic pricing behavior affects the incentives of both OEMs and drives the different equilibria of these two cases. First, the price discrimination effect may make DI an equilibrium under a strategic supplier. As explained before, the smaller OEM may choose to deviate from II to DI to take advantage of better component prices. Second, although DD may arise as an equilibrium under a non-strategic supplier, it can no longer be an equilibrium under a strategic supplier. Under a non-strategic supplier, an OEM faces the following trade-off when deviating from DD: A deviation will dampen market competition (both firms' market prices will go up), which is beneficial to both firms; however, the component price will increase for the deviating firm due to the discount-sharing effect. So DD may arise as an equilibrium when the negative discount-sharing effect outweighs the positive competition softening effect. Under a strategic supplier, however, we find that the larger OEM always finds it profitable to deviate from DD. In other words, due to the supplier's strategic pricing behavior, the competition softening effect ends up dominating the discount-sharing effect, which makes DD not a sustainable equilibrium.

7. Conclusion

This paper studies the optimal component procurement strategies of two competing OEMs in a three-tier supply chain. The OEMs depend on a contract manufacturer for processing an important input, which in turn requires a component from a supplier. The OEMs can choose to either control component procurement (i.e., direct procurement or control strategy) or delegate component procurement to the contract manufacturer (indirect procurement or delegation strategy). There are four possible equilibrium procurement structures: II (both firms use indirect procurement), DD (both firms use direct procurement), DI (the smaller firm uses direct while the larger firm uses indirect procurement), and ID (the smaller firm uses indirect while the larger firm uses direct procurement). We analyze the OEMs' equilibrium strategies under two supplier characteristics: non-strategic supplier who follows an exogenously given pricing schedule, and strategic supplier who can set prices in response to the OEMs' chosen procurement structure.

We characterize the OEMs' equilibrium procurement strategies in such a supply chain setting under competition. Under a non-strategic supplier, we find that symmetric equilibria (II or DD) may happen in general, that is, the OEMs either both use delegation or both use control. II could be an equilibrium because both OEMs will receive a large quantity discount from the supplier (i.e., the order aggregation effect). The DD equilibrium depends on the trade-off between two effects caused by a firm's deviation from it: A deviation can dampen the price competition, so it benefits both OEMs (i.e., the competition softening effect); however, the deviating OEM will receive a higher component price because the contract manufacturer and the OEM have less incentive to order a large quantity (i.e., the discount-sharing effect). Thus, DD would be an equilibrium when the negative discount sharing effect dominates the competition softening effect; and this happens as long as the products are sufficiently differentiated. Further, we show that the contract manufacturer prefers the DD structure to the II structure, which is unexpected. Under DD, the order from the larger OEM accounts for a greater portion of the contract manufacturer's demand, and the contract manufacturer can charge a higher margin to the larger OEM. Thus the contract manufacturer may have higher profits when the OEMs directly control their component procurement. Finally, the supplier's pricing behavior plays a critical role in determining the equilibrium outcome. In particular, the smaller OEM will have more incentives to deviate from II because of the supplier's price discrimination between the OEMs. Thus DI may arise as an equilibrium of the procurement game. Furthermore, the supplier's strategic pricing behavior makes the larger OEM always prefer DI to DD, and as a result, DD is no longer an equilibrium. Hence in the equilibrium under a strategic supplier, the larger OEM always uses delegation while the smaller OEM may either use delegation or control.

This research reveals several effects influencing the OEMs' component procurement strategy choices. These effects include the benefit from order aggregation, the competition softening effect, the negative impact of discount sharing, and finally, the strategic supplier's price discrimination effect. Our research results help explain the procurement practice observed in the industry and also provide useful guidance to managers for making strategic procurement decisions.

Some promising directions for future research are worth highlighting. First, it has been assumed in this study that the supplier's discount rate is exogenously given. A potential direction for future research is to relax this assumption and examine how the results may change. Second, the current model assumes that the contract manufacturer is passive with respect to the type of procurement arrangement. It would be interesting to consider other negotiation models in future research. For example, one may study a model where all parties can actively participate in deciding the procurement arrangement. Finally, we have assumed OEMs are Stackelberg followers in the second stage of the game, regardless of their firm size. Under a bargaining framework, the larger OEM might obtain additional advantages such as lower procurement price. Introducing a bargaining framework is also a natural extension to our model. All these directions may further deepen our understanding of firms' component procurement strategies in various settings.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1: Proofs.