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Research article

Research on dual outsourcing strategies for multi-component products in a competitive equipment manufacturing platform

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Abstract: In this study, we investigated dual outsourcing strategies for multi-component products on a competitive equipment manufacturing platform comprising an original equipment manufacturer (OEM), a competing contract manufacturer (CM), and a component supplier. A game-theoretic model was developed to compare four combinations of in-house and outsourced production and procurement. The results showed that the OEM's production and procurement decisions are interdependent: Procurement outsourcing is possible only when production is outsourced. When the one-time investment cost of establishing a production line is low, the OEM chooses in-house production and procurement; when the cost is high, it outsources production, while its procurement decision depends on relative market potential. For sensitivity analyses, we examined how the investment cost, relative market potential, and quantity discount level affected the OEM's production and procurement outsourcing preferences and the CM's preferences over the OEM's strategies. A distinctive finding was that, conditional on the OEM retaining procurement authority, its willingness to produce in-house is jointly affected by relative market potential and the quantity-discount level and does not exhibit a uniform monotonic response to either factor considered separately. We further identified the conditions for win-win outcomes and found that their probability decreases as the quantity discount level increases. These findings provide guidance for coordinating cooperation and competition on manufacturing platforms.

Keywords: dual outsourcing; manufacturing platforms; cooperation and competition; multi-component products; equipment manufacturing; win-win strategy
Mathematics Subject Classification: 91A05, 91A10, 91A65

1. Introduction

On a competitive manufacturing platform, an original equipment manufacturer (OEM) may outsource production and procurement activities to a contract manufacturer (CM) that also sells a partially substitutable product in the downstream market. The CM is therefore a service provider and a market competitor. Production outsourcing can save the OEM from investing in manufacturing capacity, whereas procurement outsourcing can reduce purchasing costs through order aggregation. However, both forms of outsourcing may transfer operational or cost advantages to the competing CM, making the two decisions strategically interdependent. This coexistence of cooperation and competition raises two central questions: How should the OEM jointly determine its production and procurement outsourcing strategies when the CM is a partner and a competitor? Under what conditions can the resulting arrangement benefit both parties?

Software-defined unmanned ground equipment provides a representative practical case that gives this general outsourcing problem a multi-component dimension. Intelligent technologies have developed rapidly in civilian new energy vehicles, whereas their adoption in unmanned ground equipment remains relatively limited, with many systems relying primarily on remote control [1]. To advance software-defined equipment development [2], an equipment OEM may concentrate its resources on software development, system integration, and other core activities while coordinating component production and procurement with external manufacturing partners. In this setting, to protect core intellectual property, the OEM retains control over the production of critical components and the procurement of their required parts, whereas the production and procurement of non-critical components may be coordinated with external manufacturing partners. A capable CM may provide these outsourcing services while producing partially substitutable equipment for the downstream market. Therefore, this case provides practical motivation for investigating production and procurement dual-outsourcing strategies for multi-component products.

The general problem of production and procurement outsourcing and the salient features of the practical case jointly give rise to the two core structural assumptions of our model. First, the product comprises a critical component and a non-critical component. To protect core intellectual property, the OEM produces the critical component in-house and independently procures its required parts. For the non-critical component, the OEM may either invest in a dedicated production line and produce it in-house or outsource its production to the CM. Second, the production and procurement decisions for the non-critical component are modeled jointly. The OEM may procure its required parts independently or delegate procurement to the CM, so the two binary decisions generate four combinations of in-house and outsourced production and procurement. Because the component supplier offers quantity discounts based on aggregate purchase volumes, procurement outsourcing may reduce purchasing costs through order aggregation, but it may also lower the CM's procurement cost and strengthen its competitive advantage in the downstream market. Together, these assumptions define the multi-component, dual-outsourcing framework examined in this study.

2. Literature review

Many researchers have examined production outsourcing strategies. Production outsourcing is influenced by economies of scale [3], product quality and price [4–7], and production costs [8–10]. Nagurney et al. [5] developed a network-based game model of manufacturers' production outsourcing.

They identified manufacturers' minimum production costs and suppliers' maximum profits under quality and price competition. Ni et al. [9] analyzed equilibrium outsourcing strategies under different decision sequences. They also examined how production costs and economies of scope affect manufacturers' outsourcing strategies. Their results showed that high production costs and advantages from economies of scope directly motivate manufacturers to outsource production. Although production outsourcing can reduce production costs, it also increases supply chain uncertainty and risk [11]. Chen and Xiao [12] developed a production outsourcing game model for manufacturers under multiple uncertainties. Their simulations showed that manufacturers with strong production capacity do not outsource when external risk is low. When external risk is high, manufacturers outsource production regardless of their production capacity. Related studies on investment and production flexibility under uncertainty further show how firms' production-capacity decisions depend on external conditions. Wang et al. [13] used a real-options approach to examine how subsidies affect investment decisions under uncertainty, whereas Wang et al. [14] investigated how credit risk and production flexibility influence operational and expansion strategies. Although these researchers did not directly examine production outsourcing, they found that investment timing and production flexibility affect the value of retaining internal production capacity. Moreover, since information asymmetry and delays can reduce supply chain efficiency without managerial intervention [15], contractual coordination is required during production outsourcing. Chen et al. [16] proposed a quality investment-sharing contract. The contract uses a coordinated quality investment strategy in a dynamic game to improve outsourced product quality and overall supply chain benefits.

Research on procurement outsourcing strategies has mainly focused on channel structures [17–19], supply risks [20–22], and the number of suppliers [23–26]. Tsay and Agrawal [18] examined channel cooperation and conflict arising from firms' direct sales. Gupta et al. [21] considered a low-priced supplier with supply risk and a reliable supplier with a high wholesale price; they found that most manufacturers prefer sourcing from both suppliers. Chen and Chen [23] focused on dual sourcing involving a low-priced supplier with a long lead time and a high-priced supplier with a short lead time. Beyond procurement strategies under supply risk, several researchers have investigated risk mitigation mechanisms. Cai et al. [27] examined option contracts, rebate contracts, and replenishment mechanisms in a supply chain with uncertain capacity. These mechanisms were used to offset losses caused by delivery risk. Order allocation has also been studied in competitive platform settings. Wang et al. [28] developed a dynamic order-allocation model for a duopoly platform with a hybrid workforce and used a machine-learning approach to characterize the equilibrium allocation decisions. Although their model does not directly consider procurement outsourcing, it shows that order-allocation decisions can affect the distribution of operational advantages among competing platform participants.

Studies on production outsourcing generally treat an entire product or a single critical component as the research object. Few researchers simultaneously consider the multiple components that constitute a product within a cooperative and competitive manufacturing platform. To address this gap, Yang et al. [29] examined a product whose multiple components are outsourced to a competing manufacturer. The parties used a Nash bargaining game to determine the wholesale prices of outsourced components. The study derived the equilibrium output and profit of each participant under two outsourcing strategies and identified the optimal component outsourcing strategy through comparison. Numerical analysis was used to examine how product substitutability affects supply chain members' decisions and profits. Xie et al. [30] examined competing manufacturers' sourcing strategies for mixed-component products, considering external procurement risk and consumer perceptions of

brand value and sourcing risk. They compared internal, external, and dual sourcing and investigated how blockchain-enabled information transparency affects sourcing choices. Their study and ours connect component sourcing with downstream competition. However, their focus is on sourcing risk and consumer information, whereas we jointly examine production and procurement authority for critical and non-critical components, emphasizing how pooled-procurement discounts affect the OEM's optimal strategy, the CM's preference, and their win-win regions. Related research also shows that production decisions interact with downstream-market activities. Wang et al. [31] examined the interaction between green product production and advertising investment under green reputation. Although they focus on production and marketing rather than outsourcing, they found that production decisions cannot be evaluated independently of downstream competition and market response. This insight is particularly relevant when components are outsourced to a manufacturer that also competes in the product market. Nevertheless, research has not fully characterized the interaction among multi-component production outsourcing, procurement outsourcing, and the two parties' willingness to cooperate.

Second, most studies on outsourcing strategies examine either production outsourcing alone or procurement outsourcing conditional on production outsourcing. Wang et al. [32] were the first to investigate dual production and procurement outsourcing by an OEM competing with a CM. From a broader supply-chain-boundary perspective, Wang et al. [33] examined dynamic advertising, pricing, and the optimal timing of supply-chain elongation, showing that adjustments to supply-chain boundaries interact with operational decisions and market competition. Although supply-chain elongation differs from dual outsourcing, both involve changes in firm boundaries and the allocation of operational activities. However, researchers have not jointly examined how production and procurement authority should be allocated when a product comprises critical and non-critical components and the outsourcing partner is also a product-market competitor. In this study, we address this gap by integrating multi-component production, pooled procurement, quantity discounts, and downstream competition within a unified framework, thereby enabling the OEM's optimal strategy, the CM's strategic preference, and their win-win cooperation boundaries to be analyzed jointly.

Finally, researchers comparing strategies generally derive equilibrium profits and identify the conditions under which both parties achieve a win-win outcome [32,34,35]. Mao et al. [34] proposed four combinations of procurement strategies and developed a separate game model for each combination. They found that a pure low-carbon procurement strategy yields a win-win outcome for the supplier and retailer under specific conditions. The emission-reduction cost coefficient must exceed one threshold, while the carbon tax rate remains below another. Liu et al. [35] considered a two-echelon supply chain comprising a module supplier and a manufacturer. They compared a manufacturer-provided service mode with a mode in which the manufacturer delegates service provision. The delegated service mode produces a win-win outcome when consumer quality sensitivity and service dependence are moderate or lower. When both factors are high, the manufacturer-provided service mode produces a win-win outcome. These studies provide useful insights into cooperative supply-chain decisions, but few examine how external conditions change the cooperation boundaries between competing platform participants and thereby alter the probability of a win-win outcome.

Motivated by this general class of coopetitive manufacturing platforms, we examine four dual outsourcing modes for multi-component products. From the perspectives of the OEM and the CM, we identify the OEM's optimal outsourcing strategy and the CM's strategic preference under each mode. We then examine how the competitive environment, represented by relative market potential,

and procurement conditions affect these decisions and preferences. Finally, we identify the cooperation boundaries under which the OEM and the CM can achieve a win-win outcome and analyze how changes in the external environment affect their willingness to cooperate and the likelihood of mutual benefits.

Relative to the literature, the marginal contributions of this study are threefold:

(1) Building on studies of multi-component production outsourcing [29], mixed-component sourcing under procurement risk and consumer information [30], and dual production and procurement outsourcing [32], we jointly examine multi-component production and procurement authority within a unified game-theoretic framework. Specifically, we model the interdependent production and procurement decisions for a product comprising a critical component and a non-critical component on a competitive equipment manufacturing platform. This formulation reveals that procurement outsourcing can be optimal only when production is outsourced and that the strategy combining in-house production with outsourced procurement is dominated, a structural relationship that cannot be identified when the two decisions are examined separately.

(2) Strategy comparisons mainly determine whether a win-win outcome exists under given conditions [32,34,35]. We go beyond such existence comparisons by jointly deriving the OEM's optimal strategy, the CM's strategic preference, and the cooperation boundaries between them. This analysis shows how relative market potential and quantity discounts reshape the regions in which Strategy I or Strategy D can benefit both parties, thereby explaining how changes in the external environment alter their willingness to cooperate.

(3) We further identify a comparative-static mechanism that is not captured through analyses focusing on a single influencing factor. Conditional on the OEM retaining procurement authority, that is, when comparing Strategies D and N, the OEM's willingness to produce in-house is jointly affected by its relative market potential and the quantity-discount level and does not exhibit a uniform monotonic response to either factor considered separately. Moreover, stronger quantity discounts generally narrow the win-win region and reduce the likelihood of mutual benefit.

3. Problem description and model assumptions

3.1. Problem description

Consider a supply chain comprising a component supplier, a CM, and an OEM. The CM and the OEM sell a product composed of two components. Component 1 is critical. The OEM produces it in-house and uses in-house procurement for its parts. For component 2, the OEM can choose between production outsourcing and in-house production. The OEM can also choose between procurement outsourcing and in-house procurement for the parts used in component 2. Accordingly, we consider the following four outsourcing strategies.

Strategy I: The OEM produces component 1 in-house and outsources the production of component 2. It uses in-house procurement for parts used in component 1 and outsources the procurement of parts used in component 2.

Strategy D: The OEM produces component 1 in-house and outsources the production of component 2. It uses in-house procurement for parts used in both components.

Strategy N: The OEM produces both components in-house and uses in-house procurement for parts used in both components.

Strategy O: The OEM produces both components in-house. It uses in-house procurement for parts used in component 1 and outsources the procurement of parts used in component 2.

The corresponding supply chain structures are shown in Figure 1.

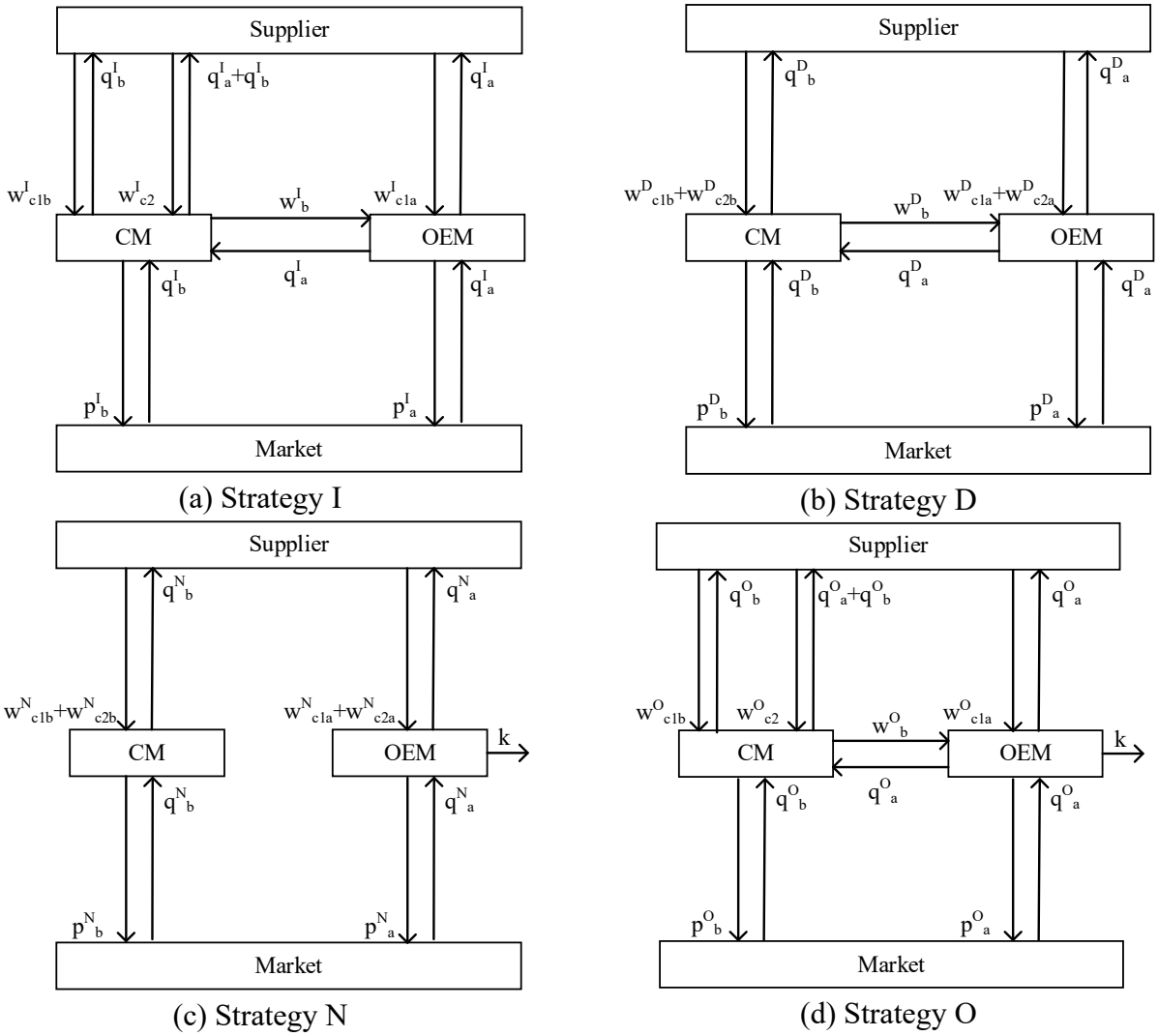


Figure 1. Supply chain structures.

3.2. Model assumptions

Assumption 1. Under Strategies I, D, and O, the OEM and the CM engage in a CM-led Stackelberg game with price leadership. The CM first announces and commits to the unit price w_b for the activity related to component 2 that is outsourced by the OEM. After observing w_b, the OEM determines its outsourcing order quantity q_a. The CM then observes q_a and determines the quantity q_b of its own product. Under Strategy N, neither production nor procurement is outsourced, and no

outsourcing-price decision is involved. The OEM and the CM therefore engage in a Cournot game by simultaneously determining their respective product quantities q_a and q_b.

The CM's Stackelberg leadership under Strategies I, D, and O arises from its ability to commit to the outsourcing price before the OEM places its order. This timing reflects the contracting process in which the CM first provides a binding quotation for the outsourced activity and the OEM subsequently determines its order quantity based on that quotation. Once the order is placed, the outsourcing price cannot be revised, whereas the CM can incorporate the observed order into its production and procurement plans before determining the quantity of its own product. Therefore, the CM's subsequent quantity decision does not contradict its Stackelberg leadership, which is established through its prior price commitment. Under Strategy N, no outsourcing contract or price-commitment stage exists; hence, the two firms make their product-quantity decisions simultaneously, consistent with Cournot competition.

Assumption 2. The one-time cost incurred by the OEM to establish a production line is k.

Assumption 3. The supplier offers linear quantity discount schedules for parts used in components 1 and 2, respectively: $w_{c1} = a_1 - dq$ and $w_{c2} = a_2 - dq$. Here, w_{c1} and w_{c2} denote the unit purchase prices charged by the supplier for parts used in components 1 and 2, respectively; a_1 and a_2 denote the corresponding base wholesale prices; d denotes the supplier's quantity discount level; and q denotes the order quantity. This discount scheme has been widely adopted in studies of procurement outsourcing, including Keskinocak and Savaşaneril [36] and Chen and Roma [37].

The quantity discount is determined by the purchase volume under each procurement mode. For the parts used in component 1, the OEM and the CM always procure independently; therefore, the discount is calculated according to each firm's individual purchase volume and is received by the corresponding firm. For the parts used in component 2, under Strategies I and O, the CM undertakes procurement for both firms. The discount is calculated based on the pooled purchase volume of the OEM and the CM and is received by the CM. Under Strategies D and N, the OEM and the CM procure independently; therefore, the discount is calculated separately according to each firm's individual purchase volume and is received by the corresponding firm.

Assumption 4. To obtain analytical results that facilitate subsequent analysis and comparison, we first consider the benchmark case in which the product substitutability parameter is set to $\gamma = 1$. This setting represents fully substitutable products. The case of imperfect product substitutability, namely $0 < \gamma < 1$, is examined in the extended model in Section 5.4. The unit price of the OEM's product is $p_a = A_a - (q_a + q_b)$, while the unit price of the CM's product is $p_b = A_b - (q_a + q_b)$. Here, A_a and A_b denote the market sizes of the OEM and the CM, respectively. The linear relationship between product price, market size, and output defines the inverse demand functions. These functions can be derived from the quadratic consumer utility function in Singh and Vives [38].

Assumption 5. Following Arya et al. [39], we define $\alpha_a = A_a - a_1 - a_2 - c_1 - c_2$ and $\alpha_b = A_b - a_1 - a_2 - c_1 - c_2$ for the OEM and the CM, respectively. Here, c_1 and c_2 denote the production costs of components 1 and 2, respectively. Thus, α_a and α_b are defined as the firms' market-size parameters net of the base wholesale prices and component production costs, and each reflects the corresponding firm's profitability to some extent. Therefore, α_a and α_b can be used to compare the

OEM's and the CM's profit-generating potential. We define α_a and α_b as the market potentials of the OEM and the CM, respectively. In this sense, they are market-potential indicators constructed on the basis of net profitability rather than raw market-size measures. Throughout this paper, relative market potential refers to $\frac{\alpha_a}{\alpha_b}$. For analytical tractability, the benchmark model assumes that the OEM and the CM have identical component production costs. This assumption enables us to focus on the effects of outsourcing decisions, relative market potential, and quantity discounts without introducing additional cost heterogeneity. The extended model in Section 5.4 further considers the case in which the production costs of the OEM and the CM differ.

To ensure the concavity of the profit functions, the parameters are restricted as follows: $0 < d < \frac{1}{2} - \frac{\sqrt{10}}{8}$.

To ensure nonnegative output under each strategy, the following parameter conditions are imposed: When $d \in \left(0, \frac{1}{2} - \frac{\sqrt{3}}{4}\right)$, $\frac{1}{1-2d} < \frac{\alpha_a}{\alpha_b} < 2-4d$;

When $d \in \left[\frac{1}{2} - \frac{\sqrt{3}}{4}, \frac{1}{2} - \frac{\sqrt{10}}{8}\right)$, $\frac{1}{1-2d} < \frac{\alpha_a}{\alpha_b} < \frac{32d^2-32d+5}{2-4d}$.

Let $f_L(d) = \frac{1}{1-2d}$, $f_H(d) = \min\left\{2-4d, \frac{32d^2-32d+5}{2-4d}\right\}$.

The admissible range of the parameter $\frac{\alpha_a}{\alpha_b}$ is therefore given by: $f_L(d) < \frac{\alpha_a}{\alpha_b} < f_H(d)$.

4. Model formulation and solution

4.1. Strategy I

Under the preceding assumptions, the respective profit functions of the OEM and the CM under Strategy I are given by:

$$\pi_a^I = \left[A_a - (q_a^I + q_b^I) - \left(a_1 - dq_a^I\right) - w_b^I - c_1\right] q_a^I \tag{1}$$

$$\pi_b^I = \left[A_b - (q_a^I + q_b^I) - \left(a_1 - dq_b^I\right) - \left(a_2 - dq_a^I - dq_b^I\right) - c_1 - c_2\right] q_b^I + \left[w_b^I - \left(a_2 - dq_a^I - dq_b^I\right) - c_2\right] q_a^I \tag{2}$$

Lemma 1. Under Strategy I, the equilibrium solution is given by:

$$w_b^{I*} = \frac{6d-1}{10d-3}\alpha_a + \frac{8d^2-2d+1}{2(2d-1)(10d-3)}\alpha_b + a_2 + c_2 \tag{3}$$

$$q_a^{I*} = \frac{2-4d}{20d^2-16d+3}\alpha_a - \frac{2-2d}{20d^2-16d+3}\alpha_b \tag{4}$$

$$q_b^{I*} = \frac{5-12d}{40d^2-32d+6}\alpha_b - \frac{2-4d}{40d^2-32d+6}\alpha_a \tag{5}$$

$$\pi_a^{I*} = \frac{2\left[(1-2d)\alpha_a - (1-d)\alpha_b\right]^2}{(1-2d)(10d-3)^2} \tag{6}$$

$$\pi_b^{I*} = \frac{\left[(1-2d)\alpha_a - (1-d)\alpha_b\right]^2}{(2d-1)^2(3-10d)} + \frac{1}{4(1-2d)}\alpha_b^2 \tag{7}$$

Under Strategy I, Lemma 1 shows that greater OEM market potential increases its equilibrium outsourcing order and reduces the CM's own-product output. The equilibrium outsourcing price also decreases, further supporting the OEM's order expansion. However, because the CM purchases parts for component 2 on behalf of both firms, a larger OEM order also increases the CM's pooled-procurement discount. Thus, Strategy I enables the OEM to avoid production investment but also strengthens the CM's procurement-cost advantage. Its attractiveness therefore depends on the balance between investment savings and competitive effects relative to other production and procurement arrangements. In Section 5.1, we compare these arrangements to determine the OEM's optimal strategy, while in Section 5.2, we examine the CM's preferences over the OEM's outsourcing choices.

4.2. Strategy D

Under the preceding assumptions, the respective profit functions of the OEM and the CM under Strategy D are given by:

$$\pi_a^D = \left[A_a - \left(q_a^D + q_b^D\right) - \left(a_1 - dq_a^D\right) - \left(a_2 - dq_a^D\right) - w_b^D - c_1\right]q_a^D \tag{8}$$

$$\pi_b^D = \left[A_b - \left(q_a^D + q_b^D\right) - \left(a_1 - dq_b^D\right) - \left(a_2 - dq_b^D\right) - c_1 - c_2\right]q_b^D + \left(w_b^D - c_2\right)q_a^D \tag{9}$$

Lemma 2. Under Strategy D, the equilibrium solution is given by:

$$w_b^{D*} = \frac{32d^2-32d+2}{2\left(32d^2-32d+3\right)}\alpha_a + \frac{\alpha_b}{2(1-2d)\left(32d^2-32d+3\right)} + c_2 \tag{10}$$

$$q_a^{D*} = \frac{2-4d}{32d^2-32d+3}\alpha_a - \frac{2}{32d^2-32d+3}\alpha_b \tag{11}$$

$$q_b^{D*} = \frac{32d^2-32d+5}{(2-4d)\left(32d^2-32d+3\right)}\alpha_b - \frac{1}{\left(32d^2-32d+3\right)}\alpha_a \tag{12}$$

$$\pi_a^{D*} = \frac{2\left(8d^2-8d+1\right)\left[(1-2d)\alpha_a - \alpha_b\right]^2}{(1-2d)\left(32d^2-32d+3\right)^2} \tag{13}$$

$$\pi_b^{D*} = \frac{\left[(1-2d)\alpha_a - \alpha_b\right]^2}{(1-2d)\left(32d^2-32d+3\right)} + \frac{1}{4(1-2d)}\alpha_b^2 \tag{14}$$

Under Strategy D, Lemma 2 shows that greater OEM market potential increases its equilibrium production-outsourcing order, whereas greater CM market potential reduces that order and raises the

outsourcing price. The OEM retains procurement authority and directly receives the quantity discount generated by its own order without increasing the CM's procurement volume. It therefore avoids production investment while retaining its purchasing benefits but still pays the CM for production. This raises two questions: whether retaining procurement is more profitable than outsourcing both activities, and whether avoiding production investment compensates for the outsourcing charge. In Section 5.1, we answer these questions by comparing Strategy D with Strategies I and N, respectively.

4.3. Strategy N

Under the preceding assumptions, the respective profit functions of the OEM and the CM under Strategy N are given by:

$$\pi_a^N = \left[A_a - \left(q_a^N + q_b^N\right) - \left(a_1 - dq_a^N\right) - \left(a_2 - dq_a^N\right) - c_1 - c_2 \right] q_a^N - k \tag{15}$$

$$\pi_b^N = \left[A_b - \left(q_a^N + q_b^N\right) - \left(a_1 - dq_b^N\right) - \left(a_2 - dq_b^N\right) - c_1 - c_2 \right] q_b^N \tag{16}$$

Lemma 3. Under Strategy N, the equilibrium solution is given by:

$$q_a^{N*} = \frac{2-4d}{16d^2-16d+3}\alpha_a - \frac{1}{16d^2-16d+3}\alpha_b \tag{17}$$

$$q_b^{N*} = \frac{2-4d}{16d^2-16d+3}\alpha_b - \frac{1}{16d^2-16d+3}\alpha_a \tag{18}$$

$$\pi_a^{N*} = \frac{(1-2d)\left[2(1-2d)\alpha_a - \alpha_b\right]^2}{\left(16d^2-16d+3\right)^2} - k \tag{19}$$

$$\pi_b^{N*} = \frac{(1-2d)\left[2(1-2d)\alpha_b - \alpha_a\right]^2}{\left(16d^2-16d+3\right)^2} \tag{20}$$

Under Strategy N, Lemma 3 shows that greater OEM market potential increases its equilibrium output, whereas greater CM market potential reduces it through stronger downstream competition. Because the OEM procures independently, a larger output also generates a larger procurement order and a greater quantity discount. However, the OEM must bear the one-time production-line investment. This fixed cost reduces its profit without changing the equilibrium output conditional on Strategy N. Therefore, higher output alone does not make in-house production preferable: its operating-profit advantage over outsourcing must cover the investment cost. In Section 5.1, we determine the corresponding investment thresholds by comparing Strategy N with Strategies I and D.

4.4. Strategy O

Under the preceding assumptions, the respective profit functions of the OEM and the CM under Strategy O are given by:

$$\pi_a^O = \left[A_a - \left(q_a^O + q_b^O\right) - \left(a_1 - dq_a^O\right) - w_b^O - c_1 - c_2 \right] q_a^O - k \tag{21}$$

$$\pi_b^O = \left[A_b - (q_a^O + q_b^O) - \left(a_1 - dq_b^O\right) - \left(a_2 - dq_a^O - dq_b^O\right) - c_1 - c_2 \right] q_b^O$$

$$+\left[w_b^O-\left(a_2-dq_a^O-dq_b^O\right)\right]q_a^O \tag{22}$$

Lemma 4. Under Strategy O, the equilibrium solution is given by:

$$w_b^{O*}=\frac{6d-1}{10d-3}\alpha_a+\frac{8d^2-2d+1}{2(2d-1)(10d-3)}\alpha_b+a_2 \tag{23}$$

$$q_a^{O*}=\frac{2-4d}{20d^2-16d+3}\alpha_a-\frac{2-2d}{20d^2-16d+3}\alpha_b \tag{24}$$

$$q_b^{O*}=\frac{5-12d}{40d^2-32d+6}\alpha_b-\frac{2-4d}{40d^2-32d+6}\alpha_a \tag{25}$$

$$\pi_a^{O*}=\frac{2\left[(1-2d)\alpha_a-(1-d)\alpha_b\right]^2}{(1-2d)(10d-3)^2}-k \tag{26}$$

$$\pi_b^{O*}=\frac{\left[(1-2d)\alpha_a-(1-d)\alpha_b\right]^2}{(2d-1)^2(3-10d)}+\frac{1}{4(1-2d)}\alpha_b^2 \tag{27}$$

Under Strategy O, Lemma 4 shows that the equilibrium quantities are identical to those under Strategy I under the benchmark assumptions. Greater OEM market potential increases its output and lowers the procurement-outsourcing price, whereas greater CM market potential has the opposite effects. Although the OEM retains production, it delegates procurement to the CM and does not directly receive the pooled-procurement discount. Compared with Strategy I, retaining production provides no additional operating profit but requires the one-time production-line investment. In Section 5.1, we formalize this comparison and further compare Strategy O with Strategy N to explain why procurement outsourcing alone cannot be the OEM's optimal choice.

5. Model discussion and analysis

5.1. Dual outsourcing decisions of the OEM on the manufacturing platform

The optimal outsourcing decisions of the OEM are obtained by first considering the four initially formulated strategies. Theorem 1 establishes that Strategy O is strictly dominated and therefore cannot be optimal. After eliminating Strategy O, Theorem 2 derives the OEM's optimal decision rules by comparing the remaining nondominated strategies, Strategies I, D, and N.

Theorem 1. If the OEM chooses in-house production, it will always choose in-house procurement; if it chooses procurement outsourcing, it will always choose production outsourcing. Thus, the OEM will not choose Strategy O.

The profit difference between Strategies N and O is given by:

$$\pi_a^{N*}-\pi_a^{O*}=\frac{(1-2d)\left[2(1-2d)\alpha_a-\alpha_b\right]^2}{\left(16d^2-16d+3\right)^2}-\frac{2\left[(1-2d)\alpha_a-(1-d)\alpha_b\right]^2}{(1-2d)(10d-3)^2}>0.$$

Therefore, under in-house production, the OEM always earns a higher profit from in-house procurement than from procurement outsourcing. Hence, whenever the OEM chooses in-house production, it will also choose in-house procurement.

In addition, the following inequality holds:

$$\pi_a^{I^*} - \pi_a^{O^*} = k > 0.$$

This inequality indicates that the OEM earns a higher profit by jointly choosing procurement outsourcing and production outsourcing than by choosing procurement outsourcing while producing in-house. Therefore, whenever the OEM chooses procurement outsourcing, it will also choose production outsourcing.

Theorem 2. The optimal outsourcing strategy of the OEM is determined as follows:

When $f_L(d) < \dfrac{\alpha_a}{\alpha_b} < f(d)$:

If $0 < k \leqslant Q_{IN}$, the OEM chooses Strategy N;

if $k > Q_{IN}$, the OEM chooses Strategy I.

When $f(d) \leqslant \dfrac{\alpha_a}{\alpha_b} < f_H(d)$:

If $0 < k \leqslant Q_{DN}$, the OEM chooses Strategy N;

if $k > Q_{DN}$, the OEM chooses Strategy D.

where

$$f(d) = \frac{(1-d)\left(32d^2-32d+3\right)-(3-10d)\sqrt{8d^2-8d+1}}{(1-2d)\left[32d^2-32d+3-(3-10d)\sqrt{8d^2-8d+1}\right]};$$

$$Q_{IN} = \frac{(1-2d)\left[2(1-2d)\alpha_a-\alpha_b\right]^2}{\left(16d^2-16d+3\right)^2} - \frac{2\left[(1-2d)\alpha_a-(1-d)\alpha_b\right]^2}{(1-2d)(10d-3)^2};$$

$$Q_{DN} = \frac{(1-2d)\left[2(1-2d)\alpha_a-\alpha_b\right]^2}{\left(16d^2-16d+3\right)^2} - \frac{2\left(8d^2-8d+1\right)\left[(1-2d)\alpha_a-\alpha_b\right]^2}{(1-2d)\left(32d^2-32d+3\right)^2}.$$

Figure 2 provides a more intuitive illustration of the OEM's outsourcing strategy decisions.

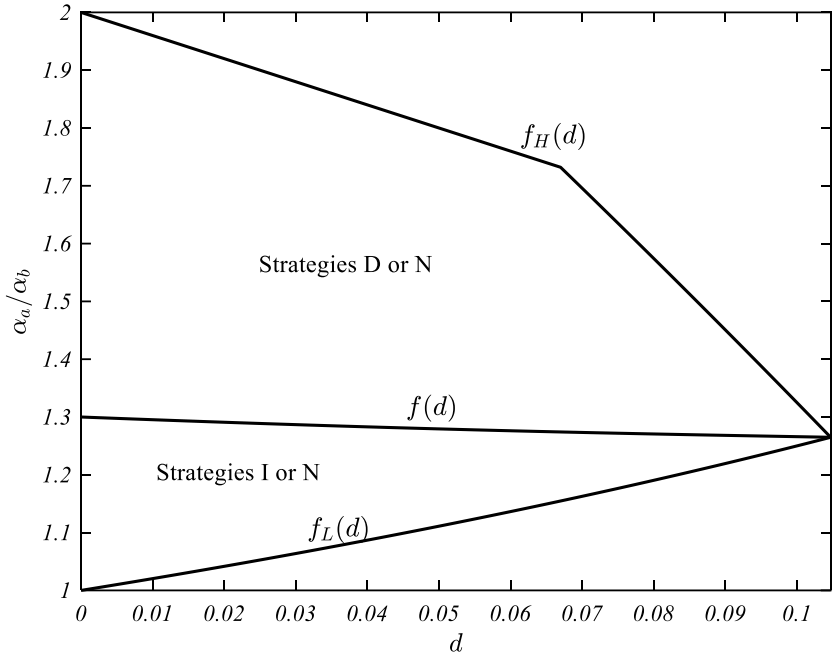


Figure 2. Outsourcing strategy decisions.

In summary, when the one-time investment cost of establishing a production line is low, the OEM should choose in-house production and in-house procurement. When this cost is high, it should choose production outsourcing. Moreover, whether procurement should also be outsourced depends on relative market potential. Procurement outsourcing is preferred when the OEM's relative market potential is low, whereas in-house procurement is preferred when it is high.

Theorem 2 shows that the OEM's outsourcing strategy is affected by the one-time investment cost of establishing a production line, the relative market potential between the OEM and the CM, and the supplier's quantity discount level. Therefore, in the following subsections, we examine the sensitivity of the outsourcing decision to each of these three factors.

5.1.1. Effect of the one-time investment cost of establishing a production line on outsourcing strategies

The following corollaries follow directly from Theorem 2:

Corollary 1. For given relative market potential and quantity-discount level, the OEM's production decision is determined by comparing the one-time investment cost k with the applicable threshold. When k is below the threshold, the OEM chooses in-house production; and when k exceeds the threshold, it chooses production outsourcing.

Corollary 2. The OEM chooses procurement outsourcing only when the one-time investment cost k exceeds a certain threshold. When k is below the threshold, the OEM chooses in-house procurement. When k exceeds the threshold, whether it chooses procurement outsourcing depends on its relative market potential.

5.1.2. Effect of relative market potential on outsourcing strategies

According to Theorem 2, relative market potential $\frac{\alpha_a}{\alpha_b}$ affects the thresholds Q_{IN} and Q_{DN}. For Q_{IN}, differentiation with respect to the relative market potential gives $\frac{\partial Q_{IN}}{\partial(\alpha_a/\alpha_b)} = 4\alpha_b^2\left[\frac{(1-2d)^2\left[2(1-2d)(\alpha_a/\alpha_b)-1\right]}{\left(16d^2-16d+3\right)^2} - \frac{(1-2d)(\alpha_a/\alpha_b)-(1-d)}{(10d-3)^2}\right]$. As proved in the Appendix, this derivative is strictly positive throughout the admissible range of $\frac{\alpha_a}{\alpha_b}$ corresponding to Q_{IN}: $\frac{\partial Q_{IN}}{\partial(\alpha_a/\alpha_b)} > 0$. For the threshold Q_{DN}, however, its relationship with relative market potential is non-monotonic. The joint effects of relative market potential and the quantity-discount level on Q_{DN}, together with the underlying reasons, are discussed in Section 5.1.4.

This result yields the following corollary:

Corollary 3. For a given quantity-discount level, when the OEM's relative market potential satisfies $f_L(d) < \frac{\alpha_a}{\alpha_b} < f(d)$, its willingness to produce in-house increases with its relative market potential.

Corollary 3 indicates that, when the OEM's relative market potential is below $f(d)$, the relevant production decision is the choice between Strategies I and N. As $\frac{\alpha_a}{\alpha_b}$ increases, the OEM's market demand and equilibrium output increase. On the one hand, the larger output enables the OEM to spread the one-time investment cost of establishing a production line over a greater production volume. On the other hand, a larger procurement volume enables the OEM to obtain a greater quantity discount under Strategy N. Under Strategy I, however, the OEM transfers procurement authority to the CM and therefore cannot directly obtain the quantity discount generated by its own order. Consequently, the relative advantage of Strategy N over Strategy I increases with $\frac{\alpha_a}{\alpha_b}$, strengthening the OEM's willingness to produce in-house.

Theorem 2 also yields the following corollary:

Corollary 4. For a given quantity-discount level, the OEM's willingness to retain procurement authority increases with its relative market potential.

Corollary 4 indicates that as the OEM's relative market potential $\frac{\alpha_a}{\alpha_b}$ increases, its output also rises. On the one hand, its own output is sufficient to secure a substantial quantity discount from the supplier. On the other hand, if it chooses procurement outsourcing, its output advantage helps the CM obtain a quantity discount far greater than what the CM's own output could secure. The CM then benefits much more than the OEM. Therefore, the OEM has a stronger incentive to use in-house procurement.

5.1.3. Effect of the supplier's quantity discount level on outsourcing strategies

According to Theorem 2, the OEM chooses procurement outsourcing when its relative market potential is below the threshold $f(d)$, whereas it retains procurement authority when its relative market potential exceeds $f(d)$. As shown in Figure 3, $f'(d) < 0$. Thus, $f(d)$ decreases as d increases. For any given level of relative market potential, an increase in d reduces the region in which the OEM chooses procurement outsourcing.

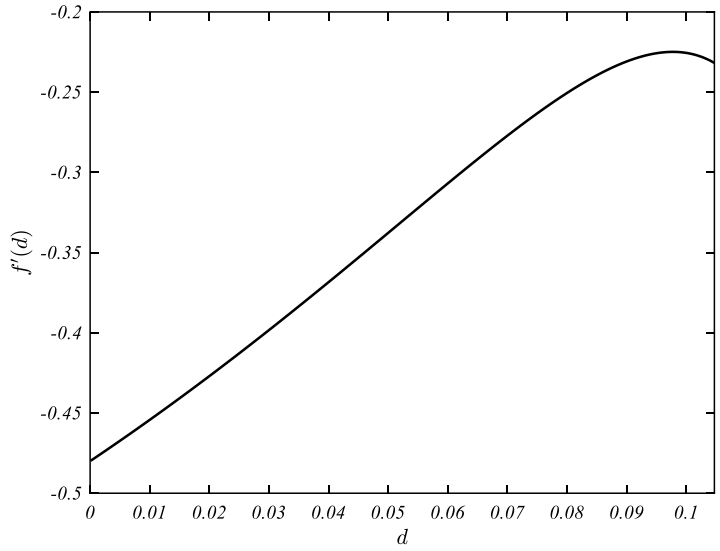


Figure 3. Plot of $f'(d)$.

This yields the following corollary:

Corollary 5. For a given level of relative market potential, the OEM's willingness to outsource procurement decreases as the supplier's quantity-discount level increases.

Corollary 5 indicates that, as the quantity-discount level d increases, the OEM can obtain a substantial quantity discount through its own procurement order, which strengthens the benefit of retaining procurement authority. Moreover, if procurement is outsourced, the CM combines the OEM's order with its own order and directly receives an even larger quantity discount. The resulting reduction in the CM's procurement cost gives it a stronger price advantage over the OEM in the product market.

To obtain the quantity discount directly and avoid further strengthening its competitor, the OEM becomes progressively less willing to outsource procurement.

We further examine the effect of the supplier's quantity-discount level on the OEM's production decision. According to Theorem 2, when $f_L(d) < \frac{\alpha_a}{\alpha_b} < f(d)$, the production decision is determined by the threshold Q_{IN}. As proved in the Appendix, $\frac{\partial Q_{IN}}{\partial d} > 0$ throughout this applicable domain. Therefore, Q_{IN} increases with the supplier's quantity-discount level. For Q_{DN}, however, the derivative $\frac{\partial Q_{DN}}{\partial d}$ does not have a constant sign. Its sign depends jointly on the quantity-discount level and relative market potential. The joint effects of these two factors on Q_{DN}, together with the underlying reasons, are discussed in Section 5.1.4.

This result yields the following corollary:

Corollary 6. For a given level of relative market potential, over the admissible range of d satisfying $f_L(d) < \frac{\alpha_a}{\alpha_b} < f(d)$, the OEM's willingness to produce in-house increases with the supplier's quantity-discount level.

Corollary 6 indicates that, when the OEM's relative market potential is below $f(d)$, the relevant production decision is the choice between Strategies I and N. Under Strategy N, the OEM retains production and procurement authority and directly obtains the quantity discount generated by its own procurement order. Under Strategy I, the OEM transfers production and procurement authority to the CM. The CM pools the OEM's procurement order with its own order and directly receives the resulting quantity discount. Therefore, as d increases, retaining procurement authority enables the OEM to obtain greater procurement-cost savings under Strategy N. Moreover, choosing Strategy I enables the CM to obtain a greater quantity discount and further strengthen its competitive advantage in the product market. Consequently, the relative advantage of Strategy N over Strategy I increases with d, strengthening the OEM's willingness to produce in-house.

5.1.4. Joint effects of relative market potential and the quantity-discount level on outsourcing strategies

According to Theorem 2, when $f(d) < \frac{\alpha_a}{\alpha_b} < f_H(d)$, the OEM chooses between Strategies D and N according to the threshold Q_{DN}. A higher Q_{DN} means that the OEM is willing to bear a higher one-time investment cost to establish its own production line and therefore indicates a stronger willingness to choose Strategy N. All discussions in this subsection are conditional on the above admissible

domain. Thus, "relatively low" and "sufficiently high" relative market potential refer to the position of $\frac{\alpha_a}{\alpha_b}$ within this d-dependent domain rather than to fixed absolute values.

The analytical expressions for $\frac{\partial Q_{DN}}{\partial d}$ and $\frac{\partial Q_{DN}}{\partial(\alpha_a/\alpha_b)}$ do not have constant signs throughout the admissible domain. Specifically, the sign of $\frac{\partial Q_{DN}}{\partial d}$ depends on $\frac{\alpha_a}{\alpha_b}$, whereas the sign of $\frac{\partial Q_{DN}}{\partial(\alpha_a/\alpha_b)}$ depends on d. Because the effects of the two parameters are interdependent, it is difficult to derive concise analytical conditions covering all possible cases. Nevertheless, their principal effects can be identified from the signs of the two derivatives and summarized as follows.

Corollary 7. Within the admissible domain $f(d) < \frac{\alpha_a}{\alpha_b} < f_H(d)$, the OEM's willingness to produce in-house is jointly affected by its relative market potential and the quantity-discount level. For a given d, this willingness increases with $\frac{\alpha_a}{\alpha_b}$ when d is relatively low, first increases and then decreases when d is moderately high, and decreases when d approaches the upper bound of its admissible domain. For a given $\frac{\alpha_a}{\alpha_b}$, the OEM's willingness to produce in-house first increases and then decreases with d when its relative market potential is in a relatively low-to-intermediate range, whereas it increases with d when its relative market potential is sufficiently high within the admissible domain.

Corollary 7 can be explained by the interaction between two effects. Relative market potential determines the extent to which the OEM benefits from production scale, whereas the quantity-discount level determines the value of retaining procurement authority. A higher relative market potential strengthens the production-scale advantage of Strategy N because the OEM can spread the one-time investment cost over a larger output and retain the production profit generated by that output. By contrast, a higher quantity-discount level increases the value of retaining procurement authority. However, the OEM does not need to retain production authority to obtain this benefit. Under Strategy D, it can retain procurement authority and receive the quantity discount while outsourcing production and avoiding the one-time investment. The OEM's production decision therefore depends on the balance between the production-scale advantage of Strategy N and the procurement-discount, investment-saving, and outsourcing-price advantages of Strategy D.

The effect of relative market potential depends on which of these two forces dominates at a given quantity-discount level. When d is relatively low, the procurement discount is limited, and the benefit of retaining procurement authority under Strategy D is correspondingly weak. An increase in $\frac{\alpha_a}{\alpha_b}$ expands the OEM's demand and output. The OEM can then spread the production-line investment over more units and retain the production profit generated by the larger output under Strategy N. The

production-scale advantage of Strategy N therefore dominates, causing Q_{DN} and the OEM's willingness to produce in-house to increase with its relative market potential.

When d is moderately high, the production-scale effect and the procurement-authority effect become more balanced. An initial increase in $\frac{\alpha_a}{\alpha_b}$ expands the OEM's production scale, so the production-scale advantage of Strategy N initially dominates and Q_{DN} increases. However, a larger relative market potential also results in a larger procurement order. Because the OEM retains procurement authority under Strategy D, it can obtain a substantial quantity discount without establishing its own production line. The CM may also reduce the outsourcing price to attract the OEM's larger production order. As the benefit of combining retained procurement authority with outsourced production becomes stronger, the advantages of Strategy D gradually offset the production-scale advantage of Strategy N. Consequently, Q_{DN} first increases and then decreases with the relative market potential.

When d approaches the upper bound of its admissible domain, the value of retaining procurement authority becomes particularly large. Under Strategy D, the OEM can obtain a substantial quantity discount from its own procurement order while avoiding the one-time investment in a production line. Thus, an increase in relative market potential not only increases the OEM's potential production scale but also enlarges the procurement-discount benefit that it can obtain without producing in-house. Together with the CM's outsourcing-price adjustment, the procurement-related and investment-saving advantages of Strategy D outweigh the additional production-scale benefit of Strategy N. Therefore, Q_{DN} decreases with the OEM's relative market potential.

Conversely, the effect of d depends on how strongly the OEM can benefit from production scale at a given relative market potential. In this regard, $\frac{\partial Q_{DN}}{\partial d}$ reflects the difference between the marginal profit gains generated by a higher quantity-discount level under Strategies N and D.

When the relative market potential is in a relatively low-to-intermediate range, the OEM's production scale is limited. An initial increase in d reduces the OEM's procurement cost and supports output expansion. Under Strategy N, the OEM produces this additional output by itself and retains the resulting production profit. The larger output also makes it easier to spread the one-time investment cost over more units. At this stage, the production-scale benefit generated by the increase in d dominates, and Q_{DN} increases.

As d continues to increase, however, the OEM's limited market potential constrains further output expansion. The additional production-scale benefit of Strategy N therefore gradually weakens. Moreover, the increasing quantity discount makes procurement authority more valuable. Because Strategy D also enables the OEM to retain procurement authority, the OEM can obtain a substantial procurement discount without bearing the one-time production investment. The CM may further reduce the outsourcing price to attract the OEM's production order. The procurement-discount,

investment-saving, and outsourcing-price advantages of Strategy D therefore become stronger relative to the limited additional scale benefit of Strategy N. Once the Strategy D effect dominates, Q_{DN} begins to decrease. Hence, when the relative market potential is in a relatively low-to-intermediate range, the OEM's willingness to produce in-house first increases and then decreases with d.

When the relative market potential is sufficiently high, the OEM has a large demand and production scale. A higher d reduces the procurement cost of a large quantity of parts and supports further output expansion. Under Strategy N, the OEM retains the procurement-cost savings and the production profit generated by the additional output. Its large production scale also enables the one-time investment cost to be spread over more units. In this case, the production-scale effect is sufficiently strong to dominate the benefit of retaining procurement authority while outsourcing production under Strategy D. Consequently, Q_{DN} increases with d, and the OEM becomes more willing to produce in-house.

Overall, relative market potential strengthens the production-scale benefit of Strategy N, whereas the quantity-discount level increases the value of retaining procurement authority, which can also be retained under Strategy D without retaining production authority. The changing balance between the production-scale effect and the attractiveness of separating procurement control from production control explains why Q_{DN} may increase, decrease, or first increase and then decrease within the admissible domain.

5.2. Outsourcing strategy preferences of the CM under platform competition

The CM's preferences regarding the OEM's outsourcing strategy decisions can be obtained by comparing its equilibrium profits under the two outsourcing strategies. The specific preferences are presented in Theorem 3.

Theorem 3. The CM's preferences over the OEM's outsourcing strategies are as follows:

When $f_L(d) < \dfrac{\alpha_a}{\alpha_b} < g(d)$, the CM prefers the OEM to choose Strategy I;

When $g(d) \leqslant \dfrac{\alpha_a}{\alpha_b} < f_H(d)$, the CM prefers the OEM to choose Strategy D.

where

$$g(d) = \frac{(1-d)\sqrt{32d^2-32d+3} - \sqrt{1-2d}\sqrt{3-10d}}{(1-2d)\left(\sqrt{32d^2-32d+3} - \sqrt{1-2d}\sqrt{3-10d}\right)}.$$

Figure 4 provides a more intuitive illustration of the CM's preferences over the OEM's outsourcing strategies.

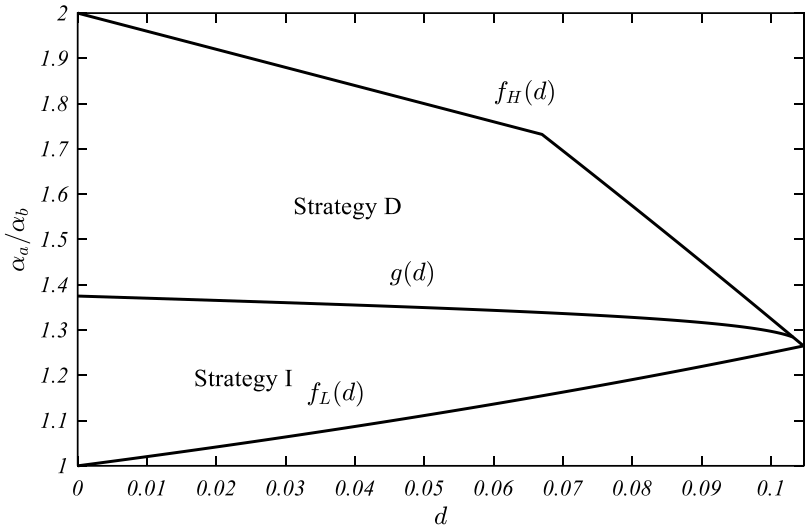


Figure 4. CM's preferences over outsourcing strategies.

Specifically, the CM's preference for the OEM to choose Strategy I is easy to understand. Under Strategy I, procurement orders are aggregated, enabling the CM to obtain the largest possible quantity discount and reduce its procurement cost. However, why does the CM instead prefer the OEM not to outsource procurement when $g(d) \leqslant \frac{\alpha_a}{\alpha_b} < f_H(d)$? The reason can be explained as follows:

Let $\rho = \frac{\alpha_a}{\alpha_b}$ denote the OEM's relative market potential, and define $\Delta q_a(\rho, d) = q_a^{I*} - q_a^{D*}$ as the difference between the OEM's equilibrium order quantities under Strategies I and D. As proved in the Appendix, $\Delta q_a(\rho, d) = q_a^{I*} - q_a^{D*}$ is strictly decreasing in $\rho = \frac{\alpha_a}{\alpha_b}$ throughout the admissible domain. Therefore, as the OEM's relative market potential increases, the difference between its order quantities under Strategies I and D continuously decreases. Once the relative market potential exceeds the corresponding threshold, the OEM's order quantity under Strategy I becomes lower than that under Strategy D.

This result has the following managerial interpretation. When the OEM's relative market potential becomes sufficiently high, the CM can obtain a substantial quantity-discount cost advantage from the OEM's outsourcing order under Strategy I. To limit this advantage, the OEM proactively reduces its outsourcing order. Under Strategy D, the OEM uses in-house procurement, so its order quantity does not enable the CM to benefit from pooled procurement. The OEM therefore has no corresponding incentive to reduce its order quantity. Consequently, when the relative market potential is sufficiently high, the OEM's order quantity under Strategy I becomes lower than that under Strategy D. The CM's profit under Strategy I is therefore lower than that under Strategy D, and the CM prefers the OEM to outsource production while retaining procurement in-house.

Theorem 3 shows that the boundary governing the CM's preference between Strategies I and D is affected by the supplier's quantity-discount level. Therefore, we next conduct a sensitivity analysis of this factor.

5.2.1. Effect of the supplier's quantity discount level on the CM's outsourcing strategy preferences

As shown in Figure 5, $g'(d) < 0$. Therefore, $g(d)$ decreases as d increases.

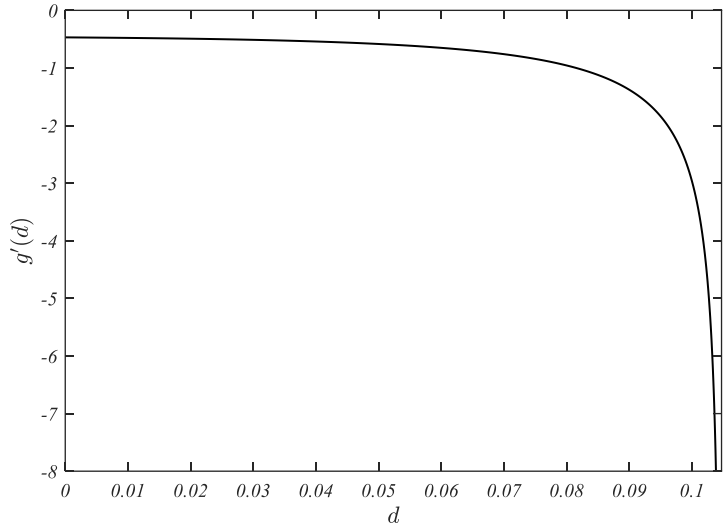


Figure 5. Plot of $g'(d)$.

This yields the following corollary:

Corollary 8. The CM's preference for Strategy I decreases as the supplier's quantity discount level increases.

Corollary 8 shows that under Strategy I, as the quantity discount level d continues to increase, the CM obtains increasingly large procurement discounts by aggregating the orders of both parties. To limit this advantage, the OEM proactively reduces its order quantity. By contrast, under Strategy D, the OEM uses in-house procurement and therefore has no incentive to reduce its order quantity. Consequently, as d increases, the CM's preference for Strategy I decreases.

5.3. Analysis of win-win strategy decisions

A win-win outcome requires the OEM to outsource production. Accordingly, in the following analysis, we consider the case in which the one-time investment cost of establishing a production line is sufficiently high for the OEM to forgo in-house production and choose production outsourcing.

In this study, a win-win outcome is defined conditional on the OEM choosing production outsourcing. Between Strategies I and D, a strategy satisfies individual rationality if the equilibrium profit of each firm under that strategy is no lower than its profit under the alternative production-outsourcing strategy. A strategy constitutes a win-win outcome when this condition holds for the OEM and the CM and at least one firm is strictly better off. Accordingly, the selected strategy represents a Pareto improvement over the alternative production-outsourcing strategy within the feasible strategy set considered in this study.

Combining Theorems 2 and 3 yields the win-win strategies for the CM and the OEM, as stated in Theorem 4.

Theorem 4. The win-win strategies for the OEM and the CM are as follows:

When $f_L(d) < \frac{\alpha_a}{\alpha_b} < f(d)$, Strategy I yields a win-win outcome;

When $g(d) \leqslant \frac{\alpha_a}{\alpha_b} < f_H(d)$, Strategy D yields a win-win outcome.

Figure 6 provides a more intuitive illustration of the ranges over which the win-win strategies arise.

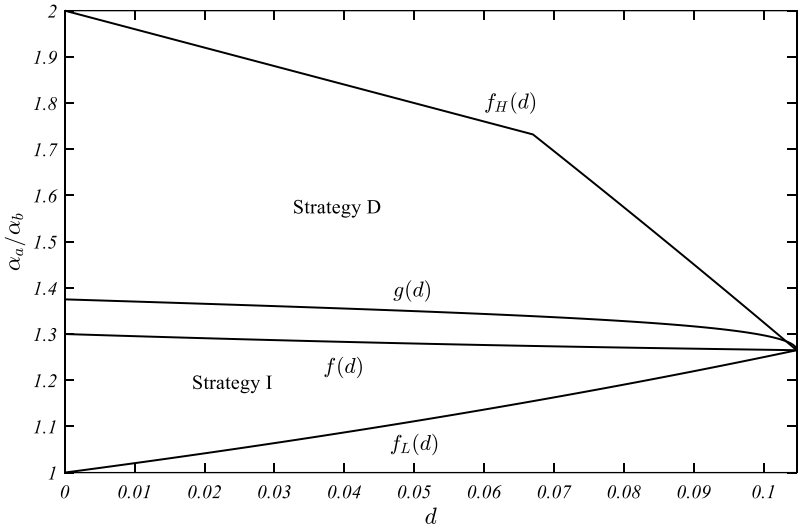


Figure 6. Win-win strategies.

It should be noted that no win-win strategy exists when $f(d) < \frac{\alpha_a}{\alpha_b} < g(d)$. In this region, conditional on production outsourcing, the OEM prefers Strategy D, whereas the CM prefers Strategy I. Therefore, neither production-outsourcing strategy satisfies the individual-rationality conditions of both firms simultaneously. Under the decentralized decision structure considered in this study, switching between Strategies I and D benefits one party at the expense of the other, so their strategic preferences remain in conflict.

5.3.1. Effect of the supplier's quantity discount level on the likelihood of a win-win outcome

Define $h(d) = \frac{f(d) - f_L(d) + \max\{f_H(d) - g(d), 0\}}{f_H(d) - f_L(d)}$ as the likelihood that the OEM and the CM achieve a win-win outcome.

Figure 7 shows how $h(d)$ changes with d.

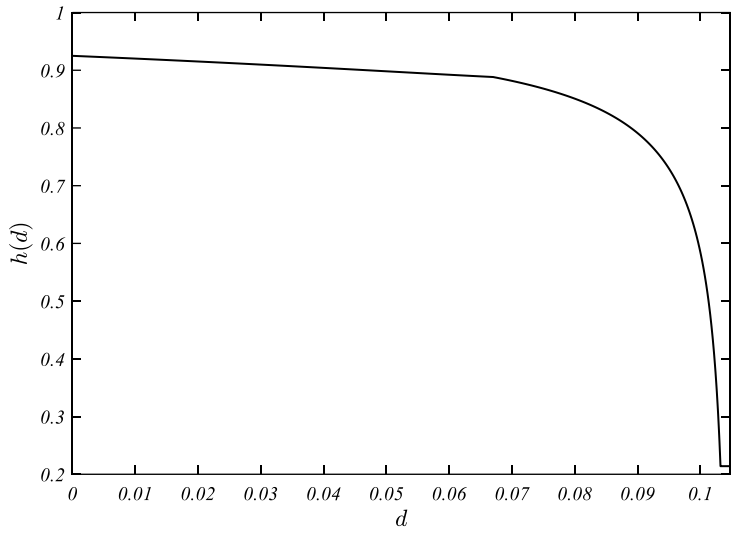


Figure 7. Variation in the likelihood of a win-win outcome.

This yields the following corollary:

Corollary 9. The likelihood of achieving a win-win outcome generally decreases as d increases. When $0.1032019 < d < 0.1047152$, it remains stable at a relatively low level of approximately 21.4%.

Here, $d = 0.1032019$ is the d-coordinate of the intersection between the $g(d)$ and $f_H(d)$ curves in Figure 6.

Figure 6 shows that a win-win outcome can be achieved only when Strategy D is chosen at a relatively high level of the OEM's relative market potential or Strategy I is chosen at a relatively low level. When relative market potential lies in an intermediate range, neither strategy yields a win-win outcome. As d increases, the OEM becomes less willing to cooperate at low relative market potential, while the CM becomes less willing to cooperate at high relative market potential. The range in which both parties are willing to cooperate therefore narrows toward an intermediate level of relative market potential. Consequently, the likelihood of a win-win outcome decreases with d and stabilizes at a low level.

The underlying mechanism is as follows: When the OEM's relative market potential is low and it chooses Strategy I, an increase in the supplier's quantity discount level d induces the OEM to deliberately reduce output. This prevents the CM from obtaining an excessive quantity discount and gaining a competitive advantage. However, the OEM's product price is also low under this market condition, so the output reduction gradually compresses its profit margin. The OEM therefore becomes less willing to cooperate with the CM at low relative market potential. When relative market potential is high and the OEM chooses Strategy D, it need not worry that the CM will obtain large discounts through procurement outsourcing. As d increases, the OEM expands output. As the OEM expands its output, the resulting increase in total market supply intensifies downstream quantity competition, which induces the CM to reduce its own market output. Under this market condition, the CM's product price is low, and the unit outsourcing price also decreases as d increases. Its profit margin therefore narrows, making the CM less willing to cooperate with the OEM at high relative market potential. As both parties' willingness to cooperate declines, the likelihood of a win-win outcome also decreases.

5.4. Extension: Imperfect product substitutability and asymmetric component costs

The benchmark model assumes that the OEM and the CM have identical component production costs and that their products are fully substitutable. We now extend the model by simultaneously relaxing these two assumptions. This extension is motivated by two practical features of the outsourcing environment. First, the OEM and the CM may have different production costs because they differ in production technology, manufacturing experience, and specialization. In particular, as a specialized manufacturer, the CM may possess a production-cost advantage over the OEM. Second, the products supplied by the OEM and the CM may not be perfectly substitutable in the market because they may differ in brand reputation, product characteristics, service quality, or consumer perception.

Following the modeling assumptions in Section 3.2, let the OEM's production costs for components 1 and 2 be c_{a1} and c_{a2}, respectively, and let the CM's production costs for components 1 and 2 be c_{b1} and c_{b2}, respectively. Because of its production specialization, the CM is assumed to have a cost advantage, such that $c_{a1} > c_{b1}$ and $c_{a2} > c_{b2}$. Accordingly, the market potentials of the OEM and the CM are defined as $\alpha_a = A_a - a_1 - a_2 - c_{a1} - c_{a2}$ and $\alpha_b = A_b - a_1 - a_2 - c_{b1} - c_{b2}$, respectively.

The benchmark model further assumes that the products of the OEM and the CM are fully substitutable. We now consider the case in which the product substitutability parameter satisfies $0 < \gamma < 1$. Following the demand specification in Section 3.2, the unit prices of the OEM's and the CM's products are given by $\bar{p}_a = A_a - (\bar{q}_a + \gamma \bar{q}_b)$ and $\bar{p}_b = A_b - (\gamma \bar{q}_a + \bar{q}_b)$, respectively. All other assumptions remain unchanged.

Under the extended model, the profit functions and equilibrium conditions are constructed by incorporating the asymmetric component production costs and the imperfect-substitutability demand functions described above. The equilibrium quantities, outsourcing prices, and profits under Strategies I, D, O, and N are reported together in the Appendix. To keep the main text concise, the detailed equilibrium expressions are not repeated here.

To ensure the concavity of the profit functions, the quantity-discount level is restricted as follows: $0 < d < \min\left\{\gamma, \frac{1}{2} - \frac{\sqrt{10}}{8}\gamma\right\}$. Let $\Delta c = c_{a2} - c_{b2}$. To ensure the non-negativity of the equilibrium quantities under all strategies, the relative market potential must satisfy:

$$\max\left\{\frac{\gamma - d}{1-2d}, \frac{\gamma}{2(1-2d)}, \frac{\gamma}{1-2d} - \frac{\Delta c}{\alpha_b}\right\} < \frac{\alpha_a}{\alpha_b} < \min\left\{\frac{2(1-2d)}{\gamma}, \frac{8(1-2d)^2 - 3\gamma^2}{2\gamma(1-2d)} - \frac{\Delta c}{\alpha_b}\right\}.$$ Define

$$\bar{f}_L(d,\gamma) = \max\left\{\frac{\gamma - d}{1-2d}, \frac{\gamma}{2(1-2d)}, \frac{\gamma}{1-2d} - \frac{\Delta c}{\alpha_b}\right\}, \quad \bar{f}_H(d,\gamma) = \min\left\{\frac{2(1-2d)}{\gamma}, \frac{8(1-2d)^2 - 3\gamma^2}{2\gamma(1-2d)} - \frac{\Delta c}{\alpha_b}\right\}.$$

Then, the admissible range of the relative market potential can be written compactly as

$\bar{f}_L(d,\gamma) < \frac{\alpha_a}{\alpha_b} < \bar{f}_H(d,\gamma)$.

The introduction of asymmetric component production costs and imperfect product substitutability increases the number of model parameters, making it difficult to derive analytical decision conditions. We therefore use numerical simulations to verify whether the main conclusions of the benchmark model remain valid under the extended model. Specifically, we set $\alpha_b = 1$ and examine the cases of $\Delta c = 0.1$ and $\Delta c = 0.2$ under two levels of product substitutability, namely, $\gamma = 0.5$ and $\gamma = 0.8$.

5.4.1. OEM's outsourcing strategy

For $\Delta c = 0.1$, Figures 8 and 9 show the OEM's outsourcing strategy decisions when $\gamma = 0.5$ and $\gamma = 0.8$, respectively.

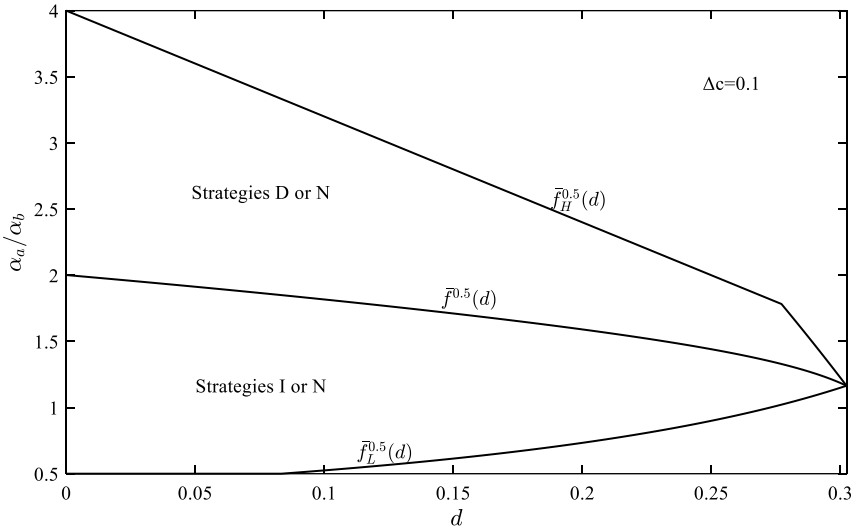


Figure 8. OEM's outsourcing strategy decision when $\Delta c = 0.1$ and $\gamma = 0.5$.

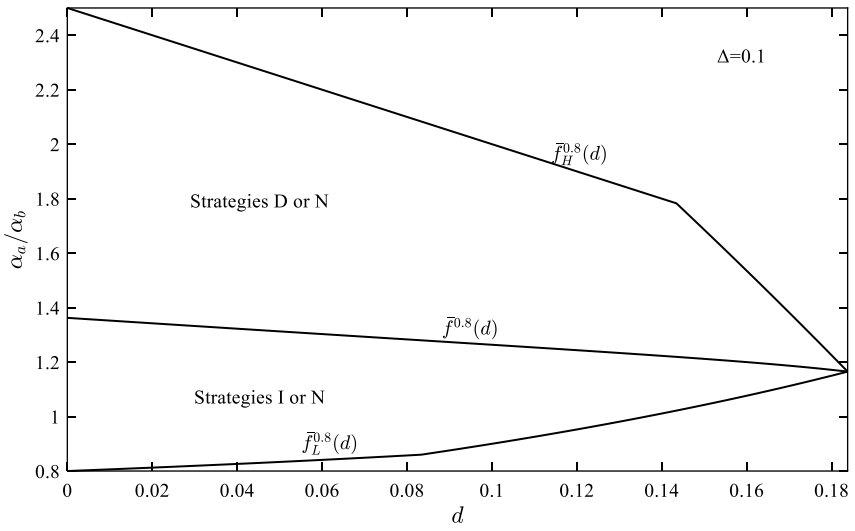


Figure 9. OEM's outsourcing strategy decision when $\Delta c = 0.1$ and $\gamma = 0.8$.

For $\Delta c = 0.2$, Figures 10 and 11 show the OEM's outsourcing strategy decisions when $\gamma = 0.5$ and $\gamma = 0.8$, respectively.

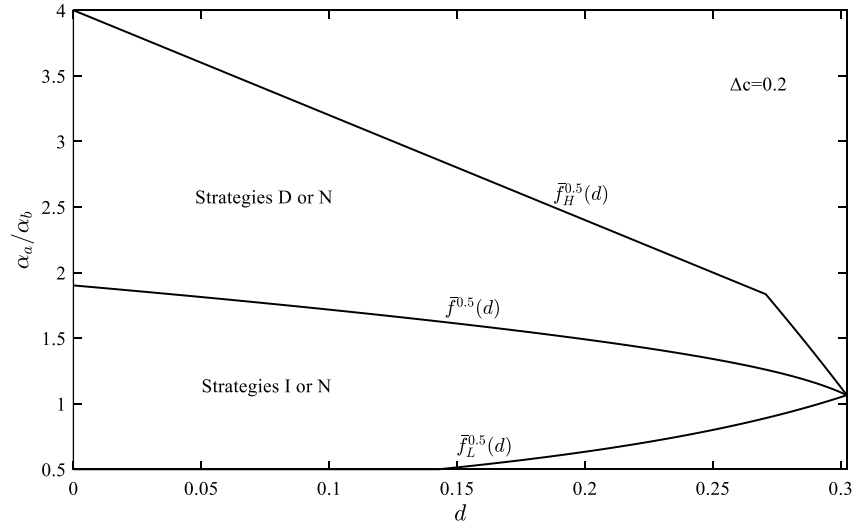


Figure 10. OEM's outsourcing strategy decision when $\Delta c = 0.2$ and $\gamma = 0.5$.

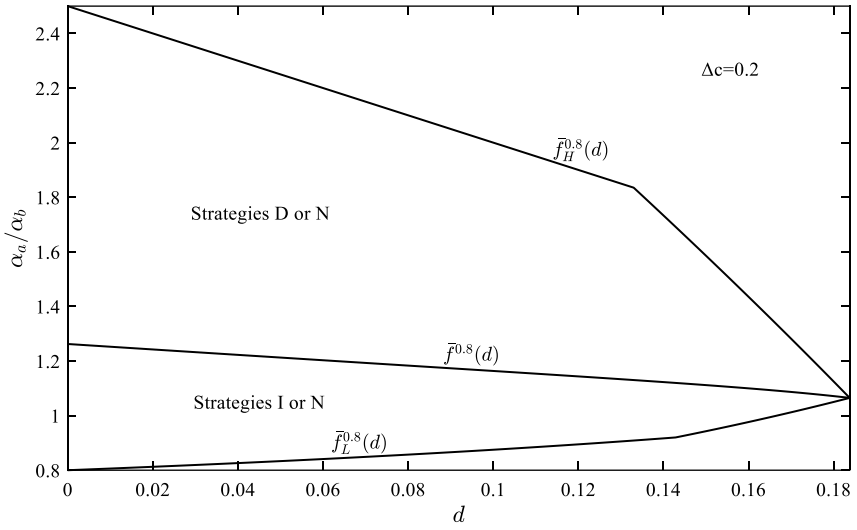


Figure 11. OEM's outsourcing strategy decision when $\Delta c = 0.2$ and $\gamma = 0.8$.

Comparing Figures 8–11 with Figure 2 shows that, under the examined parameter settings, the main conclusion regarding the OEM's outsourcing strategy remains valid in the extended model. In addition, the simulation results indicate that, for a given level of product substitutability, the region in which the OEM chooses Strategy I becomes smaller as Δc increases from 0.1 to 0.2. Thus, a larger production-cost difference reduces the OEM's relative willingness to adopt Strategy I. This is because a larger Δc represents a stronger production-cost advantage of the CM. Under Strategy I, pooled procurement enables the CM to further exploit this cost advantage and strengthen its competitive position in the product market. The OEM therefore becomes less willing to transfer procurement authority to the CM.

5.4.2. CM's strategy preference

For $\Delta c = 0.1$, Figures 12 and 13 show the CM's preferences regarding the OEM's outsourcing strategy when $\gamma = 0.5$ and $\gamma = 0.8$, respectively.

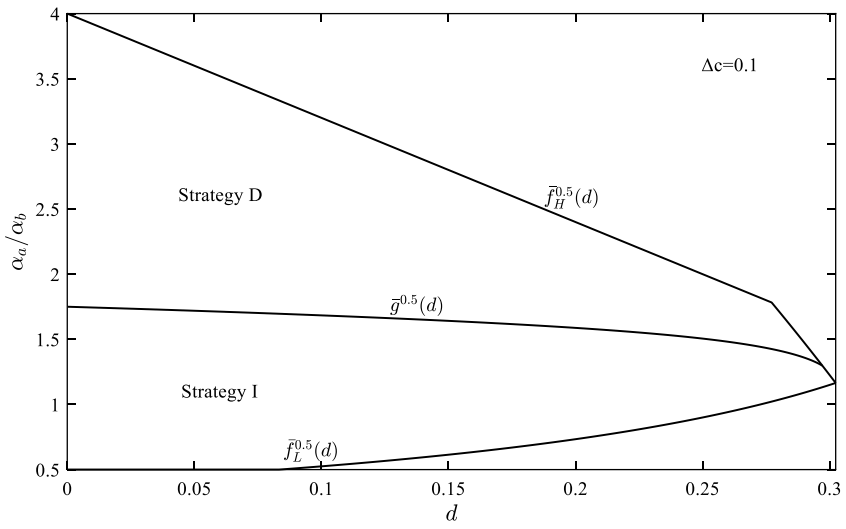


Figure 12. Contract manufacturer's strategy preference when $\Delta c = 0.1$ and $\gamma = 0.5$.

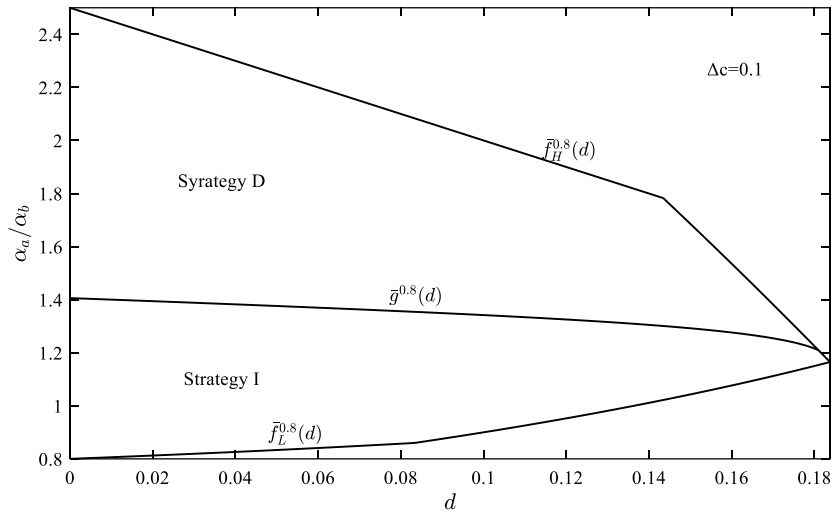


Figure 13. Contract manufacturer's strategy preference when $\Delta c = 0.1$ and $\gamma = 0.8$.

For $\Delta c = 0.2$, Figures 14 and 15 show the CM's preferences regarding the OEM's outsourcing strategy when $\gamma = 0.5$ and $\gamma = 0.8$, respectively.

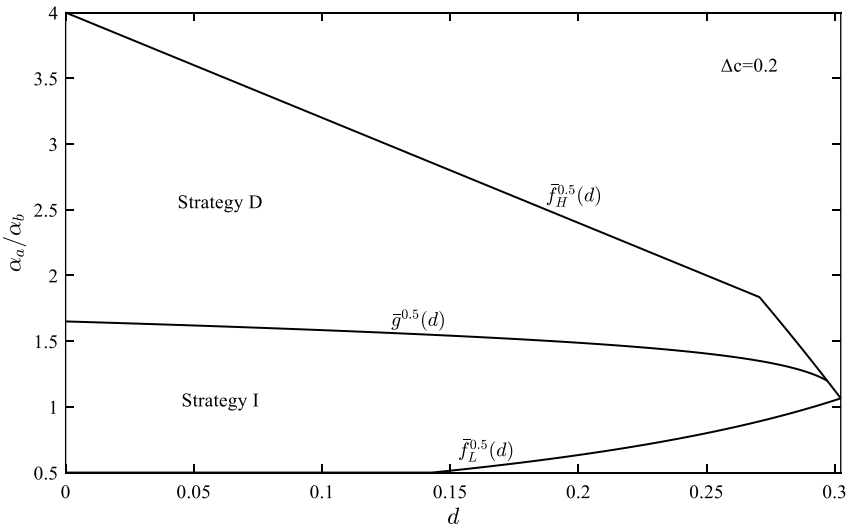


Figure 14. Contract manufacturer's strategy preference when $\Delta c = 0.2$ and $\gamma = 0.5$.

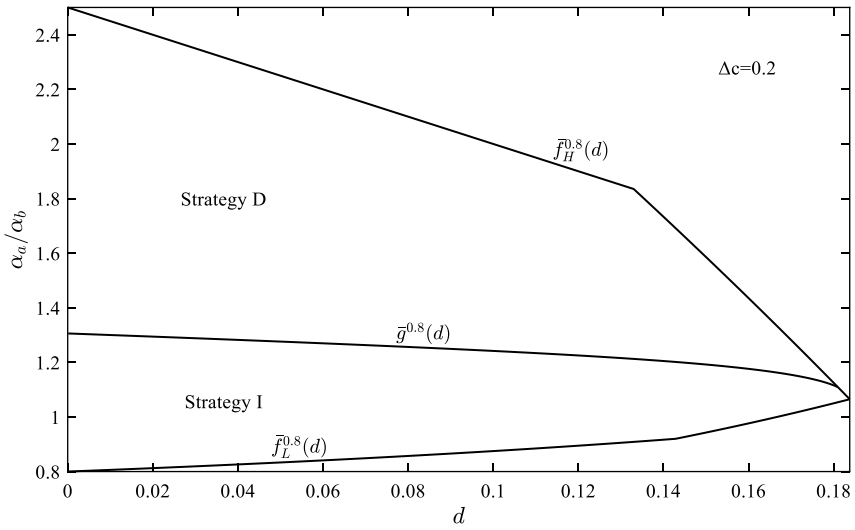


Figure 15. Contract manufacturer's strategy preference when $\Delta c = 0.2$ and $\gamma = 0.8$.

Comparing Figures 12–15 with Figure 4 shows that, under the examined parameter settings, the basic conclusion regarding the CM's strategy preference remains valid in the extended model. In addition, the simulation results indicate that, as Δc increases from 0.1 to 0.2, the region in which the CM prefers Strategy I becomes smaller, given the same level of product substitutability. Although a larger Δc strengthens the CM's production-cost advantage, it also makes the OEM more concerned about the CM's competitive position under Strategy I. The OEM therefore becomes less willing to transfer procurement authority to the CM and may reduce its outsourcing order, which weakens the benefit of pooled procurement for the CM. Consequently, the CM's relative preference for Strategy I decreases as Δc increases.

5.4.3. Win-win strategies

Finally, we examine whether the main conclusion regarding win-win strategies remains valid under different production-cost differences and product substitutability levels. Because a win-win outcome requires the OEM to outsource production, the comparison focuses on Strategies I and D.

For $\Delta c = 0.1$, Figures 16 and 17 show the win-win strategy regions when $\gamma = 0.5$ and $\gamma = 0.8$, respectively.

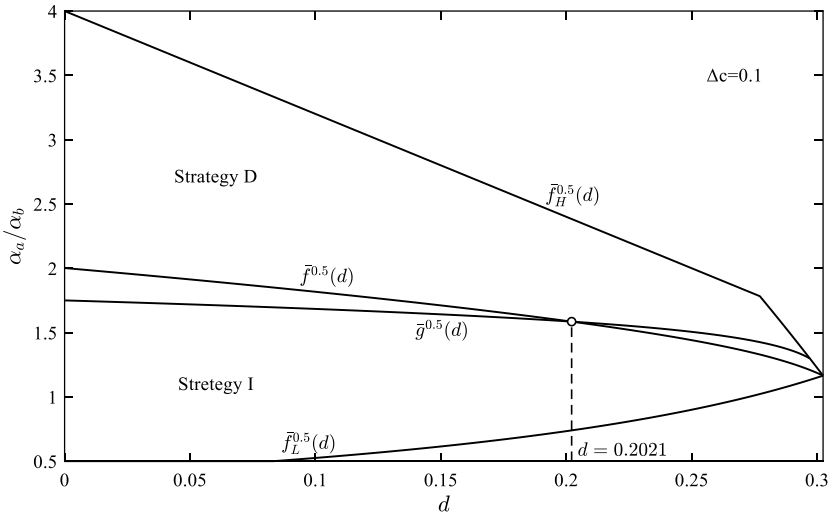


Figure 16. Win-win strategy when $\Delta c = 0.1$ and $\gamma = 0.5$.

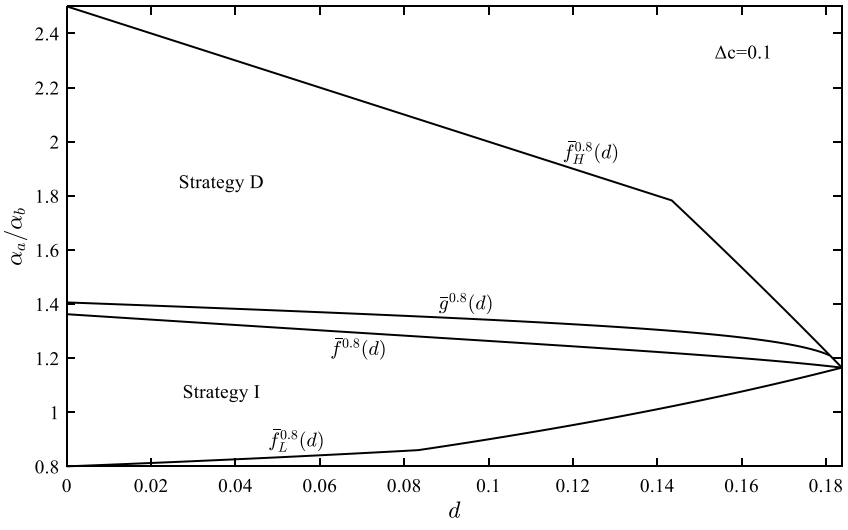


Figure 17. Win-win strategy when $\Delta c = 0.1$ and $\gamma = 0.8$.

For $\Delta c = 0.2$, Figures 18 and 19 show the win-win strategy regions when $\gamma = 0.5$ and $\gamma = 0.8$, respectively.

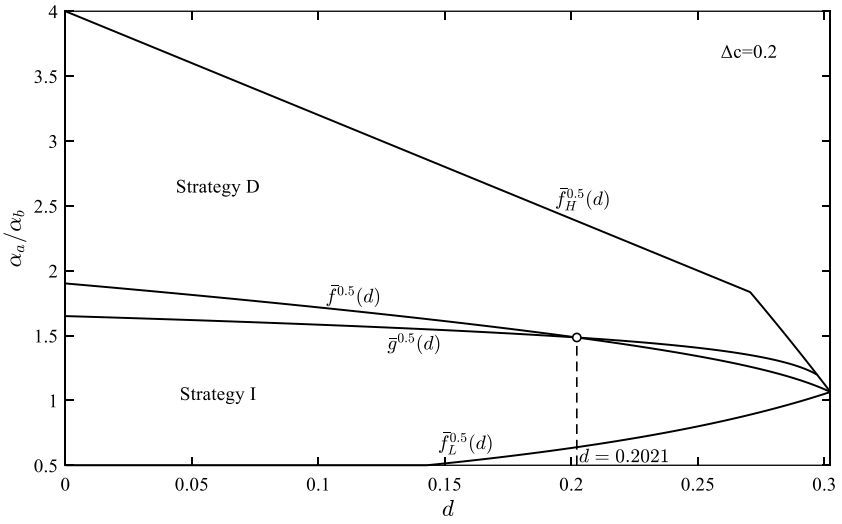


Figure 18. Win-win strategy when $\Delta c = 0.2$ and $\gamma = 0.5$.

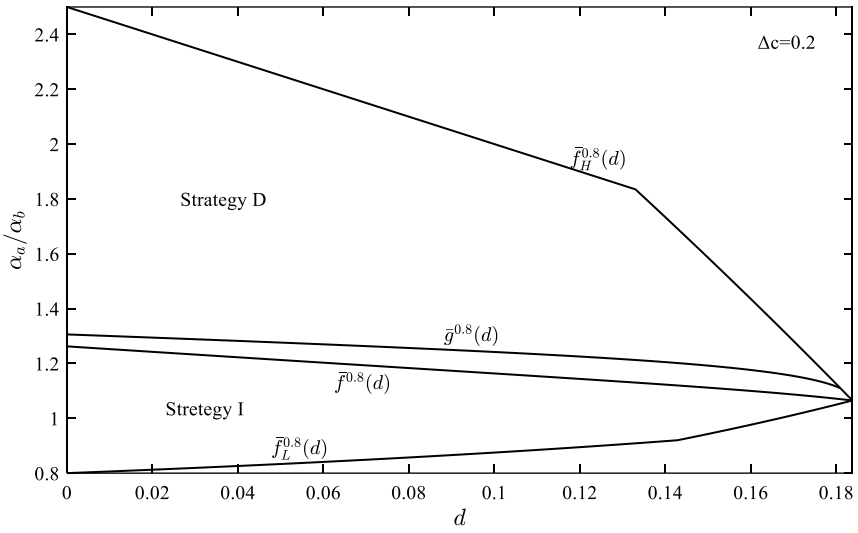


Figure 19. Win-win strategy when $\Delta c = 0.2$ and $\gamma = 0.8$.

Comparing Figures 16–19 with Figure 6 shows that, under the examined parameter settings, the basic conclusion regarding the win-win strategy is consistent with that of the benchmark model.

Overall, under the examined parameter settings, changes in production-cost differences and product substitutability may shift the corresponding strategy boundaries, but the main decision patterns regarding the OEM's outsourcing strategy, the CM's strategy preference, and the win-win strategy remain consistent with those of the benchmark model.

6. Conclusions

In this study, we develop a game-theoretic framework to examine four combinations of production and procurement decisions available to an OEM cooperating and competing with a CM. For each strategy, we derive the equilibrium prices, quantities, and profits and compare the OEM's

optimal strategy with the CM's strategic preference. The benchmark model analytically examines the effects of the one-time investment cost of establishing a production line, relative market potential, and the quantity-discount level. The extended model further relaxes the assumptions of identical component production costs and full product substitutability and uses numerical simulations to test the robustness of the benchmark conclusions.

The results yield several main findings. First, Strategy O is strictly dominated: In-house production is always accompanied by in-house procurement, whereas procurement outsourcing can be optimal only when production is outsourced. The OEM chooses Strategy N when the one-time investment cost of establishing a production line is below the corresponding threshold. When this cost exceeds the threshold, it chooses Strategy I at relatively low relative market potential and Strategy D at relatively high relative market potential. Second, conditional on the OEM retaining procurement authority, its willingness to produce in-house is jointly affected by relative market potential and the quantity-discount level and does not exhibit a uniform monotonic response to either factor considered separately. Third, the CM prefers Strategy I at relatively low relative market potential and Strategy D at relatively high relative market potential, while its preference for Strategy I decreases as the quantity-discount level increases. Finally, Strategy I can generate a win-win outcome at relatively low relative market potential, whereas Strategy D can generate a win-win outcome at relatively high relative market potential. No win-win production-outsourcing strategy exists in the intermediate conflict region, and the likelihood of a win-win outcome generally decreases as the quantity-discount level increases. Under the examined parameter settings, the extended-model simulations further show that asymmetric component production costs and imperfect product substitutability may shift the strategy boundaries but do not change these basic decision patterns.

(1) From the OEM's perspective, production and procurement decisions should be evaluated jointly. In-house production is always accompanied by in-house procurement, whereas procurement outsourcing is considered only when production is outsourced. The OEM should jointly assess the one-time investment cost of establishing a production line, its relative market potential, and the supplier's quantity-discount level. When the investment cost is below the corresponding production threshold, it should retain production and procurement in-house. When the investment cost exceeds the threshold, it should outsource both activities if its relative market potential is below the procurement threshold but outsource production while retaining procurement authority if its relative market potential exceeds that threshold. Because these thresholds vary with the quantity-discount level, the three factors should not be evaluated independently.

(2) From the CM's perspective, the preferred outsourcing arrangement depends on the trade-off between the service revenue generated by the OEM's order and the competitive pressure arising from the OEM's market position. Strategy I enables the CM to pool procurement orders and obtain a larger quantity discount, but a strong procurement-cost advantage may induce the OEM to reduce its outsourcing order. Strategy D does not provide pooled-procurement benefits to the CM, but it may generate a larger production-outsourcing order when the OEM has relatively high market potential. The CM should therefore evaluate procurement-cost savings and outsourcing-order revenue together rather than pursuing procurement outsourcing alone. Where its preference conflicts with that of the OEM, the CM cannot implement its preferred strategy unilaterally under the decentralized decision structure.

(3) From the platform perspective, governance should aim to sustain preference alignment rather than maximize the profit of only one participant. In the win-win regions identified in Theorem 4, transparent outsourcing-price quotations, disclosure of order-pooling and quantity-discount allocation

rules, and monitoring of production-capacity commitments can reduce implementation frictions and support the mutually preferred strategy. Platform managers should also monitor changes in the cooperation boundaries because stronger quantity discounts may reduce the willingness of either the OEM or the CM to cooperate. In the intermediate region where their preferences conflict, these governance measures may improve transparency but cannot, within this model, eliminate the underlying profit trade-off between the two firms.

Several directions warrant future research.

First, the model assumes that the OEM and the CM compete in the downstream product market. In practice, competing CMs may coexist with non-competing contract manufacturers that provide outsourcing services to the OEM without selling competing products. In future studies, researchers could examine hybrid supply chain structures involving competing and non-competing contract manufacturers.

Second, the model treats the CM's outsourcing price as a unilateral commitment and does not explicitly model negotiated contractual coordination. Thus, researchers could introduce Nash bargaining, side-payment, or revenue-sharing mechanisms to endogenize the outsourcing price and surplus allocation and examine whether these contractual arrangements can implement mutually beneficial outcomes in the intermediate region where the firms' strategy preferences conflict.

Use of Generative-AI tools declaration

The authors declare that no artificial intelligence (AI) tools were used in the creation of this manuscript.

Author contributions

Jinzhou He: Conceptualization, methodology, formal analysis, writing–original draft; Xiaojuan Li: Methodology, data curation, supervision, writing–review & editing. All authors have read and approved the final version of the manuscript.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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