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Research Article

Sourcing for Quality: Cooperating with a Single Supplier or Developing Two Competing Suppliers?

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Supplier efforts regarding product quality are an important issue in outsourcing and play a critical role in a manufacturer's choice of sourcing strategy. Consider a manufacturer that wants to outsource the manufacturing of two substitute products to external suppliers. This paper studies the strategic interactions under two sourcing strategies: single and dual sourcing. A four-stage noncooperative game model is established to describe each member's decisions. We further propose four decision scenarios: single sourcing with and without manufacturer quality investment sharing and dual sourcing when suppliers cooperate or do not cooperate on quality decisions. By the backward induction approach, we obtain analytical equilibrium solutions for each decision scenario. By comparing each pair of equilibrium profiles, we find that an appropriate proportion of quality investment sharing by the manufacturer can enable a cooperating strategy with a single supplier to be the dominant strategy. When the manufacturer does not want to share or does not want to share a relatively large portion of its supplier's quality investment, it will always prefer to develop two competing suppliers when the cost of dual sourcing is sufficiently low. However, dual sourcing can be extremely risky for the manufacturer because the suppliers could provide a relatively low product quality level by cooperating on the quality decision to extract the manufacturer's profit.

1. Introduction

Due to many benefits, such as reduced costs, decreased investments, increased productivity, and increased core competency, outsourcing has become a pervasive supply chain feature and has contributed significantly to the growth of the global economy [1–3]. A recent report estimated that, globally, organisations will outsource US $507 billion worth of business and information technology (IT) services in 2014 alone [4]. However, some argue that outsourcing has also created a new set of risks and challenges for organisations, as it has become an increasingly common business practice. Reduced control of supplier quality, a well-known downside of outsourcing, will drive poor product (service) quality, thus representing a risk to the buyer. For example, a 2012 Global Outsourcing and Insourcing Survey found that 48% of companies had previously terminated an outsourcing contract, primarily due to service quality concerns [5]. Therefore, how to encourage supplier quality improvement plays an important role in strategic outsourcing. The objective of this paper is to link the sourcing strategy with the supplier quality effort when the buyer wishes to outsource the manufacturing of multiple products to external suppliers.

With increasing overemphasis on cost reduction, lead time compression, and capacity expansion by the buyer, outsourcing enables suppliers to have no incentives on quality improvement, particularly when the quality cannot be regulated by a contract [6, 7]. As a result, firms typically enforce supply quality control by resorting to quality inspection policies. A more rigorous quality standard would be beneficial to the buyer for enhancing quality in the end market. However, such a standard could negatively affect the supplier and disrupt the supply chain due to the pressure of a standard implementation. For example, one factory of the giant contract manufacturer, Hon Hai Limited (also known as Foxconn Technology Group), in mainland China underwent a large-scale strike triggered by instructions to strengthen quality inspections for the iPhone 5; these instructions were given

by Hon Hai's customer, Apple Inc. [8]. Hence, enabling the supplier to participate in quality improvement could be critical to the buyer.

The majority of opinions regarding the handling of supplier quality incentives could be divided into two main streams. The first stream advocates that the buyer cooperate directly with its supplier, such as by providing technology assistance through sending technical engineers to the supplier site and offering quality management education and training to the supplier's employees [7]. For example, Boeing personnel are embedded into supplier factories at the global scale to monitor quality, work with suppliers on process improvements, and ensure adherence to Boeing standards and schedules [9]. These policies could be categorised as investments in supplier quality improvement or payment for supplier quality efforts, that is, cooperative quality investment [10].

There is another avenue for the buyer to pursue regarding supplier quality improvement—developing multiple competing suppliers. Because competition could be used as a mechanism for the buyer to elicit quality from suppliers, in practice, many giant manufacturers take pleasure in introducing competition among suppliers to mitigate the supplier quality risk in outsourcing [11]. For example, Apple Inc. continually seeks alternative suppliers and prefers to choose whoever has the best quality and best production rate [12]. Toyota invested in its auto seat supplier, Trim Masters, to introduce competition for its other supplier, Johnson Controls ([13] and reference therein).

Although vertical quality cooperation and horizontal quality competition are commonly used as supplier quality improvement mechanisms, which strategy will be more suitable for quality aspects and/or manufacturer profit remains unclear. Specifically, most of the extant literature established a quality enhancement mechanism for single product sourcing [1, 7, 10, 11, 13–15]. In many industries, however, manufacturers outsource the provisioning of a series of substitute products to external suppliers. For example, Apple provides iPads and iPad minis with different prices and features to the panel computer market. Nearly all of these iPads and iPad minis are assembled by the contract manufacturers Foxconn and Pegatron, respectively [16].

Product quality has a positive effect on market demand [10, 17, 18]. When a manufacturer outsources two substitute products and each product is manufactured by a special supplier, then the suppliers could have more incentives to improve product quality for competing for a larger demand share. Thus, each supplier's product decision could be different from the case of single sourcing. This paper aims to investigate the effects of the sourcing strategies on suppliers' quality decisions.

Consider a manufacturer that wants to outsource the manufacturing of two substitute products to external suppliers. This paper studies the strategic interactions for two sourcing strategies: single and dual sourcing. In addition, we propose four decision scenarios: single sourcing with and without manufacturer quality investment sharing and dual sourcing when suppliers cooperate or do not cooperate on quality decisions. This paper addresses the following research questions using a four-stage noncooperative model.

(i) Which strategy works better for improving supplier quality? If the manufacturer is willing to share a sufficiently large portion of quality investment for both products, cooperating with a single supplier can be a dominant strategy for the quality level; otherwise, the strategy of developing two competing suppliers can provide the highest product quality.

(ii) Which strategy works better for manufacturer profit? If the sourcing cost is sufficiently low, the manufacturer prefers to use the strategy of developing two competing suppliers. Otherwise, if the portion of the quality investment defrayed by the manufacturer is sufficiently small, cooperating with a single supplier benefits the manufacturer by increasing profit. Moreover, when the manufacturer's share is sufficiently large, using a single supplier without investing in its quality is better for the manufacturer.

(iii) Which strategy works better for product quality and manufacturer profit? An appropriate proportion of quality investment sharing by the manufacturer can enable dominance of the cooperating with a single supplier strategy; when the manufacturer does not want to share or does not want to share a relatively large portion of its quality investment funds, it will prefer to develop two competing suppliers when the cost of dual sourcing is sufficiently low.

In addition, dual sourcing can be extremely risky for the manufacturer because the suppliers could establish a relatively low product quality level by cooperating on the quality decision and extract the manufacturer profit.

The remainder of this paper is organised as follows: Section 2 briefly reviews the related literature, and Section 3 details our model's general framework. In Sections 4 and 5, we investigate four decision models of the quality choice: single sourcing with and without a manufacturer quality investment sharing and dual sourcing when the suppliers cooperate or do not cooperate on quality decisions. Section 6 studies which strategy is more effective for product quality and/or manufacturer profit. Concluding remarks and future directions are presented in Section 7. All proofs are deferred to the Appendix in Supplementary Material available online at http://dx.doi.org/10.1155/2016/3040343 for clarity of exposition.

2. Literature Review

There are three streams of literature related to our paper: strategic quality choice in a vertical channel, mechanisms of product (service) quality improvement, and sourcing strategies considering product quality.

Quality, as an important competitive feature in the majority of industries, has received considerable attention. Pioneering studies focused on the strategic quality decision that maximised social value or a monopoly firm's profit [19, 20]. Thereafter, Banker et al. [18] and Chambers et al. [17], among others, began to analyse the equilibrium quality level in a competitive environment. These studies provided fundamental insights into the issue of the effort tied to firm's quality choice. However, they did not investigate the strategic interaction among

the players in a supply chain channel environment. We refer to Chen et al. [10] for a comprehensive survey on this topic.

As a seminal work of strategic quality choice in a vertical channel, Reyniers and Tapiero [21] highlighted the importance of strategic and contractual issues in supply chain quality management. Tsay and Agrawal [22] investigated a distribution system in which a manufacturer supplies a common product to two independent retailers, who in turn use both service and retail price to directly compete for end customers. The authors derived the closed-loop equilibrium solution of retailers' price and service and then characterised the structure of wholesale pricing mechanisms to coordinate the system. Xiao and Yang [23] extended this model to two competing supply chains and considered the effect of uncertain demand and the risk attitude of the players. Xu [24] investigated a joint pricing and product quality decision in a manufacturer-retailer channel, in which the manufacturer sells a product through the retailer. Other related literature on this topic includes Balasubramanian and Bhardwaj [25], Lu et al. [26], Xie et al. [27], and Xie et al. [28]. In these studies, the information related to quality level is assumed to be symmetric among supply chain members. A number of researchers recognised that asymmetric quality-related information, such as quality level and quality cost, could be vital to quality choice for supply chain players and developed many contractual agreements for mitigating the impact of asymmetric quality information [6, 29]. However, these studies did not investigate the effects of vertical quality cooperation or horizontal quality competition on product quality.

The second stream related to our paper is that of quality improvement mechanisms and associated contract issues. Benjaafar et al. [11] developed two approaches (supplier allocation and supplier selection) to allocate fixed demand to elicit service quality from the suppliers. They concluded that a buyer could indeed orchestrate competition among potential suppliers to promote service quality. Jin and Ryan [30] extended the model into the framework of supplier's price and service competition; however, the authors only considered supplier allocation. Chen and Deng [31] introduced a certification mechanism to improve supplier quality considering asymmetric quality information. They showed that a deterministic certification may lead to underinvestment in quality improvement technology for efficient suppliers, whereas a noisy certification may alleviate this underinvestment problem. Yan [32] studied contract efficiency for a decentralised supply chain in the presence of quality improvements. Using a numerical experiment, the author also showed that a quality effort-sharing contract could be effective for improving product quality. Other examples include Ching et al. [33] and Elahi [14]. Although these studies address the competition and cooperation mechanism for improving supplier quality, they did not demonstrate which strategy would be more effective. Zhu et al. [34] considered cases in which both a buyer and a supplier invest in quality improvement. They showed that the buyer's involvement in quality investments can have a significant impact; in addition, they investigated the effect of supplier competition on quality improvement. However, they did not provide an answer for the question of which strategy is better for quality improvement when focused on quality investment decisions as well as its effects on the buyer's order quantity and the supplier's production lot size.

The third stream related to our paper is that of supplier competition under the framework of outsourcing mode. This literature focused either on price competition ([1, 35, 36], etc.) or on product competition [11]. None of them consider the case of suppliers' competitions both on price and on product quality. Jiang [37] considered a setting in which a manufacturer sequentially sources two components and uses reverse auction to select a supplier with the lowest bidding price for each component. However, the author did not investigate the effects of sourcing strategies on suppliers' decisions and the product quality decisions are not considered. Nagarajan and Bassok [38] examine a decentralised supply chain in which a single assembler buys complementary components from n suppliers and assembles the final product in anticipation of demand. The authors employed the Nash bargain technique to investigate the effects of suppliers' cooperative coalition on the manufacturer's performance. The paper also neglects the impacts of different sourcing strategies.

Recently, many scholars investigated firm product quality-related sourcing decisions. Hsieh and Kuo [15] modelled a service provision game between two vendors under symmetric and asymmetric cost structures with the objective of winning the larger share of the buyer's fixed reward. Lee and Li [7] studied three different strategies that a buyer could use to manage supplier quality: cooperation, incentivisation, and inspection. Xiao et al. [3] employed Hotelling's model to characterise the strategic outsourcing decisions of two competing manufacturers whose key components have quality improvement opportunities. Jin et al. [39] integrated supplier qualification into the manufacturer's sourcing decision and developed a dual-sourcing process model. Yim [40] derived a closed-form characterisation of the optimal quota allocation for the latent defect-undependable product-external failure in single and multiple sourcing. These articles mainly integrated product quality into sourcing decisions; they also analyse the optimal (equilibrium) decision when a buyer wishes to outsource a single product but does not consider multiproduct sourcing.

Our paper differs from the above studies in that (1) we consider a manufacturer that outsources two substitute products and develop a game model to describe strategic interactions among supply chain players; (2) we integrate quality choice into sourcing decisions; and (3) we compare single and dual sourcing in terms of quality level and profits. Moreover, we also investigate the effects of vertical cooperation and horizontal competition on product quality and profits.

3. Model Development

We consider a sourcing system in which a monopolistic manufacturer seeks to outsource the provisioning of two substitute products to external suppliers. In purchasing a high-quality product, the manufacturer can choose a strategy among three alternatives. We label these strategies separately as the traditional strategy (T-strategy), cooperation strategy (C-strategy), and competition strategy (D-strategy). With the T-strategy, the manufacturer sources two products from

a single supplier; however, with the cooperating strategy, the manufacturer partially shares the single supplier's quality investment expenses for improving quality. With the D-strategy, the manufacturer purchases substitute products from two individual suppliers. The first two strategies are single-sourcing strategies, whereas the third strategy is a dual-sourcing strategy. In addition, we consider that suppliers can cooperate or not cooperate on quality decisions when the manufacturer uses a dual-sourcing strategy, as discussed in Section 5. This paper will model the strategic interactions of supply chain players for each decision scenario. For a better understanding of these models, we first summarise the basic notations of this paper in the Notations section.

For the Notations section, P_i, W_i, and X_i are decision variables. Other related parameters are exogenous, which means that they are known to all supply chain members.

3.1. Demand Structure. In this paper, we characterise each product's demand by employing the Bertrand-style model, which has precedent in previous studies, such as Ingene and Parry [41], Liu et al. [42], and Zhang et al. [43]. We propose the demand function of product i in the following equation:

$$Q_i\left(P_i, P_j, X_i, X_j\right) = \frac{A_i + kX_i - \theta\left(A_j + kX_j\right) - P_i + \theta P_j}{1-\theta^2}. \tag{1}$$

The demand function shown in the above equation captures both product substitutability and the impact of quality effort. Equation (1) indicates that the manufacturer has an incentive to improve product quality because it could obtain more customer demand through investing in quality enhancement. However, improving product quality is not without cost. Hence, given the manufacturer's sourcing strategy, each supplier should trade off the cost and benefits of quality improvement and then optimally select the quality effort level. To facilitate our analyses, we further assume that product i's quality investment cost function is $\Theta_i X_i^2$ with $\Theta_i > 0$, that is, improving the quality level has an increasing incremental cost at high levels, which yields a diminishing return on the quality expenditure. This relationship is commonly observed in the extant literature [10, 18, 22, 26, 32].

3.2. Sequence of Events. We model the strategic interactions of vertical members in the outsourced supply chain as a four-stage noncooperative game, as shown in Figure 1.

Given the sourcing strategy, Figure 1 illustrates a standard supplier-Stackelberg game process, that is, the supplier first sets the quality level and wholesale price for each product, and the manufacturer responds and establishes each product's sales price after observing the supplier's choice. If the dual-sourcing mode is selected at stage 1, there are two independent suppliers that simultaneously set the product quality and wholesale price. This decision structure is commonly used in the literature of channel prices and quality decisions [28, 42, 44, 45].

In an outsourcing mode, one can expect that the OEM always has full power on the choice of the product quality, whereas we consider that the CM is in charge of setting the quality for the manufactured products. We suggest this assumption given the fact that contract manufacturers (CMs) have grown rapidly in many industries and often achieved some degree of power over OEMs [46]. For example, Kaya and Ozer [6] noted that several CMs in the pharmaceuticals industry have been undertaking research and development, creating a \$30 billion drug-development and manufacturing market. These facts provide some rational explanations for the assumption that the CM optimally chooses the product quality, which has also been studied in the literature [6, 11, 30].

4. Single-Sourcing Strategy

We first investigate the case in which the manufacturer selects the single-sourcing strategy at stage 1, that is, the C- and T-strategies will be analysed in this section. The C-strategy implies that the manufacturer proportionally shares the supplier quality investment under the single-sourcing configuration. We assume that the manufacturer's share of quality investment of product i is τ_i, where $0 \le \tau_i < 1$. The case of $\tau_i = 0$ means that all quality investment expenses are defrayed by the supplier, that is, the T-strategy. Hence, the equilibrium outcomes of the T-strategy can be derived by setting $\tau_i = 0$ in the equilibrium of the C-strategy.

According to (1) and the quality investment function, we derive the supply chain member's profit function of the single-sourcing case as

$$\Pi_m = \sum_{i=1, j\neq i}^{2}\left[\left(P_i - W_i\right) \cdot \left(\frac{A_i + kX_i - \theta\left(A_j + kX_j\right) - P_i + \theta P_j}{1-\theta^2}\right) - \tau_i \Theta_i X_i^2\right] - f^S, \tag{2}$$

$$\Pi_s = \sum_{i=1, j\neq i}^{2}\left[W_i\left(\frac{A_i + kX_i - \theta\left(A_j + kX_j\right) - P_i + \theta P_j}{1-\theta^2}\right) - \left(1-\tau_i\right)\Theta_i X_i^2\right]. \tag{3}$$

From (3), this paper assumes that the unit production cost of each product is zero, which is commonly used in the related literature [25, 47]. Relaxing this assumption will not change our main results or the models' managerial insights.

Based on the players' payoff functions shown in (2) and (3), we solve this dynamic game model by using the backward induction approach and derive the following proposition.

Proposition 1. *For the C-strategy case, if* $8(1-\tau_i)\Theta_i(1-\theta) \ge k^2$*, the equilibrium quality level of product i is*

Table 1: Equilibrium outcomes of the single-sourcing strategy.

Item	Equilibrium outcome
Quality level	$X_i^{C*} = \dfrac{k\left\{A_i\left[8\left(1-\tau_j\right)\Theta_j - k^2\right] - 8\theta A_j\left(1-\tau_j\right)\Theta_j\right\}}{k^4 - 8k^2\left[\left(1-\tau_i\right)\Theta_i + \left(1-\tau_j\right)\Theta_j\right] + 64\left(1-\theta^2\right)\left(1-\tau_i\right)\Theta_i\left(1-\tau_j\right)\Theta_j}$
Wholesale price	$W_i^{C*} = \dfrac{64\left(1-\theta^2\right)A_i\left(1-\tau_i\right)\Theta_i\left(1-\tau_j\right)\Theta_j - 8k^2[A_i\left(1-\tau_i\right)\Theta_i + \theta A_j\left(1-\tau_j\right)\Theta_j]}{2\left\{k^4 - 8k^2\left[\left(1-\tau_i\right)\Theta_i + \left(1-\tau_j\right)\Theta_j\right] + 64\left(1-\theta^2\right)\left(1-\tau_i\right)\Theta_i\left(1-\tau_j\right)\Theta_j\right\}}$
Sales price	$P_i^{C*} = \dfrac{6\left\{8\left(1-\theta^2\right)A_i\left(1-\tau_i\right)\Theta_i\left(1-\tau_j\right)\Theta_j - k^2[A_i\left(1-\tau_i\right)\Theta_i + \theta A_j\left(1-\tau_j\right)\Theta_j]\right\}}{k^4 - 8k^2\left[\left(1-\tau_i\right)\Theta_i + \left(1-\tau_j\right)\Theta_j\right] + 64\left(1-\theta^2\right)\left(1-\tau_i\right)\Theta_i\left(1-\tau_j\right)\Theta_j}$
Demand quantity	$Q_i^{C*} = \dfrac{2\left(1-\tau_i\right)\Theta_i\left[8\left(A_i - \theta A_j\right)\left(1-\tau_j\right)\Theta_j - A_i k^2\right]}{k^4 - 8k^2\left[\left(1-\tau_i\right)\Theta_i + \left(1-\tau_j\right)\Theta_j\right] + 64\left(1-\theta^2\right)\left(1-\tau_i\right)\Theta_i\left(1-\tau_j\right)\Theta_j}$
Manufacturer's profit	$\Pi_m^{C*} = \sum_{i=1}^{2}\left[\left(P_i^{C*} - W_i^{C*}\right)Q_i^{C*} - \tau_i\Theta_i\left(X_i^{C*}\right)^2\right] - f^s$
Supplier's profit	$\Pi_s^{C*} = \sum_{i=1}^{2}\left[W_i^{C*}Q_i^{C*} - \left(1-\tau_i\right)\Theta_i\left(X_i^{C*}\right)^2\right]$

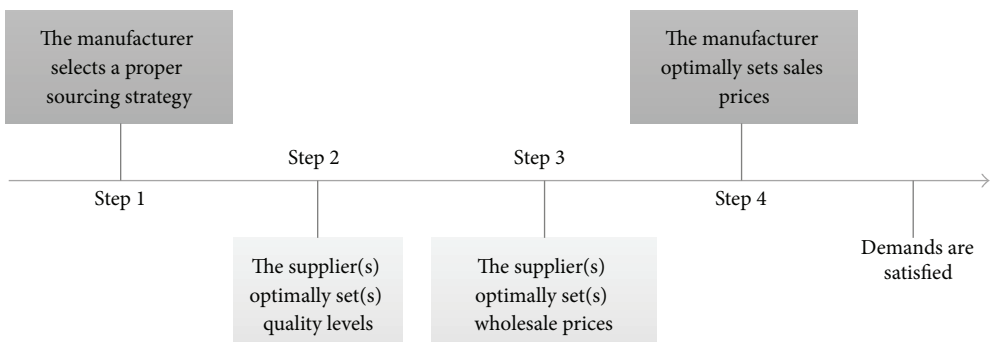

Figure 1: Sequence of decision events.

$$X_i^{C*} = \frac{k\left\{A_i\left[8\left(1-\tau_j\right)\Theta_j - k^2\right] - 8\theta A_j\left(1-\tau_j\right)\Theta_j\right\}}{k^4 - 8k^2\left[\left(1-\tau_i\right)\Theta_i + \left(1-\tau_j\right)\Theta_j\right] + 64\left(1-\theta^2\right)\left(1-\tau_i\right)\left(1-\tau_j\right)\Theta_i\Theta_j}. \tag{4}$$

In (4), the superscript C∗ denotes the optimal value for the C-strategy case. We present all proofs in the Appendix. Substituting the equilibrium product quality level into the other decision variables and the payoffs, we derive all equilibrium outcomes of this strategy, as shown in Table 1. Moreover, the equilibrium outcomes of the T-strategy can be derived by setting the proportion coefficient τ_i to zero and substituting it into the second column of Table 1. The conditions that guarantee the equilibrium can be derived by the same approach, that is, substituting $\tau_i = 0$ into the condition $8(1-\tau_i)\Theta_i(1-\theta^2) \geq k^2$.

The outcomes shown in Table 1 are not sufficiently simple to establish the effects of key parameters. Fortunately, we can investigate the effect of each parameter by imposing simplifying conditions on the remaining parameters, as is the extant literature [22, 26]. Corollaries 2 and 3 summarise the impacts of the market base, unit quality investment, and coefficient of the proportion of the quality investment share on the equilibrium outcomes under the single-sourcing setting.

Corollary 2. *For the C-strategy case, the comparison results of the equilibrium outcomes with regard to the asymmetric parameters are shown in Table 2.*

Corollary 3. *For the C-strategy case, the effects of market base, unit quality investment, and coefficient of the proportion of the quality investment share on the equilibrium outcomes are shown in Table 3.*

5. Dual-Sourcing Strategy

Supplier competition could be used as a mechanism for eliciting quality improvement in a decentralised supply chain [11, 14, 48]. A manufacturer may enable product quality improvements by choosing the dual-sourcing strategy to outsource

Table 2: Comparison results for the single-sourcing model when the parameters are asymmetric.

Case	Quality level	Wholesale price	Sales price	Demand quantity
$\Theta_i = \Theta_j, \tau_i = \tau_j, A_i > A_j$	$X_i^{C*} > X_j^{C*}$	$W_i^{C*} > W_j^{C*}$	$P_i^{C*} > P_j^{C*}$	$Q_i^{C*} > Q_j^{C*}$
$A_i = A_j, \tau_i = \tau_j, \Theta_i > \Theta_j$	$X_i^{C*} < X_j^{C*}$	$W_i^{C*} < W_j^{C*}$	$P_i^{C*} < P_j^{C*}$	$Q_i^{C*} < Q_j^{C*}$
$A_i = A_j, \Theta_i = \Theta_j, \tau_i > \tau_j$	$X_i^{C*} > X_j^{C*}$	$W_i^{C*} > W_j^{C*}$	$P_i^{C*} > P_j^{C*}$	$Q_i^{C*} > Q_j^{C*}$

Table 3: Effect of key parameters on the equilibrium outcomes in the single-sourcing case.

	X_i^{C*}	W_i^{C*}	P_i^{C*}	Q_i^{C*}	Π_m^{C*}	Π_s^{C*}
Case 1	$\Theta_i = \Theta_j = \Theta, \tau_i = \tau_j = \tau$					
A_i	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0 for $M_i^1 \geq 0$ ≤ 0 for $M_i^1 \leq 0$	≥ 0
A_j	≤ 0	≤ 0	≤ 0	≤ 0	≥ 0 for $M_j^1 \geq 0$ ≤ 0 for $M_j^1 \leq 0$	≥ 0 for $S_j^1 \geq 0$ ≤ 0 for $S_j^1 \leq 0$
Case 2	$A_i = A_j = A, \tau_i = \tau_j = \tau$					
Θ_i	≤ 0	≤ 0	≤ 0	≤ 0	≥ 0 for $M_i^2 \geq 0$ ≤ 0 for $M_i^2 \leq 0$	≤ 0
Θ_j	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0 for $M_j^2 \geq 0$ ≤ 0 for $M_j^2 \leq 0$	≤ 0
Case 3	$A_i = A_j = A, \Theta_i = \Theta_j = \Theta$					
τ_i	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0 for $M_i^3 \geq 0$ ≤ 0 for $M_i^3 \leq 0$	≥ 0
τ_j	≤ 0	≤ 0	≤ 0	≤ 0	≥ 0 for $M_j^3 \geq 0$ ≤ 0 for $M_j^3 \leq 0$	≥ 0

Note: definitions of notations M_i^1, M_i^2, M_i^3, and S_j^1 are presented in online supplements.

the provisioning of two substitute products to two external suppliers, that is, the D-strategy is selected at stage 1 of the four-stage noncooperative game process (see Figure 1). The endogenous demand function of (1) means that each product's demand is not solely dependent on price but is also relative to product quality; this creates challenges for verifying the dual-sourcing strategy's quality improvement advantage and causes our studies to differ from the extant literature, such as Benjaafar et al. [11], Jin and Ryan [30], and Elahi [14]. Those authors considered customer demand as fixed and not affected by product price and quality.

In practice, different suppliers are often employed to manufacture substitute products in business practices. For example, in mainland China, most iPads are assembled at Foxconn's factory, whereas the more inexpensive iPad mini product orders are allocated to Pegatron, Inc. [16]. To investigate whether the dual-sourcing strategy benefits quality improvement, we consider two types of decision structures for the quality decision stage: centralised and decentralised quality decisions. For centralised decisions, two suppliers jointly decide their product's quality level; however, for decentralised decisions, they simultaneously choose the quality level to maximise their own profits. For expositional simplicity, we label the former as the DC-strategy and the latter as the DD-strategy.

5.1. Centralised Quality Decision. This case considers the situation in which two suppliers cooperatively select each product's quality level after they observe the upstream firm's dual-sourcing strategy. The decision structure implies that X_i and X_j are jointly set to maximise $\Pi_i + \Pi_j$. We first characterise each supply chain entity's payoff function as follows:

$$\begin{aligned}\Pi_m &= \sum_{i=1,j\neq i}^{2}\left[(P_i - W_i)\right.\\ &\quad\left.\cdot\left(\frac{A_i + kX_i - \theta\left(A_j + kX_j\right) - P_i + \theta P_j}{1-\theta^2}\right)\right] - f^D,\\ \Pi_i &= W_i\left[\frac{A_i + kX_i - \theta\left(A_j + kX_j\right) - P_i + \theta P_j}{1-\theta^2}\right]\\ &\quad - \Theta_i X_i^2.\end{aligned} \tag{5}$$

By using the backward induction approach, we derive the following.

Proposition 4. *For the DC-strategy case, if*

$$\begin{aligned}&k^2\left(4-3\theta^2+\theta^4\right) \leq 2\left(1-\theta^2\right)\left(4-\theta^2\right)^2\Theta_i,\\ &2k^2\left(4-3\theta^2+\theta^4\right)\left(\Theta_i+\Theta_j\right)\\ &\quad\leq k^4\left(1-\theta^2\right)+4\left(1-\theta^2\right)\left(4-\theta^2\right)^2\Theta_i\Theta_j,\end{aligned} \tag{6}$$

then the equilibrium quality level of product i is

$$X_i^{DC*} = \frac{2k\left(4-3\theta^2+\theta^4\right)A_i\Theta_j - 4k\theta\left(2-\theta^2\right)A_j\Theta_j - k^3\left(1-\theta^2\right)A_i}{k^4\left(1-\theta^2\right) - 2k^2\left(4-3\theta^2+\theta^4\right)\left(\Theta_i+\Theta_j\right) + 4\left(1-\theta^2\right)\left(4-\theta^2\right)^2\Theta_i\Theta_j}. \tag{7}$$

In (7), the superscript DC∗ denotes the optimal value of the DC-strategy case. The other equilibrium outcomes of this strategy are provided in Table 4.

5.2. Decentralised Quality Decision. In this case, two suppliers noncooperatively set the product quality level at the second stage, that is, X_i is set to maximise Π_i. The following proposition is obtained from the payoff functions in (5).

Proposition 5. *For the DD-strategy case, if*

$$\begin{aligned} &k^2\left(2-\theta^2\right)^2 \le 2\left(1-\theta^2\right)\left(4-\theta^2\right)^2\Theta_i, \\ &2k^2\left(2-\theta^2\right)^2\left(4-\theta^2\right)\left(\Theta_i+\Theta_j\right) \\ &\quad \le k^4\left(2-\theta^2\right)^2 + 4\left(1-\theta^2\right)\left(4-\theta^2\right)^3\Theta_i\Theta_j, \end{aligned} \tag{8}$$

then the equilibrium quality level of product i is

$$X_i^{DD*} = \frac{k\left(2-\theta^2\right)\left[2\left(2-\theta^2\right)\left(4-\theta^2\right)A_i\Theta_j - k^2\left(2-\theta^2\right)A_i - 2\theta\left(4-\theta^2\right)A_j\Theta_j\right]}{k^4\left(2-\theta^2\right)^2 - 2k^2\left(2-\theta^2\right)^2\left(4-\theta^2\right)\left(\Theta_i+\Theta_j\right) + 4\left(1-\theta^2\right)\left(4-\theta^2\right)^3\Theta_i\Theta_j}. \tag{9}$$

In (9), the superscript DD∗ denotes the optimal value of the DD-strategy case. The other equilibrium outcomes of this strategy are provided in Table 4.

5.3. Effects of the Key Parameters. To examine the effects of the various parameters, such as market base and unit quality investment, we first compare the equilibrium outcomes with the asymmetric setting on the related parameters. We derive the following corollary based on the analytical solutions in Table 4.

Corollary 6. *For the DC- and DD-strategy cases, the comparison results of the equilibrium outcomes with regard to the asymmetric parameters are as shown in Table 5.*

Corollary 7. *For the DC- and DD-strategy cases, the effects of the market base and unit quality investment on the equilibrium outcomes are shown in Table 6.*

6. Which Sourcing Strategy Is More Effective for the Manufacturer?

We now begin the analysis of the choice of strategy in the first stage, that is, which sourcing strategy will be selected by the manufacturer. There are two quality decision channel structures for the dual sourcing. Therefore, we must compare each pair of equilibrium outcomes for the above four decision cases. To facilitate our analysis, we assume that two substitute products are identical in the market base, unit quality investment, and manufacturer's investment sharing and then define $A_i = A_j = A$, $\Theta_i = \Theta_j = \Theta$, and $\tau_i = \tau_j = \tau$. This assumption could allow this paper to focus on the comparison results of the sourcing strategy choice. In the interim, this assumption will facilitate our computation. Furthermore, we perform the comparison based on two performance aspects: product quality level and manufacturer's profit.

6.1. A Manufacturer Who Pursues Quality Level. This case primarily investigates which strategy is more effective in terms of quality improvement. To answer this question, we must compare each equilibrium quality level, which was established in the aforementioned discussion. Formally, Proposition 8 provides the preferable sourcing strategy with respect to quality level.

Proposition 8. *Assume that $A_i = A_j = A$, $\Theta_i = \Theta_j = \Theta$, and $\tau_i = \tau_j = \tau$; there exists a unique threshold value τ_0 for the manufacturer's sharing of its supplier's quality investment such that when $0 \le \tau < \tau_0$, $X_i^{DD*} > X_i^{C*} \ge X_i^{T*} > X_i^{DC*}$ (the equality is satisfied if and only if $\tau = 0$) and when $\tau_0 \le \tau < 1$, $X_i^{C*} \ge X_i^{DD*} > X_i^{T*} > X_i^{DC*}$ (the equality is satisfied if and only if $\tau = \tau_0$). The threshold value is defined as*

$$\tau_0 = \frac{\theta\left[4-\theta\left(2+\theta\right)\right]}{4\left(2-\theta^2\right)}. \tag{10}$$

The above proposition implies that if the manufacturer is willing to share a sufficiently large quality investment, it will prefer to cooperate with a single supplier. However, if the manufacturer's quality investment share is smaller than the threshold value τ_0, it will prefer to develop two competing suppliers. We illustrate this result in Figure 2. Based on the parameters in this illustration, if $0 \le \tau < \tau_0 = 0.1964$, $X_i^{\mathrm{DD}*} > X_i^{\mathrm{C}*}$, whereas if $0.1964 = \tau_0 \le \tau < 1$, then $X_i^{\mathrm{C}*} \ge X_i^{\mathrm{DD}*}$

Table 4: Equilibrium outcomes in the dual-sourcing case.

	Centralised quality decision (DC-strategy)	Decentralised quality decision (DD-strategy)
Quality level	$X_i^{DC*} = \dfrac{2k\left(4-3\theta^2+\theta^4\right)A_i\Theta_j - 4k\theta\left(2-\theta^2\right)A_j\Theta_j - k^3\left(1-\theta^2\right)A_i}{k^4\left(1-\theta^2\right) - 2k^2\left(4-3\theta^2+\theta^4\right)\left(\Theta_i+\Theta_j\right) + 4\left(1-\theta^2\right)\left(4-\theta^2\right)^2\Theta_i\Theta_j}$	$X_i^{DD*} = \dfrac{k\left(2-\theta^2\right)\left[2\left(2-\theta^2\right)\left(4-\theta^2\right)A_i\Theta_j - k^2\left(2-\theta^2\right)A_i - 2\theta\left(4-\theta^2\right)A_j\Theta_j\right]}{k^4\left(2-\theta^2\right)^2 - 2k^2\left(2-\theta^2\right)^2\left(4-\theta^2\right)\left(\Theta_i+\Theta_j\right) + 4\left(1-\theta^2\right)\left(4-\theta^2\right)^3\Theta_i\Theta_j}$
Wholesale price	$W_i^{DC*} = \dfrac{2\left(1-\theta^2\right)\left[2\left(2-\theta^2\right)\left(4-\theta^2\right)A_i\Theta_i\Theta_j - k^2\left(2-\theta^2\right)A_i\Theta_i - 2\theta\left(4-\theta^2\right)A_j\Theta_i\Theta_j - k^2\theta A_j\Theta_j\right]}{k^4\left(1-\theta^2\right) - 2k^2\left(4-3\theta^2+\theta^4\right)\left(\Theta_i+\Theta_j\right) + 4\left(1-\theta^2\right)\left(4-\theta^2\right)^2\Theta_i\Theta_j}$	$W_i^{DD*} = \dfrac{2\left(1-\theta^2\right)\left(4-\theta^2\right)\Theta_i\left[2\left(2-\theta^2\right)\left(4-\theta^2\right)A_i\Theta_j - 2\theta\left(4-\theta^2\right)A_j\Theta_j - k^2\left(2-\theta^2\right)A_i\right]}{k^4\left(2-\theta^2\right)^2 - 2k^2\left(2-\theta^2\right)^2\left(4-\theta^2\right)\left(\Theta_i+\Theta_j\right) + 4\left(1-\theta^2\right)\left(4-\theta^2\right)^3\Theta_i\Theta_j}$
Sales price	$P_i^{DC*} = \dfrac{2\left(4-5\theta^2+\theta^4\right)\left[2\left(3-\theta^2\right)A_i - \theta A_j\right]\Theta_i\Theta_j - 2k^2\left(3-3\theta^2+\theta^4\right)A_i\Theta_i - k^2\theta\left(5-3\theta^2\right)A_j\Theta_j}{k^4\left(1-\theta^2\right) - 2k^2\left(4-3\theta^2+\theta^4\right)\left(\Theta_i+\Theta_j\right) + 4\left(1-\theta^2\right)\left(4-\theta^2\right)^2\Theta_i\Theta_j}$	$P_i^{DD*} = \dfrac{\left(4-\theta^2\right)\left\{2\left(4-5\theta^2+\theta^4\right)\left[2\left(3-\theta^2\right)A_i - \theta A_j\right]\Theta_i\Theta_j - k^2\left[\left(6-7\theta^2+2\theta^4\right)A_i\Theta_i + \theta\left(2-\theta^2\right)\right]A_j\Theta_j\right\}}{k^4\left(2-\theta^2\right)^2 - 2k^2\left(2-\theta^2\right)^2\left(4-\theta^2\right)\left(\Theta_i+\Theta_j\right) + 4\left(1-\theta^2\right)\left(4-\theta^2\right)^3\Theta_i\Theta_j}$
Demand quantity	$Q_i^{DC*} = \dfrac{2\left(2-\theta^2\right)\left(4-\theta^2\right)A_i\Theta_i\Theta_j - k^2\left[\left(2-\theta^2\right)A_i\Theta_i + \theta A_j\Theta_j\right] - 2\theta\left(4-\theta^2\right)A_j\Theta_i\Theta_j}{k^4\left(1-\theta^2\right) - 2k^2\left(4-3\theta^2+\theta^4\right)\left(\Theta_i+\Theta_j\right) + 4\left(1-\theta^2\right)\left(4-\theta^2\right)^2\Theta_i\Theta_j}$	$Q_i^{DD*} = \dfrac{\left(4-\theta^2\right)\Theta_i\left[2\left(2-\theta^2\right)\left(4-\theta^2\right)A_i\Theta_j - k^2\left(2-\theta^2\right)A_i - 2\theta\left(4-\theta^2\right)A_j\Theta_j\right]}{k^4\left(2-\theta^2\right)^2 - 2k^2\left(2-\theta^2\right)^2\left(4-\theta^2\right)\left(\Theta_i+\Theta_j\right) + 4\left(1-\theta^2\right)\left(4-\theta^2\right)^3\Theta_i\Theta_j}$
Manufacturer's profit	$\Pi_m^{DC*} = \sum_{i=1}^{2}\left[\left(P_i^{DC*} - W_i^{DC*}\right)Q_i^{DC*}\right] - f^D$	$\Pi_m^{DD*} = \sum_{i=1}^{2}\left[\left(P_i^{DD*} - W_i^{DD*}\right)Q_i^{DD*}\right] - f^D$
Supplier's profit	$\Pi_i^{DC*} = W_i^{DC*}Q_i^{DC*} - \Theta_i\left(X_i^{DC*}\right)^2$	$\Pi_i^{DD*} = W_i^{DD*}Q_i^{DD*} - \Theta_i\left(X_i^{DD*}\right)^2$

Table 5: Comparison results for the dual-sourcing model when the parameters are asymmetric.

Strategy	Case	Quality level	Wholesale price	Sales price	Demand quantity	Supplier's profit
DC-strategy	$\Theta_i = \Theta_j, A_i > A_j$	$X_i^{DC*} > X_j^{DC*}$	$W_i^{DC*} > W_j^{DC*}$	$P_i^{DC*} > P_j^{DC*}$	$Q_i^{DC*} > Q_j^{DC*}$	$\Pi_i^{DC*} > \Pi_j^{DC*}$
	$A_i = A_j, \Theta_i > \Theta_j$	$X_i^{DC*} < X_j^{DC*}$	$W_i^{DC*} < W_j^{DC*}$	$P_i^{DC*} < P_j^{DC*}$	$Q_i^{DC*} < Q_j^{DC*}$	$\Pi_i^{DC*} < \Pi_j^{DC*}$
DD-strategy	$\Theta_i = \Theta_j, A_i > A_j$	$X_i^{DD*} > X_j^{DD*}$	$W_i^{DD*} > W_j^{DD*}$	$P_i^{DD*} > P_j^{DD*}$	$Q_i^{DD*} > Q_j^{DD*}$	$\Pi_i^{DD*} > \Pi_j^{DD*}$
	$A_i = A_j, \Theta_i > \Theta_j$	$X_i^{DD*} < X_j^{DD*}$	$W_i^{DD*} < W_j^{DD*}$	$P_i^{DD*} < P_j^{DD*}$	$Q_i^{DD*} < Q_j^{DD*}$	$\Pi_i^{DD*} < \Pi_j^{DD*}$

Table 6: Effect of key parameters on the equilibrium outcomes of the dual-sourcing case.

Strategy		$X_i^{DC(D)*}$	$W_i^{DC(D)*}$	$P_i^{DC(D)*}$	$Q_i^{DC(D)*}$	$\Pi_m^{DC(D)*}$	$\Pi_i^{DC(D)*}$
DC-strategy	Case 1	$\Theta_i = \Theta_j = \Theta$					
	A_i	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0 for $M_i^4 \geq 0$ ≤ 0 for $M_i^4 \leq 0$	≥ 0 for $S_i^2 \geq 0$ ≤ 0 for $S_i^2 \leq 0$
	A_j	≤ 0	≤ 0	≤ 0	≤ 0	≥ 0 for $M_j^4 \geq 0$ ≤ 0 for $M_j^4 \leq 0$	≥ 0 for $S_j^3 \geq 0$ ≤ 0 for $S_j^3 \leq 0$
	Case 2	$A_i = A_j = A$					
	Θ_i	≤ 0	≤ 0	≤ 0	≤ 0	≥ 0 for $M_i^5 \geq 0$ ≤ 0 for $M_i^5 \leq 0$	≥ 0 for $S_i^4 \geq 0$ ≤ 0 for $S_i^4 \leq 0$
	Θ_j	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0 for $M_j^5 \geq 0$ ≤ 0 for $M_j^5 \leq 0$	≥ 0 for $S_j^5 \geq 0$ ≤ 0 for $S_j^5 \leq 0$
DD-strategy	Case 1	$\Theta_i = \Theta_j = \Theta$					
	A_i	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0 for $M_i^6 \geq 0$ ≤ 0 for $M_i^6 \leq 0$	≥ 0 for $S_i^6 \geq 0$ ≤ 0 for $S_i^6 \leq 0$
	A_j	≤ 0	≤ 0	≤ 0	≤ 0	≥ 0 for $M_j^6 \geq 0$ ≤ 0 for $M_j^6 \leq 0$	≥ 0 for $S_i^7 \geq 0$ ≤ 0 for $S_i^7 \leq 0$
	Case 2	$A_i = A_j = A$					
	Θ_i	≤ 0	≤ 0	≤ 0	≤ 0	≥ 0 for $M_i^7 \geq 0$ ≤ 0 for $M_i^7 \leq 0$	≥ 0 for $S_i^8 \geq 0$ ≤ 0 for $S_i^8 \leq 0$
	Θ_j	≥ 0	≥ 0	≥ 0	≥ 0	≥ 0 for $M_j^7 \geq 0$ ≤ 0 for $M_j^7 \leq 0$	≥ 0

Note: definitions of notations M_i^4, M_i^5, M_i^6, M_i^7, S_i^2, and S_i^4 are presented in online supplements.

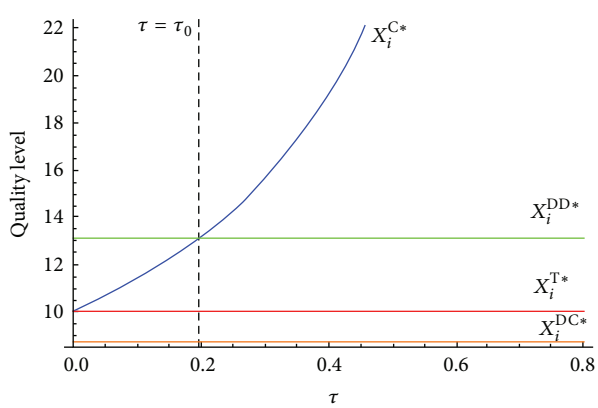

Figure 2: Comparison results of the equilibrium quality level. Note: $A = 100$, $\Theta = 2$, $k = 2$, and $\theta = 0.5$.

is observed. Moreover, the difference $X_i^{C*} - X_i^{DD*}$ increases with increases in the manufacturer's investment share when $\tau \geq \tau_0$.

The second insight observed in Proposition 8 is that the traditional strategy is dominated by the quality cooperation strategy. An interesting observation found in the above proposition is that the DC-strategy is dominated by the other three cases. Thus, the manufacturer should consider supplier quality collusion when it decides to outsource substitute products to two external suppliers. The manufacturer may obtain products with poorer quality levels if the two suppliers cooperate on quality decisions.

6.2. A Manufacturer Who Pursues Profit. We now consider which strategy can best service the manufacturer's profit pursuit. By analysing the difference between each pair of the manufacturer's equilibrium payoffs, the following proposition summarises the results of which strategy is more effective for increasing profit. For a better understanding of the effect of strategy choice on the profit, we assume that the fixed cost of single sourcing is zero (i.e., $f^S = 0$), but the dual-sourcing strategy's cost is $F > 0$ (i.e., $f^D = F > 0$). Relaxing this assumption cannot change our primary results and

managerial insights but does increase the computational complexity. Furthermore, the fixed cost F cannot exceed the manufacturer's reservation profit $F^{\max}$ (i.e., $F < F^{\max}$), which is defined in (11). Without this constraint, the manufacturer cannot derive a positive profit in the dual-sourcing case. Consider

$$\begin{aligned} F &\le F^{\max} \\ &= \min\left\{\frac{2A^2(1+\theta)\left(4-\theta^2\right)^2\Theta^2}{\left[2(2-\theta)^2(1+\theta)(2+\theta)\Theta-k^2\left(2-\theta^2\right)\right]^2},\right. \\ &\quad \left.\frac{2A^2(1+\theta)(2-\theta)^2\Theta^2}{\left[2(2-\theta)^2(1+\theta)\Theta-k^2(1-\theta)\right]^2}\right\} \\ &= \frac{2A^2(1+\theta)(2-\theta)^2\Theta^2}{\left[2(2-\theta)^2(1+\theta)\Theta-k^2(1-\theta)\right]^2}. \end{aligned} \tag{11}$$

Proposition 9. *Assume that $A_i = A_j = A$, $\Theta_i = \Theta_j = \Theta$, and $\tau_i = \tau_j = \tau$; when $0 \le \tau < \tau_1$ and $0 \le F < F_1$, the DD-strategy is the dominant strategy; however, when $0 \le \tau < \tau_1$ and $F_1 \le F < F^{\max}$, the C-strategy is the dominant strategy. When $\tau_1 \le \tau < 1$ and $0 \le F < F_2$, the DD-strategy is the dominant strategy; however, when $\tau_1 \le \tau < 1$ and $F_2 \le F < F^{\max}$, the T-strategy is the dominant strategy. The threshold values τ_1, F_1 and F_2 are defined as*

$$\begin{aligned} \tau_1 &= \frac{k^2\left[8(1+\theta)\Theta-k^2\right]}{4(1+\theta)\Theta\left[16(1+\theta)\Theta-k^2\right]}, \\ F_1 &= \max\left\{0, -2A^2\Theta\left\{\frac{4(1+\theta)(1-\tau)^2\Theta-k^2\tau}{\left[8(1+\theta)(1-\tau)\Theta-k^2\right]^2}\right.\right. \\ &\quad \left.\left.-\frac{(1+\theta)\left(4-\theta^2\right)^2\Theta}{\left[2(1+\theta)(2+\theta)(2-\theta)^2\Theta-k^2\left(2-\theta^2\right)\right]^2}\right\}\right\}, \\ F_2 &= \max\left\{0, -2A^2(1+\theta)\Theta^2\left\{\frac{4}{\left[8(1+\theta)\Theta-k^2\right]^2}\right.\right. \\ &\quad \left.\left.-\frac{\left(4-\theta^2\right)^2}{\left[2(1+\theta)(2+\theta)(2-\theta)^2\Theta-k^2\left(2-\theta^2\right)\right]^2}\right\}\right\}. \end{aligned} \tag{12}$$

The above proposition illustrates that when the fixed cost of dual sourcing is sufficiently low, the manufacturer will prefer to develop two competing suppliers regardless of the investment share. However, when the dual-sourcing cost is sufficiently high, the manufacturer will prefer to cooperate with the single supplier when sharing a sufficiently small portion of the quality investment. In contrast, the manufacturer will prefer to use the traditional strategy when the quality investment share is sufficiently high. Figure 3 illustrates these results through a numerical example.

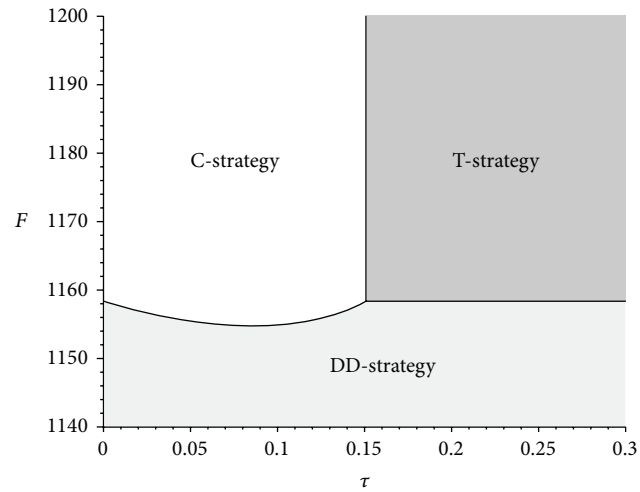

Figure 3: Dominant strategy of the manufacturer who pursues profit. Note: $A = 100$, $\Theta = 2$, $k = 2$, and $\theta = 0.5$.

In addition, the profit-pursuing manufacturer will never choose the dual-sourcing strategy when both suppliers cooperatively set product quality. In conjunction with Proposition 8, the DC-strategy cannot be a dominant strategy in both aspects of quality level and profit. Therefore, the manufacturer should prevent supplier quality collusion when it decides to use the dual-sourcing strategy. However, the suppliers have incentives for quality cooperation because they can extract more profits by producing a low-quality product (the relation $\Pi_i^{DC*} > \Pi_i^{DD*}$ can be derived by computing the difference of Π_i^{DC*} and Π_i^{DD*}). Therefore, in this situation, it is important to design an efficient contract to encourage improvements in supplier quality. A quality contest among suppliers could be used to enable quality improvement among suppliers; this is also established in the fixed demand model [11, 30]. However, with the quality-dependent demand model, contesting for demand may not be applicable because the equilibrium solution cannot be derived or, at a minimum, cannot prove the existence and uniqueness; thus, the effect of this mechanism on quality level will be unclear. The manufacturer can design a quality contest among suppliers to strive for a fixed quality investment subsidy. However, this problem is not the main focus of this study; thus, we would encourage researchers to devote additional attention to this issue in the future.

6.3. Summary. Propositions 8 and 9 summarise the results of which strategy is more effective for product quality and manufacturer profit, respectively. We now consider whether there is a sourcing strategy that benefits quality level in addition to manufacturer's profit. First, the T- and DC-strategies are excluded because the former is strictly dominated by the C-strategy in the aspect of quality and the latter is the worst case of the four strategies in both aspects. Therefore, we consider the C- and DD-strategy cases. The following observation provides useful materials for answering this question.

Observation 1. Assume that $A_i = A_j = A$, $\Theta_i = \Theta_j = \Theta$, and $\tau_i = \tau_j = \tau$; then, we obtain the following conclusions: (i) when the unit quality investment is neither sufficiently large nor sufficiently small, that is, $\Theta^{\min} \leq \Theta \leq \Theta^{\max}$, the C-strategy could be beneficial to both supplier quality improvement and manufacturer's profit enhancement if and only if $\tau_0 \leq \tau \leq \tau_1$ and $F \geq F_1$; and (ii) when the fixed cost of dual sourcing is sufficiently small, that is, $F \leq \min(F_1, F_2)$, the DD-strategy could be beneficial to both supplier quality improvement and manufacturer profit enhancement if and only if $0 \leq \tau < \tau_0$.

The Appendix provides theoretical support for this observation. Parameters $\Theta^{\min}$ and $\Theta^{\max}$ can also be found in the Appendix. The following insights can be obtained from the above observation:

(i) Quality cost information plays an important role in implementing the strategy of cooperating with a single supplier. Because the supplier has incentives to hide the private quality cost information [6], the manufacturer should design a mechanism to reveal the type of supplier, with regard to quality cost, when the manufacturer wants to employ the C-strategy to improve quality and profits. Moreover, ensuring that the quality investment share is in the appropriate range is also important to successfully implement the C-strategy. In the interim, a relatively high sourcing cost for dual sourcing could ensure that the manufacturer has an incentive to implement C-strategy.

(ii) When the manufacturer does not want to share or does not want to share a large portion of the supplier quality investment, developing two competing suppliers could be the optimal strategy for improving quality level and profit if the sourcing cost is sufficiently low. Moreover, if the supplier demands a large share of the quality investment, the manufacturer will switch to developing two competing suppliers. In this scenario, preventing collusion on the two suppliers' quality becomes a critical issue for the manufacturer. Otherwise, the manufacturer could migrate into the worst case if the two suppliers cooperatively set the product quality level.

7. Conclusions

In this paper, we examine the equilibrium quality levels of two substitute products in four decision scenarios belonging to two sourcing strategies: single sourcing and dual sourcing. There are two different decision scenarios for the single-sourcing strategy: the supplier optimally sets each product's quality level with and without the manufacturer's investment sharing. Two decision scenarios also exist for the dual-sourcing strategy: two suppliers cooperatively or noncooperatively set product quality levels. This study employs a four-stage noncooperative game process to model the strategic interactions among supply chain players. Given each decision scenario, we derive the closed-loop equilibrium outcomes of each game model and propose the conditions that guarantee that the Nash equilibrium of each game uniquely exists. Moreover, this paper examines the effects of key parameters, such as the market base, quality cost margin, and investment share, on players' decisions and the equilibrium payoffs.

Finally, we compare the equilibrium quality levels and manufacturer's profits of each decision scenario. The question of which strategy is more effective for product quality or manufacturer's profit is resolved. By combining these results, we further demonstrate that cooperating with a single supplier and developing two competing suppliers could be the dominant strategy in terms of both quality level and profit. The conditions for guaranteeing the optimal strategy are also established. These results will help to effectively implement the sourcing strategy in practice. This paper also provides valuable insights into the quality management strategy that leads to quality improvement and the selection of a supply chain channel structure for supply chain outsourcing.

There are several directions for future research. First, we derive the effects of the key parameters on the equilibrium outcomes by assuming partially or completely symmetrical parameters settings. A similar assumption could be found in the comparison results between each pair of decision scenarios. One possible extension is to compute these results with complete asymmetrical parameters. Second, we prove that suppliers' quality cooperation in the dual-sourcing strategy is dominated by the other three strategies. Hence, integrating well-known mechanisms, such as a quality contest into the vertical channel to break through suppliers' quality collusion, could be worth investigating. Finally, we assume that the quality investment margin of each product is common knowledge in this study. However, quality effort costs can be private information. Moreover, the manufacturer's strategy choice could be dependent on quality investment unit. Thus, it is interesting but challenging to discuss sourcing strategy when suppliers keep quality cost information private.

Notations

$i = 1, 2$; $j = 1, 2$, and $j \neq i$:	Index to denote each product
Q_i:	Gross demand of product i
A_i:	Market base of product i
θ $(0 \leq \theta < 1)$:	Coefficient of capturing product substitutability
k $(k > 0)$:	Coefficient of capturing the impact of quality level on market base
P_i:	Product i's sales price
X_i:	Product i's quality level
W_i:	Product i's wholesale price
Θ_i:	Unit quality investment for the ith product
f^S:	Fixed configuration cost of single-sourcing mode
f^D:	Fixed configuration cost of dual-sourcing mode
Π_m:	Manufacturer's profit

Π_s: Supplier's profit in single-sourcing mode
Π_i: Supplier i's profit in dual-sourcing mode.

Competing Interests

The author declares no competing interests.

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