

Strategic Analysis of Dual Sourcing and Dual Channel with an Unreliable Alternative Supplier

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In today's increasingly interconnected world, co-opetition has emerged as a new business practice among many high-tech firms. The boundaries between cooperation and competition becomes vague, and rivals engage in collaborative activities. This study develops an analytical model to investigate the dual sourcing decision of the original equipment manufacturer (OEM) in the presence of a competitive supplier (i.e., frenemy) as well as a non-competitive supplier who nevertheless suffers from unreliable production yield. We study the competitive supplier's dual channel decision if it prefers operating both component-selling business and self-branded business, and find that the OEM always prefers supplier diversification even though the additional non-competitive supplier is unreliable. Interestingly, our results reveal that the non-competitive supplier's expected profit is unimodal in its production technology level, which suggests the non-competitive supplier may not have incentive to improve its production technology once it reaches a threshold. Furthermore, we analyze the credibility of the competitive supplier's threat to terminate the supply of the components to OEM as a response of OEM's engagement of a new supplier. We show that this termination of component-selling business by competitive supplier is a non-credible threat to prevent OEM from seeking the alternative supplier.

Key words: co-opetitive supply chain; production technology; yield uncertainty; dual sourcing; dual channel

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1. Introduction

Apple and Samsung, two of the largest smartphone vendors in the world, have combined shipping over 533 million units in 2017, which is equivalent to 36.3% of worldwide smartphone market (IDC 2018). Although they compete fiercely in the end-user market, where consumers take them as the substitutable choices (Chowdhry 2014), they also in many ways cooperate with each other. Samsung has supplied processors for Apple's smartphone for many years (Reisinger 2015). According to a recent report on Bloomberg (Lee and King 2015), Samsung will continue manufacturing the main chips for Apple's next generation iPhone.

This "frenemy" business relationship between Apple and Samsung becomes particularly evident in many high-tech related industries. For example, Sharp who is the leading supplier of the Apple's iPad and iPhone's LCD screens, also competes with Apple in the smartphone and tablet market. Another classical example is between IBM and Cisco, where IBM buys Cisco's network equipment and Cisco also competes with IBM directly in the server market (Swartz 2009). The above illustrations epitomize the concept of "co-opetition" (Brandenburger and Nalebuff 1996), where two firms cooperate in some activities, and at the same time compete with each other in other activities.

One of the most critical challenges in the co-opetitive supply chain is the concern about the sourcing strategy. From Apple and many other original equipment manufacturers' (OEMs, that is, purchase components and then produce a new product with its brand name) perspective, it is generally risky to rely solely on their competitors to provide the key components. One noteworthy problem is the wholesale price determination, where the sole supplier maintains a strong pricing power. According to Forbes (Worstell 2013), Samsung raised the price of a key component supplied to Apple by 20% where Apple first disapproved it, but finding no replacement supplier. It seems natural for the OEM to seek an alternative supplier who will not compete directly with the OEM in the end market by engaging the dual sourcing strategy. However, due to the sophisticated and unstable technology process, many new entering non-competitive suppliers suffers the yield loss from manufacturing defects. Bohn and Terwiesch (1999) have documented that high-tech manufacturers such as Seagate experienced production yields as low as 50%. Recent media reports reveal that the yield rates for TSMC¹ who provide the fingerprint sensor for Apple is only around 70%–80% (Bora 2014). Similar to the previous literature, we capture the notion of unreliable supplier in the technology industry by proportional random yield (Tang and Kouvelis 2011, Yano and Lee 1995). Essentially, the OEM can only expect to receive a portion of what it orders from the alternative supplier. This yield uncertainty not only hurts the quality of the products but also upsets the availability of the products. OEM is facing a critical decision on whether or not to engage an alternative supplier (i.e., non-competitive supplier for the remainder of the study) by adopting the dual sourcing strategy. On the one hand, sourcing from an additional supplier may reduce the component price through upstream competition. On the other hand, the non-competitive supplier suffers from the yield uncertainty which may cause the quality and supply problems for the OEM. The above discussion leads to our first research question: *Is it beneficial for the OEM to seek a non-competitive supplier who suffers from inferior production technology? And if so, how does the OEM optimally allocate its component orders between the competitive supplier and non-competitive one?*

Securing an additional supplier may give the OEM more leverage when it comes to component procurement with its suppliers in the future. Previous literature have also established several benefits of the dual sourcing, such as mitigating the supply risk through supplier diversification (Cachon et al. 2008), fostering the upstream competition (Chen and Guo 2014), and reducing the inefficiency caused by random yield (Tang and Kouvelis 2011). However, this new

engagement of a new supplier might also irritate the competitive supplier who has enjoyed its exclusivity with the OEM, and thus it is possible that the competitive supplier terminates its component-selling business as a threat. In practice, we observe that Samsung has considered terminating its LCD supply contract with Apple when the Apple squeezes the component wholesale price through supplier diversification from LG and Sharp (Tibken 2012). Thus, the above example occurring in reality raises some intriguing issues that have not been well understood in the literature. *How will the competitive supplier respond to the OEM's seeking an alternative supplier? Will the competitive supplier terminate his component-selling business as a response?*

In this study, we consider a supply chain associated with the high-tech industry consisting of an OEM, a competitive supplier and a non-competitive supplier. We investigate the aforementioned research questions by considering the following three scenarios: (i) The base scenario where the competitive supplier acts as the sole supplier of the OEM, (ii) The dual sourcing scenario, in which the OEM sources from both the competitive supplier and the non-competitive supplier, although the non-competitive supplier's components have uncertain yield, (iii) The termination scenario, in which the OEM sources components solely from the non-competitive supplier, and the competitive supplier generates profits from self-branded business solely. We develop a stylized model to investigate the incentives of the strategic decision of each player. The main insights of our research are summarized as below.

First, OEM always prefers the supplier diversification although the non-competitive supplier suffers from inferior technology and uncertain yield. Essentially, by shifting component orders to the non-competitive supplier, OEM's dual sourcing strategy benefits itself by inducing a price war in the upstream component supply market. The price war drives down the component price, which helps the OEM to procure more components at a lower cost. This gives the OEM an advantage competing with the competitive supplier in the end product market. Although the benefits of supplier diversification have been well established in other settings (Chen and Guo 2014, Tang and Kouvelis 2011), we have extended this result to a co-opetitive supply chain where the benefits of supplier diversification come from both upstream and downstream markets.

Second, the non-competitive supplier's expected profit is *unimodal* in its production technology level in the dual sourcing scenario. That is, the non-competitive supplier has a most preferred technology level, and it has no incentive to further improve the production technology (even it's costless). The intuition driving this result is as follows: As the non-competitive

supplier improves its production technology, initially the OEM tends to purchase more components from it. However this allocation will intensify the upstream competition between the non-competitive supplier and competitive supplier, where the latter will cut his wholesale price as a response. As a result, OEM will gradually reduce her component orders to the non-competitive supplier and shift orders back to the competitive supplier. Therefore, we observe that the non-competitive supplier's profit is unimodal in its technology level.

Third, the termination of component-selling business by competitive supplier is a non-credible threat to stop the OEM from seeking an alternative supplier. As we have discussed, the OEM always prefers the dual sourcing strategy; however, one of the concerns that may hinder the OEM seeking the alternative supplier lies in the fact that the competitive supplier may terminate its component-selling business. We show that termination is never a credible threat by the competitive supplier. When the non-competitive supplier's production technology is relatively low, the competitive supplier is willing to maintain its collaboration with the OEM, because the competition in the component market is not severe. As the non-competitive supplier continues to improve its technology level, the OEM can ignore the termination threat by the competitive supplier as the production quality of the non-competitive supplier is high enough such that the OEM can be better by relying solely on the components from the non-competitive supplier.

The remainder of our study is organized as follows. In the next section, we first review the most relevant literature and position our paper with respect to the literature to highlight our contributions. This is followed by the introduction of our model setting and the base scenario in section 3. Sections 4 and 5 investigate the dual sourcing scenario and termination scenario respectively, and we also compare the companies' performances to understand their strategic decisions. Section 6 presents several extensions of our model where we consider other factors that may impact the strategic decisions, which includes capacity constraint, alternative demand models and positive production cost. This study ends with conclusions and avenues for future research. All the proofs are placed in the Appendix S1.

2. Literature Review

Our work is closely related to the studies on unreliable supply and yield uncertainty problems. Early researches are mostly concerned with optimal production, procurement and inventory replenishment in the presence of yield uncertainty. Yano and Lee (1995) provide an excellent comprehensive review for

the earlier literature. Later, there are more studies that focus on the mitigation of supply disruption risk by supplier diversification and dual sourcing. Tomlin (2006) studies the strategies to manage the supply disruption risk when there are two suppliers—one is reliable but expensive while the other is cheaper but with yield uncertainty. Tang and Kouvelis (2011) assume suppliers' products have proportional random yield and show that two competing buyers' dual sourcing strategies may be beneficial by mitigating the channel inefficiency caused by yield uncertainty. They consider exogenously given component prices and focus on the value of supplier diversification. Li et al. (2013) investigate a buyer's supply diversification decision by assuming the suppliers' random capacities are correlated and the buyer adopts a responsive pricing strategy. They find that the insight "cost is the order qualifier and reliability is the order winner" holds with two suppliers but fails to hold with more suppliers. Chen and Guo (2014) study an asymmetric two-retailer-one-supplier model where one retailer (referred to as the focal firm) can source from both the unreliable supplier and the spot market, while its rival (referred to as the rival firm) can only source from the unreliable supplier. They show that the focal firm's dual sourcing creates a win-win situation for both firms. Even if the spot market price is low, strategically sourcing from the unreliable supplier can be beneficial for the focal firm. Tang et al. (2014) characterize the buyers' trade off between sourcing from multiple suppliers and encouraging their preferred supplier to reduce the degree of yield uncertainty. They identify the conditions under which dual sourcing or sole sourcing strategy can be preferred by the buyers. More recently, Li et al. (2015) consider a setting where there exists information asymmetry between the two heterogeneous suppliers and a common retailer. They find that the equilibrium contract menus depend on how much information rent the supplier may need to pay.

Compared to the aforementioned works, especially the two most related papers—Tang and Kouvelis (2011) and Chen and Guo (2014), we investigate a co-competitive supply chain in which the competitive supplier serves as both the buyer's upstream business partner and downstream competitor. The buyer can source from a unreliable alternative supplier, whose wholesale price is endogenously determined. We focus on the channel members' strategic decisions with respect to the buyer's adoption of dual sourcing strategy, the competitive supplier's incentives of market withdrawal, and the non-competitive supplier's preference of the degree of yield uncertainty. We note that Tang and Kouvelis (2011) study a chain-to-chain competition model without the consideration of co-opetition issues, and Chen and Guo (2014) study a

Hotelling model where the product wholesale prices are exogenously given. With endogenized wholesale prices, we show that dual sourcing does not necessarily sustain as the channel members’ win–win strategy.

Our work is also closely related to the studies on co-opetition in supply chain. This stream is originated from the literature of dual channel management in economics (Spiegel 1993) and the early OM/IS interface (Tsay and Agrawal 2004). While early literature focuses mostly on the impact of a direct channel to the related firms and the supply chain, more recent studies investigate the supplier’s incentives to establish a direct channel and the strategic interaction between the supply chain members, and then the stream of literature on co-opetition gradually emerges. Kumar and Ruan (2006) assume customers are either brand-loyal or retailer-loyal, and show that the supplier has incentives to open a direct channel and hence, operates a dual channel business model. Dumrongsiri et al. (2008) assume consumers are both price and service quality sensitive, and examine the manufacturer’s incentives regarding direct and retail channels. They show that, the channel cost difference, the demand variability, and the channel centralization degree greatly influence the manufacturer’s decisions of opening a direct channel. Cai (2010) identifies a channel-adding Pareto zone and a contract-implementing Pareto zone in two single-channel and two dual-channel supply chains. In the former zone, both the retailer and supplier have profit improvements when the supplier opens a direct channel. In the latter zone, the value of contract coordination is derived. Wang et al. (2013) investigate the timing issue of two frenemies’ quantity decisions by solving an endogenous timing game. They find that the OEM tends to source solely from a competitive contract manufacturer (CM) regardless the downstream competition,

and the competitive CM tends to generate profits from both contract manufacturing and self-branded businesses. Recently, Adner et al. (2015) develop a game-theoretic model to explain the incentives for two platforms to become frenemies when the difference in their profit foci is sufficiently large.

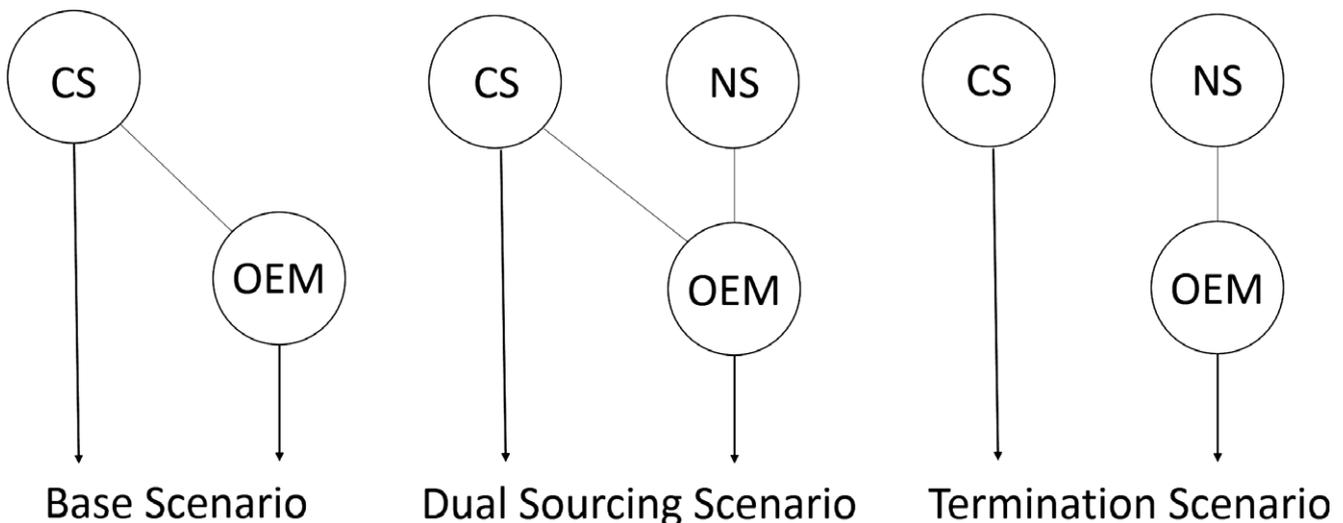
Similar to Dumrongsiri et al. (2008) and Cai (2010), we derive the outcomes in each scenario and then compare them to analyze the supply chain parties’ incentives toward alternative channel structures. However, different from the existing works, we contribute by considering the OEM’s dual sourcing strategy when it faces a competitive supplier and has the option of sourcing from an *unreliable alternative supplier*, and analyzing the strategic interactions between the OEM and the competitive supplier.

3. Model Settings and Benchmark

3.1. Notations and Assumptions

We consider a three-player game comprising a competitive supplier (CS), a non-competitive supplier (NS) and an OEM where the NS does not compete directly with the OEM in the end market. Both competitive supplier and non-competitive supplier are capable of producing a key component, which is then used to produce the end products for the consumers. Similar to Amaral et al. (2006), Chen et al. (2012), and Wang et al. (2013), we define OEM as a company that purchases components and then finalizes a new product with its brand name. For the remainder of the study, we use the pronoun “he” to represent the competitive supplier (*cs*), “she” to represent the OEM (*o*) and “it” to represent the non-competitive supplier (*ns*). Based on the motivations discussed in introduction, we analyze the following three scenarios, which are illustrated in Figure 1.

Figure 1 Illustration of Three Different Scenarios



- (1) The base scenario, in which the competitive supplier serves as the sole supplier of the OEM.
- (2) The dual sourcing scenario, in which the OEM sources from both competitive supplier and non-competitive supplier, although the non-competitive supplier suffers from yield uncertainty.
- (3) The termination scenario, where the OEM sources components solely from the non-competitive supplier. This may either result from the OEM's choice when it shifts all the orders to the non-competitive supplier, or the competitive supplier's choice when it refuses to sell components to the OEM.

Without loss of generality, we assume that both the competitive supplier and OEM employ one unit of component to assemble one unit of end product. We focus on those industries where the retail prices are mainly determined by the supply quantities. Typical examples include influenza industry (Deo and Corbett 2009), microchip industry (Tang and Kouvelis 2011), and smartphone industry in which Samsung and Apple compete (Autrey et al. 2014, Karp and Perloff 2012). Thus, we assume that the competitive supplier and the OEM engage in a Cournot-typed competition in the end-user market.

In particular, similar to Tang and Kouvelis (2011), the consumer demand for the competitive supplier's product is represented by a linear, downward sloping, (inverse) demand function $P_{cs} = a - bQ$, where P_{cs} is the retail price, a is the market potential, b represents the quantity sensitivity and Q denotes the total quantities available on the market. Without loss of generality, we assume that the market potential a is large enough such that the market demand is always positive (Wu and Zhang 2014). To capture the brand distinction between the products from the OEM and the competitive supplier, we assume that the demand for OEM's product is $P_o = a - bQ + m$ ($m \geq 0$ and $a \geq m$). Essentially, the OEM's products enjoy a premium perception from the consumers (Arruñada and Vázquez 2006). For instance, consumers are willing to pay a higher price for ThinkPad laptop (i.e., OEM) than Asus laptop (i.e., CS) although the configuration of the two computers are almost identical. This model is originated from the Cournot competition model for differentiated goods (Singh and Vives 1984). Without loss of generality, we also normalize the production costs of the competitive supplier, the non-competitive supplier, as well as the OEM's assembly cost to be zero.² In section 6.4, we analyze the situation in which there is a positive cost for the production in both the competitive and the non-competitive supplier, and we find that our main findings are robust.

When the OEM sources from a non-competitive supplier, she has to be concerned about its yield uncertainty problem. That is, for an order of size q , the realized delivered quantity is eq , where e is a random variable with mean μ and variance σ^2 (Yano and Lee 1995). We restrict the support of e to be $[0, 1]$ and $\sigma < 1/2$.³ It's worth noting that the increase of the expected yield μ and/or the decrease of the yield variance σ^2 can be interpreted as "quality improvement." In practice, these improvements can be achieved through better process management and investment in new technology. In the presence of the yield uncertainty problem, firms can only form an expectation of their own and the rival's profits. We assume that all supply chain members are risk-neutral profit maximizers. We also assume that the OEM pays for what she actually receives rather than what she orders. This is consistent with the industrial practice and previous literature.⁴ Nevertheless, we show that these two assumptions lead to almost identical results.

For the remainder of this study, we incorporate superscripts on the optimums: B, D, T to denote the base scenario, the dual sourcing scenario, and the termination scenario, respectively. For example, Π_{cs}^B stands for the competitive supplier's optimal profit in the base scenario. We denote q_o (q_b) as the OEM's (the competitive supplier's) production quantity in the end market, q_{cs} as the component order quantity allocated to the competitive supplier, and q_{ns} as the order quantity to the non-competitive supplier. In addition, W_{cs} represents the wholesale price between the competitive supplier and OEM, and W_{ns} represents that between the non-competitive supplier and the OEM.

3.2. The Benchmark: Base Scenario

In this scenario, the OEM sources solely from the competitive supplier. The event sequence is described as follows: First, the competitive supplier determines the unit wholesale price W_{cs} . Second, the OEM places an order to the competitive supplier, who also determines the production quantity for his self-branded products. Third, the OEM receives the components and both firms assemble the components to the end products. Finally, products are sold to consumers at market clearing price. Note that, the OEM's production quantity in the end market, q_o , exactly equals her order quantity placed to the competitive supplier, that is, $q_o = q_{cs}$, because the competitive supplier does not have the yield uncertainty problem.

Thus, the competitive supplier and the OEM's profit functions are given as:

$$\begin{aligned}\Pi_{cs} &= (a - bq_b - bq_{cs})q_b + W_{cs}q_{cs}, \\ \Pi_o &= (a - bq_b - bq_{cs} + m)q_{cs} - W_{cs}q_{cs}.\end{aligned}$$

The competitive supplier's profit comes from the following two sources: (i) component-selling business; (ii) self-branded business. If he competes with the OEM intensively in the downstream market, it will not only squeeze the OEM's selling quantity but also reduces the competitive supplier's own revenue from component-selling business. Hence, the OEM and the competitive supplier have a co-opetitive relationship, under which the competitive supplier has to balance his revenue from these two sources. The results are summarized in Lemma 1.

LEMMA 1. *In the base scenario, where the OEM sources solely from a competitive supplier, the equilibrium wholesale price is $W_{cs}^B = \frac{5a+4m}{10}$, the production quantities are $q_b^B = \frac{5a-2m}{10b}$, $q_o^B = q_{cs}^B = \frac{2m}{5b}$, and the supply chain parties' profits are $\Pi_{cs}^B = \frac{5a^2+4m^2}{20b}$, $\Pi_o^B = \frac{4m^2}{25b}$.*

Clearly, the competitive supplier's production quantity is decreasing in m , while the OEM's is increasing in m . This result is in line with intuition, because the OEM's brand image helps her products differentiate from the competitive supplier's. We also find that the equilibrium wholesale price is increasing in m , but the selling quantity q_o^B still increases in m because the OEM's profit margin increases. That is, the positive effect (i.e., larger selling quantity) due to the increase of m outweighs the negative effect (i.e., higher wholesale price) in this scenario. Meanwhile, the competitive supplier's overall profit is also increasing in m , indicating that his profit loss from self-branded business is compensated by its profit gains from component-selling business. When m increases, the competitive supplier gains from a higher W_{cs}^B and sells more components q_{cs}^B . On the contrary, if m approaches to 0, that is, the OEM's product has little brand advantage toward its competitor, then the OEM only gains very limited profits and can hardly survive in the market.

4. The Dual Sourcing Scenario

In this scenario, the OEM adopts dual sourcing strategy and allocates her component orders to both the competitive supplier and the non-competitive supplier. The event sequence is as follows: First, both the competitive supplier and the non-competitive supplier determine their component wholesale prices. Second, after observing both wholesale prices, the OEM and the competitive supplier determine their production quantities simultaneously. Note that the OEM's orders are allocated between the competitive and the non-competitive suppliers, which are labeled as q_{cs} and q_{ns} respectively, and her total received component quantity is $q_o = q_{cs} + eq_{ns}$, where the non-

competitive supplier suffers the yield uncertainty problem. Third, the OEM and the competitive supplier finalize the components into end products and deliver them at the market-clearing price p_o and p_s . The profit functions of the competitive supplier, the OEM and the non-competitive supplier are then:

$$\begin{aligned}\Pi_{cs} &= [a - bq_b - b(q_{cs} + eq_{ns})]q_b + W_{cs}q_{cs}, \\ \Pi_o &= [a + m - bq_b - b(q_{cs} + eq_{ns})](q_{cs} + eq_{ns}) \\ &\quad - W_{cs}q_{cs} - W_{ns}eq_{ns}, \\ \Pi_{ns} &= W_{ns}eq_{ns}.\end{aligned}$$

In the quantity-decision stage, both the competitive supplier and OEM evaluate their expected profits in anticipation of the non-competitive supplier's yield uncertainty. We summarize the optimums in the following Lemma 2.

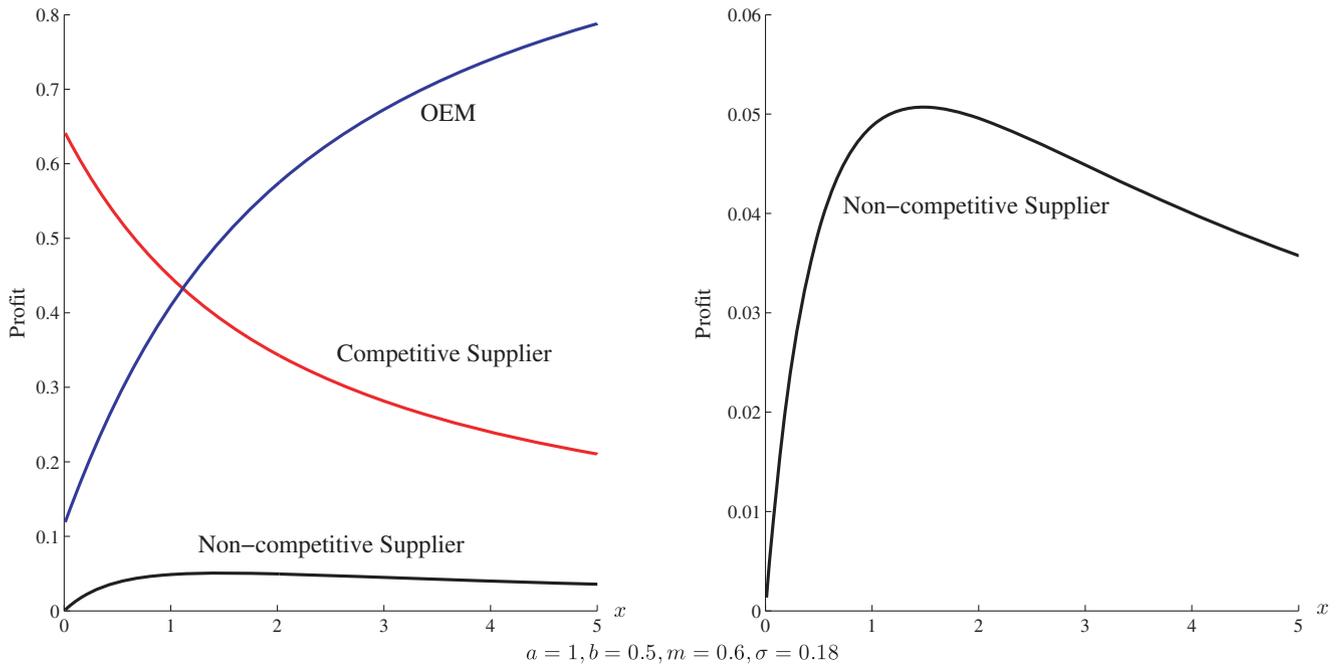
LEMMA 2. *In the dual sourcing scenario, where the OEM allocates her component orders to competitive and non-competitive suppliers, the equilibrium wholesale prices are $W_{cs}^D = \frac{4(5a+4m)\sigma^2}{40\sigma^2+27\mu^2}$, $W_{ns}^D = \frac{2(5a+4m)\sigma^2}{40\sigma^2+27\mu^2}$; the order quantities are $q_b^D = \frac{4(5a-2m)\sigma^2+9(a-m)\mu^2}{b(40\sigma^2+27\mu^2)}$, $q_{cs}^D = \frac{16m\sigma^2+4a\mu^2+14m\mu^2}{b(40\sigma^2+27\mu^2)}$, and $q_{ns}^D = \frac{(5a+4m)\mu}{b(40\sigma^2+27\mu^2)}$. Correspondingly, the equilibrium expected profits of the supply chain members are,*

$$\begin{aligned}E\Pi_{ns}^D &= \frac{2(5a+4m)^2\sigma^2\mu^2}{b(40\sigma^2+27\mu^2)^2}, \\ &\quad m^2(320\sigma^4+368\sigma^2\mu^2+81\mu^4) - 2am\mu^2 \\ E\Pi_{cs}^D &= \frac{(80\sigma^2+81\mu^2)+a^2(400\sigma^4+440\sigma^2\mu^2+81\mu^4)}{b(40\sigma^2+27\mu^2)^2} \text{ and} \\ &\quad a^2\mu^2(25\sigma^2+81\mu^2)+4am\mu^2(82\sigma^2+81\mu^2) \\ E\Pi_o^D &= \frac{+4m^2(64\sigma^4+148\sigma^2\mu^2+81\mu^4)}{b(40\sigma^2+27\mu^2)^2},\end{aligned}$$

respectively.

For the remainder of this study, we denote $x = (\mu/\sigma)^2$ as the *technology level* of the non-competitive supplier, which is an indicator of the quality in its production process, and almost all the decisions/outcomes can be represented as functions of x . It's straightforward to see that the increase of μ and/or the decrease of σ leads to a higher level of x . Essentially, the higher the technology level x is, the more reliable the non-competitive supplier's production process are. Suppliers can improve their production process not only through costly R&D innovations but also by inexpensive administrative efforts. For

Figure 2 Illustration of Impact of x on Profits of Each Supply Chain Party [Color figure can be viewed at wileyonlinelibrary.com]



example, Snow et al. (2006) have documented that the bio-technology firm Genentech worked very hard to improve its yield through “monitoring the raw materials, limiting human involvement in production, testing frequently and ensuring that all connections between pieces of equipment were tightly sealed.” Next we use x to rearrange the supply chain parties’ profits shown in Lemma 2, which leads to the following two interesting results through sensitivity analysis. The results are also illustrated in Figure 2.

PROPOSITION 1. *When the OEM adopts the dual sourcing strategy, the competitive supplier’s expected profit decreases in x while the OEM’s expected profit increases in x .*

Our findings toward the profits of the competitive supplier and the OEM are in line with expectation: The higher the technology level of the non-competitive supplier is, the more intense the competition between the suppliers will be. This reduces the competitive supplier’s profit from component-selling business. For the OEM, it always benefits from the non-competitive supplier’s production quality improvement, and the main reason is the component price war induced between the suppliers. Taking a closer look at the wholesale prices and quantities of the competitive supplier, we have the following comparative statics:

$$\frac{\partial W_{cs}^D}{\partial x} < 0, \frac{\partial q_{cs}^D}{\partial x} > 0, \frac{\partial q_b^D}{\partial x} < 0.$$

When the technology level x increases, the non-competitive supplier becomes a threat to the

competitive supplier as the non-competitive supplier has a relative price advantage ($W_{ns}^D < W_{cs}^D$). Its improvement on production quality increases the competitive supplier’s pressure significantly and hence, W_{cs} and W_{ns}^D both decrease. That is, the competitive supplier’s component price has to be lowered along with the non-competitive supplier’s. As a result, from Proposition 1, we conclude that a price war between the suppliers can be successfully induced by the OEM’s dual sourcing strategy. When the competitive supplier lowers W_{cs}^D , to respond, we observe the increase of q_{cs}^D . That is, the OEM shifts some component orders back due to the competitive supplier’s price undercutting behavior.

Regarding the OEM, when x increases, the lowered average component wholesale price provides her a larger cost advantage in the downstream market, because she can procure more components from the competitive supplier at a lower cost. Eventually, the competitive supplier’s self-branded business is hurt, and therefore q_b^D decreases in x . That is, the OEM benefits from both the suppliers’ price war and the resolved yield uncertainty at the non-competitive supplier, and thus she prefers a higher value of x . However, the competitive supplier’s loss from downstream self-branded business prevails his gains due to component order increase in the component-selling market, and thus he suffers from the non-competitive supplier’s improvement of its technology level, x . Then, we reach the following result: the OEM is strictly better off while the competitive supplier is strictly worse off in the dual sourcing scenario, because the base scenario can be

regarded as a special case when $x = 0$ and the non-competitive supplier is completely incapable. This finding is consistent with the existing literature of dual sourcing and dual channel.

PROPOSITION 2.

1. The non-competitive supplier's expected profit $E\Pi_{ns}^D$ is unimodal in x ;
2. W_{ns}^D is decreasing in x ; q_{ns}^D is unimodal in x for all given feasible σ .

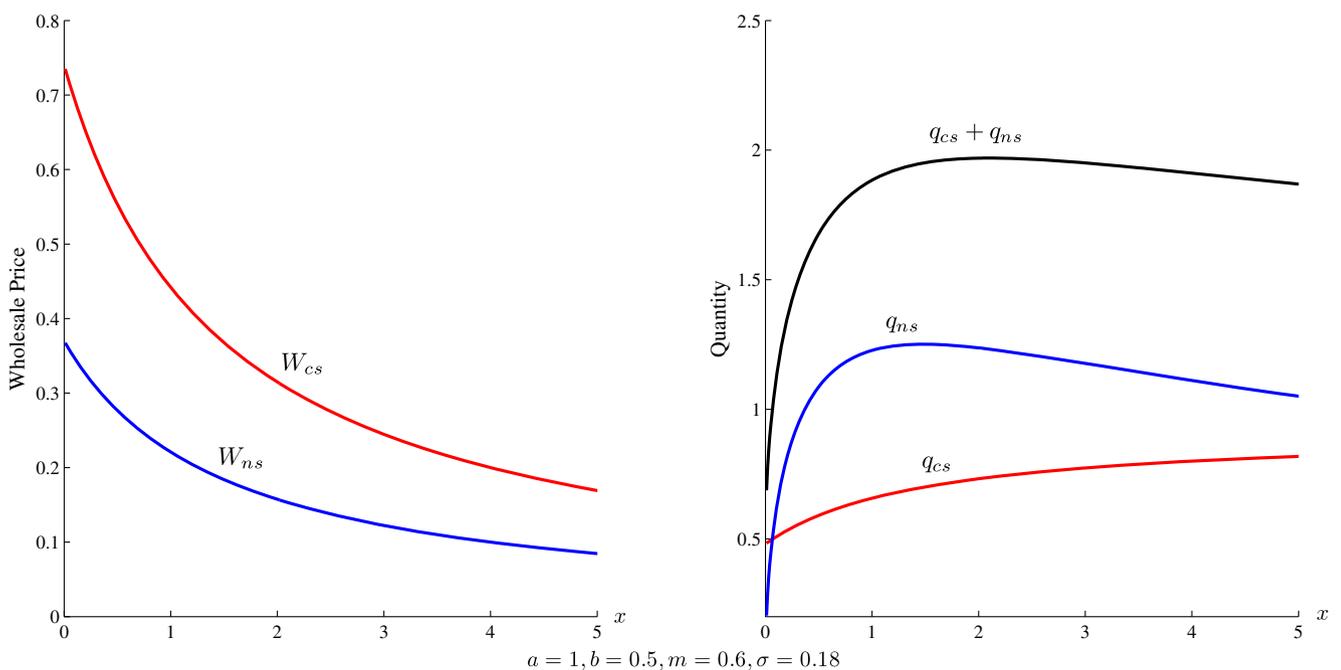
We then study the non-competitive supplier's preference of x . Conventional wisdom suggests that the non-competitive supplier should improve its technology level as much as possible in order to attract more orders from the OEM. However, our findings toward the non-competitive supplier's preference of x is rather surprising: Its profit is *unimodal* in its technology level x . In other words, the non-competitive supplier has a most preferred technology level, and it has no incentives to further improve the production technology, if it still can.

To understand this finding, we further investigate how the quantities and the wholesale prices change in the technology level x . Interestingly, we find that q_{ns}^D is non-monotone in x in the support of a given σ . This is the key reason to explain why the profit of the non-competitive supplier is unimodal in x . When the technology level x improves, the OEM tends to shift her order to the non-competitive supplier, that is, q_{ns}^D increases. Then, the competitive supplier faces a

fiercer competition in the component selling market, and its optimal response is to reduce W_{cs}^D . As a result, the non-competitive supplier will reduce W_{ns}^D correspondingly, but the price war becomes less intense because the difference between the prices becomes smaller. In anticipation of the competitive supplier's response, the OEM may be willing to shift some of her order back to the competitive supplier when x is at a high level. That is, we observe an increasing q_{cs}^D and a decreasing q_{ns}^D . The intuition is as follows: When the non-competitive supplier's quality is approaching to the competitive supplier's, although W_{ns}^D keeps decreasing, the price advantage of the non-competitive supplier is not very significant. Therefore, the OEM's gains from component price war become limited, and is more concerned about her gains from the downstream market, where the competitive supplier is her major competitor. It has been illustrated by previous literature that, placing more orders to a rival can limit the rival's incentives to develop the self-branded business (Spiegel 1993, Wang et al. 2013), and hence, reduce downstream competition. Therefore, to generate more profits from the downstream market, we observe an increasing q_{cs}^D and a decreasing q_{ns}^D , even if W_{ns}^D is further decreasing and x is increasing. Being aware of this, to snatch more component orders, the non-competitive supplier has no other choices but to further lower its wholesale price W_{ns}^D , though its production quality is already high. We illustrate the above results in Figure 3.

If we think the competitive supplier's products as "luxury goods" with high price elasticity for its high

Figure 3 Illustration of Impact of x on Wholesale Prices and Quantities [Color figure can be viewed at wileyonlinelibrary.com]



quality, and the non-competitive supplier's products as "economy substitutes" with low price elasticity for its inferior quality, then it's easy to understand that the marginal order increase due to price reduction of "luxury goods" will be more obvious. This also helps explain the finding that q_{ns}^D decreases while q_{cs}^D increases when the suppliers' wholesale prices are both decreasing. In summary, we find that when x is small, the OEM shifts orders to the non-competitive supplier as x increases, and then it has incentive of improving technology. When x becomes large, the OEM tends to shift orders back to the competitive supplier. As a result, the non-competitive supplier will lose some orders even if it has further reduced the wholesale price due to the intensive upstream competition. Combining the foregoing forces, the non-competitive supplier has no incentive to further improve its production technology when its most preferred quality level has been already achieved.

We also conduct the sensitivity analysis with respect to the price premium m . Most insights are similar to those in the base scenario: The wholesale prices is increasing in m . When m is increasing, the competitive supplier's production quantity of his own product will decrease, and the OEM's ordering quantities from both suppliers as well as her profit will increase. With an alternative supplier, the OEM can always survive in the market, even if $m = 0$, because now its supply is not fully controlled by its competitor. A different result is that, the competitive supplier's profit is decreasing in m when it is smaller than a threshold, but increasing in m when it is sufficiently large. The driving force comes from the price war induced by the OEM's dual sourcing strategy, which weakens the positive impact of an increasing W_{cs}^D and strengthens the negative effect of a decreasing q_b^D , when m is increasing. By contrast, the competitive supplier's pricing power ensures him to gain more from an increasing m in the base model, even if q_b^D is decreasing in m .

5. The Termination Scenario

In this scenario, the OEM sources solely from the non-competitive supplier. The event sequence is as follows. First, the non-competitive supplier determines the component wholesale price W_{ns} . Second, the competitive supplier and the OEM determine their production quantities simultaneously. Third, both firms assemble the components to end products. Finally, products are sold at market clearing prices. Note that the OEM's production quantity of the end products is $q_o = eq_{ns}$, where the non-competitive supplier becomes the sole supplier for the OEM.

The profit functions of the competitive supplier, the OEM and the non-competitive supplier are, respectively

$$\Pi_{cs} = (a - bq_b - beq_{ns})q_b,$$

$$\Pi_o = (a + m - bq_b - beq_{ns})eq_{ns} - W_{ns}eq_{ns},$$

$$\Pi_{ns} = W_{ns}eq_{ns}.$$

The equilibrium decisions and outcomes are summarized in Lemma 3.

LEMMA 3. *In the termination scenario, where the OEM can only source from the non-competitive supplier, the equilibrium component wholesale price is $W_{ns}^T = \frac{a+2m}{4}$, the supply chain parties' production quantities are $q_b^T = \frac{8a\sigma^2 + (5a-2m)\mu^2}{16b\sigma^2 + 12b\mu^2}$, and $q_{ns}^T = \frac{(a+2m)\mu}{8b\sigma^2 + 6b\mu^2}$; and the supply chain parties' profits are $E\Pi_{cs}^T = \frac{(8a\sigma^2 + (5a-2m)\mu^2)^2}{16b(4\sigma^2 + 3\mu^2)^2}$, $E\Pi_o^T = \frac{(a+2m)^2\mu^2(\sigma^2 + \mu^2)}{4b(4\sigma^2 + 3\mu^2)^2}$, $E\Pi_{ns}^T = \frac{(a+2m)^2\mu^2}{8b(4\sigma^2 + 3\mu^2)^2}$ respectively.*

Again, we find that the OEM's production quantity is increasing while the competitive supplier's production is decreasing in the brand difference m . The OEM's profit as well as the non-competitive supplier's profit both increase in m . Without the component-selling business, there is no tradeoff and the competitive supplier's profit will decrease in m . Regarding the impact of the non-competitive supplier's production technology level, our findings are as follows: (i) the wholesale price W_{ns}^T is a constant. (ii) q_b^T is decreasing in x , which indicates that the competitive supplier, acting as a pure competitor of the OEM, will be hurt when OEM finds a high quality alternative supplier. (iii) q_{ns}^T is unimodal in x for all given σ , which implies that the OEM's order quantity might be decreasing in x when x is sufficiently high. (iv) $E\Pi_o^T$ is increasing in x , because when the non-competitive supplier has a high quality level, although the ordering quantity at the non-competitive supplier q_{ns}^T is lower but the actual received component quantity μq_{ns}^T is higher.

Performance comparison between the termination and base scenarios. Shifting from the base scenario to the termination scenario may benefit or hurt the OEM, because the non-competitive supplier can provide the components to the OEM at a lower price but at the same time it has yield uncertainty. As for the competitive supplier, he has an incentive to terminate his component supply business because he competes with the OEM directly in the end-user market. We are interested in the changes of performances of the OEM and the competitive supplier from the base scenario to the termination scenario. The results are summarized in the following proposition.

PROPOSITION 3. *The competitive supplier is strictly worse off in termination scenario than that in the base scenario; The OEM is better off under the termination*

scenario when x exceeds a threshold value x_O , otherwise it prefers the base scenario.

Note that the competitive supplier becomes the pure competitor of the OEM in the termination scenario. Compared with the base scenario, we find that the competitive supplier's strategy of terminating his component-selling business will indeed hurt the OEM when $x < x_O$. This indicates that the competitive supplier's termination decision of the component-selling business can induce a *lose-lose situation* in the downstream competition. This situation no longer holds when $x \geq x_O$, where we find that the OEM can be better off in the termination scenario even when the non-competitive supplier's production technology is not very stable. Essentially, this is because that in the termination scenario, the wholesale price offered by the non-competitive supplier is always lower than the price offered by the competitive supplier in the base scenario, that is, $W_{ns}^T < W_{cs}^B$. When the technology level x is low, the cost advantage of the OEM in the termination scenario is not strong enough to offset the drawback brought by the low production technology. However, as x increases, the drawback in production quality becomes less significant, and eventually when x surpasses x_O , the OEM becomes better off in the termination scenario.

Proposition 3 establishes the fact that the competitive supplier always benefits from engaging the component-selling business with OEM and terminating the component supply will shrink OEM's profit when $x < x_O$. We have also shown that the OEM has strong incentives to diversify her supply sources. Thus, an intriguing and important question arise naturally, if the OEM wants to adopt the dual-sourcing strategy by purchasing from an additional unreliable supplier, can the competitive supplier prevent that by the threat of terminating his supply of components? Next, we will investigate this question by comparing the supply chain parties' performances under the termination and dual sourcing scenarios.

Performance comparison between the termination and dual sourcing scenarios. This comparison can be the most interesting one—as we have mentioned in the introduction, emerging debates have recently taken place in the OM/marketing field (Epstein 2014, Kaiser 2013, Kim 2012, Worstall 2013, Humphries 2012). Essentially, the OEM prefers the situation where the competitive supplier *does not* terminate the component-selling business even if she shifts some component orders to a new alternative supplier. Especially when $x < x_O$, the supplier's termination threat seems credible and indeed hurts the OEM's profitability. The results of our analysis are summarized in the following proposition.

PROPOSITION 4. *Comparing the profits in the dual sourcing scenario and termination scenario,*

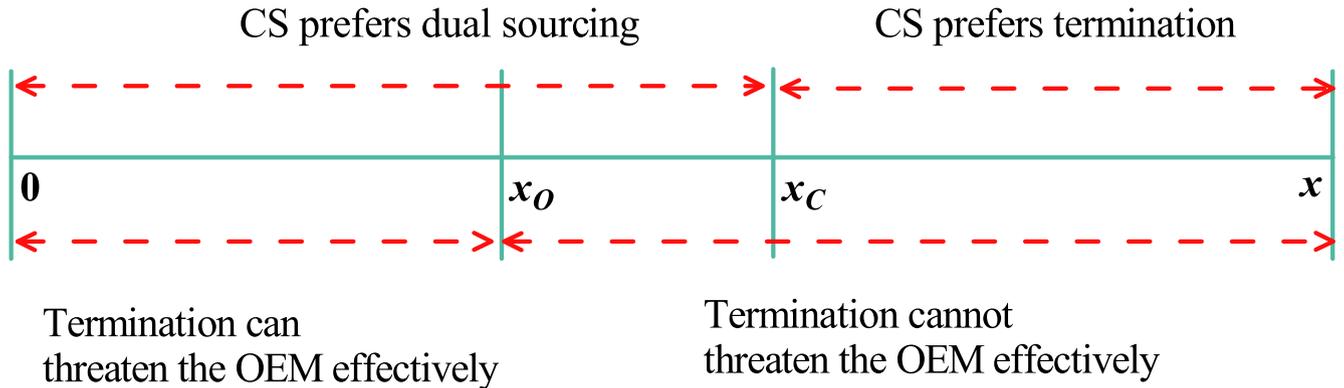
1. *the OEM is always better off in the dual sourcing scenario;*
2. *the competitive supplier is better off in the dual sourcing scenario when x is smaller than a threshold value x_C , otherwise the competitive supplier prefers the termination scenario.*

We find that the incentives of the OEM and the competitive supplier can be aligned when the newly entered non-competitive supplier's technology level is lower than the threshold value, x_C , such that both OEM and competitive supplier prefer the dual sourcing strategy to the termination scenario. For the OEM, we can conclude that the dual sourcing is its most preferred strategy as it generates the largest profit among the three scenarios. An immediate insight is that *the OEM will always benefit from the newly entered alternative supplier* even it suffers from technology inefficiency. That is, the OEM has no incentive to place all component orders to a sole supplier.

For the competitive supplier, intuitively speaking, it's more profitable to engage both component-selling business and self-branded business (Wang et al. 2013). We find that this intuition only holds when the competition in the upstream component market is not very intense. That is, when the non-competitive supplier's production technology is relatively low, the reduction in component wholesale price is not very significant. Furthermore, engaging in self-branded business will contribute to the competitive supplier's profit through revenue diversification. In practice, many technological firms have realized this and producing and selling self-branded products, such as Samsung and Intel. However, we find that this intuition breaks when the alternative non-competitive supplier's production technology is sufficiently high. The resulting fierce price war will hurt the competitive supplier while passing the gains to OEM. On the one hand, the competitive supplier's benefit from component-selling business diminishes due to the intense competition in the component market. On the other hand, the OEM benefits from the component price war which strengthens her business of the end product and hurts the competitive supplier's self-branded business. Being aware of this, it's worthwhile for the competitive supplier to terminate his component-selling business so as to increase the component costs for OEM and squeeze OEM's margin. This also benefits the competitive supplier's self-branded business. Our finding here helps explain Samsung's recent termination of LCD contract with Apple (Humphries 2012).

We now turn our attention to the critical but open question: *Is the termination of component-selling*

Figure 4 Illustration of Performance Comparison [Color figure can be viewed at wileyonlinelibrary.com]



business by the competitive supplier a credible threat for the OEM? In other words, when the OEM tries to adopt the dual sourcing strategy, is it possible that the competitive supplier terminates his supply of components as a response such that the OEM earns even less than in the base scenario? If this is true, the OEM has to consider more carefully when soliciting the alternative supplier. In Proposition 3, we show that it is possible that the OEM becomes worse off in the termination scenario than in the base scenario, and there exists a threshold value x_O . In order to determine whether this termination is a credible threat, we compare the two critical threshold value: x_C and x_O . The result is provided in the following proposition.

PROPOSITION 5. For any given parameters of a, m, μ and $\sigma, x_O < x_C$.

We illustrate this proposition in Figure 4. A direct implication of Proposition 5 is that when the technology level x is strong enough to convince the competitive supplier to terminate his component-selling business, it is also strong enough to enable the OEM to be better off in the termination scenario than in the base scenario. We summarize the strategic interactions between the OEM and the competitive supplier as follows. From the competitive supplier’s perspective, when the OEM conducts dual sourcing strategy and when x is relatively low, the competitive supplier is still willing to cooperate with the OEM since the competition in the component market is not very intense. As x gradually increases, the upstream competition in the component market becomes fiercer, and eventually when x surpasses x_C , it’s actually better for the competitive supplier to terminate his component-selling business. However, Proposition 5 indicates that it’s already “too late” for the competitive supplier to do so. The production quality of the non-competitive supplier is so high that the OEM can be better off by relying solely on the components from the non-competitive supplier,

although the yield uncertainty is not yet completely solved.

From the OEM’s perspective, dual sourcing is always the preferred strategy. When x is relatively low, the competitive supplier is willing to continue the component-selling business with OEM, hence their incentives are coordinated and the dual sourcing strategy can be successfully adopted. As the technology level x gradually increases and finally surpasses x_C , the component business will be terminated by the competitive supplier due to the intense competition in the component market. However, the OEM still becomes better off compared to the base scenario. With the foregoing analysis, we can now conclude that: *Termination is never a credible threat by the competitive supplier.* It’s always optimal for the OEM to seek an alternative supplier (even with lower production technology) and adopt the dual sourcing strategy. No matter the competitive supplier accepts it or not, the OEM will always be better off compared with the original (base) sourcing strategy. In summary, we have the general equilibrium of the supply chain structures in the following Table 1.

From the above discussions, dual sourcing is always OEM’s dominating strategy and the competitive supplier’s best response depends on x : if $x < x_C$, he chooses to maintain the co-opetition relationship with the OEM; otherwise when $x \geq x_C$, he will choose to terminate its component-selling business and become a pure competitor of the OEM. Therefore, “Dual Sourcing” and “Termination” can be the equilibrium structure in general, depending on the alternative supplier’s technology level.

Table 1 General Equilibrium of Supply Chain Structures

		Competitive supplier	
		Co-opetition	Competition
OEM	Single Dual	Base Dual sourcing ($x < x_C$)	N/A Termination ($x \geq x_C$)

6. Extensions and Discussions

6.1. Capacity Constraint of the Competitive Supplier

In practice, the capacity of technological firms is typically limited and difficult to adjust once determined in the short term. In this subsection, we explore how the capacity constraint of the competitive supplier influences our results in the dual sourcing scenario. Let K denote the competitive supplier's capacity. As long as $K \leq q_b^D + q_{cs}^D$, it is obvious that the competitive supplier will fully utilize its capacity and satisfy all the component orders by adjusting the wholesale price accordingly. That is, $q_b^{DK} + q_{cs}^{DK} = K$, where the superscript "K" is used to denote the equilibrium with limited capacity. Then, we obtain the equilibrium and outcomes similar to Lemma 2, but we omit the lengthy formulations here for exposition. We find that the competitive supplier has a most preferred level of K because his profit is concave in K . Furthermore, this "most preferred" capacity level is smaller than $q_b^D + q_{cs}^D$, the equilibrium output of the competitive supplier without capacity constraint. That is, the competitive supplier actually benefits from insufficient capacity. This finding is presented in the following proposition.

PROPOSITION 6. *Let K_{cs}^{DK} denote the most preferred capacity level that maximize $E\Pi_{cs}^{DK}$, then $K_{cs}^{DK} < q_b^D + q_{cs}^D$.*

From Proposition 6, we find that an insufficient capacity may benefit the competitive supplier. The key to understand this finding is the yield uncertainty problem of the non-competitive supplier. If the non-competitive supplier has 100% yield rate, all unmet demand will be immediately shifted to the non-competitive supplier, and the component prices will remain unchanged. However, due to yield uncertainty, the OEM can only shift a partial order. This enhances the competitive supplier's negotiation advantage, and enables him to raise the wholesale price. In other words, the capacity constraint actually alleviates the price war in the component market. Thus, a small K benefits the competitive supplier and harms his rival, the OEM. This explains why $K_{cs}^{DK} < q_b^D + q_{cs}^D$. As a result, with a tight capacity constraint the total component ordering quantity is reduced. One recent example supporting our finding is that Samsung outsmarted Apple by raising chip prices using limited production capacity. According to a report from *Financial Times*, Samsung follows a similar strategy when it sold application processors to Apple (Song 2012).

We also investigate the impact of the non-competitive supplier's production technology level x on its profit when its competitor does not have sufficient capacity. It is not difficult to show that $E\Pi_{ns}^{DK}$ is still unimodal in x . However, we find that the threshold becomes even smaller than the previous one, that is, the non-competitive supplier is less willing to improve its technology if its competitor has limited capacity. This is because when the competitive supplier has limited capacity, the OEM has to rely on the non-competitive supplier to a higher degree, which reduces the latter's incentive of improvement.

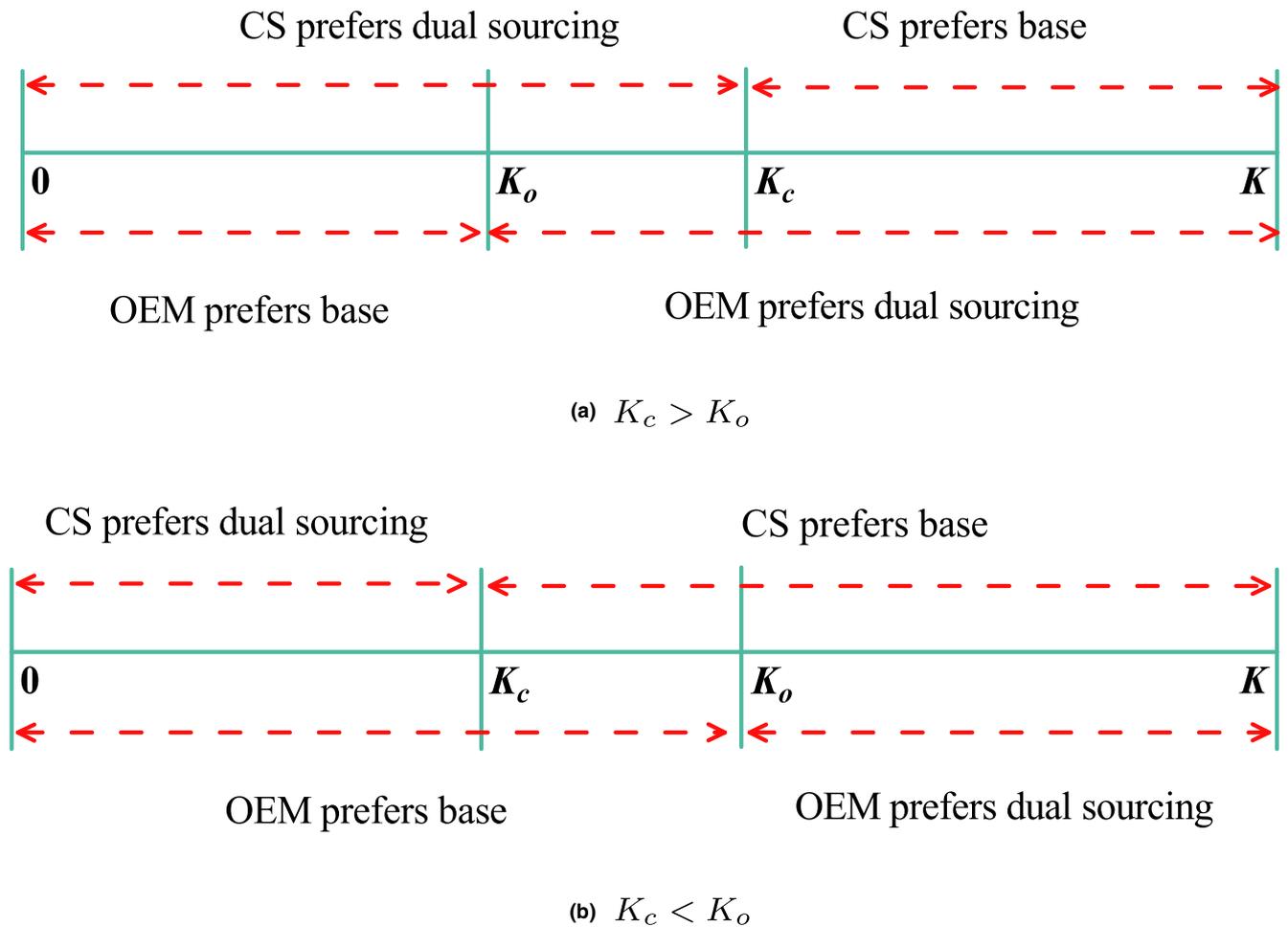
Furthermore, in section 4, we have shown that the OEM is always better off while the competitive supplier is always worse off in the dual sourcing scenario comparing with the base scenario. We now investigate if this result changes when there is a capacity constraint for the competitive supplier.

PROPOSITION 7. *When the competitive supplier's production quantity is constrained by a limited capacity K ,*

1. *There exists a threshold $K_o = \frac{14a - m + 4(a - m)x}{b(29 + 12x)}$ such that, the OEM is better off in the dual sourcing scenario when $K > K_o$, and vice versa;*
2. *There exists a threshold $K_c = \frac{12a + 4m + (5a + m)x}{b(28 + 15x)}$ such that, the competitive supplier is worse off in the dual sourcing scenario when $K > K_c$, and vice versa;*
3. *$K_c > K_o$ if and only if $x > \frac{11a - 36m}{24m}$.*

When the competitive supplier has limited capacity, the performance comparison becomes more complicated and depends on the relationship among a , m , and x . We illustrate this proposition in Figure 5 and have the following observations: (i) when the competitive supplier has very limited capacity, the performance comparison is just the reverse of traditional wisdom: the OEM is worse off while the competitive supplier is better off in the dual sourcing scenario. This is because, the component price war will bring limited gains to the OEM, and protect the competitive supplier's component-selling business. The OEM has to procure more components from the low-quality alternative supplier at the average high purchasing price, and thus its profitability is hurt. (ii) Interestingly, when the competitive supplier has moderate but limited capacity, dual sourcing may result in either a *win-win* situation or a *lose-lose* situation, depending on the OEM's price premium m and the non-competitive supplier's quality x . If the non-competitive supplier has a high quality, and/or the OEM's premium is small, both the competitive supplier and the OEM obtain more profits in the dual sourcing scenario; otherwise, both companies prefer the base scenario.

Figure 5 Illustration of Performance Comparison with Capacity [Color figure can be viewed at wileyonlinelibrary.com]



6.2. Capacity Constraint of the Non-competitive Supplier

We now explore how the capacity constraint of the non-competitive supplier influences our results. The existence of this constraint means that the OEM cannot mitigate the yield uncertainty problem by simply increasing its order quantity q_{ns} . Let τ denote the non-competitive supplier’s capacity. Similarly, it is obvious that this constraint is binding when $\tau \leq q_{ns}^D$. With this constraint, μ and σ are not homogeneous in the formulations and thus they cannot be rearranged as functions of the technology level x . As a result, we examine the comparative statics for μ and σ respectively. Let the superscript “ t ” denote the corresponding equilibrium and outcomes. We have the following proposition:

PROPOSITION 8. *When the non-competitive supplier’s total output is constrained by τ ,*

1. W_{cs}^{Dt} and q_b^{Dt} both decrease in μ and increase in σ ;
2. q_{cs}^{Dt} decreases in σ , and increases in μ if $x < 40/9$;

3. $E\Pi_{cs}^{Dt}$ decreases in μ and increases in σ ; $E\Pi_o^{Dt}$ increases in μ and decreases in σ ;
4. $E\Pi_{ns}^{Dt}$ is unimodal in μ and/or σ .

Although the comparative statics become more complicated, they share the similar qualitative insights into our previous results. The two decisions made by the competitive supplier, W_{cs}^{Dt} and q_b^{Dt} are negatively related to its competitor’s technology levels. When the competitive supplier’s wholesale price decreases, it is intuitive that the OEM should place a larger order to him, but now the effects of μ and σ become diverse. The intuition holds when σ decreases, but is not necessarily true when μ increases, unless the technology level is not very high. When the non-competitive supplier is constrained by the capacity, the effective expected quantity that the OEM can obtain is exactly $\mu\tau$. Therefore, the qualified component quantity from the non-competitive supplier that the OEM can obtain is increasing in μ , but she does not necessarily increase her order size to the competitive supplier.

Regarding the non-competitive supplier's decisions and outcomes, we find that similar insight holds: It may not have incentives to improve the technology levels, that is, increase μ or decrease σ . We show that, its profit is quasi-concave in both μ and σ , that is, (i) the non-competitive supplier is not willing to increase μ when it is large enough; (ii) the non-competitive supplier will decrease σ only when it is large enough. These insights are highly consistent with Proposition 2. Furthermore, we show that the OEM still benefits from diversifying its component orders to both suppliers, which hurts the competitive supplier.

We also consider a different scenario in which the non-competitive supplier has sufficient capacity. We show that it will produce at its full capacity and sells the excess components to an outside spot market at a constant market price W . Then, the non-competitive supplier's profit function becomes

$$\Pi_{ns} = W_{ns}e q_{ns} + We(\tau - q_{ns}).$$

We further investigate the non-competitive supplier's incentives to cooperate with the OEM, and use “ \sim ” on the top of the equilibrium and outcomes in this scenario.

PROPOSITION 9. *If $W < \frac{10a+8m}{20+9x}$, then $\tilde{W}_{cs}^{Dt} > \tilde{W}_{ns}^{Dt} > W$ and $\tilde{q}_{ns}^{Dt} > 0$; otherwise, $\tilde{q}_{ns}^{Dt} = 0$.*

This proposition shows that, when the market price of the spot market is sufficiently high, the non-competitive supplier is more likely to sell its components to the spot market than to cooperate with the OEM, because the equilibrium wholesale price is lower than W . We also note that, this threshold is a decreasing function of the technology level x . That is, a firm of a lower technology level is more willing to cooperate with the OEM. Furthermore, we re-examine the non-competitive supplier's profit function with respect to its technology level,

$$\tilde{\Pi}_{ns}^{Dt} = \tau W \mu + \frac{x(10a + 8m - 20W - 9Wx)^2}{2b(40 + 27x)^2}.$$

It can be shown that the second part is *unimodal* in x . However, the first part is a linear increasing function of μ , representing the potential profit that the non-competitive supplier can obtain from the spot market. Therefore, it has a strong incentive to improve its technology level, especially the average yield rate μ , when it has such an outside option. This incentive is even stronger when the non-competitive supplier has more excess capacity.

6.3. Alternative Demand Models

In this subsection, we examine whether our findings are robust under two alternative demand models.

The first one is an extension to the original model with a variable price premium of the OEM, $m = \beta Q$ and $\beta > 0$, that is, the OEM's price premium is a linear increasing function of the total output quantity. In this case, the OEM has a greater advantage toward its competitor as the total market becomes larger due to the OEM's branding effect. The OEM's inverse demand function can also be rewritten as $P_o = a - bQ + m = a - (b - \beta)m$, that is, the OEM's product has a smaller price elasticity than its competitor's. It is worth noting that β cannot be too large ($\beta < \frac{\sqrt{19}-2}{3}b \approx 0.786b$). Otherwise the competitive supplier will charge a sufficiently high wholesale price leading to a boundary solution.

The second one is the Cournot competition model with substitutable products $P_i = a - q_i - \gamma q_j$, $i, j \in \{cs, o\}$, where γ ($0 < \gamma < 1$) measures the degree of product substitutability. The larger the γ is, the less distinction between the end products of the competitive supplier and the OEM. Correspondingly, the downstream competition will become more intense. The price premium m is thus absent in this model.

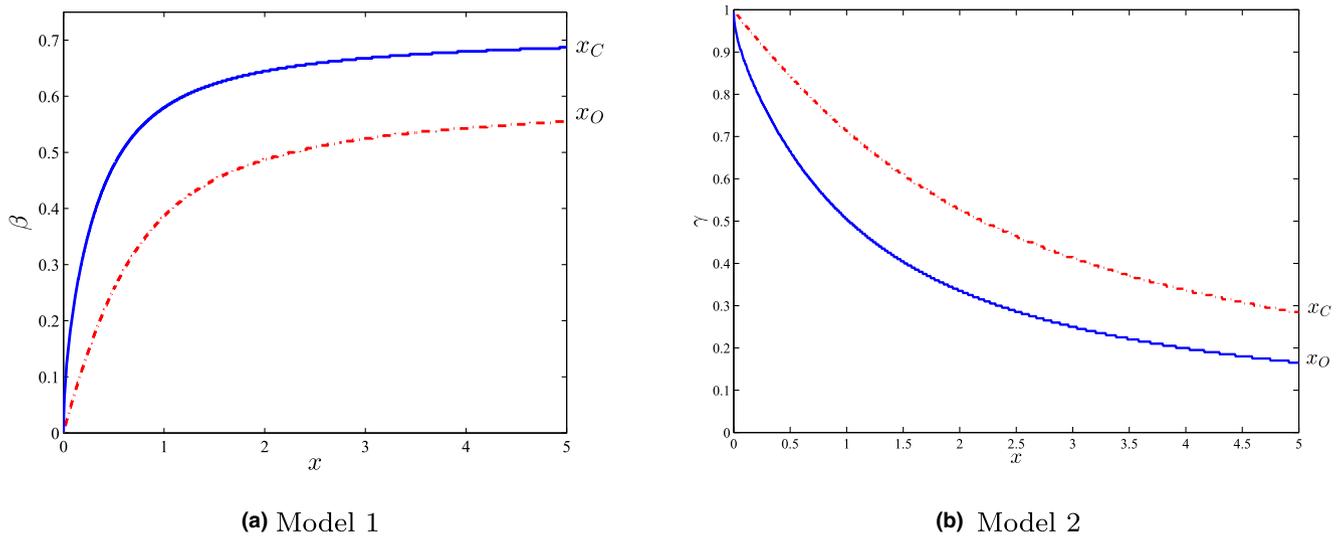
To verify the robustness of our findings, we conduct the same analysis in the previous sections for these alternative demand models. We first derive the equilibrium of the three scenarios: Base, Dual Sourcing and Termination, under the two alternative models, and compare the profits among the three scenarios. We find that, under either alternative model, the OEM still benefits from dual sourcing, but the competitive supplier suffers from this strategy. We also find that, similar to that in section 4, we can rearrange the non-competitive supplier's profit function with the notation $x = (\mu/\sigma)^2$, and the non-competitive supplier's expected profit is *unimodal* in x . It affirms that our findings and explanations are robust under these alternative demand models.

We next consider the strategic interaction between the competitive supplier and the OEM. Similarly, we study how the competitive supplier responds to the OEM's order-shifting behavior, and whether termination is a credible threat to the competitive supplier. Unfortunately, it is too complicated to derive analytical results. We thus conduct extensive numerical studies to see how β (in the first model), γ (in the second model) and x affect the outcomes. Parameters that we used are provided in Table 2. We have varied thousands of different feasible combinations and find that the results are robust to the changes of

Table 2 Summary of Parameters

Market potential	$a = 2, b = 1$
Brand effect	$\beta \in [0, 0.75]$, step length = 0.025
Substitutability	$\gamma \in [0, 1]$, step length = 0.025
Technology level	$x \in [0, 5]$, step length = 0.025

Figure 6 Illustration of Strategic Interaction with Alternative Demand Models [Color figure can be viewed at wileyonlinelibrary.com]



parameters. We illustrate one of the typical curves in Figure 6.

The bottom-right corner in Figure 6a and top-right corner in Figure 6b represents the cases when the competitive supplier decides to terminate his component-selling business, but the OEM also performs better than the base scenario (i.e., Competitive supplier's termination is not threatening). The top-left corner in Figure 6a and bottom-left corner in Figure 6b represents the cases when both the competitive supplier and the OEM are happy with continuing their component-selling business. The area in the middle represents the cases where termination could make the OEM perform worse than the base scenario, but the competitive supplier tends to continue the component-selling business (i.e. Competitive supplier has no incentive of termination). x_C and x_O are two curves to divide the three areas. For either model, we observe $x_C > x_O$, so there does not exist an area where the competitive supplier's termination threatens the OEM effectively to stop the order-shifting behavior as well as benefits himself.

Regarding the sensitivity analysis, we have the following observations. For the first alternative model, we observe that the larger the β is, the less likely that the competitive supplier will terminate his component-selling business. For the second alternative model, we observe that the smaller the γ is, the less likely that the competitive supplier will terminate. These observations consistently imply that the competitive supplier will be more tolerant toward the competition in the up-stream component market if his end product in the downstream market is highly differentiated from the OEM's.

In short, under the alternative demand models, we find that our main qualitative insights hold. The

non-competitive supplier's profit is unimodal in x . The competitive supplier will terminate his component-selling business when the non-competitive supplier's production technology level is higher than a threshold value and the competitive supplier's termination of component-selling business is not a credible threat to prevent the OEM engaging an additional alternative supplier.

6.4. Suppliers' Positive Production Costs

In this subsection, we relax the zero production cost assumption by assuming a positive unit production cost c for both suppliers. Although all equilibriums can be obtained in closed-form, additional analysis becomes intractable. Therefore, we resort to the numerical analysis to derive the findings here.

We first re-investigate the impact of x on the ordering quantity q_{cs} and q_{ms} . When there is a positive production cost, the non-competitive supplier may not be able to gain profits, if its quality x is too low. We observe $q_{ms} \leq 0$, in either the dual sourcing scenario or the termination scenario. Then, the base scenario is the OEM's sole choice. The reason is that, when the non-competitive supplier has a positive production cost, if x is too low, the received payment from the OEM may not cover the production cost. In other words, when the OEM considers the dual sourcing scenario, she should seek a relatively reliable alternative supplier, so that the dual sourcing strategy is feasible. It is also obvious that the threshold of x increases in c . That is, the higher the production cost is, the larger x the non-competitive supplier should have for surviving.

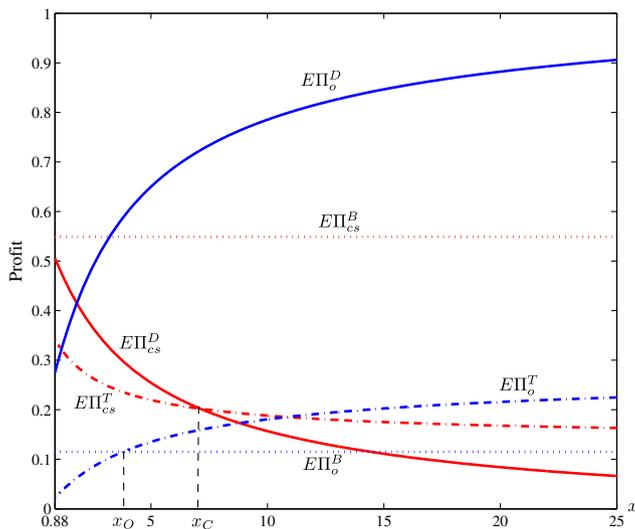
Our second observation is that, Proposition 2 may not hold when c is sufficiently high. When c becomes

very high, q_{ns} is no longer unimodal but increasing in x . An explanation is, when there is a large production cost related to both suppliers, their component prices will be raised correspondingly, because they still need a reasonable profit margin. This induces the OEM to keep increasing the order size to the non-competitive supplier with the hope of further lowering the average component purchasing cost. This also affects the non-competitive supplier's profit and changes the result in Proposition 2. Since the increasing order quantity may have larger impact than the decreasing wholesale price on its profit, the non-competitive supplier's profit is increasing in x .

We find the remaining results are consistent with the results derived from the base model when there is a positive production $c > 0$ both suppliers:

1. The blue lines in Figure 7 represent the OEM's profits in the three scenarios. We observe that $E\Pi_o^D$ is the highest one and dominates the other two, and the OEM is better off in the termination scenario than in the base scenario when $x > x_O$.
2. The red lines represent the competitive supplier's profits in the three scenarios. We observe that $E\Pi_{cs}^B$ is the largest one and dominates the other two, and he is better off in the dual sourcing scenario than in the termination scenario when $x < x_C$.
3. We note that $x_C > x_O$, that is, the competitive supplier's threat on termination is non-credible.
4. In the dual sourcing scenario, the competitive supplier's expected profit $E\Pi_{cs}^D$ decreases while the OEM's expected profit $E\Pi_o^D$ increases in x .

Figure 7 Illustration of Impact of x on the Competitive Supplier's and the OEM's Profits with a Positive Cost [Color figure can be viewed at wileyonlinelibrary.com]



7. Conclusion

The co-opetitive relationship between Apple and Samsung motivates their strategic decisions such as the component sourcing quantity allocation and self-branded business development. In this study, we characterize the main properties of such a co-opetitive supply chain and find that the dual sourcing strategy is always in the OEM's best interest. It induces a price war between component suppliers, which reduces the OEM's total procurement cost. Such a cost reduction further strengthens the OEM's competition advantage in the downstream market of end products. However, the OEM's component order-shifting seriously harms the competitive supplier, resulting in two possible strategic choices: stop its self-branded business, or terminate the component-selling business and become a pure competitor of the OEM. We show that the latter is never a credit threat for the competitive supplier to prevent the OEM from engaging an additional alternative supplier.

Contrary to conventional wisdom, we also find that the non-competitive supplier may not have incentive to improve its technology and raise its yield rate. When its quality indicator has surpassed a most preferred level, the upstream price competition becomes so intense that the price advantage of the non-competitive supplier almost vanishes. Thus, the OEM tends to shift back most component orders to the competitive supplier who has 100% yield rate. This indicates that the OEM may fail to find a non-competitive supplier that has sufficiently good quality of components. Interestingly, we find that the non-competitive supplier's wholesale prices are decreasing and production quantities are unimodal in its quality level, which helps explain the non-competitive supplier's incentive to manage its yield uncertainty problem. We also consider the impacts of the two suppliers' capacity constraints respectively and find that the upstream component price war will be alleviated and the downstream market supply will be reduced when the competitive supplier has limited capacity.

We note a few limitations of this study and provide promising avenues for future research. First, we adopt a Stackelberg game framework to facilitate our analysis. For the future research, it will be interesting to study the wholesale price negotiation problems among the three players, rather than the take-it-or-leave-it pricing scheme that we assumed here. Second, in this study, we consider the scenario that OEM does not have the capability to influence the non-competitive supplier's production technology. It is possible that the OEM can co-invest in the non-competitive supplier's quality improvement so as to give more pressure to the competitive supplier. The

corresponding cost-sharing mechanisms and contract types may influence the supply chain parties' strategic decisions.

We find that termination is always better for the non-competitive supplier because in this scenario it becomes the sole supplier of the OEM and the upstream price war no longer exists. Then, the non-competitive supplier may have more incentives in improving its technology level x to be higher than x_C and induce the competitive supplier to terminate its component-selling business. However, in practice, the improvement of x can be prohibitively costly. If the non-competitive supplier can afford this technology improvement cost, the global equilibrium must be Termination. Otherwise, the global equilibrium will be Dual-sourcing. Noting that the technology improvement cost issue can be overly complicated that distract readers from the main objectives of our research, we chose to keep x exogenously given and derived the global equilibriums conditional on the level of x . Notwithstanding these limitations, this study presents a first step in understanding the OEM and competitive supplier's attitude toward the dual sourcing and dual channel strategies. We believe the growing popularity of frenemy relationship in the high-tech industry presents an exciting area of research.

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Notes

¹TSMC is a non-competitive supplier of Apple and it declares that it will be "staying away from designing, manufacturing or marketing semiconductor products under its own brand name so it can avoid competing against its customers" (Forbes 2017).

²A positive assembly cost is equivalent to the reduction of m , which does not affect our main results.

³Note that $\text{Var}(e) = E(e^2) - (E(e))^2$. e ranges from 0 to 1, thus $E(e^2) < E(e)$. We have $\text{Var}(e) < E(e) - (E(e))^2$. Because $E(e)$ also ranges from 0 to 1, $E(e) - (E(e))^2$ reaches its maximum $1/4$ when $E(e) = 1/2$. Hence, $\text{Var}(e) < 1/4$. This indicates that σ is smaller than $1/2$.

⁴If the OEM pays for what she orders instead of what she received, as Tang and Kouvelis (2011), we find that all our results and findings remain unchanged, except that the

non-competitive supplier's wholesale price $W_{ns}^{T'} = \mu W_{ns}^T$ which becomes lower, because it does not bear the yield cost in that case. We realize that these two payment schemes (i.e., pay for what is ordered, and, pay for what is received) are mostly equivalent. Similar results and explanations can be found in Tang and Kouvelis (2011).

References

- Adner, R., J. Chen, F. Zhu. 2015. Frenemies in platform markets: The case of Apple' iPad vs. Amazon' Kindle. Harvard Working Paper Series No. 15–087.
- Amaral, J., C. Billington, A. Tsay. 2006. Safeguarding the promise of production outsourcing. *Interfaces* 36: 220–233.
- Arruñada, B., X. Vázquez. 2006. When your contract manufacturer becomes your competitor. *Harv. Bus. Rev.* 84(9): 135–144.
- Autrey, R., F. Bova, D. Soberman. 2014. When gray is good: Gray markets and market-creating investments. *Prod. Oper. Manag.* 24(4): 547–559.
- Bohn, R., C. Terwiesch. 1999. The economics of yield-driven processes. *J. Oper. Manag.* 18: 41–59.
- Bora, K. 2014. Apple iPhone 6 rumors: TSMC to use 8-inch processing method to produce fingerprint sensors for next-Gen iPhone. Available at <http://www.ibtimes.com/apple-iphone-6-rumors-tsmc-use-8-inch-processing-method-produce-fingerprint-sensors-1554550>. February 11 (accessed date August 10, 2017).
- Brandenburger, A., B. Nalebuff. 1996. *Co-opetition: A Revolution Mindset that Combines Competition and Cooperation*. Bantam Doubleday Dell Press. New York.
- Cachon, G., C. Terwiesch, Y. Xu. 2008. On the effects of consumer search and firm entry in a multiproduct competitive market. *Market. Sci.* 27: 461–473.
- Cai, G. 2010. Channel selection and coordination in dual-channel supply chains. *J. Retail.* 86: 22–36.
- Chen, J., Z. Guo. 2014. Strategic sourcing in the presence of uncertain supply and retail competition. *Prod. Oper. Manag.* 23: 1748–1760.
- Chen, Y., S. Shum, W. Xiao. 2012. Should an OEM retain component procurement when the CM produces competing products? *Prod. Oper. Manag.* 21: 907–922.
- Chowdhry, A. 2014. Apple and Samsung drop patent disputes against each other outside of the U.S. Available at <https://www.forbes.com/sites/amitchowdhry/2014/08/06/apple-and-samsung-drop-patent-disputes-against-each-other-outside-of-the-u-s/#656d7c8418ca>. August 6 (accessed date August 10, 2017).
- Deo S., C. Corbett. 2009. Cournot competition under yield uncertainty: The case of the US influenza vaccine market. *Manuf. Serv. Oper. Manag.* 11: 563–576.
- Dumrongsiri, A., M. Fan, A. Jain, K. Moinzadeh. 2008. A supply chain model with direct and retail channels. *Eur. J. Oper. Res.* 187(3): 691–718.
- Epstein, Z. 2014. Apple and Samsung: Doomed to be frenemies forever? Available at <http://bgr.com/2014/07/01/apple-a9-processor-production-samsung/>. July 1 (accessed date August 10, 2017).
- Forbes, 2017. Taiwan's richest: Morris Chang, pioneering chipmaker and list newcomer. Available at <https://www.forbes.com/sites/luisakroll/2017/06/28/taiwans-richest-morris-chang-pioneering-chipmaker-and-list-newcomer/#4d2a1e056d40>. June 28 (accessed date May 24, 2018).
- Humphries, M. 2012. Samsung terminates LCD contract with Apple. Available at <http://www.geek.com/apple/samsung->

- terminates-lcd-contract-with-apple-1523689/. October 22 (accessed date August 10, 2017).
- IDC. 2018. Smartphone shipments down 6.3% in Q4 2017, Apple overtakes Samsung for top spot. Available at <https://www.techspot.com/news/73082-idc-apple-overtakes-samsung-smartphone-market-global-shipments.html>. February 2 (accessed date March 2, 2018).
- Kaiser, T. 2013. Samsung takes hit as Apple partners with TSMC for iPhone, iPad chips. Available at <http://www.dailytech.com/Samsung+Takes+Hit+as+Apple+Partners+with+TSMC+for+iPhone+iPad+Chips/article31871.htm>. July 1 (accessed date August 10, 2017).
- Karp, L., J. Perloff. 2012. Vertical contracts and mandatory universal distribution. *BE J. Econ. Anal. Policy* 13: 595–626.
- Kim, M. 2012. Analysis: Friend and foe; Samsung, Apple won't want to damage parts deal. <http://www.reuters.com/article/us-samsung-apple-supply-idUSBRE87Q06N20120827>. August 27 (accessed date August 10, 2017).
- Kumar, N., R. Ruan. 2006. On manufacturers complementing the traditional retail channel with a direct online channel. *Quant. Market. Econ.* 4: 289–323.
- Lee, J., I. King. 2015. Samsung said to win Apple A9 chip orders for next iPhone. Available at <https://www.bloomberg.com/amp/news/articles/2015-04-03/samsung-said-to-win-apple-a9-chip-orders-for-next-iphone>. April 2 (accessed date August 10, 2017).
- Li, T., S. Sethi, J. Zhang. 2013. Supply diversification with responsive pricing. *Prod. Oper. Manag.* 22: 447–458.
- Li, Z., K. J. Ryan, L. Shao, D. Sun. 2015. Supply contract design for competing heterogeneous suppliers under asymmetric information. *Prod. Oper. Manag.* 24: 791–807.
- Reisinger, D. 2015. Apple, Samsung to remain bedfellows for next iPhone—report. Available at <https://www.cnet.com/news/apple-samsung-still-bedfellows-as-they-eye-next-iphone-report-says/>. January 26 (accessed date August 10, 2017).
- Singh, N., X. Vives. 1984. Price and quantity competition in a differentiated duopoly. *RAND J. Econ.* 15(4): 546–554.
- Snow, D. C., S. C. Wheelwright, A. B. Wagonfeld. 2006. Genentech—Capacity planning. *Harv. Bus. School Case* 606–052.
- Song, J. 2012. Samsung: Playing tough with Apple. Available at <http://blogs.ft.com/beyond-brics/2012/11/13/samsung-playing-tough-with-apple/>. November 13 (accessed date August 10, 2017).
- Spiegel, Y. 1993. Horizontal subcontracting. *RAND J. Econ.* 24: 570–590.
- Swartz, J. 2009. Cisco goes up against IBM, HP in computer server market. Available at <http://abcnews.go.com/Business/story?id=7098334>. May 27 (accessed date August 10, 2017).
- Tang, S., P. Kouvelis. 2011. Supplier diversification strategies in the presence of yield uncertainty and buyer competition. *Manuf. Serv. Oper. Manag.* 13: 439–451.
- Tang, S., H. Gurnani, D. Gupta. 2014. Managing disruptions in decentralized supply chains with endogenous supply process reliability. *Prod. Oper. Manag.* 23: 1198–1211.
- Tibken, S. 2012. Samsung kicking Apple to curb for LCD panels, report says. Available at <https://www.cnet.com/news/samsung-kicking-apple-to-curb-for-lcd-panels-report-says/>. May 23 (accessed date August 10, 2017).
- Tomlin, B. 2006. On the value of mitigation and contingency strategies for managing supply chain disruption risks. *Management Sci.* 52: 639–657.
- Tsay, A., N. Agrawal. 2004. Modeling conflict and coordination in multi-channel distribution systems: A review. D. Simchi-Levi, D. Wu, and M. Shen, eds. *Handbook of Quantitative Supply Chain Analysis: Supply Chain Analysis in the Ebusiness Era*. Springer, Boston, MA, 557–606.
- Wang, Y., B. Niu, P. Guo. 2013. On the advantage of quantity leadership when outsourcing production to a competitive contract manufacturer. *Prod. Oper. Manag.* 22: 104–119.
- Worstell, T. 2013. No surprise in Global Foundries being used to make Apple's processors by Samsung. Available at <https://www.forbes.com/sites/timworstell/2013/11/12/no-surprise-in-globalfoundries-being-used-to-make-apples-processors-by-samsung/>. November 12 (accessed date August 10, 2017).
- Wu, X., F. Zhang. 2014. Home or overseas? An analysis of sourcing strategies under competition. *Management Sci.* 60: 1223–1240.
- Yano, C., H. Lee. 1995. Lot sizing with random yields: A review. *Oper. Res.* 43: 311–334.

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix S1: Proofs.