Strategically decentralize when encroaching on a dominant supplier

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Abstract:

A manufacturer may encroach on his suppliers by developing substitutable components. In the presence of encroachment, the manufacturer could assemble products using (high-end) components purchased from the supplier, and assemble products using (low-end) components produced in-house. Thus, the manufacturer must deliberate on how to manage the expanded organization consisting of competing product divisions. In this paper, we examine the quintessential organizational structure decision – the centralization versus decentralization choice – from the perspective of the manufacturer. Our model assumes that the supplier is a dominant player in the supply chain, moving first by pricing the high-end component, and consumers have a higher willingness-to-pay of the product containing the high-end component. In such a context, we find that the manufacturer may encroach on the supplier even if producing one unit low-end component costs more than producing one unit high-end component. The supplier should strategically price to deter or accommodate downstream encroachment contingent on the manufacturer's organizational structure decision. If the unit cost of low-end components is high enough, product-based decentralization is preferred to centralization due to the supplier's lower wholesale price. Furthermore, we find that the manufacturer's strategic decentralization always hurts the supplier, always benefits the customers, and could benefit or hurt the entire supply chain under certain conditions.

Keywords: Supply chain management; Centralization; Decentralization; Downstream encroachment

1. Introduction

The role a firm plays in supply chains is not fixed. Some firms may expand their business and encroach on their supply chain partners, for instance, a downstream manufacturer may develop substitutable components and become a rival to his suppliers. This kind of encroachment is not uncommon nowadays, especially in emerging markets.

The expanded business generally results in an expanded organization because more divisions need to be established to operate the new business. In addition, the new product with the substitutable component may cannibalize the sales of the original product, which leads to an internal conflict between new divisions and original divisions within the expanded organization. Thus, in the case of downstream encroachment, the manufacturer needs to deliberate on how to manage the expanded organization. This paper focuses on the manufacturer's organizational structure decision – the centralization versus decentralization choice. Here, centralization means that all divisions within the organization behave as one player and pursue the profit maximization of the whole organization, while decentralization implies that divisions are allowed to pursue the maximization of their own profits. Despite the theoretical allure of centralized decision-making, there are several extant justifications for decentralization (reviewed in the next section).

Downstream encroachment was first observed in the retailing industry, where downstream retailers develop private labels competing with national brands. Now, it prevails in almost all industries. Specifically, our research is substantially motivated by the practice in Chinese auto industry. The Chinese policymakers used to try to acquire advanced car manufacturing technology by opening up the market. In the 2000s, China became one of the largest auto markets, however, Chinese automakers still had little ability to design and produce high-quality key components such as engine and gearbox. They were heavily dependent on powerful foreign suppliers. Such a situation is changing because the Chinese government is supporting domestic automakers to conduct *indigenous innovation*, which could be viewed as a downstream manufacturer's encroachment on suppliers of high-quality key components. Now, some Chinese automakers can produce all key components by themselves, although these components are prone to be valued by customers as being somewhat inferior or less worthy. For

expositional clarity, the component produced by the supplier (the manufacturer) is called as the high-end (low-end) component, and correspondingly, the final product containing the high-end (low-end) component is called as the high-end (low-end) product in this paper.

For these Chinese automakers who have successfully developed substitutable components, the expanded business can be divided into three parts: assembling the high-end product, producing the low-end component, and assembling the low-end product. In practice, these operations are run by different divisions. In this paper, we consider centralization and three kinds of decentralization, as shown in Figure 1. Under product-based decentralization, market prices/production quantities of high-end and low-end products are decided to maximize the profit from a single product. This type of decentralization is called non-product-line pricing in the literature as well. Under function-based decentralization, the intra-company transfer price of low-end components will be higher than the unit cost due to the effect of double marginalization. Full decentralization is a combination of product-based decentralization and function-based decentralization.

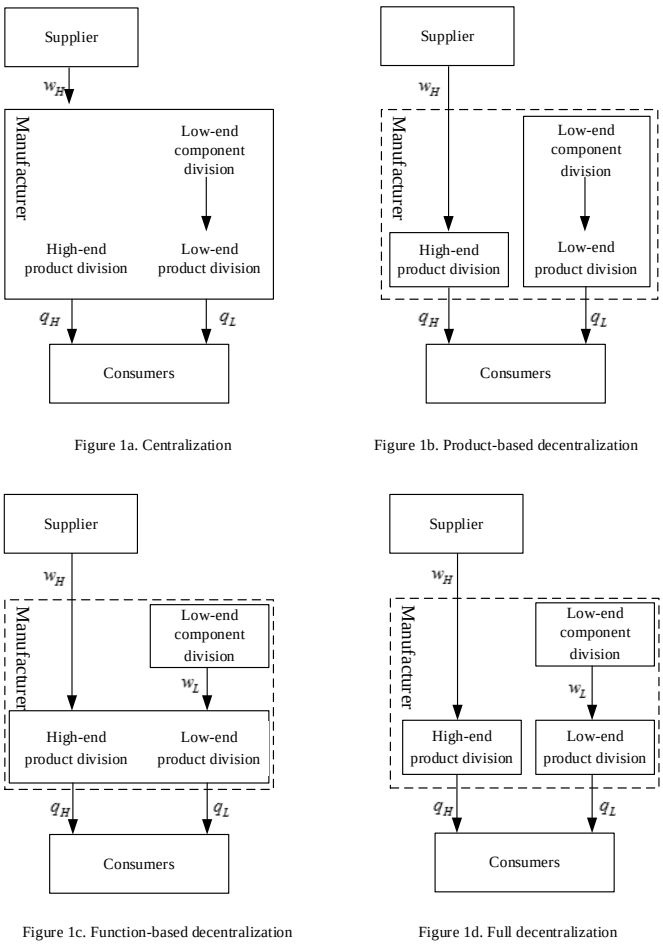

Figure 1. The organizational structure choices of the downstream manufacturer

Thus, a research question is naturally emerging: what is the manufacturer's optimal organizational structure choice? Our primary objective in this paper is to develop a general understanding of the desirability of centralization and decentralization from the perspective of the manufacturer when he encroaches on a dominant supplier by developing the substitutable component. But, how to achieve centralization or decentralization within the organization is out of the scope of this paper[1]. Although channel conflict and strategic decentralization have received a fair amount of research attention in the supply chain management literature, few papers consider these two issues together. As ever more companies from emerging countries are seeking to expand around the world, our work is of both theoretical and practical importance.

[1] In general, the firm consisting of wholly-owned subsidiaries operates in a decentralized way.

We summarize the main analytical results and discuss their practical implications as follows. Firstly, our analysis reveals the big risk for the supplier to be encroached. In light of the manufacturer's internally produced substitutable component is less valued by the customers, the supplier may feel she is immune from downstream encroachment as long as the low-end component has no cost advantage. However, regardless of the organizational structure choice, the manufacturer may start up producing low-end component even if he has to produce at a higher unit cost. Secondly, we derive the optimal pricing policy for the supplier in the presence of downstream encroachment. Downstream encroachment is detrimental to the supplier since she always has to reduce the wholesale price as a response. However, an appropriate pricing policy could minimize the detrimental impact; especially, if the unit cost of low-end components is relatively high, then the supplier should price aggressively to drive low-end products out of the market. In this case, the supplier's optimal wholesale price of high-end components is independent of the unit cost of high-end components. Thirdly and most importantly, our analysis shows that product-based decentralization is the manufacturer's optimal organizational structure choice if the unit cost of low-end components is high enough. This finding identifies a roadmap for the manufacturer to encroach on the supplier. When starting up encroachment, the manufacturer likely has no sophisticated skill to produce the low-end component cost-efficiently. Then, the low-end component division should be operated as a cost center, which implies that the internal transfer price of low-end components is equal to the unit cost; while the low-end product division should be operated as a profit center, which implies this division is authorized to make production decisions to maximize its own profit. Due to the effect of learning-by-doing, the manufacturer may develop his know-how to produce cost-efficiently after a period of time. Then, the manufacturer must coordinate the operations of all divisions to maximize the combined profits.

Our observations of the development of self-owned brand automobile in China seem to support the model's predictions. Chinese automakers made a big fortune by assembling high-end components purchased from their suppliers. They were reluctant to develop substitutable components due to concerns about the cannibalization of higher-margin high-end product sales. Pushing by the indigenous innovation project, most automakers establish new subsidiaries and adopt product-based decentralization as their organizational structure to start up encroachment. For these vehicles containing

internally produced components, they use new logos and even new brand names. The launch of self-owned brand automobile provides a low price alternative for the customers, and effectively induces the foreign suppliers and automakers to reduce prices. As a result, the Chinese car market enjoys a double-digit growth rate for years.

The rest of the paper is organized as follows. Next section reviews the relevant literature. Section 3 outlines the model. Section 4 analyses the interaction between the supplier and the manufacturer. Section 5 examines the manufacturer's preferred organizational structure choice. Section 6 discusses the impacts of the manufacturer's strategic decentralization. Section 7 concludes this paper. All the mathematical proofs are put in Appendixes.

2. Literature Review

There are mainly two streams of literature that are related to this study: (1) the literature on channel conflict in light of encroachment; and (2) the literature on strategic decentralization that reveals the benefits of decentralized decision-making within one organization. However, the first stream generally does not cover the issue of organizational structure decision, while the second is typically set in a context with no channel conflict. This paper is one of the few that bridge the gap between these two distinct streams. In what follows, we provide an overview of the relevant literature and position our work.

There are a growing amount of studies on channel conflict which pay attention to supply chain structure design, e.g., Pun (2013), Wang et al. (2013), Xia et al. (2013). Channel conflict could be raised when one upstream or downstream incumbent expands its business to directly compete with a channel partner. In the case of upstream encroachment, the upstream player sells the product through a downstream player, and sells to the final customers directly. Upstream encroachment forms a dual-channel supply chain, which has received a fair amount of research attention. Chiang et al. (2003) find that the manufacturer benefits from direct marketing even when no direct sales occur. Lim and Tan (2010) identify firm-level capabilities (both ordinary and dynamic) which are crucial in determining the sourcing strategy with the threat of the supplier as a potential competitor in the downstream marketplace. Li et al. (2014) and Xu et al. (2014) examine the impact of risk preference on the performance of the dual-channel supply chain and how to coordinate the supply chain. The emergence of direct

marketing would induce the upstream player to reduce the wholesale price, and then the downstream player's profit could also be increased. Many papers demonstrate that all parties in the conflicted channel are better off with an upstream encroachment, e.g., Cattani et al. (2006), Arya et al. (2007), Yoo and Lee (2011).

By contrast, our paper consider the case of downstream encroachment in which the downstream player sells the product purchased from the upstream player, and sells a substitutable product at the same time. This kind of encroachment is equally relevant but relatively understudied. Groznik and Heese (2010) find that only an upstream player with commitment ability can strategically adjust the wholesale price to prevent downstream encroachment. Similarly, considering the potential threat of downstream encroachment, Nasser et al. (2013) from the perspective of an upstream player investigate and compare these three strategies: accommodate, displace, or buffer. Specifically, Chen et al. (2011) consider a retailer's decision of whether to develop an internally produced substitute of a manufacturer's product. Their model assumes that the perceived quality of the substitute is lower than that of the manufacturer's product. They find that the threat of downstream encroachment helps to mitigate the well-known effect of double marginalization by inducing the manufacturer to reduce the wholesale price. As a result, the development of the internally produced substitute benefits the retailer, but hurts the manufacturer. It is worth noting that, in the case of either upstream or downstream encroachment, the relevant literature generally defaults a centralized decision-making policy for each player. Our work contributes to the stream of literature by examining the appropriateness of strategic decentralization within the downstream player in the presence of downstream encroachment. We borrow some modeling elements from the literature, and confirm the main result of Chen et al. (2011); in addition, we find that strategic decentralization could be the downstream manufacturer's optimal choice if the unit cost of the low-end component is high enough. The manufacturer's strategic decentralization would further mitigate the effect of double marginalization. As a result, strategic decentralization will enhance both the positive impact of downstream encroachment on the manufacturer and the negative impact of downstream encroachment on the upstream supplier.

Although most of the literature on supply chain management makes a great attempt to achieve a centralized performance, there is a stream of literature that exploits the benefits of strategic decentralization within a supply chain or an integrated

organization. McGuire and Staelin (1983) are the first to demonstrate that competing manufacturers are more likely to use decentralized distribution systems for highly competitive goods, which is subsequently extended by Moorthy (1988), Lee and Staelin (1997), Anderson and Bao (2010), and Li et al. (2013). Essentially, our paper can be viewed as a generalization of McGuire and Staelin (1983)[2]. We consider an alternative channel structure where the manufacturer controls multiple parts of the competing supply chains; and McGuire and Staelin (1983)'s channel structure can be obtained if the manufacturer adopts full decentralization, as shown in Figure 1d. Under this situation, the manufacturer's profit is the combined profits from three agents, which is heavily influenced by the supplier's wholesale pricing. Although function-based decentralization could benefit competing supply chains by softening competition, the supplier in our study always charges a higher wholesale price if the low-end component division operates as an independent player. Therefore, both function-based decentralization and full decentralization are sub-optimal for the manufacturer. This finding also implies that the channel inefficiency due to double marginalization in one supply chain may spill over to a competing supply chain the manufacturer is also involved, which, to the best of our knowledge, is novel in the supply chain management literature. Since the manufacturer consists of two competing product divisions, we also examine the performance of product-based decentralization, which is known as non-product-line pricing in some papers, e.g., in a channel with two products (substitutes or complements), Xia and Gilbert (2007) and Dong et al. (2009) prove either the manufacturer or the retailer may choose non-product-line pricing strategy, which means each product is priced to maximize the profit from the single product rather than the total profit of the firm. However, note that, in these papers, there is no channel conflict. Although product-based decentralization causes a severer cannibalization problem within the manufacturer, it could be the manufacturer's preferred organizational structure choice in that it induces the supplier to lower the wholesale price if the unit cost of low-end component is high enough and then the gain due to the lower wholesale price may outweigh the loss due to cannibalization.

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[2] We are particularly grateful to the anonymous referees for their insightful comments on theoretical contributions of our work.

Our work is one of the few papers that bridge the gap between these two distinct streams of literature by exploring the manufacturer's incentive of strategic decentralization in a context with channel conflict. To the best of our knowledge, Arya et al. (2008) make the first attempt in this direction, and find that an upstream player can benefit from function-based decentralization, allowing the intra-company transfer price higher than the marginal cost, in the case of upstream encroachment. Our study complements the literature and demonstrates product-based decentralization (and only this kind of decentralization) can be a dominant strategy for the downstream player in the case downstream encroachment. This result highlights the interesting link between the type of encroachment and the optimal organizational structure choice.

3. The Model

To focus on the impact of the manufacturer's organizational structure choice, we consider a basic bilateral monopoly. The context of our model is illustrated in Figure 1. All players are assumed to be risk-neutral and profit-seeking, and have access to the same information. The supplier (she) produces high-end components. The manufacturer (he) consists of three divisions: the high-end product division assembles high-end products using high-end components purchased from the supplier; the low-end component division produces low-end components; the low-end product division assembles low-end products using low-end components. Without loss of generality, we assume that one unit product contains one unit component.

We assume that the unit production costs of high-end and low-end components are constant, denoted as c_H and c_L, respectively. Without loss of generality, the unit assembly costs of high-end and low-end products are assumed to be the same and constant, and normalized to 0.

As for modelling customers' purchasing behavior, we follow Mussa and Rosen (1978) and assume that the customer's willingness-to-pay of the high-end product v is heterogeneous and uniformly distributed in $[0,1]$ with the density of 1, and for each customer, the willingness-to-pay ratio of the low-end product to the high-end one is $\delta \in (0,1)$, which measures how closely customers judge the low-end product as a comparable substitute for the high-end one. This assumption captures the vertical

differentiation between the high-end product and the low-end product. Let p_H (p_L) denote the price of the high-end (low-end) product, the customer obtains the net utility $v - p_H$ if one high-end product is bought, $\delta v - p_L$ if one low-end product is bought, and 0 if neither product is bought. Each customer buys at most one unit product that offers the most utility, as long as the net utility is positive. In order to guarantee the potential demand for either the high-end product or the low-end product is positive, our model requires $c_H < 1$ and $c_L < \delta$. Thus, similar to Mantin et al. (2014) and Xiong et al. (2013), we have the linear inverse demand functions for the high-end product and the low-end product as follows.

$$p_H = 1 - q_H - \delta q_L, \tag{1}$$

$$p_L = \delta\left(1 - q_H - q_L\right), \tag{2}$$

where q_H (q_L) denotes the production quantity of the high-end (low-end) product.

The sequence of decision-making in this research is boiled down to a three-stage process. The choice of organizational structure is typically a strategic decision, while pricing is tactical. Therefore, at stage one, we let the manufacturer choose his organizational structure prior to observing the supplier's pricing. Given that the manufacturer's organizational structure has been chosen, the interaction between the supplier and the manufacturer is modelled as a Stackelberg game in which the supplier, as a dominant player in the supply chain, sets the wholesale price of high-end components w_H at stage two. Finally, these divisions within the manufacturer take their actions: if centralization is adopted, all divisions jointly determine the production quantities of high-end and low-end products; if product-based decentralization is adopted, the production quantities are determined separately and simultaneously; otherwise, the low-end component division moves first by setting the wholesale price of low-end components w_L, and then the production quantities are determined jointly by two product divisions if function-based decentralization is adopted, or determined separately and simultaneously if full decentralization is adopted.

To rule out the distortion due to the efficiency difference among different organizational structure choices, we assume that all choices are equivalent in terms of efficiency, which means there is no shift in the manufacturer's cost structure when he switches from one organizational structure choice to another.

There are four sub-games between the dominant supplier and the downstream manufacturer contingent on the manufacturer's organizational structure choice. To focus on the most significative cases, we analyses and compare the performance of centralization and product-based decentralization in the main text only. The analysis and comparison of the other two organizational structure choices can be found in the additional Appendix.

4. Analysis

The interaction between the dominant supplier and the downstream manufacturer could be analyzed using backward induction. For ease of exposition, we define that $c_1 = \delta - 2(1 - c_H)$, $c_2 = \delta - (1 - c_H)$, $c_3 = \delta(1 - \delta + c_H)/(2 - \delta)$, $c_4 = \delta(1 + c_H)/2$, $c_5 = \delta(6 + 2c_H - \delta)/(8 - \delta)$, $c_6 = \delta(3 + c_H)/4$, and provide the following lemma.

LEMMA 1. $c_1 < c_2 < c_3 < c_4 < c_5 < c_6$.

These values in Lemma 1 separate the unit cost of low-end components into 7 segments, as we will see later. All of these separating values are increasing in the unit cost of high-end components.

4.1 Benchmark: no encroachment

In this subsection, we analyze the case of no encroachment as a benchmark (denoted by the superscript B) to examine the impact of downstream encroachment on the interaction between the dominant supplier and the downstream manufacturer. Provided $q_L = 0$, for a given w_H, the manufacturer's optimization problem is

$$\max \Pi_m^B \left(q_H^B ; w_H^B \right) = \left(p_H - w_H^B \right) q_H^B . \tag{3}$$

It is easy to prove that Π_m^B is concave in q_H^B. From the first-order condition, we have $q_H^{B*} = \left(1 - w_H^B\right)/2$. And then, the dominant supplier's optimization problem is

$$\max \Pi_s^B\left(w_H^B\right) = \left(w_H^B - c_H\right)\left(1 - w_H^B\right)/2. \tag{4}$$

Clearly, Π_s^B is concave in w_H^B. Thus, we have $w_H^{B*} = \left(1 + c_H\right)/2$, and then $q_H^{B*} = \left(1 - w_H^B\right)/2 = \left(1 - c_H\right)/4$.

In line with intuition, in the case of no encroachment, the optimal wholesale price of high-end components is increasing in the unit cost of high-end components, and the optimal production quantity of high-end products is decreasing in this unit cost.

4.2 Encroachment under centralization

In this subsection, we analyze downstream encroachment under centralization (denoted by the superscript C). All divisions within the downstream manufacturer behave as one player, and jointly determine the production quantities of high-end and low-end products to maximize the following profit function:

$$\max \Pi_m^C\left(q_H^C, q_L^C; w_H^C\right) = \left(p_H - w_H^C\right)q_H^C + \left(p_L - c_L\right)q_L^C. \tag{5}$$

By solving Equation (5), we get the optimal production quantities $q_H^{C*}\left(w_H^C\right)$ and $q_L^{C*}\left(w_H^C\right)$. When setting w_H^C, the dominant supplier does so with anticipation of the manufacturer's optimal production quantities, and then her optimization problem is

$$\max \Pi_s^C\left(w_H^C\right) = \left(w_H^C - c_H\right)q_H^{C*}. \tag{6}$$

Solving Equation (6) gives the supplier' optimal wholesale price of high-end components w_H^{C*}, and substituting it back into $q_H^{C*}\left(w_H^C\right)$ and $q_L^{C*}\left(w_H^C\right)$ leads us to the following proposition.

PROPOSITION 1. *In the case of downstream encroachment under centralization, the optimal solutions of the supplier and the manufacturer are as follows:*

	$c_L < c_2$	$c_2 \le c_L \le c_3$	$c_3 < c_L \le c_4$	$c_L > c_4$
w_H^{C*}	c_H	$(1+c_H-\delta+c_L)/2$	c_L/δ	$(1+c_H)/2$
q_H^{C*}	0	$1/4-(c_H-c_L)/4(1-\delta)$	$(\delta-c_L)/2\delta$	$(1-c_H)/4$
q_L^{C*}	$(\delta-c_L)/2\delta$	$1/4+[\delta c_H-(2-\delta)c_L]/4\delta(1-\delta)$	0	0

In our analysis, we consider players' strategic behavior on the whole parameter space; therefore, our analytical results can be applied to a variety of industries. If the unit cost of low-end components is very high ($c_L > c_4$ in this case), in line with intuition, customers do not consider buying the low-end product even if its market clearing price reduces to its unit cost. And then, the supplier could behave as in the benchmark case of no encroachment, i.e., both the optimal wholesale price of high-end components and the optimal production quantity of high-end products are independent of c_L. In contrast, if the unit cost of low-end components is very low ($c_L < c_2$ in this case), high-end products will be driven out of the market, and then the optimal production quantity of low-end products is independent of c_H. Otherwise, consumers will be likely to buy either the high-end product or the low-end product, and then the supplier has to deliberate on how to compete with the manufacturer.

Given that the entry of low-end products cannot be blockaded, according to Tirole (1998), the supplier has two possible strategies – to deter entry or to accommodate entry. We find that, if the unit cost of low-end components is relatively high ($c_3 < c_L \le c_4$ in this case), the manufacturer's low-end product business just starts turning a profit, and then the supplier is better off deterring entry by pricing the high-end component in an aggressive way, i.e., pricing it low enough to drive low-end products out of the market. In such a situation, the supplier cares only how costly producing the low-end component is, but not how costly producing the high-end component is. However, if the unit cost of low-end components is relatively low ($c_2 < c_L \le c_3$ in this case), deterring entry is too costly for the supplier, and then she has

to accommodate entry. In this situation, the supplier's optimal price is increasing in both the unit cost of high-end components and that of low-end components, the optimal production quantity of high-end products (low-end products) is decreasing in the unit cost of high-end components (low-end components), and increasing in the unit cost of low-end components (high-end components).

A further analysis shows that $c_3 > c_H$ if $\delta > 2c_H$, which implies that the supplier has to consider the entry threat of low-end products even if the unit cost of low-end components is higher than that of high-end components. Our model has assumed that the customers have a reduced utility on the low-end product, why would the manufacturer like to produce the low-end product at a higher unit cost? The economic intuition behind this behavior is cost savings. Although the supplier produces one unit high-end component at c_H, the manufacturer purchases one unit high-end component at the price of w_H. A profit seeking supplier must set $w_H > c_H$, and then the manufacturer measures cost savings by comparing c_L and w_H. Therefore, it may be profitable for the manufacturer to provide a low-end substitute at the unit cost of $c_L \in \left(c_H, w_H^C\right)$.

4.3 Encroachment under product-based decentralization

In this subsection, we analyze downstream encroachment under product-based decentralization (denoted by the superscript P). The low-end component division and the low-end product division within the downstream manufacturer behave as one player, whose optimization problem is

$$\max \pi_L^P\left(q_L^P; w_H^P\right) = \left(p_L - c_L\right) q_L^P . \tag{7}$$

At the same time, the high-end product division decides the production quantity of high-end products to maximize its own profit

$$\max \pi_H^P\left(q_H^P; w_H^P\right) = \left(p_H - w_H^P\right) q_H^P . \tag{8}$$

Solving Equations (7) and (8) simultaneously gives the equilibrium production quantities $q_H^{P*}\left(w_H^P\right)$ and $q_L^{P*}\left(w_H^P\right)$. Similar to the case of encroachment under centralization, the supplier's optimization problem is

$$\max \Pi_s^P\left(w_H^P\right)=\left(w_H^P-c_H\right)q_H^{P*}. \tag{9}$$

Solving Equation (9) gives the supplier's optimal wholesale price w_h^{P*}. All optimal solutions in this subsection are characterized by the following proposition.

PROPOSITION 2. *In the case of downstream encroachment under product-based decentralization, the optimal solutions of the supplier and the manufacturer are as follows:*

	$c_L<c_1$	$c_1\le c_L\le c_5$	$c_5<c_L\le c_6$	$c_L>c_6$
w_H^{P*}	c_H	$\left(1+c_H\right)/2-\left(\delta-c_L\right)/4$	$2c_L/\delta-1$	$\left(1+c_H\right)/2$
q_H^{P*}	0	$\left[2\left(1-c_H\right)-\delta+c_L\right]/2\left(4-\delta\right)$	$\left(\delta-c_L\right)/\delta$	$\left(1-c_H\right)/4$
q_L^{P*}	$\left(\delta-c_L\right)/2\delta$	$\left[\delta\left(6+2c_H-\delta\right)-\left(8-\delta\right)c_L\right]/4\delta\left(4-\delta\right)$	0	0

The economic intuition behind Proposition 2 is similar to that behind Proposition 1, the supplier will strategically price the high-end component in response to downstream encroachment. However, it is worth noting that, in this case, the low-end component division and the low-end product division within the manufacturer forms an independent profit center, it does not consider the cannibalization of high-end product sales when deciding the production quantity of low-end products. As a result, the supplier has to consider the entry threat in situations with a higher unit cost of low-end components, i.e., $c_L\le c_6$. In addition, the supplier has to price the high-end component lower to drive low-end products out of the market, i.e., $2c_l/\delta-1<c_l/\delta$.

5. Comparison

It is clear how the dominant supplier strategically responds to downstream encroachment by comparing her optimal pricing strategies in cases of no encroachment and downstream encroachment. Now, we examine the manufacturer's optimal organizational structure choice by comparing his total profits in different cases.

Substituting the supplier's optimal wholesale price of high-end components and the manufacturer's optimal production quantities of high-end and low-end products in Propositions 1 and 2 back into Equations (5), (7), and (8) gives the manufacturer's profit expressions. It is worth noting that, the feasibility conditions for these profit expressions are different. Thus, we have 7 scenarios to compare the manufacturer's profits, as follows: (1) $c_L < c_1$; (2) $c_1 \le c_L < c_2$; (3) $c_2 \le c_L < c_3$; (4) $c_3 \le c_L < c_4$; (5) $c_4 \le c_L < c_5$; (6) $c_5 \le c_L < c_6$; (7) $c_L \ge c_6$.

In order to reveal the economic intuition behind the manufacturer's optimal organizational structure choice, following from Propositions 1 and 2, we first compare the supplier's optimal wholesale price of high-end components.

PROPOSITION 3. *There exists* $c_L' = \dfrac{\delta\left(2-\delta+2c_H\right)}{4-\delta} \in \left(c_3, c_4\right)$ *such that (i) if* $c_1 < c_L < c_L'$, *then* $w_H^{C*} < w_H^{P*}$; *(ii) if* $c_L' < c_L < c_6$, *then* $w_H^{C*} > w_H^{P*}$; *and otherwise,* $w_H^{C*} = w_H^{P*}$.

The following Figure 2 graphically illustrates the value of c_L'. Note that, in Figure 2 (a), (b), and (c), we set $\delta = 0.1, 0.5, 0.9$, respectively. Proposition 3 is very important for us to understand the manufacturer's optimal organizational structure choice. It is shown that if the unit cost of low-end components is high enough, product-based decentralization may benefit the manufacturer due to a lower wholesale price of high-end components. This is because, if the unit cost of low-end components is high enough, e.g., $c_4 \le c_L < c_5$, encroaching by producing the low-end product is independently profitable but cannibalizes the higher-margin high-end product sales. Thus, only if the manufacturer operates under product-based decentralization, both high-end and low-end products will be produced; otherwise, the manufacturer will produce only the high-end product. With anticipation of the manufacturer's production

strategy under product-based decentralization, the supplier has to strategically charge a lower wholesale price of high-end components.

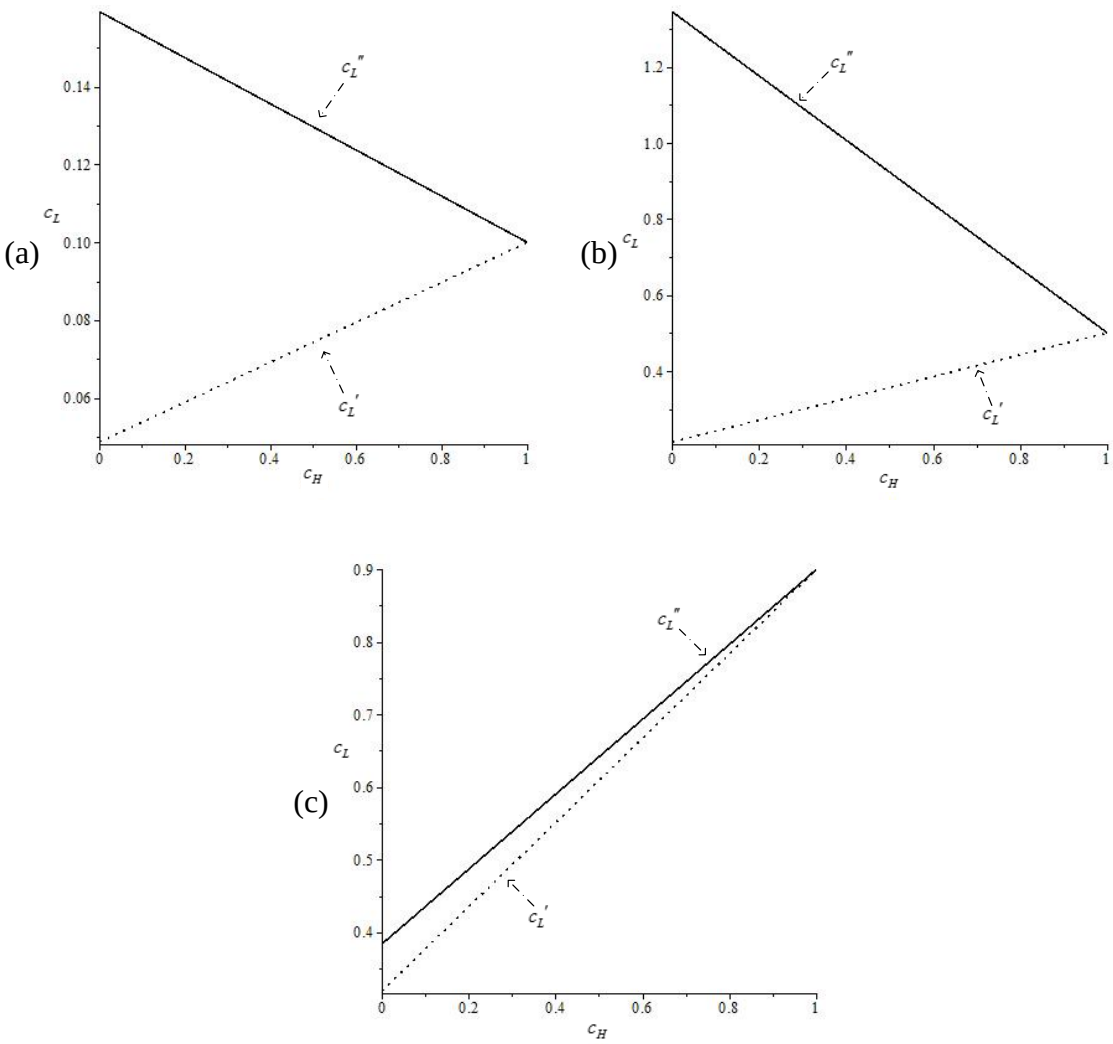

Figure 2. The graphical illustrations of thresholds

Next, we compare the manufacturer's profits in cases of encroachment under centralization and product-based decentralization, and have the following proposition.

PROPOSITION 4. *From the perspective of the manufacturer, there exists* $c_L'' \in \left(c_L', c_4\right)$ *such that (i) if* $c_1 < c_L < c_L''$*, then the optimal organizational structure choice is centralization; (ii) if* $c_L'' < c_L < c_6$*, then the optimal choice is product-based*

decentralization; here, $c_L'' = \begin{cases} \dfrac{\delta(\Lambda-\Gamma)}{\delta^3-16\delta^2+96\delta-64}, \text{ if } 0<\delta<0.758 \\ \dfrac{\delta(\Lambda+\Gamma)}{\delta^3-16\delta^2+96\delta-64}, \text{ if } 0.758\le\delta<1 \end{cases}$ *; here*

$\Lambda = \delta^3 - 2c_H\delta^2 - 14\delta^2 + 24c_H\delta + 72\delta - 64$ *and* $\Gamma = 4(4-\delta)(1-c_H)\sqrt{4-3\delta}$.

The value of c_L'' is also clearly illustrated in Figure 2. Proposition 4 demonstrates that the manufacturer is better off with product-based decentralization if the unit cost of low-end components satisfies certain conditions.

Following from the supplier's high-end component pricing strategy as shown in Proposition 3, the economic intuition behind this interesting finding is straightforward: product-based decentralization within the manufacturer does cause the problem of cannibalization, but if the unit cost of low-end components is high, the gain due to the lower high-end component price could outweigh the loss due to cannibalization, that is to say, product-based decentralization then outperforms centralization from the perspective of the manufacturer.

A further analysis and comparison of downstream encroachment under function-based decentralization and full decentralization in the additional Appendix shows that, given that the low-end component division within the manufacturer operates as an independent profit center, it must set the wholesale price of low-end components higher than the unit cost. As a result, the supplier could strategically charge a higher wholesale price of high-end components, which makes the total profit of the manufacturer shrunk. That is to say, the organizational structure choice (function-based decentralization or full decentralization) in which the low-end component division behaves as one independent player is always sub-optimal from the perspective of the manufacturer.

6. Discussions

We have identified the conditions for the manufacturer to strategically decentralize. In this section, we discuss the impacts of the manufacturer's strategic decentralization on stakeholders.

Substituting these optimal decisions in Propositions 1 and 2 back into Equations (6) and (9) gives the supplier's profit expressions. By comparing the supplier's profitability in the cases of encroachment under centralization and product-based decentralization, we have the following proposition.

PROPOSITION 5. *The manufacturer's strategic decentralization always hurts the supplier.*

Proposition 5 shows that the supplier's profit is always decreased once if the manufacturer strategically decentralizes. In line with intuition, with anticipation of an intensified competition between the high-end and the low-end product divisions within the manufacturer under product-based decentralization, the supplier has to charge a lower wholesale price. Although the high-end product division will purchase more new components due to the lower price, i.e., $q_H^{C*} < q_H^{P*}$ if $c_L > c_4$, from the perspective of the supplier, the increase in sales could never outweigh the decrease in price.

Next, we examine the impact on the entire supply chain by comparing the total profits of the supplier and the manufacturer.

PROPOSITION 6. *There exists* $c_L''' \in (c_4, c_5)$ *such that the manufacturer's strategic decentralization hurts the entire supply chain if and only if* $c_L < c_L'''$ *; here*

$$c_L''' = \frac{\delta\left(24 + 40c_H + 2\delta - 6c_H\delta - \delta^2 + (1 - c_H)\sqrt{320 - 208\delta + 44\delta^2 + 3\delta^3}\right)}{64 - 4\delta - \delta^2}.$$

Proposition 6 reveals that the manufacturer's strategic decentralization could increase or decrease the entire supply chain's profit. From the perspective of the entire supply chain, the manufacturer's strategic decentralization may have both positive and negative impacts. The positive impact stems from the lower wholesale price, which alleviates the well-known double marginalization in the supply chain. On the negative side, the strategic decentralization leads to a severer cannibalization problem within the manufacturer. However, if the unit cost of low-end components is sufficiently high, e.g., $c_L \in (c_5, c_6)$, revisiting Proposition 2, we find that the supplier will price so aggressively to drive low-end products out of the market; in this case, the negative impact is not significant and then the entire supply chain's profit is increased. In contrast, if the unit cost of low-end components is sufficiently low, e.g., $c_L \in (c_L', c_4)$, revisiting Propositions 1 and 2, we find that the cannibalization problem exists only under product-based decentralization; in this case, the negative impact dominates and then the entire supply chain's profit is decreased.

Finally, we consider the impact of the manufacturer's strategic decentralization on consumer surplus, which could be calculated as follows.

$$\upsilon = \frac{1}{2}(1 - p_H)q_H + \frac{1}{2}(\delta - p_L)q_L . \tag{10}$$

PROPOSITION 7. *The manufacturer's strategic decentralization always benefits the customers.*

The customers, not surprisingly, always benefits from the manufacturer's strategic decentralization. The economic intuition is straightforward: both the alleviated double marginalization and the severer cannibalization problem lead to a reduced market clearing price of high-end products; in addition, the existence of low-end products, which would be driven out of the market under centralization, generates the positive surplus for customers who cannot afford the high-end product.

7. Conclusions

Many managers and researchers routinely view centralized decision-making as an ideal organizational structure. In this paper, we consider a downstream manufacturer's organizational structure decision when he encroaches on the dominant supplier by developing the substitutable component. Inspired by the literature on strategic decentralization, we design three kinds of decentralization. Our analysis characterizes the interaction between the supplier and the manufacturer contingent on the latter's organizational structure choice, and generates interesting implications.

In line with the findings in the literature of channel conflict (e.g., Nasser et al. 2013), our analytical results show that the supplier should strategically price the high-end component to deter or accommodate downstream encroachment. However, it is worth noting that, we find the supplier needs to consider the threat of downstream encroachment even if the manufacturer has to produce the low-end component at a higher unit cost. To the best of our knowledge, this finding has not been established from a theoretical perspective in that the relevant literature typically assumes that producing a low-end product does not cost more than a high-end one.

More importantly, our work demonstrates that if the unit cost of low-end component is high enough, the manufacturer operating under centralization does not encroach, but the dominant strategy for the manufacturer is to operate under product-based decentralization and encroach. It implies that willingness to cannibalize is a powerful driver of encroachment and a fulfilling antecedent of potential commercial

interests. However, in the case of downstream encroachment, the low-end component division should always be operated as a cost center because we find that both function-based decentralization and full decentralization are sub-optimal. That is to say, unlike Arya et al. (2008), the manufacturer's intra-company transfer price of low-end components should be set as the unit cost.

We also examine the impact of the manufacturer's strategic decentralization on stakeholders. We find that product-based decentralization forms a loss-win situation for the supplier and the manufacturer because the latter will not choose decentralization unless he could obtain a lower wholesale price under decentralization. However, it could form a win-win situation for the entire supply chain and the customers, i.e., a Pareto improvement in terms of social welfare. Thus, the government sometimes should encourage manufacturers to encroach the supplier under product-based decentralization and subsidize the supplier at the same time; such an industrial policy has a potential to improve social welfare but hurt no one.

Although we believe that this research helps us to understand the manufacturer's organizational structure choice and its impacts in the presence of encroachment, it is not without limitations. In order to deliver a general understanding of the appropriateness of decentralization within the manufacturer, our model involves strict assumptions on player behaviors and costs. The impacts of relaxing these assumptions, as well as empirical research directed at testing the validity of our conclusions, are worthy topics for future research. First, we could relax the assumption of perfect information and consider the situation where one player in our model has no cost information of the other one. Li et al. (2013) have shown that asymmetric information could reverse the impact of upstream encroachment, but its effect in the case of downstream encroachment has not been revealed. Second, our model can be extended to incorporate more players, e.g., one competing manufacturer who also purchases high-end components from the supplier. It will be interesting to see whether the supplier is still willing to lower the wholesale price as a response to downstream encroachment. Lastly, our analytical findings yield empirically testable predictions: the conditions for the manufacturer to strategically encroach and decentralize, and the impacts of downstream encroachment and strategic decentralization. Some of them seem to be supported by our casual observations, however, a formal empirical research would be very helpful to explain the reasonability of our work.

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Appendix

Proof of Lemma 1

Provided $c_H < 1$ and $\delta < 1$, we have

$$c_6 - c_5 = (1 - c_H)\delta^2 / 4(8 - \delta) > 0,$$

$$c_5 - c_4 = \delta(1 - c_H)(4 - \delta) / 2(8 - \delta) > 0,$$

$$c_4 - c_3 = \delta^2 (1 - c_H) / 2(2 - \delta) > 0,$$

$$c_3 - c_2 = 2(1 - c_H)(1 - \delta) / (2 - \delta) > 0,$$

$$c_2 - c_1 = 1 - c_H > 0.$$

In conclusion, $c_1 < c_2 < c_3 < c_4 < c_5 < c_6$.

Proof of Proposition 1 (PP1)

The downstream manufacturer's optimization problem

We begin with the downstream manufacturer's optimization problem, as follows:

$$\max \Pi_m^C \left(q_H^C, q_L^C; w_H^C\right) = \left(p_H - w_H^C\right) q_H^C + \left(p_L - c_L\right) q_L^C,$$

subject to $q_H^C, q_L^C \geq 0$. The Lagrangean and the KKT optimality conditions are:

$$L\Pi_m^C = \left(1 - q_H^C - \delta q_L^C - w_H^C\right) q_H^C + \left(\delta\left(1 - q_H^C - q_L^C\right) - c_L\right) q_L^C + \lambda_1^C q_H^C + \lambda_2^C q_L^C,$$

$$\partial L\Pi_m^C / \partial q_H^C = \partial L\Pi_m^C / \partial q_L^C = 0,$$

$$\lambda_1^C q_H^C = \lambda_2^C q_L^C = 0,$$

$$q_H^C, q_L^C, \lambda_1^C, \lambda_2^C \geq 0.$$

Because the multipliers can be either zero or positive, we have 4 scenarios to examine. However, we discard Scenario $\left(\lambda_1^C > 0, \lambda_2^C > 0\right)$ in that it requires $q_H^C = q_L^C = 0$.

Scenario 1PP1 with $\left(\lambda_1^C = 0, \lambda_2^C > 0\right)$: $q_H^C = \left(1 - w_H^C\right)/2$, $q_L^C = 0$; $\lambda_2^C = c_L - \delta w_H^C$, which must be positive, leading to the feasibility condition $w_H^C < c_L/\delta$.

Scenario 2PP1 with $\left(\lambda_1^C = 0, \lambda_2^C = 0\right)$: $q_H^C = \left(1 - w_H^C - \delta + c_L\right)/2(1-\delta)$, $q_L^C = \left(\delta w_H^C - c_L\right)/2\delta(1-\delta)$; $q_H^C, q_L^C \geq 0$, leading to $c_L/\delta \leq w_H^C \leq 1 - \delta + c_L$.

Scenario 3PP1 with $\left(\lambda_1^C > 0, \lambda_2^C = 0\right)$: $q_H^C = 0$, $q_L^C = \left(\delta - c_L\right)/2\delta$; $\lambda_1^C = w_H^C + \delta - c_L - 1$, leading to $w_H^C > 1 - \delta + c_L$.

The dominant supplier's optimization problem

Now we examine the dominant supplier's optimization problem. It is worth noting that the optimal wholesale price must be not lower than the unit cost. If the supplier holds that inducing the manufacturing to choose $q_H^C = \left(1 - w_H^C\right)/2$ and $q_L^C = 0$ is the optimal strategy, then the optimization problem is $\max \Pi_s^C\left(w_H^C\right) = \left(w_H^C - c_H\right)\left(1 - w_H^C\right)/2$, subject to $w_H^C < c_L/\delta$. It is easy to get the unconstrained solution $w_H^C = \left(1 + c_H\right)/2$, which is the optimal wholesale price in this case if $c_L > \delta\left(1 + c_H\right)/2$; otherwise, due to the constraint, the optimal wholesale price in this case is infinitely close to c_L/δ, which is dominated by the solution in Scenario 6PP1.

If the supplier holds that inducing the manufacturer to choose $q_H^C = \left(1 - w_H^C - \delta + c_L\right)/2(1-\delta)$ and $q_L^C = \left(\delta w_H^C - c_L\right)/2\delta(1-\delta)$ is the optimal strategy, then the optimization problem is $\max \Pi_s^C\left(w_H^C\right) = \left(w_H^C - c_H\right)\left(1 - w_H^C - \delta + c_L\right)/2(1-\delta)$, subject to $c_L/\delta \leq w_H^C \leq 1 - \delta + c_L$. The Lagrangean and the KKT optimality conditions are

$$L\Pi_s^C = \left(w_H^C - c_H\right)\left(1 - w_H^C - \delta + c_L\right)/2\left(1-\delta\right) - \mu_1^C\left(c_L/\delta - w_H^C\right) - \mu_2^C\left(w_H^C - 1 + \delta - c_L\right),$$

$$\partial L\Pi_s^C / \partial w_H^C = 0,$$

$$\mu_1^C\left(c_L/\delta - w_H^C\right) = \mu_2^C\left(w_H^C - 1 + \delta - c_L\right) = 0,$$

$$c_L/\delta \le w_H^C \le 1 - \delta + c_L,\ \mu_1^C, \mu_2^C \ge 0.$$

Scenario 4PP1 with $\left(\mu_1^C = 0, \mu_2^C > 0\right)$: $w_H^C = 1 - \delta + c_L$; $\mu_2^C = \left[c_H - \left(1 - \delta + c_L\right)\right]/2\left(1-\delta\right) \le \left[w_H^C - \left(1 - \delta + c_L\right)\right]/2\left(1-\delta\right) = 0$. Thus, this solution is discarded.

Scenario 5PP1 with $\left(\mu_1^C = 0, \mu_2^C = 0\right)$: $w_H^C = \left(1 + c_H - \delta + c_L\right)/2$, leading to the necessary condition $c_H + \delta - 1 \le c_L \le \delta\left(1 - \delta + c_H\right)/\left(2-\delta\right)$.

Scenario 6PP1 with $\left(\mu_1^C > 0, \mu_2^C = 0\right)$: $w_H^C = c_L/\delta$; $\mu_1^C = \left[\left(2-\delta\right)c_L - \delta\left(1 + c_H - \delta\right)\right]/2\delta^2\left(1-\delta\right)$, leading to $c_L > \delta\left(1 - \delta + c_H\right)/\left(2-\delta\right)$.

If the supplier holds that inducing the manufacturer to choose $q_H^C = 0$ and $q_L^C = \left(\delta - c_L\right)/2\delta$ is the optimal strategy, then the optimization problem is $\max \Pi_s^C\left(w_H^C\right) = \left(w_H^C - c_H\right)\cdot 0$, subject to $w_H^C > 1 - \delta + c_l$. Here, $q_H^C = 0$ implies that high-end products have been driven out of the market and there must be no scope for the supplier to enhance the high-end product demand by reducing the price of high-end components, then we have $w_H^C = c_H$, the feasibility condition for this case is $c_L < c_H + \delta - 1$.

Note that, if $c_L > \delta\left(1 + c_h\right)/2$, the supplier has two choices: (1) pricing $w_H^C = \left(1 + c_H\right)/2$ and inducing the manufacturing to choose $q_H^C = \left(1 - w_H^C\right)/2$ and $q_L^C = 0$; (2) pricing $w_H^C = c_L/\delta$ and inducing the manufacturer to choose $q_H^C = \left(1 - w_H^C - \delta + c_L\right)/2\left(1-\delta\right)$ and $q_L^C = \left(\delta w_H^C - c_L\right)/2\delta\left(1-\delta\right)$. A simple comparison

of the supplier's profits in these two cases shows that pricing $w_H^C = (1+c_H)/2$ is a dominant solution.

Combining the supplier's optimal solutions and substituting them back into the manufacturer's optimal responses gives Proposition 1.

Proof of Proposition 2

Similar to the proof of Proposition 1, omitted.

Proof of Proposition 3 (PP3)

As shown in the main text, we have seven scenarios to compare the supplier's optimal wholesale price of high-end components. Let's define $\Delta_i = w_H^{C*} - w_H^{P*}$ in Scenario i PP3.

Scenario 1PP3 with $c_L < c_1$: $\Delta_1 = c_H - c_H = 0$.

Scenario 2PP3 with $c_1 \le c_L < c_2$: $\Delta_2 = c_H - \left((1+c_H)/2 - (\delta - c_L)/4\right)$, which is decreasing in c_L. Substituting $c_L = c_1$ into Δ_2 gives 0. Thus, we have $\Delta_2 \le 0$.

Scenario 3PP3 with $c_2 \le c_L < c_3$:

$\Delta_3 = (1+c_H-\delta+c_L)/2 - \left((1+c_H)/2 - (\delta - c_L)/4\right) = -(\delta - c_L)/4 < 0$.

Scenario 4PP3 with $c_3 \le c_L < c_4$: $\Delta_4 = c_L/\delta - \left((1+c_H)/2 - (\delta - c_L)/4\right)$, which is increasing in c_L. Let $\Delta_4 = 0$, we have $c_L = \dfrac{\delta(2-\delta+2c_H)}{4-\delta} \in (c_3, c_4)$. Thus, $\Delta_4 < 0$ if $c_3 \le c_L < \dfrac{\delta(2-\delta+2c_H)}{4-\delta}$, and $\Delta_4 > 0$ if $\dfrac{\delta(2-\delta+2c_H)}{4-\delta} < c_L < c_4$.

Scenario 5PP3 with $c_4 \le c_L < c_5$:

$\Delta_5 = (1+c_H)/2 - \left((1+c_H)/2 -\right) = (\delta - c_L)/4 > 0$.

Scenario 6PP3 with $c_5 \le c_L < c_6$: $\Delta_6 = (1+c_H)/2 - (2c_L/\delta - 1)$, which is decreasing in c_L. Substituting $c_L = c_6$ into Δ_6 gives 0. Thus, we have $\Delta_6 > 0$.

Scenario 7PP3 with $c_L \ge c_6$: $\Delta_7 = (1+c_H)/2 - (1+c_H)/2 = 0$.

Combining the results in these seven scenarios gives Proposition 3.

Proof of Proposition 4 (PP4)

Similar to the proof of Proposition 3, we define $M_i = \Pi_m^C - \Pi_m^P$ in Scenario i PP4.

Scenario 1PP4 with $c_L < c_1$: $M_1 = \frac{(\delta - c_L)^2}{4\delta} - \frac{(\delta - c_L)^2}{4\delta} = 0$.

Scenario 2PP4 with $c_1 \le c_L < c_2$: $\frac{\partial^2 M_2}{\partial c_L{}^2} = -\frac{20-3\delta}{8(4-\delta)^2} < 0$, H_2 is concave in c_L, its minimum value will be got at the end-points. Substituting $c_L = c_1$ into M_2 gives 0, and substituting $c_L = c_2$ into M_2 gives $\frac{(12-5\delta)(1-c_H)^2}{16(4-\delta)^2} > 0$. Thus, we have $M_2 \ge 0$.

Scenario 3PP4 with $c_2 \le c_L < c_3$: $\frac{\partial^2 M_3}{\partial c_L{}^2} = -\frac{4\delta^2 - 30\delta + 8}{16(1-\delta)(4-\delta)^2}$. If $0 < \delta \le \frac{15-\sqrt{193}}{4}$, $\frac{\partial^2 M_3}{\partial c_L{}^2} \le 0$, M_3 is concave in c_L. Substituting $c_L = c_2$ into M_3 gives $\frac{(12-5\delta)(1-c_H)^2}{16(4-\delta)^2} > 0$, and substituting $c_L = c_3$ into M_3 gives $\frac{(48-40\delta-\delta^2)(1-c_H)^2}{16(2-\delta)^2(4-\delta)^2} > 0$. If $\frac{15-\sqrt{193}}{4} < \delta < 1$, $\frac{\partial^2 M_3}{\partial c_L{}^2} > 0$, H_3 is convex in c_L. At the point $c_L = \frac{2\delta^3 - (16-c_H)\delta^2 + (22-18c_H)\delta - 8(1-c_H)}{2\delta^2 - 15\delta + 4}$, the minimum value of M_3 is $\frac{(4-11\delta)(1-c_H)^2}{16(2\delta^2 - 15\delta + 4)} > 0$. Thus, we have $M_3 \ge 0$.

Scenario 4PP4 with $c_3 \le c_L < c_4$: $\frac{\partial^2 M_4}{\partial c_L{}^2} = -\frac{\delta^3 - 16\delta^2 + 96\delta - 64}{8\delta^2(4-\delta)^2}$, substituting $c_L = c_3$ into M_4 gives $\frac{\delta(48-40\delta-\delta^2)(1-c_H)^2}{16(2-\delta)^2(4-\delta)^2} > 0$, and substituting $c_L = c_4$ into M_4 gives $-\frac{\delta(1-c_H)^2}{64} < 0$. Thus, there must exist $c_L'' \in (c_3, c_4)$ such that $M_3 > 0$ if $c_3 \le c_L < c_L''$ and $M_3 < 0$ if $c_L'' < c_L < c_4$. If $0 < \delta < 0.758$, $\frac{\partial^2 M_4}{\partial c_L{}^2} > 0$, we have

$$c_L'' = \frac{\delta\left(\delta^3 - 2c_H\delta^2 - 14\delta^2 + 24c_H\delta + 72\delta - 64 - 4(4-\delta)(1-c_H)\sqrt{4-3\delta}\right)}{\delta^3 - 16\delta^2 + 96\delta - 64}$$; if

$0.758 \le \delta < 1$, $\frac{\partial^2 M_4}{\partial c_L^{\ 2}} \le 0$, we have

$$c_L'' = \frac{\delta\left(\delta^3 - 2c_H\delta^2 - 14\delta^2 + 24c_H\delta + 72\delta - 64 + 4(4-\delta)(1-c_H)\sqrt{4-3\delta}\right)}{\delta^3 - 16\delta^2 + 96\delta - 64}$$. In addition,

we have $c_L'' < c_L'$. Note that, it is extremely hard to analytically prove this result. However, given $c_H \in [0,1]$ and $\delta \in [0,1]$, similar to Wu and Zhou (2015), we apply the enumeration method to obtain the result by numerically observing the graphical illustrations of c_L'' and c_L'.

Similar to Scenarios 2PP4 and 3PP4, we have $M_5 < 0$ and $M_6 < 0$.

Scenario 7PP4 with $c_L \ge c_6$: $M_7 = (1-c_H)^2/16 - (1-c_H)^2/16 = 0$.

Combining the results in these seven scenarios gives Proposition 4.

Proof of Proposition 5 (PP5)

We focus on the scenarios with $c_L'' < c_L < c_6$ to examine the impact of the manufacturer's strategic decentralization on the supplier's profit, and define $S_i = \Pi_s^P - \Pi_s^C$ in Scenario i PP5.

Scenario 1PP5 with $c_L'' < c_L < c_4$: $S_1 = \frac{(2-2c_H-\delta+c_L)^2}{8(4-\delta)} - \frac{(c_L-\delta)(\delta c_H - c_L)}{2\delta^2}$.

$\frac{\partial^2 S_1}{\partial c_L^{\ 2}} = \frac{(16-4\delta+\delta^2)c_L}{4(4-\delta)\delta^2} > 0$, letting $\frac{\partial S_1}{\partial c_L} = 0$, we have $c_L = \frac{\delta(8+8c_H-4\delta+\delta^2)}{16-4\delta+\delta^2}$,

which is less than c_4; substituting $c_L = c_4$ into S_1 gives $-\frac{\delta(1-c_H)^2}{32} < 0$. Letting

$\frac{\partial^2 S_1}{\partial c_L^{\ 2}} = 0$, we have $c_L = \frac{\delta\left(8+8c_H-4\delta+\delta^2 \pm 2(1-c_H)\sqrt{\delta(4-\delta)}\right)}{16-4\delta+\delta^2}$, i.e., $S_1 > 0$ if and

only if $c_L < \frac{\delta\left(8+8c_H-4\delta+\delta^2 - 2(1-c_H)\sqrt{\delta(4-\delta)}\right)}{16-4\delta+\delta^2}$. In addition, similar to the proof of Proposition 4, we apply the enumeration method to numerically observe the graphical

illustrations of c_L'' and $\frac{\delta\left(8+8c_H-4\delta+\delta^2-2\left(1-c_H\right)\sqrt{\delta\left(4-\delta\right)}\right)}{16-4\delta+\delta^2}$, and have

$c_L'' > \frac{\delta\left(8+8c_H-4\delta+\delta^2-2\left(1-c_H\right)\sqrt{\delta\left(4-\delta\right)}\right)}{16-4\delta+\delta^2}$. Therefore, we have $S_1 < 0$.

Scenario 2PP5 with $c_4 \le c_L < c_5$: $S_2 = \frac{\left(2-2c_H-\delta+c_L\right)^2}{8\left(4-\delta\right)} - \frac{\left(1-c_H\right)^2}{8}$.

$\frac{\partial^2 S_1}{\partial {c_L}^2} = \frac{c_L}{4\left(4-\delta\right)} > 0$, letting $\frac{\partial S_1}{\partial c_L} = 0$, we have $c_L = 2c_H + \delta - 2$, which is less than c_4.

Thus, in this scenario, S_2 is increasing in c_L. Substituting $c_L = c_5$ into S_2 gives

$-\frac{\left(1-c_H\right)^2\delta^2}{8\left(8-\delta\right)^2} < 0$, i.e., $S_2 < 0$.

Scenario 3PP5 with $c_5 \le c_L < c_6$:

$$S_2 = \frac{\left(c_L-\delta\right)\left(\delta+c_H\delta-2c_L\right)}{\delta^2} - \frac{\left(1-c_H\right)^2}{8} = -\frac{\left(3\delta+c_H\delta-4c_L\right)^2}{8\delta^2} < 0.$$

Proof of Proposition 6 (PP6)

Similar to the proof of Proposition 5, we focus on the scenarios with $c_L'' < c_L < c_6$ to examine the impact of the manufacturer's strategic decentralization on the entire supply chain's profit, and define $T_i = \Pi_s^P + \Pi_m^P - \Pi_s^C - \Pi_m^C$ in Scenario i PP6.

Scenario 1PP6 with $c_L'' < c_L < c_4$: $\frac{\partial^2 T_1}{\partial {c_L}^2} = \frac{\left(64+32\delta-\delta^3\right)c_L}{8\delta\left(4-\delta\right)^2} > 0$, i.e., T_1 is

convex in c_L. Substituting c_4 into T_1 gives $-\frac{\delta\left(1-c_H\right)^2}{64} < 0$. Letting $T_1 = 0$, we have

$c_L = \frac{\delta\left(64c_H+8c_H\delta-2c_H\delta^2+24\delta+2\delta^2-\delta^3 \pm 4\left(1-c_H\right)\sqrt{64-16\delta-4\delta^2+\delta^3}\right)}{64+32\delta-\delta^3}$, which

implies $T_1 < 0$ if

$\frac{\delta\left(64c_H+8c_H\delta-2c_H\delta^2+24\delta+2\delta^2-\delta^3-4\left(1-c_H\right)\sqrt{64-16\delta-4\delta^2+\delta^3}\right)}{64+32\delta-\delta^3} < c_L < c_4$ in

this scenario. In addition, similar to the proof of Proposition 4, we apply the

enumeration method to numerically observe the graphical illustrations of c_L'' and

$$\frac{\delta\left(64c_H+8c_H\delta-2c_H\delta^2+24\delta+2\delta^2-\delta^3-4\left(1-c_H\right)\sqrt{64-16\delta-4\delta^2+\delta^3}\right)}{64+32\delta-\delta^3}$$, and have

$$c_L''>\frac{\delta\left(64c_H+8c_H\delta-2c_H\delta^2+24\delta+2\delta^2-\delta^3-4\left(1-c_H\right)\sqrt{64-16\delta-4\delta^2+\delta^3}\right)}{64+32\delta-\delta^3}.$$

Therefore, we have $T_1<0$.

Scenario 2PP6 with $c_4\le c_L<c_5$: $\frac{\partial^2 T_2}{\partial c_L^{\ 2}}=\frac{\left(64-4\delta-\delta^2\right)c_L}{8\delta\left(4-\delta\right)^2}>0$, i.e., T_1 is convex in c_L. Substituting c_4 into T_2 gives $-\frac{\delta\left(1-c_H\right)^2}{64}<0$, and substituting c_5 into T_2 gives $\frac{\delta\left(16-3\delta\right)\left(1-c_H\right)^2}{16\left(8-\delta\right)^2}>0$. Letting $\frac{\partial T_2}{\partial c_L}=0$, we have

$c_L=\frac{\delta\left(24+40c_H+2\delta-6c_H\delta-\delta^2\right)}{64-4\delta-\delta^2}$, which is less than c_4. Letting $T_2=0$, we have

$$c_L=\frac{\delta\left(24+40c_H+2\delta-6c_H\delta-\delta^2\pm\left(1-c_H\right)\sqrt{320-208\delta+44\delta^2+3\delta^3}\right)}{64-4\delta-\delta^2}$$, which implies

$$T_2<0 \text{ if } c_4\le c_L<\frac{\delta\left(24+40c_H+2\delta-6c_H\delta-\delta^2+\left(1-c_H\right)\sqrt{320-208\delta+44\delta^2+3\delta^3}\right)}{64-4\delta-\delta^2}$$

in this scenario.

Scenario 3PP6 with $c_5\le c_L<c_6$: $\frac{\partial^2 T_3}{\partial c_L^{\ 2}}=-\frac{2c_L}{\delta^2}<0$; Letting $\frac{\partial T_3}{\partial c_L}=0$, we have $c_L=\frac{1}{2}\delta\left(1+c_H\right)$, which is less than c_5, i.e., T_3 is decreasing in c_L. Substituting c_6 into T_3 gives 0. Thus, in this scenario, we have $T_3>0$.

Proof of Proposition 7 (PP7)

Similar to the proof of Proposition 5, we focus on the scenarios with $c_L''<c_L<c_6$ to examine the impact of the manufacturer's strategic decentralization on the customers' surplus, and define $W_i=\upsilon^P-\upsilon^C$ in Scenario i PP7.

Scenario 1PP7 with $c_L'' < c_L < c_4$: $\frac{\partial^2 W_1}{\partial c_L^{\ 2}} = -\frac{64-96\delta+48\delta^2-5\delta^3}{16\delta\left(4-\delta\right)^2} < 0$, i.e., W_1 is concave in c_L. Substituting c_4 into W_1 gives $\frac{5\delta\left(1-c_H\right)^2}{128} > 0$. Letting $W_1 = 0$, we have

$$c_L = \frac{\delta\left(64-5\delta^3+8c_H\delta+46\delta^2+2c_H\delta^2-104\delta \pm 4\left(1-c_H\right)\sqrt{64-144\delta+124\delta^2-39\delta^3+4\delta^4}\right)}{64-96\delta+48\delta^2-5\delta^3}$$

, which implies $W_1 > 0$ if

$$c_L > \frac{\delta\left(64-5\delta^3+8c_H\delta+46\delta^2+2c_H\delta^2-104\delta - 4\left(1-c_H\right)\sqrt{64-144\delta+124\delta^2-39\delta^3+4\delta^4}\right)}{64-96\delta+48\delta^2-5\delta^3}$$

in this scenario. In addition, similar to the proof of Proposition 4, we apply the enumeration method to numerically observe the graphical illustrations of c_L'' and

$$\frac{\delta\left(64-5\delta^3+8c_H\delta+46\delta^2+2c_H\delta^2-104\delta - 4\left(1-c_H\right)\sqrt{64-144\delta+124\delta^2-39\delta^3+4\delta^4}\right)}{64-96\delta+48\delta^2-5\delta^3}$$

, and have

$$c_L'' > \frac{\delta\left(64-5\delta^3+8c_H\delta+46\delta^2+2c_H\delta^2-104\delta - 4\left(1-c_H\right)\sqrt{64-144\delta+124\delta^2-39\delta^3+4\delta^4}\right)}{64-96\delta+48\delta^2-5\delta^3}$$

. Therefore, we have $W_1 > 0$.

Scenario 2PP7 with $c_4 \le c_L < c_5$: $\frac{\partial^2 W_2}{\partial c_L^{\ 2}} = \frac{\left(64-44\delta+5\delta^2\right)c_L}{16\delta\left(4-\delta\right)^2} > 0$; letting $\frac{\partial W_2}{\partial c_L} = 0$, we have $c_L = \frac{\delta\left(72-8c_H-42\delta-2c_H\delta+5\delta^2\right)}{64-4\delta-\delta^2}$, which is greater than c_5, i.e., W_2 is decreasing in c_L in this scenario. Substituting c_5 into W_2 gives $\frac{\delta\left(16-\delta\right)\left(1-c_H\right)^2}{32\left(8-\delta\right)^2} > 0$, which implies $W_2 > 0$.

Scenario 3PP7 with $c_5 \le c_L < c_6$: $\frac{\partial^2 W_3}{\partial c_L^{\ 2}} = \frac{1}{\delta^2} > 0$; letting $\frac{\partial W_3}{\partial c_L} = 0$, we have $c_L = \delta$, which is greater than c_6, i.e., W_3 is decreasing in c_L in this scenario. Substituting c_6 into W_2 gives 0, which implies $W_3 > 0$.

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