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How to Escape Supply Chain Dilemmas? Manufacturer encroachment and supplier cost-reduction investment

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Abstract: Component suppliers and manufacturers in a supply chain have long faced different dilemmas. The component supplier intends to adopt new technologies to reduce production costs, but the new technologies usually require significant investment costs. The encroachment into retailing can bring more revenue to manufacturers, but the significant costs of establishing and maintaining direct channels and the potential conflicting interests with the retailer might discourage the manufacturer's encroachment. This study aims to address these dilemmas facing the component supplier and manufacturer by investigating an interesting scenario in which they both can obtain benefits. Within the given context, the manufacturer's encroachment increases the order of the components, which motivates the supplier to make more technological investments to reduce production costs. The reduction of component costs enables suppliers and manufacturers to reduce the wholesale prices of components and final products. In this case, the manufacturer's encroachment can benefit both the manufacturer and the retailer. This study is one of the first to investigate how the interaction between the manufacturer and supplier helps solve their respective dilemmas and provide benefits to the whole supply chain. Additionally, we extend the literature on manufacturer encroachment on retailers by considering supplier investment in cost-reduction production.

Keywords: supply chain management; manufacturer encroachment; supplier investment; game theory

1. Introduction

In the manufacturing industry, especially in technology-intensive industries, manufacturers usually rely on upstream suppliers to supply key components that are used to manufacture final products (Liker and Choi 2004). For example, chips for computers and mobile phones are produced by suppliers, such as Intel and Qualcomm; and batteries for electric vehicles are produced by suppliers, such as Panasonic and CATL. The production of these components often requires high cost and complex production processes. In Industry 4.0, many component suppliers, such as Intel,[1] Infineon,[2] and Jabil,[3] are investing in advanced technologies, such as additive manufacturing, the Internet of Things, big data analytics (BDA), artificial intelligence, and automation simulations. These technologies can effectively improve production efficiency and reduce production costs. For example, additive manufacturing can help firms quickly generate prototypes for automated testing, thus reducing engineering costs. Real-time production monitoring and predictive maintenance of industrial IOT equipment may prevent 70% of manufacturing failures and thus reduce costly equipment repair and downtime.[4] According to PwC's Global Industry 4.0 Survey on Building Digital Enterprises in 2016, surveyed companies that successfully implement Industry 4.0 are estimated to achieve an average annual cost reduction of 3.6%.[5]

However, investing in these advanced technologies is costly for most companies.

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1 https://www.nexteratechs.com/use-cases/usecase-manufacturing-electronics/

[2] https://www.edb.gov.sg/en/our-industries/company-highlights/infineon-technologies-e.html

[3] https://www.jabil.com/news/jabil-realizes-distributed-manufacturing-vision-with-new-additive-manufacturing-network.html

[4] https://eagletechnologies.com/2020/05/12/how-industry-4-0-technologies-save-costs-for-manufacturers/

[5] https://jbcole.co.uk/blog/the-financial-benefits-of-industry-4-0-cost-reductions-and-increased-productivity

Suppliers have long been facing a dilemma regarding cost reduction investments. Underinvestment in cost reduction can not only undermine the earnings of supply chain members but also weaken the competitiveness of products and decrease the success rates of new products in the long term (Dahan and Srinivasan 2011). Improving the investment in reducing components' cost is an issue that must be addressed by the whole chain. Measures to enhance investment have been proposed, such as investment cost sharing (Fernando Bernstein and Gürhan Kök 2009) and collaborative innovation (Kim and Netessine 2013). However, due to the negative effects of cooperation, such as opportunistic behaviors, managerial complexity of joint activities, and inequal resources, investment in cost reduction is often discouraged (Wu et al. 2020). Thus, both academics and business managers have been looking for an appropriate incentive mechanism to enhance cost reduction investment in the supply chain.

In addition to the production of key components, another crucial issue associated with supply chains is the distribution of the final products. Higher production efficiency upstream requires a higher distribution efficiency downstream. In recent years, manufacturers have established direct channels and competed with retailers in the consumer market, which is referred to as manufacturer encroachment (Huang et al. 2018). Compared with traditional single retailer channels, dual channels with manufacturer encroachment tend to sell more products (Sun et al. 2019). However, although the rapid development of e-commerce in recent decades has made it easier for manufacturers to encroach, many manufacturers still choose to sell their products only through retailers. There are many reasons that prevent a manufacturer from establishing a direct channel. The first reason is associated with the high costs of channel establishment operations. These costs include the cost of maintaining online websites, training and enrolling a salesforce, or the cost of inventory and transportation of products (Huang et al. 2018; Tian et al. 2018). The second is that manufacturer

encroachment may cause a rupture in its relationship with the retailer (Yoon 2016). If the manufacturer encroaches, the conventional wisdom suggests that the competition between the two channels hurts the retailer and thereby threatens existing channel relationships (Huang et al. 2018). Faced with these obstacles, many manufacturers abandon encroachment, which results in a situation in which product sales are still limited by the single traditional channel. Although previous studies have claimed that manufacturer encroachment is profitable, few studies have explored how to motivate manufacturers to encroach. In practice, manufacturers in industry with extensive investment often encroach (Yoon 2016). For instance, smart phone manufacturers, such as Huawei, OPPO, and Vivo, sell their phones to consumers not only through retailers but also through established direct channels, including company-owned franchises and online retail websites. This finding indicates that the investment can enable the manufacturer to obtain extra profits from the encroachment, thereby making the manufacturer more likely to encroach. Since suppliers are extensively engaged in cost-reduction investment in Industry 4.0, we seek answers to the following questions. First, how does manufacturer encroachment affect the supplier's cost-reduction investment? Secondly, how does the supplier's cost reduction investment influence the manufacturer encroachment? Third, can the interaction between the manufacturer's encroachment and the supplier's cost-reduction investment help each other relieve the dilemma facing them?

To answer these questions, we establish a three-level supply chain consisting of a supplier, a manufacturer, and a retailer. The supplier produces key components that the manufacturer uses to manufacture final products. The encroachment of the manufacturer creates a higher order for components. Therefore, the supplier is better off with the manufacturer's encroachment decision. Regarding the retailer, our analysis shows that if

the supplier does not make cost-reduction investment, the manufacturer's encroachment always hurts the retailer.

Compared with the benchmark case, the supplier's cost-reduction investment allows for a reduction in the wholesale price to induce the manufacturer to order more components. Second, because of more component orders, the supplier is willing to invest more when the manufacturer encroaches. The profit of cost reduction spills over to the manufacturer and the retailer through the wholesale price of components and final products. Consequently, when the supplier invests to reduce production costs, the manufacturer is more likely to encroach. Additionally, different from the previous literature, e.g., Arya et al. (2007), Xiong et al. (2012), this study finds that a manufacturer's encroachment benefits the retailer by encouraging the supplier to invest more in cost-reduction technologies. From this, we can conclude that the interaction between the manufacturer and supplier helps solve supply chain dilemmas. There exists a condition in which investment and encroachment can create a Pareto gain.

This paper makes a few significant contributions. First, this research is one of the first to consider the impacts of the supplier investment strategy on the manufacturer's encroachment decision, which enriches the literature on manufacturer encroachment. Second, this study adds new insights into suppliers' strategy of cost-reduction investments in the supply chain. Third, this study extends the literature on manufacturer encroachment by identifying a new interesting condition in which the manufacturer's encroachment might benefit the retailer.

The rest of the paper is organized as follows. Section 2 reviews the relevant literature on manufacturer encroachment and supplier investment. Section 3 develops the model using game theory. Section 4 analyzes the equilibrium of the model and discusses the impacts of manufacturer encroachment and supplier investment. Section 5

summarizes this study and indicates future research directions. All proofs are included in online Appendix.

2. Relevant literature

This paper related to manufacturer encroachment. Earlier studies in this stream focus on the negative effects of manufacturer encroachment. For example, Frazier and Lassar (1996) show that manufacturer encroachment reduces system efficiency because it weakens brand image. Park and Keh (2003) and Liu and Zhang (2006) demonstrate that encroachment hurts the profit of the retailer due to intensified market competition. Li et al. (2014) study the impact of information asymmetry on supplier encroachment and find that demand information asymmetry can amplify the double marginalization of wholesale prices. However, the following literature mostly argues that encroachment can create a win-win outcome for manufacturers and retailers. For example, Arya et al. (2007) demonstrate that an encroaching manufacturer reduces the wholesale price to support the retailer's demand and that the particularly efficient retailer may benefit from the encroachment. This viewpoint is robust by considering durable (Xiong et al. 2012) nonlinear pricing (Li et al. 2015), quality differentiation (Ha et al. 2016), channel power (Niu et al. 2017), and a retailer's incentive to share demand information (Huang et al. 2018). Although some of these studies demonstrate that manufacturer encroachment can create a win-win outcome, few of them have explored how to help manufacturers encroach. In addition, the change in the production efficiency of upstream members has not been considered in their research. If the supplier invests in reducing production costs, it is not known whether the original distribution channel strategy can still adapt to the improved production efficiency. Thus, we examine the manufacturer encroachment strategy by considering that the component supplier is investing in cost reduction and

exploring whether the investment helps the manufacturer to encroach and the impact of the encroachment on the supply chain members in our setting.

In the stream related to cost-reduction investment, a number of papers focus on the manufacturer's cost-reduction investment, e.g., Gupta (2008), Ha et al. (2017), retailer innovation, e.g., Arya and Mittendorf (2013), Hu et al. (2019); or collaboration innovation, e.g., Kim and Netessine (2013), Wang and Liu (2016). However, it is difficult to reduce the cost of the final product if the production cost of the component is high. Thus, it is important to study how manufacturers motivate component suppliers to reduce the production cost. The existing literature has explored this topic. For example, in the researches of Kim and Netessine (2013) and Wang and Liu (2016), the manufacturer and the supplier collaboratively reduce components' production cost. Fernando Bernstein and Gürhan Kök (2009) show that buyers of components can subsidize a fraction of the investment cost. Hu et al. (2017) prove that the technology opening can induce suppliers to invest in cost reduction. However, these methods may be inefficient or unworkable in some situations (Wu et al. 2020). In fact, if the orders of components are limited by the poor sales of the final product, it will be difficult to incentivize the supplier to improve the investment level. Manufacturer encroachment is considered to increase the total sales volume of products (Sun et al. 2019). Therefore, we investigate the interaction between supplier investment and manufacturer encroachment and examine the effect of manufacturer encroachment on improving the investment level.

Several papers have investigated manufacturer encroachment that incorporates investment. For example, Arya and Mittendorf (2013) investigate the manufacturer's encroachment when the retailer can invest to alter its own and the rival's market demand. In their research, the investment serves to enlarge the market demand, thus

they does not examine how downstream sales activities interact with upstream production activities. In contrast, the investment discussed in our work is implemented by the component supplier to reduce its production cost and examine how manufacturer encroachment should interact with the supplier's investment. In addition, Yoon (2016) and Sun et al. (2019) consider that the manufacturer can make cost-reducing investments. In their research, both investment and encroachment are conducted by the manufacturer. In contrast, this paper investigates the manufacturer encroachment strategy based on the supplier's investment strategy.

3. Model

We consider the model of a three-level supply chain consisting of one supplier, one manufacturer, and one retailer. The retailer purchases the products from the manufacturer, and then resells to the end consumers. Each product produced by the manufacturer requires one unit of key component from the supplier. In addition, the manufacturer has opportunities to encroach on the retailer's business by establishing its own channel and selling products to consumers directly. For instance, computer manufacturers, such as Lenovo, HP, and ASUS, have established their own company-owned franchises and online retail websites in addition to selling through retailers, such as Suning.com. And, producing each of their computers requires one CPU from a supplier, such as Intel. Figure 1 illustrates the channel structure under encroachment.

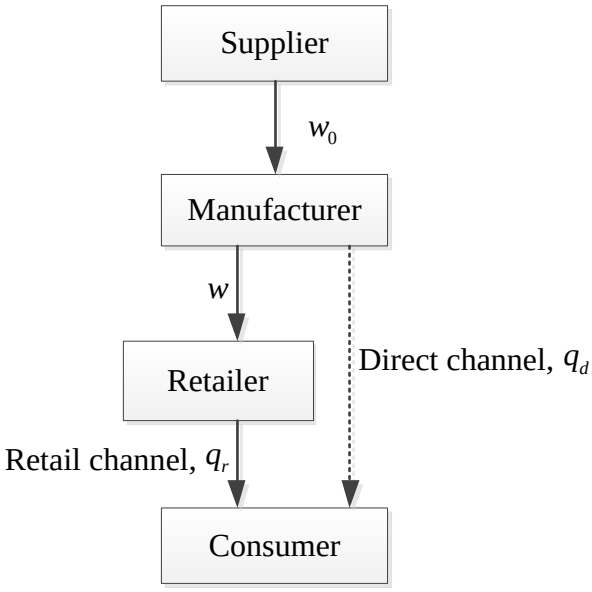

Figure 1. Channel structure under manufacturer encroachment

Market demand

If the manufacturer does not encroach, the inverse demand is given by $p_r = a - q_r$. If the manufacturer establishes a direct channel, then the supplier and the retailer engage in competition by selling the same product in different channels. Note that two channels can be completely or incompletely substitutable in the market. Therefore, we utilize the Cournot model, which is widely used in the literature related to channel competition (Yoon 2016; Huang et al. 2018; Tian et al. 2018; Dong et al. 2020), to characterize the competition of two channels. The demand functions of each channel are respectively given by

$$p_r = a - q_r - bq_d\,,\ p_d = a - q_d - bq_r\,, \tag{1}$$

where a represents the market size, and p_i and q_i refer to the selling price and quantities in the channel $i\left(i = r, d\right)$, respectively. Subscripts "*r*" and "*d*" denote the

retailer's channel and the direct channel, respectively. $b \in [0,1]$ captures the substitution degree of two channels. A higher b represents a greater competition between channels.

Profit functions

The supplier's production cost $c \in (0, a)$. The supplier can make cost-reduction efforts to reduce its production cost. Specifically, it can reduce its unit production cost to $c(1-x)$ with investment cost $\frac{1}{2}kx^2$, where $k \in (0,1)$ represents the supplier's efficiency in cost-reduction investment and x captures the cost investment level. A higher k means a lower efficiency of investment. This cost function is widely used in the literature (Ha et al. 2017; Sun et al. 2019). To avoid the trivial situation, we assume $k > k_0$ so that the supplier cannot always set x to 1 (Sun et al. 2019), where $k_0 = \frac{ac(12-6b-b^2)}{4(8-3b^2)}$. We normalize the selling costs for the manufacturer and the retailer and the production cost for the manufacturer to zero (Dan et al. 2014; Tian et al. 2018). Thus, the profit functions of three firms are

$$\pi_S = (w_0 - c(1-x))(q_r + q_d) - \frac{1}{2}kx^2, \tag{2}$$

$$\pi_M = (w - w_0)q_r + (p_d - w_0)q_d - F, \tag{3}$$

$$\pi_R = (p_r - w)q_r, \tag{4}$$

where w_0 is the unit wholesale price of the key component set by the supplier and w is the unit wholesale price of the final product charged by the manufacturer. The term F captures the fixed cost of establishing the direct channel, which is common knowledge to all supply chain members. The fixed cost F includes the cost of maintaining an online website, training and enrolling a salesforce, or the cost of inventory and

transportation of product (Huang et al. 2018; Tian et al. 2018).

The sequence of events and decisions is illustrated in Figure 2. In stage 1, the supplier determines whether to invest to reduce the unit production cost. In stage 2, the manufacturer decides whether to encroach. In stage 3, the supplier sets the wholesale price of the key component. In stage 4, the manufacturer sets the wholesale price of the product. In stage 5, the retailer decides its order quantity, and the manufacturer decides the direct channel quantity simultaneously (if necessary). In stage 6, the market clearing price is determined, and consumers buy the product.

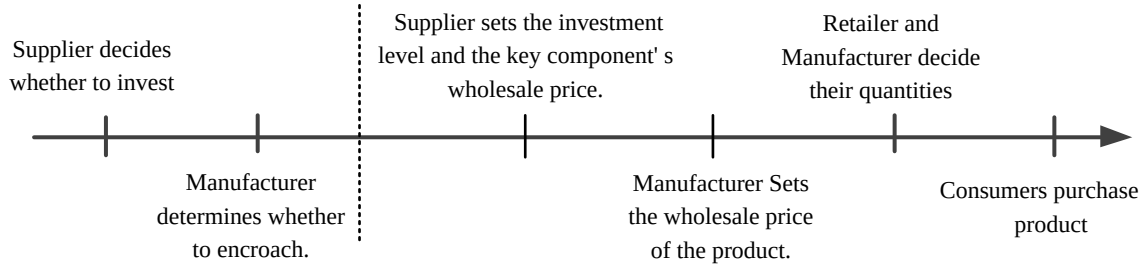

Figure 2. Decision sequence.

4. Analysis

This section analyzes the interplay of manufacturer's encroachment and supplier's investment and its' impacts on the profits of members. Let superscripts NN, IN, NE, and IE denote the four possible scenarios, in which the first (second) letter refers to the supplier (manufacturer)'s choice; I denotes investment, E denotes encroachment, and N denotes no investment or no encroachment.

4.1 Benchmark: No cost-reduction investment

We first study the manufacturer's encroachment strategy if the supplier does not make investment to reduce its unit production cost. If the manufacturer does not encroach, the

traditional retail channel is the only approach that the manufacturer uses to sell its product. In this setting, the retailer operates as a monopoly in the market. The problems of firms respectively are

$$\underset{q_r}{Max}\, q_r\left(a-q_r-w\right),\ \underset{w}{Max}\left(w-w_0\right)q_r,\ \pi_S=w_0q_r. \tag{5}$$

Using backward induction, we obtain the optimal decision of each firm as

$$w_0^{NN}=\frac{a+c}{2},\ w^{NN}=\frac{3a+c}{4},\ \ q_r^{NN}=\frac{a-c}{8}, \tag{6}$$

and the equilibrium profits as

$$\pi_S^{NN}=\frac{\left(a-c\right)^2}{16},\ \ \pi_M^{NN}=\frac{\left(a-c\right)^2}{32},\ \ \pi_R^{NN}=\frac{\left(a-c\right)^2}{64}. \tag{7}$$

If the manufacturer encroaches, the retailer and the manufacturer compete with each other in the end market. Therefore, the retailer and the manufacturer maximize

$$\underset{q_r}{Max}\, q_r\left(a-q_r-bq_d-w\right), \text{ and} \tag{8}$$

$$\underset{q_d}{Max}\left[q_r\left(w-w_0\right)+q_d\left(a-q_d-bq_r-w_0\right)-F\right]. \tag{9}$$

Given the wholesale price w_0 of the component and the wholesale price w of the product, the retailer's and the manufacturer's quantities are given by

$$q_r^{NE}\left(w,w_0\right)=\frac{2\left(a-w\right)-b\left(a-w_0\right)}{4-b^2},\ q_d^{NE}\left(w,w_0\right)=\frac{2\left(a-w_0\right)-b\left(a-w\right)}{4-b^2}. \tag{10}$$

Substituting firms' quantities into the manufacturer's profit function, we can obtain that given w_0, its wholesale price is

$$w^{NE}=\frac{w_0\left(8-2b^2-b^3\right)+a\left(2-b\right)\left(4+2b-b^2\right)}{2\left(8-3b^2\right)}. \tag{11}$$

Solving the maximized problem of the supplier yields the optimal key component's wholesale price as $w_0^{NE}=\frac{a+c}{2}$. Consequently, the wholesale price of the product and the optimal quantities are

$$w^{NE} = \frac{\left(24-10b^2+b^3\right)a + c\left(8-2b^2+b^3\right)}{4\left(8-3b^2\right)}, \tag{12}$$

$$q_r^{NE} = \frac{(a-c)(1-t)}{8-3b^2},\ q_d^{NE} = \frac{(a-c)(2-b)(4+b)}{4\left(8-3b^2\right)}. \tag{13}$$

Substituting all the decisions into firms' profit functions, we have firms' profits as

$$\pi_S^{NE} = \frac{\left(12-6b-b^2\right)(a-c)^2}{8\left(8-3b^2\right)},\ \pi_M^{NE} = \frac{(2-b)(6-b)(a-c)^2}{16\left(8-3b^2\right)} - F, \tag{14}$$

$$\pi_R^{NE} = \frac{(1-b)^2(a-c)^2}{\left(8-3b^2\right)^2}. \tag{15}$$

Comparing the manufacturer's profit with and without encroachment, we obtain the manufacturer's encroachment strategy under no cost-reduction investment.

LEMMA 1. *Without investment, the manufacturer encroaches if* $F \le F_N$, *in which* F_N *is strictly decreasing in the supplier's production cost* c.

Given that the supplier does not invest to reduce production costs, the manufacturer encroaches only when the entry cost is lower than F_N. If the supplier's production cost is low, it can charge a low wholesale price for the component. The low w_0^{NE} allows the manufacturer to earn more profits in the direct channel to cover the entry cost. Therefore, F_N is strictly decreasing in the supplier's production cost c. That is, the manufacturer is more likely to encroach in a lower c.

LEMMA 2. *Without investment, the manufacturer's encroachment increases the supplier's profit, but it hurts the retailer's profit.*

The direct channel and the retailer channel are not perfectly substitutable if $b<1$.

Therefore, encroachment increases the total market size from a to $\frac{2a}{1+b}$. In addition, encroachment creates channel competition, which results in a higher total retail quantity even if the two channels are perfectly substitutable. The manufacturer needs to procure more components from the supplier to fulfill the demand. Therefore, the supplier always benefits from manufacturer encroachment. Regarding the retailer, the encroachment is detrimental to the retailer. The manufacturer's direct channel shares the market that originally belongs to the retailer. Unlike Arya et al. (2007), the retailer has no retail efficiency advantage in our setting, and even if the encroachment lowers the wholesale price of the product, it is not enough to make up the loss for a cut of sales of the retailer.

4.2 Investment

If the manufacturer does not encroach, the analysis is the same as in case *NN*, the retailer's quantity decision is $q_r^{IN}(w)=\frac{a-w}{2}$ and the manufacturer's product wholesale price decision is $w^{IN}(w_0)=\frac{a+w_0}{2}$. Anticipating downstream members' response, the supplier maximizes its profit

$$\underset{w_0,x}{Max}\left[\left(w_0-c(1-x)\right)q_r^{IN}(w_0)-\frac{1}{2}kx^2\right], \tag{16}$$

which yields the optimal investment level $x^{IN}=\frac{c(a-c)}{8k-c^2}$ and the supplier's wholesale price $w_0^{IN}=\frac{4k(a+c)-ac^2}{8k-c^2}$. Consequently, the wholesale price of the product and the optimal order quantity of the retailer are

$$w^{IN}=\frac{a\left(6k-c^2\right)+2ck}{8k-c^2},\ q_r^{IN}=\frac{k(a-c)}{8k-c^2}. \tag{17}$$

Firms' equilibrium profits are

$$\pi_S^{IN} = \frac{k(a-c)^2}{2(8k-c^2)},\ \pi_M^{IN} = \frac{2k^2(a-c)^2}{(8k-c^2)^2},\ \pi_R^{IN} = \frac{k^2(a-c)^2}{(8k-c^2)^2}. \tag{18}$$

If the manufacturer encroaches, the retailer's order quantity, the manufacturer's direct channel quantity and the wholesale price of the product are the same as in case *NE* for a given w_0. However, the supplier's problem becomes

$$\underset{w_0,x}{Max}\left[(w_0 - c(1-x))\left(q_r^{IE}(w_0) + q_d^{IE}(w_0)\right) - \frac{1}{2}kx^2\right]. \tag{19}$$

Therefore, the supplier's investment level and the wholesale price of the component are

$$x^{IE} = \frac{c(12-6b-b^2)(a-c)}{4(8-3b^2)k - c^2(12-6b-b^2)}, \tag{20}$$

$$w_0^{IE} = \frac{2(8-3b^2)(1+c)k - c^2(12-6b-b^2)}{4(8-3b^2)k - c^2(12-6b-b^2)}. \tag{21}$$

Consequently, the wholesale price of the product and the optimal quantities are

$$w^{IE} = \frac{\left((24-10b^2+)b^3k - (12-6b-b^2)c^2\right)a + (8-2b^2-b^3)ck}{4(8-3b^2)k - c^2(12-6b-b^2)}, \tag{22}$$

$$q_r^{IE} = \frac{4k(1-b)(a-c)}{4(8-3b^2)k - c^2(12-6b-b^2)},\ q_d^{IE} = \frac{k(4+b)(2-b)(a-c)}{4(8-3b^2)k - c^2(12-6b-b^2)}. \tag{23}$$

Firms' equilibrium profits are

$$\pi_S^{IE} = \frac{(12-6b-b^2)(a-c)^2 k}{2\left(4(8-3b^2)k - c^2(12-6b-b^2)\right)}, \tag{24}$$

$$\pi_M^{IE} = \frac{k^2(2-b)(6-b)(8-3b^2)(a-c)^2}{\left(4(8-3b^2)k - c^2(12-6b-b^2)\right)^2} - F, \tag{25}$$

$$\pi_R^{IE} = \frac{16k^2(1-b)^2(a-c)^2}{\left(4(8-3b^2)k - c^2(12-6b-b^2)\right)^2}. \tag{26}$$

Obviously, the investment level in case *IE* is different from that in case *IN*. Comparing the investment levels in these two cases, we can obtain the following

proposition.

Proposition 1. *The supplier's investment level with manufacturer encroachment is greater than that without manufacturer encroachment, that is,* $x^{IE} > x^{IN}$.

Proposition 1 indicates that the supplier invests more under encroachment than under no encroachment (see Figure 3). The reason is that the total sales of final products with encroachment are higher than those without encroachment ($q_d^{IE} + q_r^{IE} > q_r^{IN}$). Since each unit product requires one unit component, the order quantities of the key components with encroachment are greater than those without encroachment. The increase in component orders makes it more profitable for the supplier to invest in reducing the unit production cost so that the supplier exerts a higher investment level if the manufacturer encroaches. In addition, x^{IE} is strictly decreasing in b because a higher substitution rate of two channels means a higher competition of these two channels. Intensified competition in the end market directly leads to a decrease in total sales, which thereby leads to a decrease in manufacturers' order for components and finally weakens the supplier's incentive to invest. This proposition reveals that manufacturer encroachment can help suppliers escape the dilemma of underinvestment.

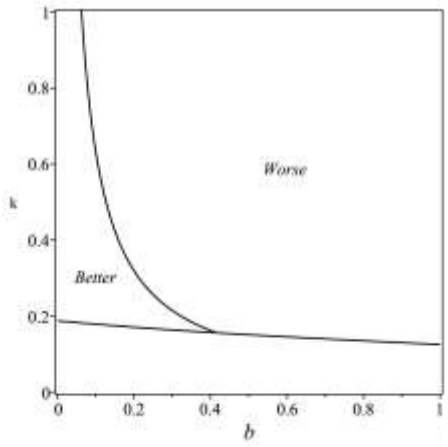

Figure 3. Investment level under investment and no investment ($a = 1,\ c = 0.5$).

Next, we present the manufacturer's encroachment strategy under supplier investment as proposition 2.

Proposition 2. *(a) If the supplier invests to reduce the production cost of the key component, the manufacturer encroaches when* $F \le F_I$*, where* F_I *decreases with* b*. (b)* $F_I > F_N$*, compared with the case without investment, the region of manufacturer encroachment with investment is larger.*

Proposition 2 implies that the supplier's investment endows the manufacturer with more flexibility for encroaching. When the entry cost is low ($F \le F_N$), the manufacturer should always encroach. When the entry cost is high ($F > F_I$), the manufacturer should never encroach. However, when the entry cost is moderate ($F_N < F \le F_I$), the manufacturer's encroachment strategy relies on the supplier's investment strategy. Specifically, the manufacturer should encroach if the supplier invests, while he should not encroach if the supplier abandons to invest (see figure 4).

That is, the manufacturer is more likely to encroach when the supplier invests. The reason is as follows. The encroachment increases the sales of final products and thereby brings a higher order quantity of the component so that the supplier is willing to exert a higher investment level under encroachment than under no encroachment ($x^{IE} > x^{IN}$). The higher investment level allows the supplier to charge a lower components wholesale price, to induce the manufacturer order more components. Consequently, if the manufacturer encroaches, it can order the component at a much lower wholesale price ($w_0^{IE} < w_0^{IN}$). This dynamic implies that the supplier's investment can make the manufacturer's encroachment more profitable and relieve the pressure of the manufacturer's entry cost.

Furthermore, F_I decreases with b, which means that the effect of investment on the manufacturer increases with the substitution rate because a higher substitution results in lower sales of final products and lower orders of components, which consequently weakens the investment level of the supplier.

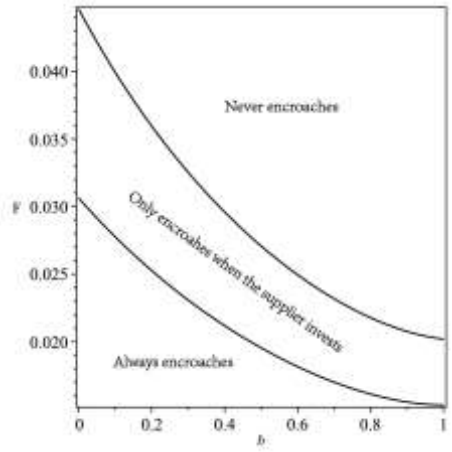

Figure 4. Manufacturer's encroachment strategy under investment and no investment ($a=1,\ c=0.3, k=0.25$)

In Lemma 2, we present that encroachment is always detrimental to the retailer. Proposition 3 shows that how it affects the retailer with supplier investment.

Proposition 3. *Under investment, manufacturer encroachment is beneficial to the retailer when* $k \le k_1$ *and detrimental otherwise, where* $k_1 = \dfrac{\left(8-2b-b^2\right)c^2}{4b\left(8-3b\right)}$.

Proposition 3 shows that the manufacturer's encroachment is beneficial to the retailer when investment efficiency is high (see Figure 4), because the interplay of encroachment and investment can induce an additional reduction in the wholesale price of the final product. Comparing the wholesale prices of the product under each case yields

$$w^{IN} - w^{IE} > w^{NN} - w^{NE}, \tag{27}$$

which confirms that the reduction of the wholesale price of the product with the supplier's investment is greater than that without the supplier's investment. Additionally,

$w^{IN} - w^{IE}$ is decreasing in investment efficiency k as the investment level is increasing in k. That is, a higher investment efficiency means a greater reduction in the product's wholesale price induced by the encroachment. When the investment efficiency is high enough, w^{IE} is much lower than w^{IN}, so the retailer benefits from the manufacturer encroachment. However, if investment efficiency is low, the reduction in the wholesale price is weak, so manufacturer encroachment is still detrimental to the retailer.

Furthermore, k_1 decreases with the substitution rate b, which means that a lower channel substitution rate increases the likelihood that the retailer will benefit from the encroachment. On the one hand, the lower substitution rate, the retailer suffers less competition from the manufacturer's direct channel. On the other hand, a lower substitution rate will induce a higher investment level of the supplier.

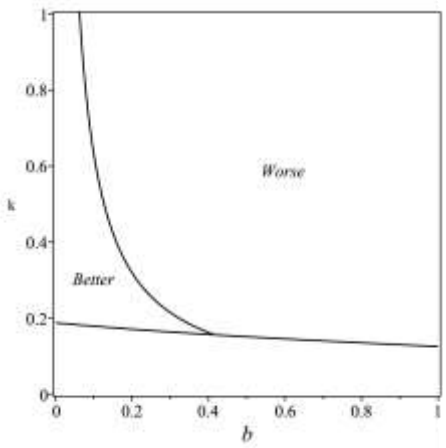

Figure 5. Impact of manufacturer encroachment on the retailer's profit without investment ($a = 1, c = 0.5$)

Actually, manufacturer encroachment has two effects on the retailer: a negative effect in which the direct channel shares the consumer market and a positive effect in which encroachment can further reduce the wholesale price of the final product by attracting more investment of the supplier. When the positive effect dominates, the encroachment is beneficial to the retailer. Accordingly, supplier investment can not only

allow the manufacturer to obtain more profits from encroachment but may also enable the manufacturer no need to worry about conflicts of interest with the retailer.

4.3. Impacts of supplier investment

In subsections 4.2, we discuss the manufacturer's encroachment strategy under supplier investment. One might wonder the optimal investment strategy of the supplier. The answer is present in proposition 4.

Proposition 4. *The supplier would always choose to invest in reducing production costs, and the best investment is (a)* x^{IE} *if* $F \le F_I$ *and (b)* x^{IN} *if* $F > F_I$.

When the entry cost is low ($F \le F_N$), the manufacturer always encroaches, regardless of the supplier's investment decision. Anticipating the manufacturer's response, the supplier's best investment level is x^{IE}. When the entry cost is high ($F > F_I$), the manufacturer never encroaches regardless of whether the supplier invests. Anticipating the manufacturer's response, the supplier's best investment level is x^{IN}. When $F_N < F \le F_I$, the manufacturer encroaches only if the supplier invests to reduce production costs. Owing to the increased sales of the product created by the dual channel, the supplier would like to exert a higher investment x^{IE}. In this case, in addition to the direct profits from the investment, the supplier also gains indirect profits from the encroachment. Consequently, the supplier is rewarded by investing in reducing production costs.

Of course, cost-reduction investment can enhance supply chain profits:

$$\pi_S^{Ij} + \pi_M^{Ij} + \pi_R^{Ij} > \left[\pi_S^{Nj} + \pi_M^{Nj} + \pi_R^{Nj} \right] \left(j = E, N \right). \tag{28}$$

However, for each supply chain member, the effect of supplier investment is not always positive owing to the existence of manufacturer encroachment. Proposition 5 presents the condition of Pareto gain.

Proposition 5. *Given* $k_2 = \frac{\left(12-6b-b^2\right)c^2}{4b\left(8-3b\right)}$, *investment and encroachment create a Pareto gain when* $F \le F_N$ *and* $k < k_1$, $F_N < F \le F_I$ *and* $k \le k_2$, *or* $F > F_I$.

When $F \le F_N$ and $F > F_I$, the manufacturer's encroachment strategy is independent of the supplier investment strategy. The manufacturer benefits from supplier investment. When $F_N < F \le F_I$, the manufacturer maintains a dual channel only if the supplier invests. Supplier investment helps the manufacturer encroaches. In this case, the manufacturer benefits from both the encroachment and a lower component's wholesale price. As to the retailer, when $F \le F_N$, the manufacturer always encroaches, which improves the retailer's profit only if $k < k_1$. When $F_N < F \le F_I$, we have

$$\pi_R^{IE} - \pi_R^{NN} = -\frac{\left(a-c\right)^2\left(\frac{4\left(b+4\right)\left(3-3b\right)k}{\left(12-6b-b^2\right)}-c^2\right)\left(\frac{4\left(8-3b\right)bk}{\left(12-6b-b^2\right)}-c^2\right)}{64\left(\frac{4\left(8-3b^2\right)k}{\left(12-6b-b^2\right)}-c^2\right)^2}. \qquad (29)$$

$\pi_R^{IE} \ge \pi_R^{NN}$ only when $k \le k_2$. When $F > F_I$, the manufacturer never encroaches. Furthermore, both investment and encroachment are always profitable to the supplier. Consequently, investment and encroachment create a Pareto gain when $F \le F_N$ and $k < k_1$, $F_N < F \le F_I$ and $k \le k_2$, or $F < F_I$, in which the supplier and manufacturer can both overcome their dilemmas.

6. Conclusions

This paper explores the interaction of component supplier cost-reduction investment and manufacturer encroachment to explore how to escape supply chain dilemmas. We demonstrate that when the manufacturer's entry cost is low or high, its encroachment strategy is independent to the supplier's investment decision. When the entry cost is moderate, the manufacturer should encroach if the supplier invests but should not encroach if the supplier does not invest. This proves that supplier investment can help the manufacturer encroach. Regarding the supplier, manufacturer encroachment is beneficial to the supplier regardless of whether the supplier invests. The supplier should exert a higher investment level if it anticipates that the manufacturer will encroach, while it should exert a lower investment level otherwise.

In addition, we examine the impact of manufacturer encroachment on the retailer. Without supplier investments, manufacturer encroachment always hurts the retailer. In contrast, when the supplier starts the investing, the profit of the cost reduction spills over to the manufacturer and retailer through the wholesale prices of components and products. The retailer may benefit from the encroachment since the encroachment encourages the supplier to invest more. That is, the supplier's cost-reduction investment can reduce potential interest conflicts between the manufacturer and the retailer. Accordingly, the manufacturer and supplier can help each other escape their dilemmas by applying encroachment and investment, respectively, thereby creating a Pareto gain.

This study makes theoretical contributions in three aspects. First, this research is one of the first to consider the impacts of the supplier investment on the manufacturer's encroachment decision, which extends the literature on manufacturer encroachment. The majority of past studies do not alleviate the manufacturer's dilemma regarding its encroachment primarily because these studies normally investigate the interaction

between the manufacturer and retailer but do not consider the impacts of the component supplier, who is not involved in product distribution. This study finds that the supplier's cost-reduction investment can motivate the manufacturer to encroach on retail channels.

Second, this study adds new insights to the suppliers' strategy of cost-reduction investments in the supply chain. Although previous studies attempted to explore how cooperation between the manufacturer and supplier motivates the supplier to improve its investment level, they usually ignored the side effects, such as opportunistic behaviors, managerial complexity of joint activities, which can lead to the failure of cooperation or investment enhancement (Wu et al. 2020). Our work abandons the traditional perspective, which limits itself to cooperation between firms, and investigates how the manufacturer encroachment can boost the supplier's investment in cost reduction.

Third, this study enriches the literature on the impact of manufacturer encroachment by identifying a new interesting condition in which the supplier's investments in cost-reduction production can help the manufacturer's encroachment benefit the retailer. Traditional studies usually argue that manufacturer encroachment is detrimental to retailers (Park and Keh 2003; Liu and Zhang 2006). Unfortunately, many of those studies have not reflected the business reality because they ignore the impacts of the component supplier. Compared with these previous views, we find that manufacturer encroachment may create a Pareto gain to the supply chain by considering the supplier's cost-reduction investment. Further, a few extreme conditions, e.g., efficient retailer, nonlinear pricing, channel power, have been previously reported in which the manufacturer's encroachment may benefit the retailer (Arya et al. 2007; Li et al. 2015; Niu et al. 2017). Our work goes beyond those studies and argues that the benefits of the manufacturer encroachment still hold in common three-tier supply chains.

The practical implications of this work are as follows. First, for manufacturers with moderate entry costs, they should encroach when the supplier invests. Due to the

concern of direct selling costs and possible conflicts with retailers, many manufacturers have abandoned direct selling channels in the past. However, in the era of Industry 4.0, suppliers are engaged in investing in new technologies to build smart factories, which can effectively reduce production costs. According to our studies, encroachment can benefit both the manufacturer and retailer when the supplier invests in cost-reduction technologies, thus providing opportunities for manufacturers to encroach.

Second, the supplier should maintain a relatively low investment level if the manufacturer does not encroach on retailing. However, if the manufacturer encroaches, then suppliers should exert a relatively high investment in cost-reduction technologies. If the manufacturer encroaches after the supplier starts to invest, then the supplier can raise its investment, which has a positive effect on the whole supply chain.

Third, the retailer should be more optimistic about manufacturer encroachment when the component supplier is committed to investing in cost-reduction technologies because the manufacturer's encroachment can be beneficial to the retailer when the supplier's investment efficiency is high. In this case, the retailer does not need to prevent the manufacturer from encroaching.

Our research has some limitations. First, demand uncertainty, information asymmetry and general cost structures are not considered in our model. These factors can be expanded in future research. In addition, it could be interesting to examine manufacturer encroachment and supplier investment in the competitive supply chain.

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