RAIRO-Oper. Res. 54 (2020) 693–718
https://doi.org/10.1051/ro/2019027

RAIRO Operations Research
www.rairo-ro.org

SUPPLY CHAIN ENCROACHMENT WITH QUALITY DECISION AND DIFFERENT POWER STRUCTURES

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Abstract. This paper studies a supply chain with manufacturer encroachment and different power structures where product quality is an endogenous decision. We investigate the effects of encroachment and power structure on quality and profits for chain members. Employing a game-theoretic approach, we find that, first, in a manufacturer-led supply chain, encroachment makes both manufacturer and retailer better off when the quality investment efficiency is relatively high. And, the manufacturer's profit exhibits nonmonotonicity with respect to the extent of consumers acceptance on the direct channel in a retailer-led setting. Second, our result shows that the pure equilibrium outcomes are driven by the quality investment efficiency and the extent of consumers' acceptance on the direct channel. An interesting result is that, for the manufacturer, establishing encroachment channel and occupying the leader position simultaneously are always not the optimal choice. Additionally, the options of encroaching and striving for leader position can lead to lose-win, win-win, and win-lose situations for the manufacturer and the retailer. Finally, a prisoner's dilemma may occur with a low quality investment efficiency, a moderately fixed encroachment cost and a high extent of consumers' acceptance on the direct channel when a fixed encroachment cost is considered.

Mathematics Subject Classification. 90B50, 91A80.

Received October 22, 2018. Accepted February 21, 2019.

1. Introduction

Given the advances in Internet technologies and e-commerce, establishing encroachment channel along with retail channel has been an effective policy for manufacturer to promote his profit. For example, the world-wide sportswear leader, Nike, channels its products through a wide range of retailers, from mainstream stores like Foot Locker to small, independent sneakerhead shops keeping the "cool" factor churning. Like many other manufacturers, effects have been promoted by Nike to increase its online and direct sales business [20]. As a result, manufacturer encroachment triggers competition between upstream manufacturer and the retail partners. Also, the firms' product quality and pricing strategies have been significantly affected by channel structures [42, 44].

Most existing literature on manufacturer encroachment, such as [1,5,6] focuses on a manufacturer-led setting. However, the emergence of power retailers have generated significant impacts on the performance of supply chain [38]. For the supply chain members who are often guided by maximizing their own profits, there are two topics

Keywords. Channel encroachment, power structure, supply chain, game theory.

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revolving of dual channel (encroachment channel and retailer channel). One is who, manufacturer or retailer, should occupy the leadership of the supply chain. This topic refers to the power structure, which is represented by the ability of controlling the process of decision making in the supply chain. The other topic is how the competition between the two conflict channels affects pricing and product quality decisions. To the best of our knowledge, the preference for leadership/followership and the role of quality decision in opening encroachment channel with different power structures of supply chain remain unclear. To fill these gaps, this study focuses on addressing the following research questions: (1) How does channel encroachment affect pricing and product quality decisions as well as profits of members with different power structures setting in a supply chain? (2) What is the equilibrium policy for the manufacturer, establishing encroachment channel or not, and what is the equilibrium policy for the retailer, choosing to occupy leadership or abandoning it? (3) What are the managerial implications of the options of encroaching and striving for leader position of supply chain?

To answer these research questions, we consider a supply chain, which consists of a manufacturer and a retailer. The retailer resells product from the manufacturer. The product quality level in our model setting is an endogenous decision made by the manufacturer. If the manufacturer opens an encroachment channel, it engages in channel competition with the retailer. Setting different power structures of the supply chain and employing a game-theoretic approach, we obtain the equilibrium outcomes and gain some managerial insights: (1) In a manufacturer-led supply chain, encroachment could make both manufacturer and retailer better off when the quality investment efficiency is relatively high, leading to a Pareto outcome. (2) In a retailer-led setting supply chain, establishing encroachment channel may induce the manufacturer to reduce product quality level when the quality investment efficiency is relatively high, while it may induce the manufacturer to promote product quality when the quality investment efficiency is relatively low. (3) The manufacturer's profit exhibits nonmonotonicity with respect to the extent of consumers' acceptance on the direct channel in a retailer-led setting supply chain. When the quality investment efficiency is relatively high, the manufacturer's profit first decreases and then increases as the extent of consumers' acceptance on the direct channel increases. When the quality investment efficiency is relatively low, an increasing in the extent of consumers acceptance on the direct channel exhibits a positive effect on the manufacturer's profit. For the retailer's profit, it first increases and then decreases as the extent of consumers' acceptance on the direct channel increases in a manufacturer-led setting supply chain.

Additionally, we further study the interaction of manufacturer encroaching and the power structure of supply chain. The case that the manufacturer can decide to choose encroaching or not, and the retailer can decide to choose leadership or followership in the supply chain is considered. The pure equilibrium strategies for the manufacturer and the retailer are given to derive further managerial insights. Our results indicate that the pure equilibrium strategies are driven by the quality investment efficiency and the extent of consumers' acceptance on the direct channel. An interesting result is that, for the manufacturer, establishing encroaching channel and occupying the leader position simultaneously is always not the optimal strategy. This result suggests that the manufacturer should abandon leadership of the supply chain when having the right of designing the quality level no matter establishing encroaching channel or not. We also employ numerical study to identify the profit implications of the options of encroaching and striving for leader position. We find that the options of encroaching and striving for leader position in a supply chain can result in lose-win, win-win, and win-lose situations for the manufacturer and the retailer, which provides new insights to the literature on encroachment.

Moreover, with considering a fixed cost of encroachment, we find an interesting result that a prisoner's dilemma may occur with a low quality investment efficiency, a moderately fixed cost and a high extent of consumers' acceptance on the direct channel. For the supply chain members, improving the quality investment efficiency or reducing the extent of consumers' acceptance on the direct channel can help them to escape from the prisoner's dilemma.

The contribution of this paper lies on the fact that we focus on investigating how quality investment efficiency and consumers' acceptance on the encroachment channel affect the strategies of supply chain members as well as the preferences of the manufacturer and the retailer under different power structures. Also, we further investigate the interaction effects of the option of encroaching and striving for leader position in a supply chain. The results of this research can be used to determine the implications of encroachment and the power structure in a supply chain.

The remainder of this paper is organized as follows. In Section 2, we review the existing literature related to our study. In Section 3, we formulate the basic model, and derive the equilibrium strategies with the manufacturer controlling the supply chain as well as the retailer controlling the supply chain, respectively. In Section 4, we compare the equilibrium outcomes of different subgames. In Section 5, we employ numerical studies to illustrate the analytical results about the effect of manufacturer's encroachment. In Section 6, an extension of the model is discussed. Section 7 makes the conclusion.

2. Literature review

Literature related to our work is from the following two aspects: dual-channel supply chain system and power structure in supply chain management.

The dual-channel supply chain has drawn attention in the literature. Chiang *et al.* [5] find that establishing a direct channel may not always be a threat to the retailer through constructing a price-setting game between a manufacturer and an independent retailer. Tsay and Agrawal [42] give a review on quantitative approaches employed to model the dual-channel supply chain. Tsay and Agrawal [41] indicate that the manufacturer's threat of launching its direct channel can benefit both manufacturer and retailer, when the former is efficient in boosting demand by sales effort. Cattani *et al.* [6] also reveal that adding a direct channel can lead to gains for both channel members when the manufacturer commits that the selling price of the direct channel can match the price of the traditional channel. Similarly, Arya *et al.* [1] show encroachment can result in a win-win situation if an encroaching channel has a cost disadvantage relative to the retailer. Dumrongsiri *et al.* [12] show that demand variability generates a major effect on the equilibrium selling prices and on the manufacturer's incentive for adding a direct channel. Bernstein *et al.* [3] study the pricing problem in a multi-channel supply chain on the basis of a willingness-to-pay model. Cai *et al.* [7] investigate how price discount contracts and pricing schemes affect the dual-channel supply chain. Huang and Swaminathan [21] characterize four prevalent pricing strategies with considering the case that a product was sold on two channels such as the Internet and a traditional channel. In the context of two single-channel and two dual-channel supply chains, Cai [8] studies the effect of channel structures and channel coordination on the supplier, the retailer and the entire supply chain. Chen *et al.* [9] propose the conditions where the manufacturer and the retailer both prefer a dual-channel structure by employing a manufacturer-Stackelberg game model. Li *et al.* [28, 29] incorporate asymmetric information and show that encroachment could lead to win-win, win-lose, lose-win, or lose-lose outcomes. Ha *et al.* [22] focus on how manufacturer encroachment affect product quality strategy. Chen *et al.* [11] investigate price and quality decisions in dual-channel supply chains, and indicate that the supply chain performance could be improved due to a new channel augmented. Letizia *et al.* [30] highlight the pivotal role of online and retail channels in the manufacturers' sales strategies in a market which is characterized by product returns. Yan *et al.* [49] show how product durability and the channel structure create strategic issues by developing a two-period dual-channel model for a durable goods manufacturer. Yang *et al.* [50] consider the firms can bilaterally negotiate over the wholesale price and the quantity by applying nonlinear pricing, and explore the impact of nonlinear pricing on the supplier's encroachment in a supply chain. With considering bi-level credit period, possibility/necessity/credibility measures, two storage facilities under reliability consideration, the noise effect with bundling and stochastic lead time demand, References [14,32,33,36,43] study the production and inventory system in a supply chain, respectively. Modak *et al.* [35] investigate structure of a two-echelon closed-loop supply chain in the presence of corporate social responsibility. With applying the genetic algorithm approach, Das *et al.* [13] and Manna *et al.* [34] study production control problem in a supply chain system. Das *et al.* [15, 16] and Das [17] study production-inventory problem in a supply chain under fuzzy environment. Our work are different from these papers with two aspects. First, we consider product quality as an endogenous decision under different power structures setting in a supply chain, and show that it leads to some different results. Second, we consider endogenous channel choice and power structure choice, that is, the manufacturer can choose whether encroaching or not and the retailer can choose leadership or followership.

Table 1. Contribution of the most related papers.

Authors	Supply chain management	Quality decision	Power structures
Chiang *et al.* [5]	✓		
Arya *et al.* [1]	✓		
Cai [8]	✓		
Li *et al.* [28]	✓		
Li *et al.* [29]	✓		
Ha *et al.* [22]	✓	✓	
Chen *et al.* [11]	✓	✓	
Yang *et al.* [50]	✓		
Our work	✓	✓	✓

In the context of power structure in supply chain, Iyer and Villas-Boas [23] study how the bargaining relationship between a manufacturer and a retailer affects channel coordination. Zhang *et al.* [52] investigate how products' substitutability and channel position affect pricing decision with different power structures in two dual-exclusive channels. Shi *et al.* [38] apply a game theory-based framework to model power in a supply chain with random demand to investigate how power structure and demand models affect the performance of supply chain members. Xue *et al.* [45] investigate how power schemes affect the supply chain partners' performance and consumer surplus in the context of a dominant manufacturer, a dominant retailer, and no single-agent dominance. Chen *et al.* [10] focus on a retail service supply chain with an online-to-offline mixed dual-channel in the presence of different power structure setting. Considering product quality as an endogenous decision, this paper investigates the interaction of manufacturer encroaching and the power structure of supply chain, and identifies the profit implications of the options of encroaching and striving for leader position. This contributes to the growing body of research on the power structure. For the ease of presentation, we summarize the contribution of the most related references in Table 1 to better illustrate the contribution of our work.

3. Model formulation

3.1. Notations and assumption

The model in this research is developed on the basis of the following notations and assumptions. We give the notations in Table 2.

We make the following assumptions:

(i) Let v denote consumers' reservation value representing consumers' willingness to pay for the product [25]. We model heterogeneous consumers' reservation value on the product by assuming that v is uniformly distributed on the interval $[0, 1]$. This assumption is common in the literature, such as [27, 40, 51, 54].
(ii) To ensure positive equilibrium strategies and profits, an assumption is proposed such that $k > \frac{1}{2}$.
(iii) It is supposed that the cost $c(q)$ takes a quadratic function of the quality level q, *i.e.*, $c(q) = \frac{k}{2}q^2$, implying the increasing marginal costs of quality improvement. Such quadratic function reflecting the decreasing returns to scale is popular in the literature, *e.g.*, [4, 18, 37, 53].

3.2. The model

In this section, we outline the basic model. Consider a supply chain which consists of a manufacturer and a retailer. The manufacturer sells a product through a retailer (traditional store channel) but may also build his direct channel encroaching the market to sell product to consumers. We first omit the cost for opening a direct channel, and consider it in Section 5. The manufacturer charges a wholesale price w to the retailer, and the

TABLE 2. List of notations.

Symbol	Description
Indices	
π_m	The profit of the manufacturer
π_r	The profit of the retailer
D	The demand without encroachment
D_r	The demand for retail channel with encroachment
D_m	The demand for direct channel with encroachment
Parameters	
v	Consumers' reservation value
k	The quality investment efficiency
θ	The extent of consumers' acceptance on the direct channel
Decision variables	
w	The wholesale price
q	The product quality
p_r	The selling price of retail channel
p_m	The selling price of direct channel

retailer sets price p_r to sell the product to consumers. The manufacturer also decides the product quality level denoted by q with a cost $c(q)$.

Following [46–48], we suppose that each consumer in the market consumes at most one unit of the product as long as his/her utility surplus is positive. The market size is normalized to 1 without loss of generality. Similar to [25], the utility of a consumer buying through the retailer channel is $U_r = v + q - p_r$. If the manufacturer does not establish his own channel, a consumer will buy through the retail channel if $U_r > 0$ is satisfied. Thus, we can obtain the product demand without manufacturer encroachment as

$$D = 1 - p_r + q. \tag{3.1}$$

When the manufacturer establishes a direct channel, he sets selling price p_m to sell product to consumers. The utility of a consumer buying through the direct channel is $U_m = \theta(v + q) - p_m$. Further, $\theta \in (0, 1)$ represents the discount factor of the consumer utility obtained from products sold through the direct channel [31]. θ can be explained as consumers' acceptance on the direct channel. A higher θ means a higher extent of consumers' acceptance on the direct channel. As θ decreases, the products obtained through the direct channel give the consumer less utility than those purchased from the retail channel, which also implies that the retailing inefficiency of the manufacturer relative to the retailer is greater. From the utility functions presented above, we find the consumers' choices are based on their utility obtained from the retail channel and the direct channel. A consumer will buy from the retail channel when the following conditions are satisfied

$$\begin{cases} v + q - p_r > 0 \Rightarrow v > p_r - q, \\ v + q - p_r > \theta(v + q) - p_m \Rightarrow v > \frac{p_r - p_m + (\theta - 1)q}{1 - \theta}. \end{cases}$$

Analogously, a consumer will purchase through the direct channel when the following conditions are satisfied

$$\begin{cases} \theta(v + q) - p_m > 0 \Rightarrow v > \frac{p_m - \theta q}{\theta}, \\ \theta(v + q) - p_m > v + q - p_r \Rightarrow v < \frac{p_r - p_m + (\theta - 1)q}{1 - \theta}. \end{cases}$$

Similar to [31], we focus on $\theta > \frac{p_m}{p_r}$ to guarantee the coexistence of products in both the retail and direct channels if the manufacturer establishes the direct selling channel. Therefore, we can obtain the demand expression for the retail channel and direct channel, respectively, given as

$$D_r = 1 - \frac{p_r - p_m + (\theta - 1)q}{1 - \theta}, \; D_m = \frac{p_r - p_m + (\theta - 1)q}{1 - \theta} - \frac{p_m - \theta q}{\theta}. \tag{3.2}$$

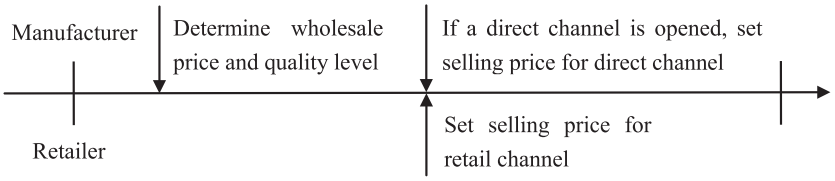


FIGURE 1. The sequence of events for manufacturer-led stackelberg.

In order to investigate how supply chain encroachment interacts with different power structures, two different structures are defined in the supply chain. According to [19], the power of a supply chain member can be expressed by its ability to control the decision variables of another member at a different level. In this paper, we follow this definition. The power structure is represented by different decision sequences determined by the manufacturer and the retailer. We employ manufacturer and retailer Stackelberg games to model the supply chain dominated by the manufacturer and retailer, respectively.

3.3. Manufacturer-led stackelberg

In this section, we study the case that the manufacturer controls the supply chain. The manufacturer acts as a leader, and the retailer responds as a follower. Let u denote this case. The timeline considered in this section is shown in Figure 1.

Specifically, the sequence of events is as follows: (i) the manufacturer decides the quality level of product q and the wholesale price w; (ii) the retailer decides the selling price p_r after observing the quality level and wholesale price. If there exists a direct channel, the manufacturer decides the direct price p_m. Then, the profits of the manufacturer and the retailer are realized. This decision sequence entails two models: no encroachment and encroachment. Without encroachment, the manufacturer sells the product through the retail channel only. If there exists manufacturer encroachment, the manufacturer decides the selling price to sell directly. We assume that the manufacturer and the retailer decides the selling price simultaneously.

3.3.1. No encroachment under manufacturer-led stackelberg model

Here we consider the case without manufacturer encroachment. The retailer acts as a merchant that procures products from the manufacturer and then sells them to the customers. We employ backward induction to identify the equilibrium of the game. Given the quality q and wholesale price w, the retailer chooses his retail price p_r in the retail channel by maximizing his profit

$$\pi_r = (p_r - w)(1 - p_r + q). \tag{3.3}$$

Anticipating the retailer's price, the manufacturer decides the quality level q and wholesale price w to maximize his profit given as

$$\pi_m = w(1 - p_r + q) - \frac{k}{2}q^2. \tag{3.4}$$

The following proposition characterizes the stackelberg equilibrium. All proofs are given in the appendix.

Proposition 3.1. *At the equilibrium of manufacturer-led stackelberg model without encroachment, the wholesale price, the quality level, and the selling price are*

$$w_u^{n*} = \frac{2k}{4k-1}, \tag{3.5}$$

$$q_u^{n*} = \frac{1}{4k-1}, \tag{3.6}$$

$$p_{ur}^{n*} = \frac{3k}{4k-1}, \tag{3.7}$$

respectively, and the corresponding profits of the manufacturer and the retailer are given by

$$\pi_{um}^{n*} = \frac{k}{8k-2}, \tag{3.8}$$

$$\pi_{ur}^{n*} = \frac{k^2}{(4k-1)^2}. \tag{3.9}$$

3.3.2. Encroachment under manufacturer-led stackelberg model

In this case, the direct channel is introduced in addition to the retail channel. The manufacturer's profit is derived from two segments: the first is from the retail channel, where he sells products with charging a wholesale price; and the second is from his own channel, where he directly sells to consumers. The manufacturer decides his retail price p_m in the direct channel. Thus, the profit of the manufacturer is given as

$$\pi_m = w\left(1 - \frac{p_r - p_m + (\theta-1)q}{1-\theta}\right) + p_m\left(\frac{p_r - p_m + (\theta-1)q}{1-\theta} - \frac{p_m - \theta q}{\theta}\right) - \frac{k}{2}q^2. \tag{3.10}$$

The retailer determines his retail price p_r in the retail channel, and the profit of the retailer is given as

$$\pi_r = (p_r - w)\left(1 - \frac{p_r - p_m + (\theta-1)q}{1-\theta}\right). \tag{3.11}$$

From the above mentioned profit functions of the manufacturer and retailer, we can obtain the equilibrium of both parties, which are presented in the following proposition.

Proposition 3.2. *At the equilibrium of manufacturer-led stackelberg model with encroachment, the wholesale price, the quality level, the manufacturer's selling price and the retailer's selling price are*

$$w_u^{e*} = \frac{k(8+\theta^2)}{2k(8+\theta) - (2+\theta)^2}, \tag{3.12}$$

$$q_u^{e*} = \frac{(2+\theta)^2}{2k(8+\theta) - (2+\theta)^2}, \tag{3.13}$$

$$p_{um}^{e*} = \frac{k\theta(10-\theta)}{2k(8+\theta) - (2+\theta)^2}, \tag{3.14}$$

$$p_{ur}^{e*} = \frac{k(12-\theta(2+\theta))}{2k(8+\theta) - (2+\theta)^2}, \tag{3.15}$$

respectively, and the corresponding profits of the manufacturer and the retailer are given by

$$\pi_{um}^{e*} = \frac{k(2+\theta)^2}{4k(8+\theta) - 2(2+\theta)^2}, \tag{3.16}$$

$$\pi_{ur}^{e*} = \frac{4k^2(1-\theta)(2+\theta)^2}{(2k(8+\theta) - (2+\theta)^2)^2}. \tag{3.17}$$

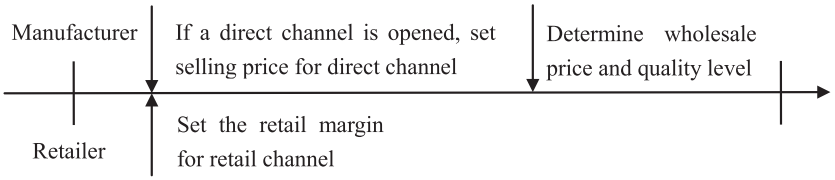


FIGURE 2. The sequence of events for retailer-led stackelberg.

3.4. Retailer-led stackelberg

In this section, we study the case that the retailer controls the supply chain. The retailer acts as the leader, and the manufacturer responses as the follower. Let s denote this case. The timeline considered in this section is shown in Figure 2.

Specifically, the timeline of retailer being the leader is as follows: (i) the retailer determines its retail margin m with $m = p_r - w$. If there exists a direct channel, the manufacturer decides the direct selling price p_m; (ii) the manufacturer decides the quality level of product q and the wholesale price w after observing retail margin m. Then, the profits of the manufacturer and the retailer are realized. We also consider the two cases: no encroachment and supply chain encroachment. Similar to Section 3.3, we first characterize the case in which the direct channel is not introduced. Then, we investigate the complex case where the direct channel is introduced.

3.4.1. No encroachment under retailer stackelberg-led model

In this part, we explore the case in which the direct channel is not introduced with retailer being the leader of the supply chain. Backward induction is applied to identify the equilibrium of the game. Given retail margin m, the manufacturer chooses the quality level q and wholesale price w in the retail channel by maximizing his profit

$$\pi_m = w(1 - (m + w) + q) - \frac{k}{2}q^2. \tag{3.18}$$

Anticipating the quality level and wholesale price, the retailer decides the retail margin m to maximize his profit given as

$$\pi_r = m(1 - (m + w) + q). \tag{3.19}$$

The equilibrium for this Stackelberg game is characterized by the following proposition.

Proposition 3.3. *At the equilibrium of retailer-led stackelberg model without encroachment, the wholesale price, the quality level, and the selling price are*

$$w_s^{n*} = \frac{k}{4k - 2}, \tag{3.20}$$

$$q_s^{n*} = \frac{1}{4k - 2}, \tag{3.21}$$

$$p_{sr}^{n*} = \frac{3k - 1}{4k - 2}, \tag{3.22}$$

respectively, and the corresponding profits of the manufacturer and the retailer are given by

$$\pi_{sm}^{n*} = \frac{k}{16k - 8}, \tag{3.23}$$

$$\pi_{sr}^{n*} = \frac{k}{8k - 4}. \tag{3.24}$$

3.4.2. Encroachment under retailer-led stackelberg model

In this subsection, the manufacturer establishes the direct channel in addition to the retail channel. Next, we give the profit functions of the manufacturer and the retailer. Similar to (3.10), the profit of the manufacturer is given as

$$\pi_m = w\left(1 - \frac{m + w - p_m + (\theta - 1)q}{1 - \theta}\right) + p_m\left(\frac{m + w - p_m + (\theta - 1)q}{1 - \theta} - \frac{p_m - \theta q}{\theta}\right) - \frac{k}{2}q^2. \tag{3.25}$$

Similar to (3.11), the profit of the retailer is given as

$$\pi_r = m\left(1 - \frac{m + w - p_m + (\theta - 1)q}{1 - \theta}\right). \tag{3.26}$$

From the mentioned profit functions of the manufacturer and retailer, we can obtain the equilibrium of both parties, which are given by the following proposition.

Proposition 3.4. *At the equilibrium of retailer-led stackelberg model with encroachment, the wholesale price, the quality level, the manufacturers selling price and the retailer's selling price are*

$$w_s^{e*} = \frac{k(2k(1 + \theta) + \theta(\theta - 1))}{8k^2 - 4k + \theta - \theta^2}, \tag{3.27}$$

$$q_s^{e*} = \frac{2k(1 + \theta) + \theta(\theta - 1)}{8k^2 - 4k + \theta - \theta^2}, \tag{3.28}$$

$$p_{sm}^{e*} = \frac{k\theta(4k + \theta - 1)}{8k^2 - 4k + \theta - \theta^2}, \tag{3.29}$$

$$p_{sr}^{e*} = \frac{k(6k + 3\theta - \theta^2 - 2\theta k - 2)}{8k^2 - 4k + \theta - \theta^2}, \tag{3.30}$$

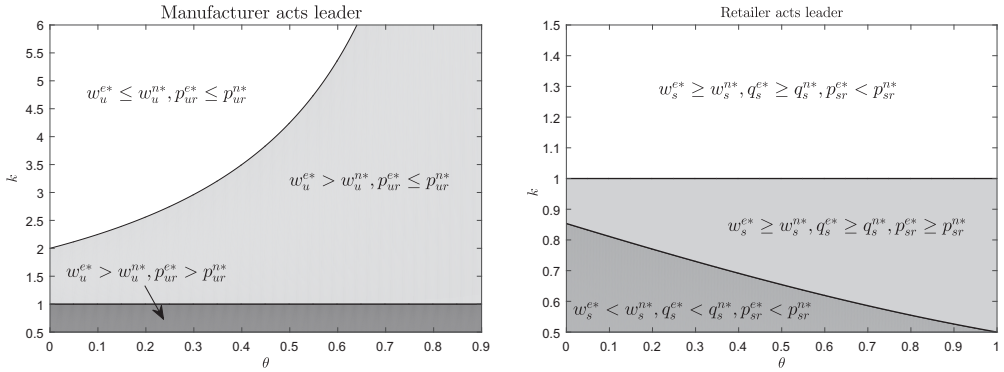
respectively, and the corresponding profits of the manufacturer and the retailer are given by

$$\pi_{sm}^{e*} = \frac{k(-(\theta - 1)^2\theta^2 + 2k\theta(1 - \theta)(3 + \theta) + 8k^3(1 + 3\theta) + 4k^2(-1 + 3\theta(\theta - 2)))}{2(8k^2 - 4k + \theta - \theta^2)^2}, \tag{3.31}$$

$$\pi_{sr}^{e*} = \frac{4k^3(1 - \theta)(2k + \theta - 1)}{(8k^2 - 4k + \theta - \theta^2)^2}. \tag{3.32}$$

4. Analysis of the results

In this section, we will compare the equilibrium outcomes of the different subgames analyzed above. We explore the effects of encroachment on the quality level, wholesale price, selling prices and supply chain member's profit under different power structures. Also, we identify the condition in which the manufacturer decides whether to introduce the direct channel with different power structures in the supply chain. Here, it is assumed that the manufacturer firstly determines whether to introduce the direct channel. In other words, the decision on the channel structure is a longer-term decision compared to other decisions. This timing is in line with modeling choices in the previous literature, *e.g.*, [2, 24].



(a) (b)

FIGURE 3. An illustration of Proposition 4.1.

4.1. The effects of encroachment under different power structures

First, we explore the impacts of manufacturer encroaching on the strategies of supply chain members under different power structures, as described in the following proposition.

Proposition 4.1. *(1) When the manufacturer acts the leader of the supply chain, the results are as follows: for the wholesale prices, if* $\frac{1}{2} < k < \frac{8+\theta}{4(1-\theta)}$, *we have* $w_u^{e*} > w_u^{n*}$; *if* $k \ge \frac{8+\theta}{4(1-\theta)}$, $w_u^{e*} \le w_u^{n*}$; *for the product quality, we have* $q_u^{e*} > q_u^{n*}$; *for the selling prices of retailer's channel, if* $\frac{1}{2} < k < 1$, *we have* $p_{ur}^{e*} > p_{ur}^{n*}$; *if* $k \ge 1$, *we have* $p_{ur}^{e*} \le p_{ur}^{n*}$.

(2) When the retailer acts the leader of the supply chain, the results are as follows: for the wholesale prices and product quality, if $\frac{1}{2} < k < k_1$, *we have* $w_s^{e*} < w_s^{n*}$ *and* $q_s^{e*} < q_s^{n*}$; *if* $k \ge k_1$, *we have* $w_s^{e*} \ge w_s^{n*}$ *and* $q_s^{e*} \ge q_s^{n*}$; *for the selling prices of retailer's channel, if* $\frac{1}{2} < k < k_1$ *or* $k > k_2$, *we have* $p_{sr}^{e*} < p_{sr}^{n*}$; *if* $k_1 \le k \le k_2$, *we have* $p_{sr}^{e*} \ge p_{sr}^{n*}$, *where* $k_1 = \frac{2-\theta+\sqrt{2+\theta(\theta-2)}}{4}$ *and* $k_2 = 1$.

The following figure depicts the conditions in Proposition 4.1 to clearly illustrate them.

Proposition 4.1 provides lights on how the manufacturer encroaching affects the strategies of supply chain members under different power structures. We make a few observations on this proposition. For the product quality, we find that the manufacturer always promotes product quality level when he encroaches in a manufacturer-led setting. The parameter k has no impact on this finding. This result is in line with [11], which states that boosting product quality level can increase both channels' demand resulting in increasing the total product demand. Hence, the encroachment setting can induce manufacturer's quality enhancement in a supply chain. For the wholesale prices and selling prices, the results are conditional on k representing the quality investment efficiency. From Figure 3(a), when the quality investment efficiency is relatively high, *i.e.*, k is relatively low, we find that $w_u^{e*} > w_u^{n*}$ and $p_{ur}^{e*} > p_{ur}^{n*}$. In other words, both the manufacturer and retailer have incentives to increase prices under manufacturer encroachment with a high quality investment efficiency. Due to selling channel encroachment and a high quality investment efficiency, the manufacturer can rely on less the wholesale price to influence the demand from the retail channel. Thus, a more aggressively wholesale price is applied to reap profit from the retail channel. For the retailer, when the quality investment efficiency is high, the positive effect of boosting demand from an increasing quality level dominates the negative competition effect from manufacturer encroachment, the retailer increases the selling price facing a higher wholesale price.

When k becomes higher, *i.e.*, the quality investment efficiency is moderate, Figure 3(a) shows that $w_u^{e*} > w_u^{n*}$ and $p_{ur}^{e*} \le p_{ur}^{n*}$. This indicates that the manufacturer also has an incentive to use more aggressive wholesale price to reap profit, however, the retailer decreases its selling price. This is because the negative competition

effect from manufacturer encroachment dominates the positive effect of boosting demand from an increasing quality level, thus, the retailer applies a lower selling price to promote product demand of the retail channel. When k continuously becomes higher, *i.e.*, the quality investment efficiency is relatively low, Figure 3(a) shows that $w_u^{e*} \leq w_u^{n*}$ and $p_{ur}^{e*} \leq p_{ur}^{n*}$. This means that, with a manufacturer-led setting in a supply chain, a relatively low efficiency in quality investment dampens the manufacturer's incentive to rely on the encroachment channel, hence, the manufacturer has to apply a lower wholesale price to maintain product's demand .

Moreover, Figure 3(a) gives a new insight that a higher product quality level does not necessarily mean a higher wholesale price. Encroachment can induce the manufacturer to promote the product quality level but charge a low wholesale price when the quality investment efficiency is relatively low. The manufacturer can provide a product with a higher quality but charge a lower wholesale price when he has his own channel.

The part (2) in Proposition 4.1 and Figure 3(b) indicate what happens when the retailer acts the leader in a supply chain. For the product quality, Figure 3(b) illustrates that the result is dependent on k, which is different from the case that the manufacturer acts the leader. Specifically, when the quality investment efficiency is relatively high, *i.e.*, k is relatively low, the manufacturer has an incentive to cut down the product quality level, while the manufacturer increases product quality level when the quality investment efficiency is relatively low. This result is non-intuitive and can be explained as follows. In a retailer-led setting supply chain, the manufacturer relies less on the retailer channel to contend against the powerful retailer when there exists a direct selling channel. Also, we find that the product's demand of both channels is decreasing in k. When k is relatively small, both channels' demand is relatively high. Thus, from the manufacturer's perspective, facing a relatively high demand of both channels, he has no incentive to promote the product quality level, and shifts to rely more on the encroachment channel to compete with the retailer. Sequentially, the wholesale price is decrsased with a reduced quality level. However, a relatively low quality investment efficiency, *i.e.*, a relatively high k, would aggravate inferior position of the manufacturer. At the same time, a relatively high k will lead to a relatively low demand of both channels. Being the follower, the manufacturer has an incentive to promote the quality level in order to boost product demand of both channels with the purpose of softening the inferior position. Because k is large, the manufacturer cannot afford to change quality level as much as he wants, he sets a more aggressive wholesale price. For the selling prices, part (2) in Proposition 4.1 demonstrates that the results are conditional on k. When $\frac{1}{2} < k < k_1$ or $k > k_2$, we have $p_{sr}^{e*} < p_{sr}^{n*}$. Facing a relatively high quality investment efficiency or a relatively low quality investment efficiency, the retailer should set a lower selling price for the retail channel if encroaching channel exists. When the quality investment efficiency is moderate ($k_1 \leq k \leq k_2$), we have $p_{sr}^{e*} \geq p_{sr}^{n*}$, meaning the retailer should set a higher selling price for the retail channel. This suggests that setting a higher selling price can be optimal with facing competition from the direct channel.

The following proposition characterizes the manufacturer's selling price decision under different power structures.

Proposition 4.2. *When* $\frac{1}{2} < k < \frac{4+\theta+\sqrt{80+11\theta(3\theta-8)}}{16}$, *we have* $p_{um}^{e*} < p_{sm}^{e*}$; *when* $k \geq \frac{4+\theta+\sqrt{80+11\theta(3\theta-8)}}{16}$, *we have* $p_{um}^{e*} \geq p_{sm}^{e*}$.

The following figure illustrates the result in Proposition 4.2.

From Figure 4, the sign of $p_{um}^{e*} - p_{sm}^{e*}$ is conditional on k. When the quality investment efficiency is relatively high (k is relatively low), the manufacturer charges a higher selling price for the encroachment channel in a retailer-leader setting. In contrast, when the quality investment efficiency is relatively low (k is relatively high), our result suggests that the manufacturer can charge a higher selling price for the encroachment channel in a manufacturer-leader setting.

4.2. The preferences of the manufacturer and the retailer

Next, we explore the preferences of the manufacturer and the retailer under the manufacturer acting the leader in the supply chain, as described in the following proposition.

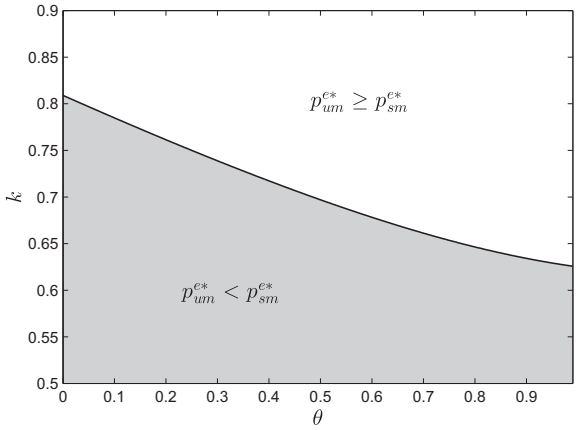


FIGURE 4. Manufacturer's selling price under different power structures.

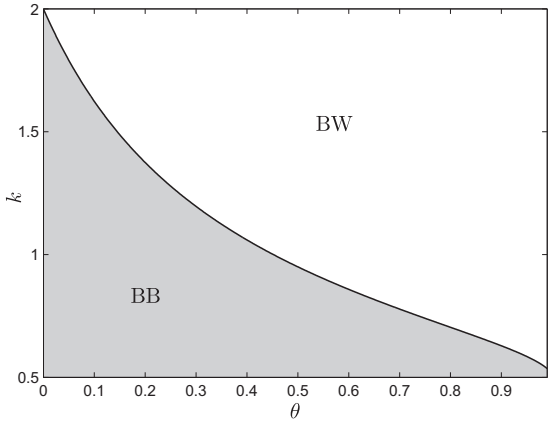


FIGURE 5. The effect of manufacturer encroachment on retailer's profit with manufacturer being leader.

Proposition 4.3. *When the manufacturer acts the leader of the supply chain,* $\pi_{um}^{n*} < \pi_{um}^{e*}$*, i.e., the manufacturer is always better off from encroachment. For the retailer, if* $\frac{1}{2} < k < \frac{9\theta(4+\theta)+36+2\sqrt{(1-\theta)(2+\theta)^2(7+2\theta)^2}}{32+98\theta+32\theta^2}$*, we have* $\pi_{ur}^{n*} < \pi_{ur}^{e*}$*; if* $k \geq \frac{9\theta(4+\theta)+36+2\sqrt{(1-\theta)(2+\theta)^2(7+2\theta)^2}}{32+98\theta+32\theta^2}$*, we have* $\pi_{ur}^{n*} \geq \pi_{ur}^{e*}$.

The following figure depicts the effect of manufacturer encroachment on retailer's profit to illustrate Proposition 4.3. We use "BB" to denote the area where both manufacturer and retailer are better off with manufacturer encroachment, and "BW" to denote the area where the manufacturer is better off with manufacturer encroachment while the retailer is worse off.

Proposition 4.3 states that the manufacturer encroachment always makes the manufacturer better off. In other words, for the manufacturer, the positive effect of obtaining extra profit from direct channel dominates the negative effect of profit loss from the retail channel due to channel conflict when he acts the leader, hence, the manufacturer is always better off from encroachment. Furthermore, as illustrated in Figure 5, the manufacturer encroachment doesn't always make the retailer worse off. When the quality investment efficiency is relatively high, *i.e.*, k is relatively low, the retailer can benefit from manufacturer encroachment. This is because the

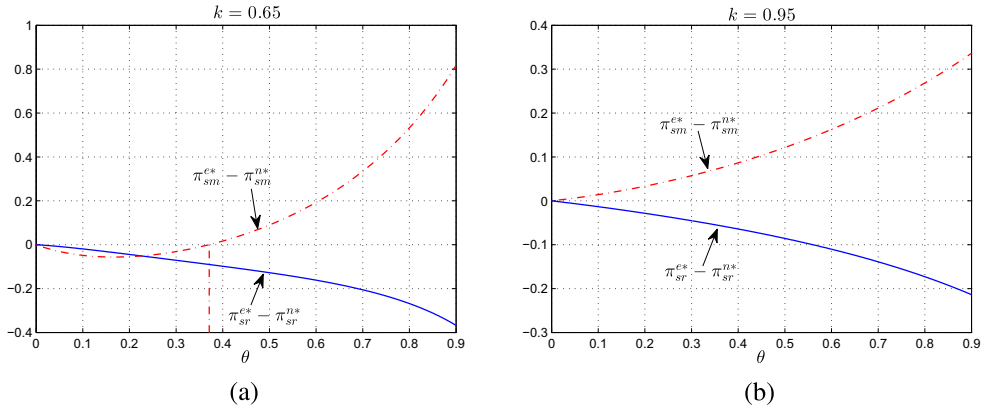


FIGURE 6. The effects of encroachment on the profits of manufacturer and retailer with retailer being the leader.

positive effect of boosting demand from an increasing quality level dominates the negative competition effect from manufacturer encroachment, hence, the retailer is better off when k is relatively low. These effects are reversed when k is relatively high, thus, the retailer loses. Proposition 4.3 also indicates that, in a manufacturer-led setting supply chain, manufacturer encroachment can make both manufacturer and retailer better off resulting in a Pareto outcome when the quality investment efficiency is relatively high.

In addition, from Figure 5, we can find that the threshold $\frac{9\theta(4+\theta)+36+2\sqrt{(1-\theta)(2+\theta)^2(7+2\theta)^2}}{32+98\theta+32\theta^2}$ is decreasing in θ. This indicates that the area where the supply chain reaches Pareto improvements becomes smaller as θ increases, which means the supply chain becomes less likely to gain Pareto improvements with manufacturer encroachment. The parameter θ can be explained as consumers' acceptance on the direct channel. The result indicates increasing consumers' acceptance on the direct channel can result in the supply chain being less likely to reach Pareto outcome with an encroaching manufacturer.

Although the profits of the manufacturer and the retailer are fully analytically characterized with retailer being the leader, we are unable to compare them analytically. We resort to a numerical study to investigate the preferences of the manufacturer and the retailer under the retailer acting the leader in the supply chain. Then, we investigate how changes in parameter θ affect the profits of the manufacturer and retailer under different power structures.

First, we investigate the preferences of the manufacturer and the retailer in a retailer-led setting supply chain. We set the k in the sequel at the following values as $k = 0.65, 0.95$. The following figures depict $\pi_{sm}^{e*} - \pi_{sm}^{n*}$ and $\pi_{sr}^{e*} - \pi_{sr}^{n*}$.

We make some observations on Figure 6. From Figure 6, we find that, in a retailer-led setting supply chain, although the retailer occupies a dominant position, manufacturer encroachment always hurts the retailer ($\pi_{sr}^{e*} - \pi_{sr}^{n*} < 0$) because the channel conflict dampens the retailer's dominant position. This also indicates that manufacturer encroachment does not induce a Pareto outcome in a retailer-led setting, which differs from the results in a manufacturer-led setting.

For the manufacturer, Figure 6(a) shows that it is not always beneficial with encroaching channel. In particular, when the quality investment efficiency is relatively high, *i.e.*, k is relatively low, if consumers' acceptance on the direct channel is low (θ is low), encroaching hurts the manufacturer itself ($\pi_{sm}^{e*} - \pi_{sm}^{n*} < 0$). Under this condition, a lose-lose situation is derived with encroaching channel. If consumers' acceptance on the direct channel is high (θ is high), encroaching channel can make the manufacturer better off. These results can be explained as follows. When the quality investment efficiency is relatively high but consumers' acceptance on the direct channel is low, for the manufacturer's outcome, the negative competition effect from channel

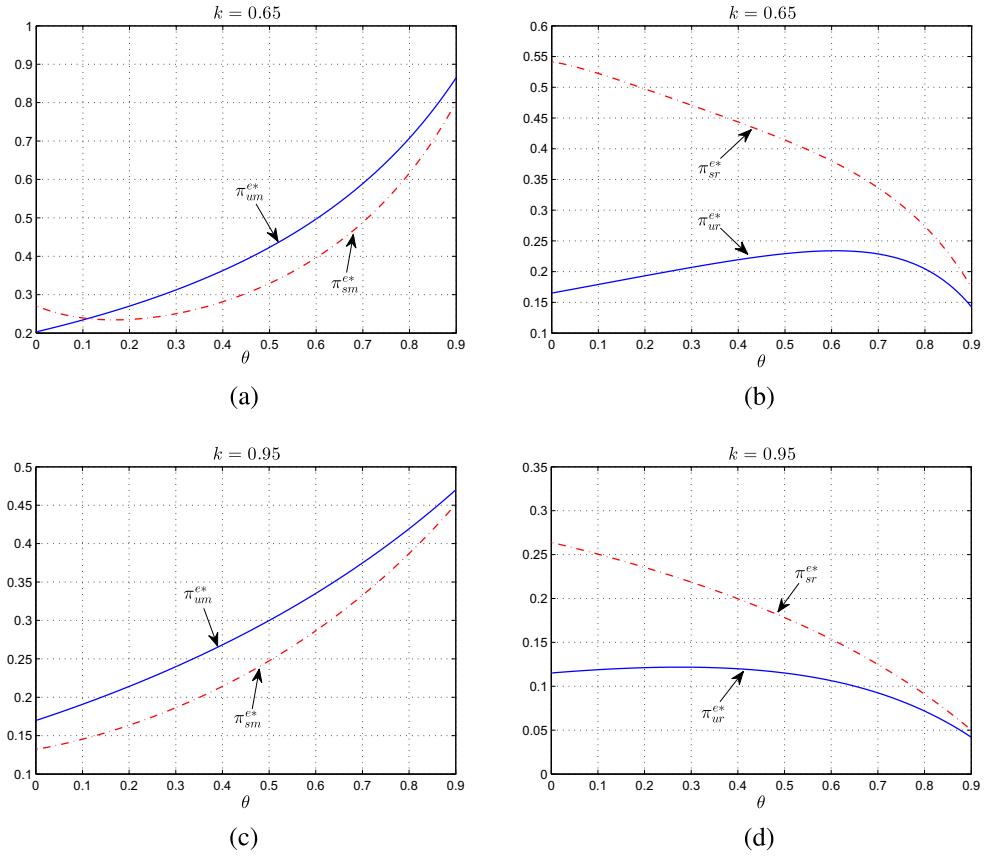


FIGURE 7. The effects of θ on the profits of manufacturer and retailer under different power structures.

conflict dominates the positive effect of encroaching, thus, the incremental profit from encroaching can't cover the lost profit induced by channel conflict. This means the outcome of the manufacturer becomes worse off with encroaching. When the quality investment efficiency is relatively high but consumers' acceptance on the direct channel is high, these effects are reversed. So the outcome of the manufacturer would becomes better off with encroaching ($\pi_{sm}^{e*} - \pi_{sm}^{n*} > 0$). Combining above analysis, for the retailer, we should point out that relatively large attractiveness of the retailer channel may be an effective anti-encroachment way in a retailer-led setting supply chain.

From Figure 6(b), we find that when the quality investment efficiency is relatively low, *i.e.*, k is relatively high, the manufacturer is always better off with encroaching ($\pi_{sm}^{e*} - \pi_{sm}^{n*} > 0$). This result is independent of the extent of consumers' acceptance on the direct channel. The incremental profit from encroaching dominates the lost profit induced by channel conflict when the quality investment efficiency is relatively low, thus, encroaching always makes the manufacturer better off.

Next, we will show how changes in parameter θ affect the profits of the manufacturer and retailer under different power structures, as shown in the following figures. We set k in the sequel values as $k = 0.65, 0.95$.

Figure 7(a) and (c) depicts how changes in parameter θ affect the profits of the manufacturer under different power structures. We can find that π_{um}^{e*} is always increasing as θ increases. This is intuitive. When the manufacturer acts the leader of the supply chain, he is able to rely on its dominant position and encroaching channel

to reap profit. Thus, an increasing in the extent of consumers' acceptance on the direct channel has a positive effect on the profit of the manufacturer.

However, when the retailer acts the leader of the supply chain, the result is conditional on k. In a retailer-led setting supply chain, Figure 7(a) shows that the manufacturer's profit first decreases and then increases as θ increases when k is relatively low. When the quality investment efficiency is relatively high, the manufacturer has an incentive to improve product quality. The dominant retailer can rely on the dominant position and increasing demand induced by improving product quality to set a more aggressively selling price to reap profit, which hurts the manufacturer. This negative competition effect from channel conflict dominates the positive effect of encroaching resulting in the incremental profit from encroaching can't cover the lost profit when the extent of consumers' acceptance on the direct channel is low. Thus, the manufacturer's profit is decreasing in θ. When the extent of consumers' acceptance on the direct channel becomes high, the positive effect of encroaching will dominates the negative competition effect from channel conflict, which indicates the manufacturer's profit will be increasing in θ. When the quality investment efficiency is relatively low, the manufacturer has no incentive to improve product quality. Under this condition, channel conflict and the reduced product demand induce the retailer to set a less aggressively selling price, which will soften the retailer's dominant position. The manufacturer can reap profit from the encroaching channel. So an increasing in the extent of consumers' acceptance on the direct channel exhibits a positive effect on the manufacturer's profit.

Figure 7(b) and (d) shows that the retailer's profit is always decreasing in θ with a retailer-led setting supply chain. From the retailer's perspective, manufacturer encroachment can dampen its dominant position. So an increasing in the extent of consumers' acceptance on the direct channel exhibits a negative effect on the retailer's profit. However, when the manufacturer acts the leader of the supply chain, both Figure 7(b) and (d) illustrates that the retailer's profit first increases and then decreases as θ increases. Recall Proposition 4.1, we show that the product quality is always improved with manufacturer encroachment when the manufacturer acts the leader in a supply chain. For the retailer, the incremental profit from boosting retailer's demand induced by the improved quality dominates the portion of the retailer's channel profit lost to the direct channel when the extent of consumers' acceptance on the direct channel is relatively low, and θ has a positive effect on q_u^{e*} ($\frac{\mathrm{d}q_u^{e*}}{\mathrm{d}\theta} > 0$), thus, the retailer's profit is first increasing as the extent of consumers' acceptance on the direct channel becomes higher. As θ increases, the effects are reversed, *i.e.*, the portion of the retailer's channel profit lost to direct channel dominates the incremental profit from boosting retailer's channel demand induced by improved quality, thus, the retailer's profit is decreasing as the extent of consumers' acceptance on the direct channel continuously increases.

4.3. The equilibrium strategies

We consider the case that the manufacturer has an option to choose encroaching or not, and the retailer can decide to whether occupy the leader of the supply chain or abandon the leader position. Abandoning the leader position of the supply chain for the retailer means the manufacturer takes over the leader of the supply chain. For simply notation, we apply "N" to denote the case that the manufacturer does not encroach, "Y" to denote the case that the manufacturer encroaches, "A" to denote the case that the retailer abandons the right of leader, "O" to denote the case that the retailer occupies the right of leader. The sequence of events occurs as follows: First, the manufacturer decides encroaching or not and the retailers decides occupying the right of leader or not. Then, according to the power structure, the quality level of product and the wholesale price are decided by the manufacturer; the selling price is set by the retailer. If there exists a direct channel, the manufacturer sets the direct price. After that, the profits of the manufacturer and the retailer are realized.

There are four game cases between the manufacturer and the retailer: manufacturer does not encroach and retailer abandons the right of leader (denoted by "NA"); manufacturer does not encroach and retailer occupies the right of leader (denoted by "NO"); manufacturer encroaches and retailer abandons the right of leader (denoted by "YA"); manufacturer encroaches and retailer occupies the right of leader (denoted by "YO"). Recalling Propositions 3.1–3.4, we summary the payoffs associated with each cases in the matrix below (Tab. 3).

TABLE 3. The payoffs associated with four cases.

	Case "A" for retailer	Case "O" for retailer
Case "N" for manufacturer	$(\pi_{um}^{n*}, \pi_{ur}^{n*})$	$(\pi_{sm}^{n*}, \pi_{sr}^{n*})$
Case "Y" for manufacturer	$(\pi_{um}^{e*}, \pi_{ur}^{e*})$	$(\pi_{sm}^{e*}, \pi_{sr}^{e*})$

Comparing profits across the subgames, the pure strategy equilibriums for the manufacturer and the retailer are given in the following proposition.

Proposition 4.4. *The equilibrium strategies for the manufacturer and the retailer are as follows:*

(i) For the retailer, abandoning the leader position of the supply chain is never the optimal strategy no matter the manufacturer encroaches or not.

(ii) When $\frac{1}{2} < k < \frac{3+\sqrt{3}}{6}$ *and* $0 < \theta < \tau$*, the manufacturer chooses to not encroach while the retailer chooses to occupy the leader position; otherwise, the manufacturer chooses to encroach while the retailer chooses to occupy the leader position.*

Here, the threshold τ *is the solution to* $f(\theta) = 0$*, where* $f(\theta)$ *is given in the Appendix.*

The various equilibrium outcomes in Proposition 4.4 is illustrated in the following Figure 8.

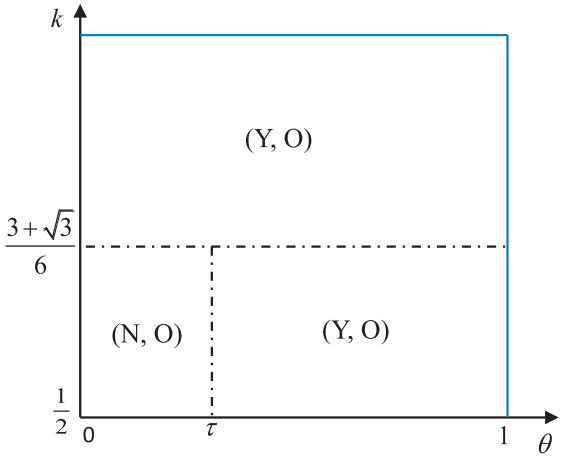


FIGURE 8. The equilibriums of Proposition 4.4.

Proposition 4.4 is driven by the quality investment efficiency (k) and the extent of consumers' acceptance on the direct channel (θ). When the quality investment efficiency is relatively high (k is low) and consumers are biased towards retail channel (θ is low), the manufacturer does not encroach while the retailer occupies the leader position. The manufacturer has no incentive to establish encroaching channel facing a low quality investment cost and direct channel attractiveness. When consumers are biased towards encroachment channel (θ is high), the equilibrium outcome deviates to the "YO", *i.e.*, the manufacturer chooses to encroach while the retailer chooses to occupy the leader position. A high direct channel attractiveness can induce manufacturer to establish the direct channel.

When the quality investment efficiency is relatively low (k is high), the equilibrium outcome is always at "YO". This equilibrium is independent on θ, which indicates consumer's channel preference does not effect

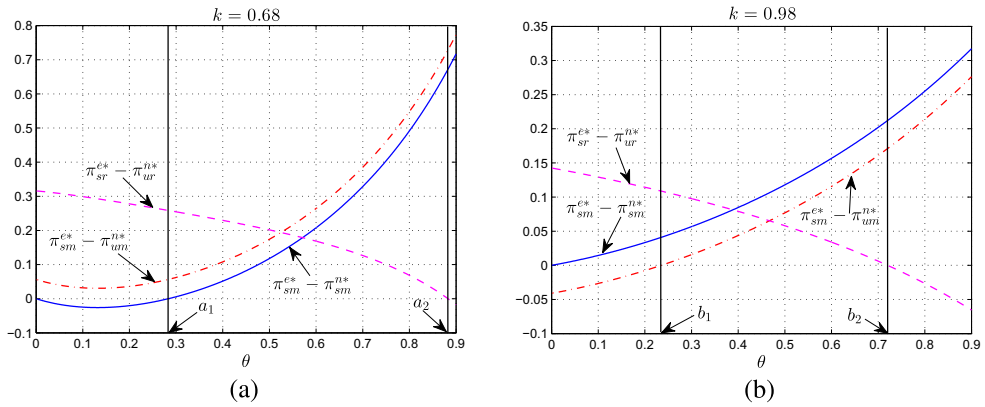


FIGURE 9. Profit implications of option of encroaching and striving for leader position.

the equilibrium strategies. Facing a relatively high quality investment cost, the manufacturer always has an incentive to encroach for snatching profit from encroaching channel to make up for the cost inferiority.

Furthermore, the equilibrium outcomes in Proposition 4.4 indicate that, for the retailer, occupying the leader position in the supply chain is always the optimal choice. A leader position always benefits the retailer. From the manufacturer's perspective, establishing encroaching channel and occupying the leader position simultaneously is always not the optimal choice, which is counterintuitive. This can be explained as follows. We can find that $q_s^{n*} > q_u^{n*}$ and $q_s^{e*} > q_u^{e*}$ always hold. That is to say, the optimal quality level in a retailer-led supply chain is always higher than that in a manufacturer-led supply chain no matter encroaching channel exists or not. For the manufacturer, the positive effect of an increasing quality level resulted from abandonment of the leader position dominates the effect of occupying the leader position. Thus, the manufacturer should abandon leadership of the supply chain when having the right of designing the quality level no matter establishing encroaching channel or not. The dominant position in the supply chain does not always mean a higher profit for the manufacturer. In practice, the number of powerful retailers, such as Wal-Mart and Amazon, is increasing, which changes the power structure of the supply chain. The above results give insights on the option of encroaching and the preferences for leadership/followership for supply chain members, suggesting some guidelines for decision making.

In the following, we resort to numerical study to identify the profit implications of the option of encroaching and striving for leader position. In this light, we compare the equilibrium profits in the case where the manufacturer encroaches and the retailer occupies the leader position with the profits under the case where the manufacturer does not encroach and the retailer abandons the right of leader. We set the k in the sequel at the following values as $k = 0.68, 0.98$. The following figures illustrate the results.

For the manufacturer and the retailer, Figure 9 illustrate that the option of encroaching and striving for leader position in a supply chain can result in three distinct profit predictions: lose-win, win-win, and win-lose.

Figure 9(a) shows the option of encroaching and striving for leader position in a supply chain can result in win-win and win-lose situations when the quality investment efficiency is relatively high (k is small). From 9(a), we can find $\pi_{sm}^{e*} - \pi_{sm}^{n*} > 0$ when $\theta > a_1$, meaning the equilibrium outcome is always at "YO", *i.e.*, the manufacturer chooses to encroach while the retailer chooses to occupy the leader position. If $a_1 < \theta < a_2$, *i.e.*, the extent of consumers' acceptance on the direct channel is medium, $\pi_{sm}^{e*} - \pi_{um}^{n*} > 0$ and $\pi_{sr}^{e*} - \pi_{ur}^{n*} > 0$, which mean the manufacturer and the retailer enjoy a win-win situation. The manufacturer can benefit from encroaching when there is a relatively high quality investment efficiency and a moderate extent of consumers' acceptance on the direct channel, while these conditions can not hurt retailer's leader position, leading to a win-win situation. When $\theta > a_2$, as shown in Figure 9(a), $\pi_{sm}^{e*} - \pi_{um}^{n*} > 0$ and $\pi_{sr}^{e*} - \pi_{ur}^{n*} < 0$. As θ increases, the retailer is dampened by consumers' bias towards encroachment channel, thus, a win-lose situation is derived.

From Figure 9(b), we can find that $\pi_{sm}^{e*} - \pi_{sm}^{n*} > 0$, meaning the equilibrium outcome is always at "YO". As shown in Figure 9(b), $\pi_{sm}^{e*} - \pi_{um}^{n*} < 0$ and $\pi_{sr}^{e*} - \pi_{ur}^{n*} > 0$ when $\theta < b_1$. In other words, the equilibrium outcome is a lose-win situation. This can be explained as follows. When the quality investment efficiency is relatively low (k is high) and θ ($\theta < b_1$) is low, the manufacturer faces a high quality investment cost and a low extent of consumers' acceptance on the direct channel. Meanwhile, the retailer crushes the manufacturer to reap profit relying on its leader position. All these factors have negative effects on the manufacturer's profit. Thus, for the manufacturer, if the extent of consumers' acceptance on the direct channel is relatively low, the gain in encroaching can not compensate for the loss from a high quality investment cost and inferior position, allowing the manufacturer to earn a lower profit with encroachment channel. For the dominant retailer, channel conflict induces the manufacturer to reduce a lower wholesale price to promote product demand in the retailer's channel, allowing the retailer to reap a higher profit with an increasing demand. This result makes contribution to the literature on encroachment. At the pure equilibrium outcome, establishing encroachment channel can benefit the retailer but hurt the manufacturer itself under certain condition.

When the extent of consumers' acceptance on the direct channel is moderate, *i.e.*, $b_1 < \theta < b_2$ as shown in Figure 9(b), $\pi_{sm}^{e*} - \pi_{um}^{n*} > 0$ and $\pi_{sr}^{e*} - \pi_{ur}^{n*} > 0$. This implies that manufacturer encroaching and retailer occupying leader position increase profits for the manufacturer and the retailer, leading to a win-win situation. Although facing a high quality investment cost, the manufacturer can benefit from encroachment with a moderate extent of consumers' acceptance on the direct channel. For the retailer, the positive effect of the leader position also outweighs the negative effect from channel conflict, so the retailer enjoys an increasing profit. As $\theta > b_2$, *i.e.*, the extent of consumers' acceptance on the direct channel is relative high, $\pi_{sm}^{e*} - \pi_{um}^{n*} > 0$ and $\pi_{sr}^{e*} - \pi_{ur}^{n*} < 0$, meaning a win-lose situation as shown in Figure 9(b). A relative high extent of consumers' acceptance on the direct channel benefits the manufacturer with encroaching while it hurts the retailer. The negative effect from channel conflict outweighs the positive effect of the leader position with a relative high extent of consumers' acceptance on the direct channel, the retailer becomes worse off.

Combining above analysis, our results indicate that a moderate extent of consumers' acceptance on the direct channel benefits both manufacturer and retailer. When the extent of consumers' acceptance on the direct channel is neither too small nor too large, it is possible for the manufacturer and the retailer to reach a win-win situation from manufacturer encroaching and retailer occupying leader position.

5. Numerical study

In this section, we employ numerical studies to illustrate the analytical results about the effect of manufacturer's encroachment presented in Proposition 4.1. Figure 10 depict the effect of manufacturer's encroachment on the wholesale price and selling price of the retail channel when the manufacturer acts the leader with θ taking the value of 0.1.

From Figure 10, we can clearly find that the results are conditional on k. For the wholesale price, Figure 10(a) shows that $w_u^{n*} < w_u^{e*}$ when k is below the threshold $\frac{8+\theta}{4(1-\theta)}$ and otherwise. From Proposition 4.1, we have q_u^{e*} is always bigger than q_u^{n*}. Thus, when the quality investment efficiency is relatively high, the manufacturer has an incentive to increase wholesale price. Otherwise, a relatively low efficiency in quality investment dampens the manufacturer incentive to rely on the encroachment channel, thus, the manufacturer applies a lower wholesale price to boost product's demand. For the selling price of the retail channel, Figure 10(b) shows that, when the quality investment efficiency is relatively high, the retailer has an incentive to increase selling price with a higher wholesale price, because the positive effect of boosting demand from an increasing quality level dominates the negative competition effect from manufacturer encroachment under this condition. Otherwise, the retailer has to apply a lower wholesale price to maintain product's demand.

Next, we give numerical examples to show the effect of manufacturer's encroachment with the retailer being the leader. Figure 11 depicts the effect of manufacturer's encroachment on the wholesale price, product quality and selling price of the retail channel when the retailer acts the leader with θ taking the value of 0.4.

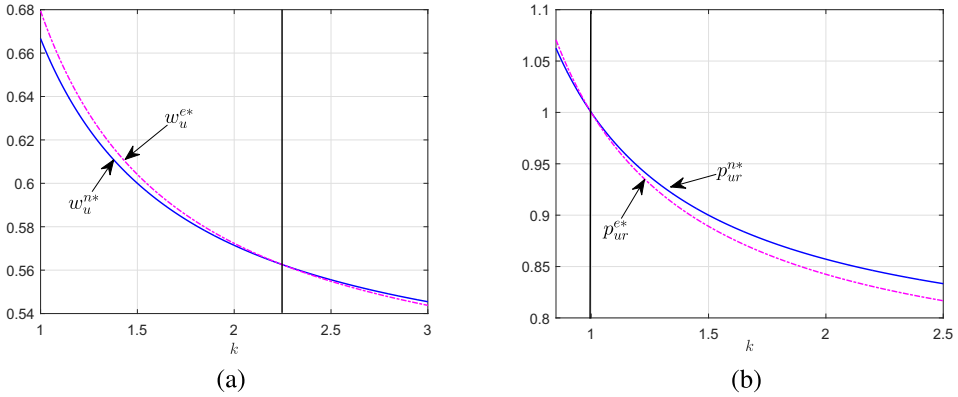


FIGURE 10. The effect of encroachment on wholesale price and selling price when manufacturer acts leader.

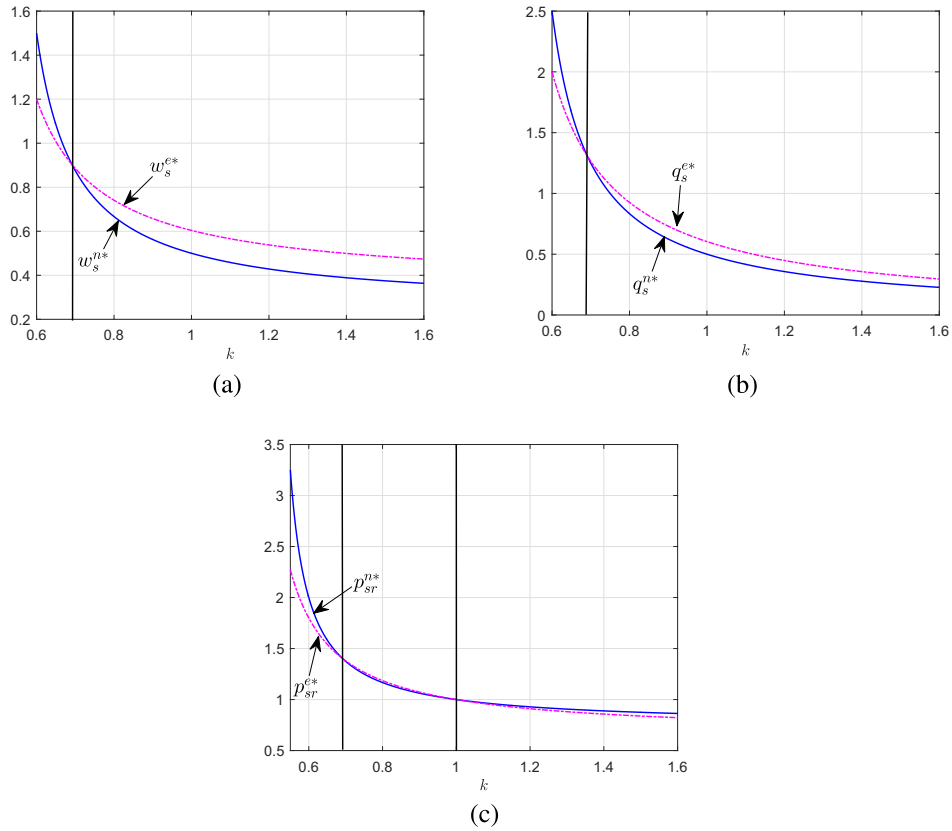


FIGURE 11. The effect of encroachment on wholesale price, product quality and selling price of direct channel when retailer acts leader.

From Figure 11, we can clearly find that the results are also conditional on k. Figure 11(b) illustrates that when k is relatively low, the manufacturer would cut down the product quality level, otherwise, the manufacturer can increase product quality level. The manufacturer has no incentive to promote the product quality level, and would shifts to rely more on the encroachment channel to compete with the retailer, facing a relatively high demand of both channels. Sequentially, the wholesale price is decreased, as shown in Figure 11(a). For the selling price of the retail channel, Figure 11(c) clearly shows that the results are also conditional on k. There are two thresholds k_1 and k_2 as demonstrated by Proposition 4.1. We have $p_{sr}^{e*} < p_{sr}^{n*}$ when $\frac{1}{2} < k < k_1$ or $k > k_2$, otherwise, we have $p_{sr}^{e*} \geq p_{sr}^{n*}$. The retailer can set a lower selling price of the retail channel if encroaching channel exists with facing a relatively high quality investment efficiency or a relatively low quality investment efficiency. When the quality investment efficiency is moderate, the retailer can decide a higher selling price of the retail channel.

6. Extension: The effect of a fixed cost for encroachment

In this section, we consider the case that opening a direct channel for the manufacturer incurs a fixed cost. Following [26], it is assumed that there exists a fixed cost F for establishing a direct channel. Denote $F_e = \pi_{sm}^{e*} - \pi_{sm}^{n*}$ and $F_m = \pi_{sm}^{e*} - \pi_{um}^{n*}$. Recalling Proposition 4.4, we obtain $\pi_{sr}^{n*} - \pi_{ur}^{n*} > 0$ and $\pi_{sr}^{e*} - \pi_{ur}^{e*} > 0$ always hold. Thus, with the fixed cost, the equilibrium strategy for the manufacturer and the retailer is also at either "NO" or "YO". Next, we employ a numeral study to show how the fixed cost affects the equilibrium outcomes. We also set the k in the sequel at the following values as $k = 0.68, 0.98$. The following figures show the results.

According to Figure 12, some observations are presented. From Figure 12, we can observe that $\pi_{sm}^{e*} - \pi_{sm}^{n*} > 0$ when F is below F_e, indicating the equilibrium strategies are at "YO"; $\pi_{sm}^{e*} - \pi_{sm}^{n*} < 0$ when F is above F_e, indicating the equilibrium strategies are at "NO". Intuitively, with considering the fixed cost F, the manufacturer's decision on encroachment is mainly dependent on F. When facing a small fixed cost, the manufacturer will decide to encroach, otherwise, the manufacturer will not encroach. For the profit implication, the main difference with introducing a fixed cost F is that there exists a prisoner's dilemma when the equilibrium strategies "YO" are adopted by chain members. From Figure 12(b), when the fixed cost is moderate ($F_m < F < F_e$), $\pi_{sm}^{e*} - \pi_{sm}^{n*} > 0$, meaning "YO" is the equilibrium strategy. For the profits of chain members, as shown in Figure 12(b), we have $\pi_{sr}^{e*} - \pi_{ur}^{n*} < 0$ and $\pi_{sm}^{e*} - \pi_{um}^{n*} < 0$ due to $F > F_m$. In other words, with a low quality investment efficiency, a moderately fixed cost and a high extent of consumers' acceptance on the direct channel ($\theta > d_1$), for the manufacturer, although encroaching is a better choice, encroaching brings less profit ($\pi_{sm}^{e*} - \pi_{um}^{n*} < 0$). Similarly, for the retailer, occupying the leadership of the supply chain brings less profit than abandoning the leadership

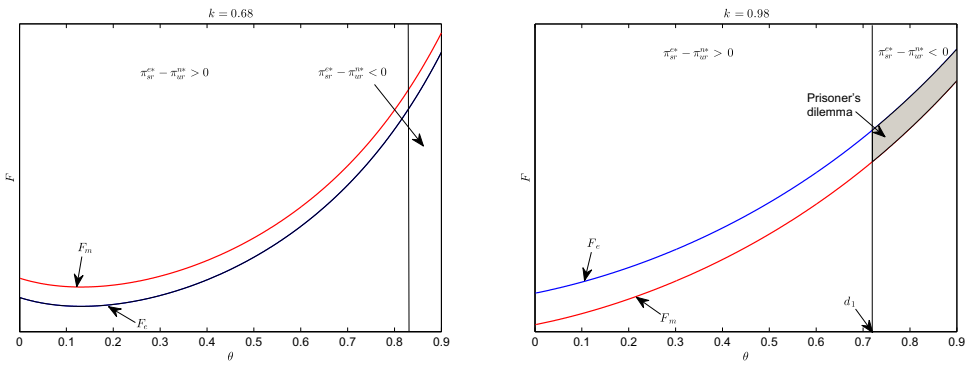


Figure 12. The effect of fixed cost on the equilibrium outcomes.

($\pi_{sm}^{e*} - \pi_{um}^{n*} < 0$) even though it is an equilibrium strategy. As a result, there exists a prisoner's dilemma in the grey zone as shown in Figure 12(b).

From Figure 12, it is worth noting that the prisoner's dilemma zone will disappear when k and θ are relatively small (there does not exist prisoner's dilemma zone in Fig. 12(a)). Thus, improving the quality investment efficiency or reducing the extent of consumers' acceptance on the direct channel can be effective ways to escape from the prisoner's dilemma.

7. Conclusion

It is quite common today for a manufacturer to add a direct channel along with the traditional retail channel. With the diversification of the power structure in the supply chain, the incentives of choosing leadership/followership and the role of quality decision in opening encroachment channel with different power structures are intriguing but under-explored. In this paper, we study manufacturer encroachment problem with setting the product quality as an endogenous decision in the presence of different power structures of supply chain. We also investigate the interaction of manufacturer encroaching and the power structure of supply chain, and identify the profit implications of the option of encroaching and striving for leader position. The novel insights obtained from the model contribute to the theories of both encroachment and power structure in a supply chain.

We summary our main results in the following: First, we find that, in a manufacturer-led supply chain, encroachment could make both manufacturer and retailer better off when the quality investment efficiency is relatively high, resulting in a Pareto outcome. The profits of the manufacturer and the retailer may exhibit nonmonotonicity with respect to the extent of consumers' acceptance on the direct channel. Second, we show that the quality investment efficiency and the extent of consumers' acceptance on the direct channel derive the pure equilibrium outcomes. The results suggest that, for the manufacturer, establishing encroaching channel and occupying the leader position simultaneously is always not the optimal choice. Moreover, the option of encroaching and striving for leader position in a supply chain can lead to lose-win, win-win, and win-lose situations for the manufacturer and the retailer. Finally, with considering a fixed cost of opening a direct channel, there exists a prisoner's dilemma with a low quality investment efficiency, a moderately fixed cost and a high extent of consumers' acceptance on the direct channel. These results provide new insights to the literature on encroachment.

Our research can be extended in the following directions. Our model set that consumers are homogeneous in their appreciation of product quality. Future study can investigate the effect of heterogeneity in quality preferences, and allow this heterogeneity to be correlated with consumers' willingness to pay for the product [39]. Additionally, future research can investigate consumers' "Showrooming". Showrooming describes the phenomenon that consumers visit a brick-and-mortar store to learn about products, and then they buy online to gain a lower price. It will be interesting to embrace this phenomenon in the future study.

Appendix A. Proof of Proposition 3.1

The backward induction is applied to solve for the optimal strategies of the manufacturer and the retailer. First, we calculate the optimal pricing policy for the retailer reacting to the wholesale prince and quality level. We apply the first-order condition to maximize the profit (3.3) w.r.t. the decision variables p_r, obtaining $p_{ur}^n = \frac{1+w+q}{2}$. Substituting it into the manufacturers objective function (3.4), we get $\pi_{um}^n = (1 + q + \frac{1}{2}(-1 - q - w))w - \frac{kq^2}{2}$. The manufacturer chooses w and q to maximize its profit. Applying the first-order condition, we obtain $w_u^{n*} = \frac{2k}{4k-1}$ and $q_u^{n*} = \frac{1}{4k-1}$. Substituting w_u^{n*} and q_u^{n*} into p_{ur}^n yields $p_{ur}^{n*} = \frac{3k}{4k-1}$. With the optimal wholesale price w_u^{n*}, the quality level of product q_u^{n*} and optimal selling price p_{ur}^{n*}, we can easily get the optimal profit of the manufacturer π_{um}^{n*} and the optimal profit of the retailer π_{ur}^{n*}.

Appendix B. Proof of Proposition 3.2

When the direct channel is established along with the retailer channel, the profits of the manufacturer and the retailer are given as (3.10) and (3.11), respectively. Following the time line mentioned in the main body, we first calculate the retailer channel price p_{ur}^e and the direct channel p_{um}^e. The manufacturer and the retailer set the selling prices p_{ur}^e and p_{um}^e to maximize their profits. Employing the first-order condition yields

$$p_{ur}^e = 2 + 2q - w + \frac{6(1+q-w)}{-4+\theta},\ p_{um}^e = \frac{\theta(-1-3w+q(-1+\theta)+\theta)}{-4+\theta}. \tag{B.1}$$

Substituting equation (B.1) into (3.10), we can get the manufacturer's profit as

$$\pi_{um}^e = -\frac{kq^2(-4+\theta)^2 + 2(-1-q+w)(-(1+q)(-1+\theta)\theta + w(8+\theta))}{2(-4+\theta)^2}. \tag{B.2}$$

We apply the first-order condition to maximize the manufacturer's profit value w.r.t. the decision variables w and q, giving

$$w_u^{e*} = \frac{k(8+\theta^2)}{2k(8+\theta)-(2+\theta)^2},\ q_u^{e*} = \frac{(2+\theta)^2}{2k(8+\theta)-(2+\theta)^2}. \tag{B.3}$$

Substituting (B.3) into (B.1) and solving equation (B.1) simultaneously, we obtain that

$$p_{ur}^{e*} = \frac{k(12-\theta(2+\theta))}{2k(8+\theta)-(2+\theta)^2},\ p_{um}^{e*} = \frac{k\theta(10-\theta)}{2k(8+\theta)-(2+\theta)^2}. \tag{B.4}$$

With the optimal wholesale price w_u^{e*}, the quality level of product q_u^{e*} and optimal selling prices p_{ur}^{e*} and p_{um}^{e*}, we can easily get the optimal profit of the manufacturer π_{um}^{e*} and the optimal profit of the retailer π_{ur}^{e*}.

Appendix C. Proof of Proposition 3.3

In the retailer-led Stackelberg game, first, the manufacturer chooses w and q to maximize its profit (3.18). We apply the first-order condition to maximize the manufacturer's profit value w.r.t. the decision variables w and q, giving

$$w_s^n = \frac{k(1-m)}{2k-1},\ q_s^n = \frac{1-m}{2k-1}. \tag{C.1}$$

Substituting equation (C.1) into (3.19), we can get the retailer's profit as

$$\pi_{ur}^n = \frac{k(1-m)m}{2k-1}. \tag{C.2}$$

We apply the first-order condition to maximize the profit (C.2) w.r.t. the decision variable retailer margin m, obtaining $m^* = \frac{1}{2}$. Substituting m^* into (C.1), we can get w_s^{n*} and q_s^{n*}. The optimal selling price for the retailer channel $p_{sr}^{n*} = m^* + w_s^{n*} = \frac{3k-1}{4k-2}$. With the optimal wholesale price w_s^{n*}, the quality level q_s^{n*} and optimal selling price p_{sr}^{n*}, we can easily get the optimal profit of the manufacturer π_{sm}^{n*} and the optimal profit of the retailer π_{sr}^{n*}.

Appendix D. Proof of Proposition 3.4

In the retailer-led Stackelberg game, the profits of the manufacturer and the retailer are given as (3.25) and (3.26) respectively when the direct channel is established along with the retailer channel. The manufacturer first sets w and q to maximize its profit. By solving the first-order conditions, we can obtain

$$w_s^e = -\frac{k(-1+m-2p_m+\theta)}{-1+2k+\theta},\ q_s^e = -\frac{-1+m-2p_m+\theta}{-1+2k+\theta}. \tag{D.1}$$

Substituting equation (D.1) into (3.25) and (3.26), we can obtain the profits for the manufacturer and the retailer respectively as

$$\pi_{sm}^{e} = -\frac{2(-1+2k)p_m^2(-1+\theta) - 2(2k-m)p_m(-1+\theta)\theta + k\theta(-1+m+\theta)^2}{2(-1+\theta)\theta(-1+2k+\theta)}, \tag{D.2}$$

$$\pi_{sr}^{e} = \frac{m(p_m(-1+\theta) + k(-1+m+\theta))}{(-1+\theta)(-1+2k+\theta)}. \tag{D.3}$$

The manufacturer and the retailer set the selling price of the direct channel p_{sm}^{e} and the retailer margin of the retail channel m to maximize their profits, respectively. Employing the first-order condition yields

$$m_s^* = -\frac{2k(-1+\theta)(-1+2k+\theta)}{-4k+8k^2+\theta-\theta^2},\ p_{sm}^{e*} = \frac{k\theta(-1+4k+\theta)}{-4k+8k^2+\theta-\theta^2}. \tag{D.4}$$

Substituting (D.4) into (D.1), we can get w_s^{e*} and q_s^{e*}. The optimal selling price for the retailer channel $p_{sr}^{e*} = m_s^* + w_s^{e*} = \frac{k(2-2k-5\theta+6k\theta+3\theta^2)}{8k^2-4k+\theta-\theta^2}$. With the optimal wholesale price w_s^{e*}, the quality level q_s^{e*} and optimal selling prices p_{sr}^{e*} and p_{sm}^{e*}, we can easily get the optimal profit of the manufacturer π_{sm}^{e*} and the optimal profit of the retailer π_{sr}^{e*}.

Appendix E. Proof of Proposition 4.1

We first compare the strategies with manufacturer encroaching to that without manufacturer encroaching under manufacturer-led setting. For the wholesale prices, it can be calculated that $w_u^{e*} - w_u^{n*} = \frac{k\theta(8+4k(-1+\theta)+\theta)}{(-(2+\theta)^2+2k(8+\theta))(4k-1)}$. Since $0 < \theta < 1$ and $k > \frac{1}{2}$, it is easily to obtain $-(2+\theta)^2 + 2k(8+\theta) > 0$ and $4k-1 > 0$. Thus, it can obtained a threshold $\frac{8+\theta}{4(1-\theta)}$ such that $w_u^{e*} > w_u^{n*}$ when $\frac{1}{2} < k < \frac{8+\theta}{4(1-\theta)}$ and $w_u^{e*} \le w_u^{n*}$ when $k \ge \frac{8+\theta}{4(1-\theta)}$.

For the product quality, it can be calculated that $q_u^{e*} - q_u^{n*} = \frac{2k\theta(7+2\theta)}{(4k-1)(-(2+\theta)^2+2k(8+\theta))} > 0$. Thus, we have $q_u^{e*} > q_u^{n*}$.

For the selling prices, we have $p_{ur}^{e*} - p_{ur}^{n*} = \frac{2(1-k)k\theta(7+2\theta)}{(4k-1)(-(2+\theta)^2+2k(8+\theta))}$. We can obtain $p_{ur}^{e*} > p_{ur}^{n*}$ when $\frac{1}{2} < k < 1$ and $p_{ur}^{e*} \le p_{ur}^{n*}$ when $k \ge 1$. Since $0 < \theta < 1$, we have $\frac{8+\theta}{4(1-\theta)} > 1$. Thus, one can get the results shown in Figure 3(a).

Next, we compare the strategies with manufacturer encroaching to that without manufacturer encroaching under retailer-led setting. Let $A = 16+2\theta(-8+3\theta)+\sqrt{64+2\theta(-5+3\theta)(20+\theta(-13+6\theta))}$ to simplify notation. For the wholesale prices and product quality, we have $w_s^{e*} - w_s^{n*} = \frac{k\theta(1+8k^2-\theta+k(-8+4\theta))}{(-4k+8k^2+\theta-\theta^2)(4k-2)}$ and $q_s^{e*} - q_s^{n*} = \frac{\theta(1+8k^2-\theta+k(-8+4\theta))}{(-4k+8k^2+\theta-\theta^2)(4k-2)}$. Since $0 < \theta < 1$ and $k > \frac{1}{2}$, it is easily to obtain $-4k+8k^2+\theta-\theta^2 > 0$ and $4k-2 > 0$. Denote $f_1(k) = 1+8k^2-\theta+k(-8+4\theta)$. We can find that the signs of $w_s^{e*} - w_s^{n*}$ and $q_s^{e*} - q_s^{n*}$ are dependent on $f_1(k)$. Note that the function $f_1(k)$ is convex in k. Solving the root for $f_1(k)$ gives a threshold $k_1 = \frac{2-\theta+\sqrt{2+\theta(\theta-2)}}{4}$. Then, when $\frac{1}{2} < k < k_1$, $f_1(k) < 0$ giving $w_s^{e*} < w_s^{n*}$ and $q_s^{e*} < q_s^{n*}$; when $k \ge k_1$, $f_1(k) \ge 0$ giving $w_s^{e*} \ge w_s^{n*}$ and $q_s^{e*} \ge q_s^{n*}$.

For the selling prices, we have $p_{sr}^{e*} - p_{sr}^{n*} = \frac{\theta(1-8k^3+k^2(16-4\theta)-\theta+k(-9+5\theta))}{(-4k+8k^2+\theta-\theta^2)(4k-2)}$. We denote

$$f_2(k) = 1-8k^3+k^2(16-4\theta)-\theta+k(-9+5\theta)). \tag{E.1}$$

It is found that the sigh of $p_{sr}^{e*} - p_{sr}^{n*}$ is dependent on $f_2(k)$. Note that $f_2(k)$ is a cubic function in k. Calculating $\frac{\mathrm{d}f_2(k)}{\mathrm{d}k} = -24k^2+k(32-8\theta)+5\theta-9$. Denote $f_3(k) = -24k^2+k(32-8\theta)+5\theta-9$. $f_3(k)$ is a concavely quadratic function in k, and its symmetry axis is $\frac{(4-\theta)}{6}$. It can be verified that $\frac{(4-\theta)}{6} > \frac{1}{2}$. And $f_3(\frac{1}{2}) = 1+\theta > 0$. Solving the root for $f_3(k) = 0$ gives a stationary point $t = \frac{8-2\theta+\sqrt{10-2\theta+4\theta^2}}{12}$ such that $f_3(k) > 0$ when $\frac{1}{2} < k < t$ and

$f_3(k) \le 0$ when $k \ge t$. Thus, $f_2(k)$ is increasing when $\frac{1}{2} < k < t$ and decreasing when $k \ge t$. Furthermore, we can obtain $f_2(\frac{1}{2}) = \frac{\theta-1}{2} < 0$ and $f_2(t) > 0$. Consequently, there exists two roots belonging to $(\frac{1}{2}, +\infty)$such that $f_2(k) = 0$. Solving the roots for $f_2(k) = 0$ gives $k_1 = \frac{2-\theta+\sqrt{2+\theta(\theta-2)}}{4}$ and $k_2 = 1$. If $\frac{1}{2} < k < k_1$ or $k > k_2$, $f_2(k) < 0$, giving $p_{sr}^{e*} < p_{sr}^{n*}$; if $k_1 \le k \le k_2$, $f_2(k) \ge 0$, giving $p_{sr}^{e*} \ge p_{sr}^{n*}$. Combing the results, one can obtain that there exists two thresholds k_1 and k_2 such that if $\frac{1}{2} < k < k_1$ or $k > k_2$, we have $p_{sr}^{e*} < p_{sr}^{n*}$, and if $k_1 \le k \le k_2$, we have $p_{sr}^{e*} \ge p_{sr}^{n*}$.

Appendix F. Proof of Proposition 4.2

We compare the manufacturers selling price decision under different power structures. It can be calculated that $p_{um}^{e*} - \pi_{sm}^{e*} = \frac{2k(1-\theta)\theta(-2+8k^2+3\theta-\theta^2-k(4+\theta))}{(2k(8+\theta)-(2+\theta)^2)(-4k+8k^2+\theta-\theta^2)}$. Since $0 < \theta < 1$ and $k > \frac{1}{2}$, the sign of $p_{um}^{e*} - \pi_{sm}^{e*}$ is dependent on the part $-2 + 8k^2 + 3\theta - \theta^2 - k(4 + \theta))$. Denote $f(k) = -2 + 8k^2 + 3\theta - \theta^2 - k(4 + \theta)$. Note that function $f(k)$ is convex in k. Solving the roots for $f(k)$ gives a threshold $r_1 = \frac{4+\theta+\sqrt{80+11\theta(3\theta-8)}}{16}$. When $\frac{1}{2} < k < \frac{4+\theta+\sqrt{80+11\theta(3\theta-8)}}{16}$, $f(k) < 0$ giving $p_{um}^{e*} < p_{sm}^{e*}$; when $k \ge \frac{4+\theta+\sqrt{80+11\theta(3\theta-8)}}{16}$, $f(k) > 0$ giving $p_{um}^{e*} \ge p_{sm}^{e*}$.

Appendix G. Proof of Proposition 4.3

When the manufacturer acts the leader of the supply chain, it can be calculated that $\pi_{um}^{e*} - \pi_{um}^{n*} = \frac{k^2\theta(7+2\theta)}{(4k-1)(-(2+\theta)^2+2k(8+\theta))}$. Since $0 < \theta < 1$ and $k > \frac{1}{2}$, it is easily to obtain $(4k - 1)(-(2 + \theta)^2 + 2k(8 + \theta)) > 0$, implying $\pi_{um}^{e*} > \pi_{um}^{n*}$. For the retailer's profit, one can get $\pi_{ur}^{e*} - \pi_{ur}^{n*} = \frac{-4(-1+\theta)(2+\theta)^2-(2+\theta)^4+k(32(-1+\theta)(2+\theta)^2+4(2+\theta)^2(8+\theta))+k^2(-64(-1+\theta)(2+\theta)^2-4(8+\theta)^2)}{((2+\theta)^2-2k(8+\theta))^2(1-4k)^2}$. Denote $f_4(k) = -4(-1+\theta)(2+\theta)^2-(2+\theta)^4+k(32(-1+\theta)(2+\theta)^2+4(2+\theta)^2(8+\theta))+k^2(-64(-1+\theta)(2+\theta)^2-4(8+\theta)^2)$. Since $0 < \theta < 1$, it is easily obtained that $f_4(k)$ is concave in k, and its symmetry axis is $\frac{16(-1+\theta)(2+\theta)^2+2(2+\theta)^2(8+\theta)}{64(-1+\theta])(2+\theta)^2+4(8+\theta)^2} < \frac{1}{2}$. Solving the root gives a threshold $t_1 = \frac{9\theta(4+\theta)+36+2\sqrt{(1-\theta)(2+\theta)^2(7+2\theta)^2}}{32+98\theta+32\theta^2}$. Thus, when $\frac{1}{2} < k < t_1$, $\pi_{ur}^{e*} - \pi_{ur}^{n*} > 0$, implying $\pi_{ur}^{n*} < \pi_{ur}^{e*}$; when $k \ge t_1$, $\pi_{ur}^{e*} - \pi_{ur}^{n*} \le 0$, implying $\pi_{ur}^{n*} \ge \pi_{ur}^{e*}$.

Appendix H. Proof of Proposition 4.4

First, we show that π_{sr}^{n*} is always larger than π_{ur}^{n*}. It can be calculated that $\pi_{sr}^{n*} - \pi_{ur}^{n*} = \frac{k(1-4k+8k^2)}{((1-4k)^2)(8k-4)}$. $1-4k+8k^2 > 0$ for any $k > \frac{1}{2}$, implying $\pi_{sr}^{n*} > \pi_{ur}^{n*}$. Next, we also show that π_{sr}^{e*} is always larger than π_{ur}^{e*}. It can be calculated that $\pi_{sr}^{e*} - \pi_{ur}^{e*} = \frac{4k^2(1-\theta)(k(-1+2k+\theta)((2+\theta)^2-2k(8+\theta))^2-(2+\theta)^2(4k-8k^2+(-1+\theta)\theta)^2)}{(4k-8k^2-\theta+\theta^2)^2((2+\theta)^2-2k(8+\theta))^2}$. It is noted that the sign of $\pi_{sr}^{e*} - \pi_{ur}^{e*}$ is dependent on the part $k(-1+2k+\theta)((2+\theta)^2-2k(8+\theta))^2-(2+\theta)^2(4k-8k^2+(-1+\theta)\theta)^2$. Denote $f_5(k) = \frac{k(-1+2k+\theta])((2+\theta)^2-2k(8+\theta))^2}{(2+\theta)^2(4k-8k^2+(-1+\theta)\theta)^2}$. We get $f_5(\frac{1}{2}) = \frac{(4+\theta)^2}{2\theta(2+\theta)^2} > 1$ for any $0 < \theta < 1$. And it can be noted that $f_5(k)$ is increasing in k. Then, $f_5(k) > 1$, giving $k(-1 + 2k + \theta)((2 + \theta])^2 - 2k(8 + \theta))^2 > (2+\theta)^2(4k-8k^2+(-1+\theta)\theta)^2$. Thus, $k(-1+2k+\theta)((2+\theta)^2-2k(8+\theta))^2-(2+\theta)^2(4k-8k^2+(-1+\theta)\theta)^2) > 0$, implying $\pi_{sr}^{e*} > \pi_{ur}^{e*}$. These results indicate that the pure equilibrium strategies for the manufacturer and the retailer is at either "NO" or "YO" ("N" denotes manufacturer does not encroach, "Y" denotes manufacturer encroaches, "O" to denote retailer occupies the right of leader). Denote $\Delta = \pi_{sm}^{e*} - \pi_{sm}^{n*}$. Next, we can obtain that

$$\Delta = \frac{2k\theta(192k^4 + 96k^3(-3 + \theta) + 3(-1 + \theta)^2\theta - 8k(2 + (-3 + \theta)\theta^2) - 16k^2(-8 + \theta(4 + \theta)))}{2(4k - 8k^2 + (-1 + \theta)\theta)^2(16k - 8)}. \tag{H.1}$$

It can be found that the sign of Δ is dependent on

$$f(\theta) = 192k^4 + 96k^3(-3 + \theta) + 3(-1 + \theta)^2\theta - 8k(2 + (-3 + \theta)\theta^2) - 16k^2(-8 + \theta(4 + \theta)). \tag{H.2}$$

$f(\theta)$ is a in cubic function in θ. Calculating the derivatives of $f_6(k)$ in θ, one can easily get $\Delta' = 3 - 64k^2 + 96k^3 + (-12 + 48k - 32k^2)\theta + (9 - 24k)\theta^2$. And $\Delta'(1) = 24(1-2k)^2k > 0$, $\Delta'(0) = 3 + 32k^2(-2 + 3k)$. Note that Δ' is a concave function in θ. Thus, if $\Delta'(0) > 0$, we have $\Delta' > 0$ for any $0 < \theta < 1$. If $\Delta'(0) < 0$, there exists a stationary point s such that $\Delta' = 0$, implying $f(\theta)$ first decreases and the increases in θ. Numerically, we can get when $k \approx 0.571$ such that $\Delta'(0) = 0$. Thus, when $\frac{1}{2} < k < 0.571$, $\Delta'(0) < 0$ for $0 < \theta < s$ and $\Delta'(0) > 0$ for $s < \theta < 1$. Furthermore, we can get $f(1) = 48(1-2k)^2k^2 > 0$ and $f(0) = 16k(2k-1)(1 + 6(-1+k)k)$. When $\frac{1}{2} < k < \frac{3+\sqrt{3}}{6}$, $f(0) < 0$, when $k \geq \frac{3+\sqrt{3}}{6}$, $f(0) \geq 0$. Note that $\frac{3+\sqrt{3}}{6} > 0.571$. Combining these analysis, when $\frac{1}{2} < k < \frac{3+\sqrt{3}}{6}$, $f(\theta)$ has two cases: (1) $f(\theta)$ is increasing in θ, (2) $f(\theta)$ first decreases and then increases in θ. Recalling $f(0) < 0$ if $\frac{1}{2} < k < \frac{3+\sqrt{3}}{6}$, we can obtain there exists a threshold τ such that $\Delta < 0$ if $0 < \theta < \tau$ and $\Delta > 0$ if $\tau < \theta < 1$ where τ is the solution to $f(\theta) = 0$. When $k \geq \frac{3+\sqrt{3}}{6}$, $f(0) \geq 0$ and $\Delta' > 0$ for $0 < \theta < 1$, implying $f(\theta)$ is increasing in θ. Then $f(\theta) > 0$ for $0 < \theta <$. Combining above analysis, we obtain when $\frac{1}{2} < k < \frac{3+\sqrt{3}}{6}$, if $0 < \theta < \tau$, $\pi_{sm}^{e*} < \pi_{sm}^{n*}$, the equilibrium is at "NO" meaning he manufacturer chooses to not encroach while the retailer chooses to occupy the leader position; if $\tau < \theta < 1$, $\pi_{sm}^{e*} > \pi_{sm}^{n*}$, the equilibrium is at "YO" meaning the manufacturer chooses to encroach while the retailer chooses to occupy the leader position. When $k \geq \frac{3+\sqrt{3}}{6}$, $\pi_{sm}^{e*} > \pi_{sm}^{n*}$, implying the equilibrium is at "YO".

Acknowledgements. This work was supported by the Tianjin Philosophy and Social Sciences Planning Year Project No. TJGLQN17-010.

References

[1] A. Arya, B.Mittendorf and D.E.M. Sappington, The bright side of supplier encroachment. *Market. Sci.* **26** (2007) 651–659.

[2] V. Abhishek, K. Jerath and Z.J. Zhang, Agency selling or reselling? Channel structures in electronic retailing. *Manage. Sci.* **62** (2015) 2259–2280.

[3] F. Bernstein, J. Song and X. Zheng, Free riding in a multi-channel supply chain. *Naval Res. Logist.* **56** (2009) 745–765.

[4] C.L. Chen, Design for the environment: A quality-based model for green product development. *Manage. Sci.* **47** (2001) 250–263.

[5] W.K. Chiang, D. Chhajed and J.D. Hess, Direct marketing, indirect profits: A strategic analysis of dual-channel supply-chain design. *Manage. Sci.* **49** (2003) 1–20.

[6] K. Cattani, W. Gilland, H.S. Heese and J. Swaminathan, Boiling frogs: Pricing strategies for a manufacturer adding a direct channel that competes with the traditional channel. *Prod. Oper. Manage.* **15** (2006) 40–56.

[7] G.G. Cai, Z.G. Zhang and M. Zhang, Game theoretical perspectives on dual-channel supply chain competition with price discounts and pricing schemes. *Int. J. Prod. Econ.* **117** (2009) 80–96.

[8] G.G. Cai, Channel selection and coordination in dual-channel supply chains. *J. Retail.* **86** (2010) 22–36.

[9] J. Chen, H. Zhang and Y. Sun, Implementing coordination contracts in a manufacturer stackelberg dual-channel supply chain. *Omega- Int. J. Manage. Sci.* **40** (2012) 571–583.

[10] X. Chen, X.J. Wang and X.K. Jiang, The impact of power structure on the retail service supply chain with an O2O mixed channel. *J. Oper. Res. Soc.* **67** (2016) 294–301.

[11] J.X. Chen, L. Liang, D.Q. Yao and S.N. Sun, Price and quality decisions in dual-channel supply chains. *Eur. J. Oper. Res.* **259** (2017) 935–948.

[12] A. Dumrongsiri, M. Fan, A. Jain and K. Moinzadeh, A supply chain model with direct and retail channels. *Eur. J. Oper. Res.* **187** (2008) 691–718.

[13] B. Das, K.L. Maity, S. Mondal and M. Maitii, A supply-chain production control problem via genetic algorithm. In: *Proc. of International Conference of Operation Research and Development-V (ICORD-V). International Federation of Operational Research Society, India* (2005) 279–286

[14] B. Das, K. Maity and M. Maiti, A two warehouse supply-chain model under possibility/necessity/credibility measures. *Math. Comput. Model.* **46** (2007) 398–409.

[15] B. Das and M. Maiti, A volume flexible fuzzy production inventory model under interactive and simulation approach. *Int. J. Math. Oper. Res.* **4** (2012) 422–438.

[16] B. Das and M. Maiti, Fuzzy stochastic inequality and equality possibility constraints and their application in a production-inventory model via optimal control method. *J. Comput. Sci.* **4** (2013) 360–369.

[17] B. Das, An integrated supply chain model under fuzzy chance constraints. *Adv. Model. Optim.* **16** (2014) 113–132.

[18] R. Dai, J.X. Zhang and W.S. Tang, Cartelization or Cost-sharing? Comparison of cooperation modes in a green supply chain. *J. Clean. Prod.* **156** (2017) 159–173.

[19] A. El-Ansary, L. Stern, Power measurement in the distribution channel. *J. Market. Res.* **9** (1972) 47–52.

[20] S. Germano, Nike earnings: What to watch. *Wall Street J.* (2014). Available at: http://stream.wsj.com/story/corporate-intelligence/SS-2-60962/SS-2-696191/.
[21] W. Huang and J.M. Swaminathan, Introduction of a second channel: Implications for pricing and profits. *Eur. J. Oper. Res.* **194** (2009) 258–279.
[22] A. Ha, X. Long and J. Nasiry, Quality in supply chain encroachment. *Manuf. Serv. Oper. Manage.* **18** (2016) 280–298.
[23] G. Iyer and J.M. Villas-Boas, A bargaining theory of distribution channels. *J. Market. Res.* **40** (2003) 80–100.
[24] K. Jerath and Z.J. Zhang, Store within a store. *J. Market. Res.* **47** (2010) 748–763.
[25] D. Kuksov and Y.F. Lin, Information provision in a vertically differentiated competitive marketplace. *Market. Sci.* **29** (2010) 122–138.
[26] Y. Liu and Z.J. Zhang, Research note-the benefits of personalized pricing in a channel. *Market. Sci.* **25** (2006) 97–105.
[27] Q. Liu and S. Shum, Pricing and capacity rationing with customer disappointment aversion. *Prod. Oper. Manage.* **22** (2013) 1269–1286.
[28] Z. Li, S.M. Gilbert and G. Lai, Supplier encroachment under asymmetric information. *Manage. Sci.* **60** (2014) 449–462.
[29] Z. Li, S.M. Gilbert and G. Lai, Supplier encroachment as an enhancement or a hindrance to nonlinear pricing. *Prod. Oper. Manage.* **24** (2015) 89–109.
[30] P. Letizia, M. Pourakbar and T. Harrison, The impact of consumer returns on the multichannel sales strategies of manufacturers. *Prod. Oper. Manage.* **27** (2017) 323–349.
[31] B. Mantin, H. Krishnan, and T. Dhar, The strategic role of third-party marketplaces in retailing. *Prod. Oper. Manage.* **23** (2014) 1937–1949.
[32] A.K. Manna, B. Das, J.K. Dey and S.K. Mondal, Two layers green supply chain imperfect production inventory model under bi-level credit period. *Tékhne* **15** (2017) 124–142.
[33] A.K. Manna, J.K. Dey and S.K. Mondal, Two layers supply chain in an imperfect production inventory model with two storage facilities under reliability consideration. *J. Ind. Prod. Eng.* **35** (2018) 57–73.
[34] A.K. Manna, B. Das, J.K. Dey and S.K. Mondal, An EPQ model with promotional demand in random planning horizon: Population varying genetic algorithm approach. *J. Intel. Manuf.* **29** (2018) 1515–1531.
[35] N.M. Modak, N. Kazemi and L.E. Cárdenas-Barrónc, Investigating structure of a two-echelon closed-loop supply chain using social work donation as a Corporate Social Responsibility practice. *Int. J. Prod. Econ.* **207** (2019) 19–33.
[36] R.K. Mallick, A.K. Manna and S.K. Mondal, A supply chain model for imperfect production system with stochastic lead time demand. *J. Manage. Anal.* **5** (2018) 309–333.
[37] H.Y. Shi, Y.C. Liu and N.C. Petruzzi, Consumer heterogeneity, product quality, and distribution channels. *Manage. Sci.* **59** (2013) 1162–1176.
[38] R.X. Shi, J. Zhang and J. Run, Impact of power structure on supply chains with uncertain demand. *Prod. Oper. Manage.* **22** (2013) 1232–1249.
[39] J.D. Shulman and X.J. Geng, Add-on pricing by asymmetric firms. *Manage. Sci.* **59** (2013) 899–917.
[40] S. Shum, S.L. Tong and T.T. Xiao, On the impact of uncertain cost reduction when selling to strategic customers. *Manage. Sci.* **63** (2016) 843–860.
[41] A.A. Tsay and N. Agrawal, Channel conflict and coordination in the e-commerce age. *Prod. Oper. Manage.* **13** (2004) 93–110.
[42] A.A. Tsay and N. Agrawal, Modeling conflict and coordination in multichannel distribution systems: A review. In: Handbook of Quantitative Supply Chain Analysis. Springer, Boston, MA (2004) 557–606
[43] A.A. Taleizadeh, L.E. Cárdenas-Barrón and R. Sohani, Coordinating the supplier-retailer supply chain under noise effect with bundling and inventory strategies. *J. Ind. Manage. Optim.* **15** (2019) 1701–1727.
[44] X. Xu, Optimal price and product quality decisions in a distribution channel. *Manage. Sci.* **55** (2009) 1347–1352.
[45] W. Xue, O.C. Demirag and B.Z. Niu, Supply chain performance and consumer surplus under alternative structures of channel dominance. *Eur. J. Oper. Res.* **239** (2014) 130–145.
[46] Y. Xu, H. Gurnani and R. Desiraju, Strategic supply chain structure design for a proprietary component manufacturer. *Prod. Oper. Manage.* **19** (2010) 371–389.
[47] M.S. Xue and J.X. Zhang, Impacts of heterogeneous environment awareness and power structure on green supply chain. *RAIRO: OR* **52** (2018) 143–157.
[48] M. Yu, L. Debo and R. Kapuscinski, Strategic waiting for consumer-generated quality information: Dynamic pricing of new experience goods. *Manage. Sci.* **62** (2016) 410–435.
[49] W. Yan, Y. Xiong, J.H. Chu, G.D. Li and Z.K. Xiong, Clicks versus Bricks: The role of durability in marketing channel strategy of durable goods manufacturers. *Eur. J. Oper. Res.* **265** (2018) 909–918.
[50] H.X. Yang, J.W. Luo and Q.H. Zhang, Supplier encroachment under nonlinear pricing with imperfect substitutes: Bargaining power versus revenue-sharing. *Eur. J. Oper. Res.* **267** (2018) 1089–1101.
[51] D. Zhang and W.L. Cooper, Managing clearance sales in the presence of strategic customers. *Prod. Oper. Manage.* **17** (2008) 416–431.
[52] R. Zhang, B. Liu and W.L. Wang, Pricing decisions in a dual channels system with different power structures. *Econ. Model.* **29** (2012) 523–533.
[53] L. Zhang, J. Wang and J. You, Consumer environmental awareness and channel coordination with two substitutable products. *Eur. J. Oper. Res.* **241** (2015) 63–73.
[54] R.J. Zhu and M.S. Xue, Two-period pricing strategies in a two-echelon supply chain with conspicuous consumption. *RAIRO: OR* **53** (2019) 667–685.