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Optimal channel decision of retailers in the dual-channel supply chain considering consumer preference for delivery lead time

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ABSTRACT

Facing competition from manufacturers' online direct channels, how retailers make sales channel decisions to increase consumer stickiness has become the core concern of the industry and academia. Empirical research showed that delivery lead time is a key factor that affects consumers' preference for online channels. To analyze the impact of consumer delivery time preference on channel selection and pricing strategy of retailers, consumer delivery lead time preference function was improved from a linear function to an exponential function and consumer demand under the mixed dual-channel supply chain of manufacturer and retailer was derived. Then, the Stackelberg game models under different channel strategies of retailer were established and solved. Results show that consumer preference for delivery lead time has four implications on the channel decision of retailers under manufacturer encroachment in the dual-channel supply chain. First, the dual retail channels strategy is the optimal choice for retailers, and the profit margins that a retailer obtains from dual retail channels supply chain and single online retail channel supply chain will increase as consumers' delivery lead time preference coefficient increases. Second, the optimal pricing of online retail channel and offline retail channel is positively related to consumers' delivery lead time preference coefficient. By contrast, the optimal pricing of online direct channel is negatively related to consumers' delivery lead time preference coefficient. Third, the optimal pricing of online retail channel is higher than that of offline retail and online direct channels. Fourth, a retailer and a manufacturer can adopt a compensation-based whole price contract to address the conflict brought about by the optimal channel choice of the retailer. This study introduces consumer delivery lead time preference into retailer channel decision making and provides a theoretical reference for retailer's mixed channel construction in practice.

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1. Introduction

The advent of the Internet has made consumers accustomed to purchasing products online. To expand market coverage, control sales prices, and increase profits, a growing number of manufacturers who traditionally distribute their products through retail stores are engaging in online direct sales [1-2]. For example, Nike increased its consumer penetration and achieved success via the online direct channel [3]. According to the financial report released by Nike on June 27, 2019, Nike Direct generated a revenue of US$ 11.8 billion in the fiscal year 2018-2019, which increased by 16 % year-on-year on a constant exchange rate basis. In particular, online direct channel sales increased by 35 %, whereas the growth of offline channel sales was only 6 %. The online direct channel established by manufacturers has complicated the relationships among supply chain members. Here, manufacturers are not only the suppliers but also the competitors of retailers, which may result in manufacturer encroachment. As a result, manufacturer encroachment will reduce the revenue of online retailers. Some traditional online retailers believe that the online direct channel of manufacturers will cannibalize their market share, and they need to take measures to cope with such manufacturer encroachment.

Listening to the voice of consumers is an important way of retailer to improve the market competitiveness [4]. In a supply chain, customers have heterogeneity preferences [5], which is an important factor that affects the decision-making strategies of enterprises [6]. Empirical results have shown that delivery service is a more important factor than product prices in the preference of consumers for the online channel [7-9]. Some consumers are willing to pay high prices for fast delivery. Therefore, an increasing number of online retailers are beginning to shorten delivery lead time to cope with the competition from the online direct channel of manufacturers. Delivery lead time refers to the duration between the order time and the time of receiving the products, which mainly includes order handling time, collecting time, binding time, and delivery time from the warehouse to consumers [1]. In practice, online retailers take two measures to shorten delivery lead time. One is increasing the construction of smart warehouses and innovative distribution models [10-11], such as Alibaba and JD. These online retailers have vigorously built pre-warehouses in recent years on the basis of predicting consumer demand via data mining [12]. Pre-warehouses, which are warehouses that are closest to consumers, are where retailers deliver goods in anticipation of future consumer demand. As long as consumers place orders on the e-platform, the products will be delivered to consumers in the shortest time, even within 24 hours. The other measure is building physical stores and using them as distribution centers. Amazon has opened a variety of physical retail stores worldwide, such as Whole Foods, Amazon Go, Amazon Go Grocery, Amazon Books, Amazon 4-star, and Amazon Pop-up. These physical stores improve consumers' shopping experience and the timeliness of delivery. However, shortening delivery lead time will lead to increased service cost no matter what online retailers takes. Retailers should balance delivery lead time and service cost under manufacturer encroachment, which increases the difficulties of retailers in choosing between single online retail channel or dual retail channel supply chain.

The aforementioned phenomenon is the key motivation of our research, which seeks to answer the following questions. How do retailers choose between single online retail channel or dual retail channels to cope with manufacturer encroachment in consideration of consumer preference for delivery lead time? What are the optimal pricing strategies for retailers and manufacturers? How does consumer preference of delivery lead time influence the optimal equilibrium strategies?

The remainder of this study is organized as follows. Section 2 briefly reviews the related literature. Section 3 develops two game models based on the different channel selection decisions of the online retailer. Section 4 presents a comparison of the optimal equilibrium strategies and the corresponding profits under different channel selection decisions. Section 5 concludes the study with managerial implications and future extensions.

2. State-of-the-art

The research is closely related to two streams of literature, that is, channel decision for retailers and the impact of consumer time preference on supply chain decision.

Different from the traditional supply chain, manufacturers can sell products to consumers through online direct channel besides traditional retail channel in the e-commerce environment. In this set-up, manufactures are not only a partner but also a competitor of retailers. Facing competition from manufacturers, retailers need to consider the impact of dual-channel operation on their own profits. If retailers choose dual channel, then they need to address the problems of cooperation and competition between their offline channel and online channel besides the competition and cooperation with the manufacturer. Additionally, Zhou *et al*. [13] found that channel decisions can be used by retailers to weaken the information advantage of service providers. Therefore, the channel decision of retailers is an important issue worthy of discussion in dual-channel supply chain.

Is the opening of online retail channels necessary for offline retailers? Should online retailers open offline retail channels? Karray and Sigue [14] believed that retailers should not dive into the online market when the online market is not yet large enough. Otherwise the expansion of online retail would erode the sales of offline retail channels. Shi *et al*. [15] explored online retailers with an existing resale channel that are introducing an additional market channel and found that the strategy of introducing a new market does not always improve the realization of cost–to-value ratio. Nie *et al*. [16] investigated the influence of cross-channel effects on the distribution channel strategies of two competing traditional retailers and found that retailers may abandon the online-and-offline channel strategy when the cross-channel effects are significantly negative. Wang and Goldfarb [17] used evidence from store openings by a dual-channel retailer to examine the drivers of substitution and complementarity between online and offline retail channels. They found that opening of an offline store is related to a decrease in online sales in the place where the retailer has a strong influence, whereas opening offline store is related to an increase in online sales in places where the retailer is not strong.

A large number of studies have shown that dual retail channels are important channel structures. If retailers choose dual channel, then how can they organize and coordinate the operations of the two channels? Huang *et al*. [18] explored how a large retailer combined its online and offline department by using Suning as a case study and found that an online–offline hybrid organization is hybridized through three multiple and conflicting boundary penetration paths, namely complete, partial, and preventive penetration paths.

The time preference of consumers reflects the importance that consumers place on near-term benefits over long-term benefits. At present, a lot of literature on supply chain decision-making considered the delivery lead time of goods. After studying a duopoly market in which customers are heterogeneous, Jayaswal and Jewkes [19] found that the firm with a larger market base and the firm with capacity cost advantage should always maintain a large price and lead time differentiation between different market segments. Considering two companies competing based on price and delivery decisions in the common market, Pekgun *et al*. [20] found that decentralized operations may not lead to low prices or long lead times if the production department chooses capacity along with lead time.

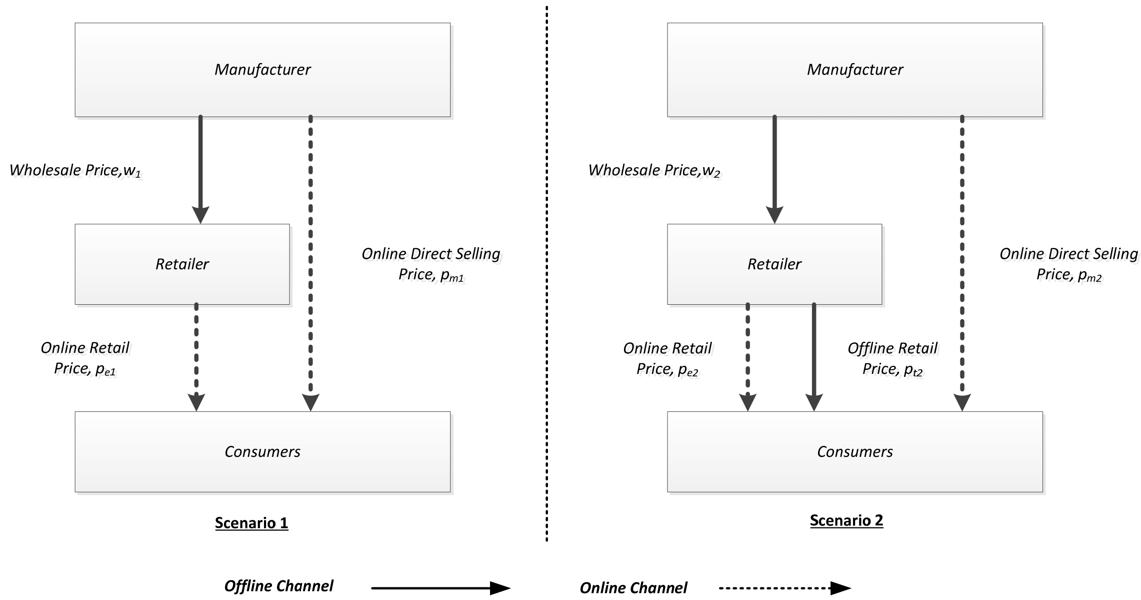


Fig. 1 Supply chain structure of Scenario 1 and Scenario 2

Other researchers transferred the research on consumer time preference from manufacturing to retail. Li *et al*. [21] found that the optimal price of a retailer's online/offline channel has a linear relationship with the delivery lead time of the online channel. In addition, the profit of the manufacturer would not be affected by retailer decisions if consumers in online and offline channels show consistent time preferences in a retailer-led dual-channel supply chain. Zhao *et al*. [22] studied price and promised delivery lead time competition between two online retailers considering product returns and found that the retailer with lower basic return rates or lower return rate sensitivities always quote higher prices and shorter promised delivery lead times. Considering the impact of promised delivery time into the choice of sales channel, Ye *et al*. [23] found that the logistics capability of the third-party logistics providers has a significant impact on the optimal sales channel. In addition, the introduction of an online channel would hurt the retailer's profit when the logistics capability coefficient is sufficiently small or large because logistics capability has a significant impact on the promised delivery time and demand. Aiming at the inventory competition of perishable products in dual-channel supply chain, Yang et al. [24] explored the manufacturer's optimal delivery lead time decision in the online direct channel and found that consumers in online direct channel enjoy shorter delivery lead time and the service in decentralized scheme is better compared with the centralized scheme.

The above-mentioned literature explored the channel selection decisions under different conditions. However, the impacts of consumer preference for delivery lead time on retailer channel selection decision under the mixed dual-channel structure of manufacturers and retailers are not considered. Moreover, most research on the influence of preferences on supply chain decision-making focuses on the preferences of decision makers, and research from the perspective of consumer preferences is still relatively limited [25]. Due to the complexity of model construction, most literature used linear functions to describe consumer preference for delivery lead time in the dual-channel supply chain, which may affect the accuracy of decisions. Therefore, we analyze the impact of consumers' preference of delivery lead time on retailers' channel decision in the mixed dual-channel supply chain under manufacturer encroachment. Game models under single online retail channel supply chain and dual retail channels supply chain are developed to obtain the optimal retail channel selection for retailers and the according optimal pricing strategy.

3. Methodology

3.1 Problem description

We consider a retailer-led dual-channel supply chain with a single manufacturer and a single retailer. The manufacturer wholesales products to the retailer at price w and to end consumers through an online direct channel at price p_m. Facing competition from the online direct channel of the manufacturer, the retailer can adopt two different channel strategies, namely single online retail channel strategy or dual retail channel strategy. Accordingly, two types of supply chain structures are studied in this paper, as shown in Fig. 1. In Scenario 1, the retailer sells products exclusively through an online retail channel, whereas in Scenario 2, the retailer sells products through an online retail channel as well as an offline retail channel. Both the manufacturer and the retailer are risk-neutral and maximize their profits.

In the retailer-led dual-channel supply chain, the game sequence is summarized as follows. In stage 1, the retailer determines the online retail price and offline retail price. In stage 2, the manufacturer determines the wholesale price and online direct selling price.

Furthermore, we use U_e to represent the utility that customers gain from per unit product in the online retail channel, U_t in the offline retail channel, and U_m in the online direct channel. We use q_e to represent the demand in the online retail channel, q_t in the offline retail channel, and q_m in the online direct channel. The online retail price and offline retail price offered by the retailer to customers is denoted by p_e and p_t, respectively. Assume that consumers are heterogeneous in the valuation of the product. Following Chiang *et al*. [26], we denote the consumption value (alternatively called "willingness to pay") by v, where $0 \leq v \leq 1$. In addition, assume that

v is uniformly distributed within the consumer population from 0 to 1, with a density of 1. The profits earned by the retailer from selling per unit product through the online retail channel and the offline retail channel are denoted by λ_e and λ_t, respectively. The profits earned by the retailer and the manufacturer are denoted by Π_r and Π_m, respectively. The delivery lead time in the online retail channel and online direct channel is denoted by t_e and t_m, respectively. We use β to represent consumers' delivery lead time preference coefficient, where $\beta > 0$. Table 1 summarizes the notations used in this paper.

Let $g(t_i) = e^{-\beta t_i}(t_i \geq 0, i = e, m)$ represent the consumer preference for delivery lead time. Previous studies mentioned that the delivery lead time in the online channel (no matter online retail channel or online direct channel) affects the perceived value of a product, thus influencing the utility of customers [3-5]. The utility that consumers obtain in the online channel is not only negatively related to its delivery lead time, but positively related to the delivery lead time of its competing online channels. Hence, the utilities of the customers purchasing products from the online retail channel and online direct channel are represented as follows, respectively:
$U_e = [g(t_e)/g(t_m)]v - p_e = e^{-\beta(t_e - t_m)}v - p_e$, and $U_m = [g(t_m)/g(t_e)]v - p_m = e^{-\beta(t_m - t_e)}v - p_m$.

Let $\Delta t = t_m - t_e$, and we obtain $U_e = e^{\beta \Delta t}v - p_e$ and $U_m = e^{-\beta \Delta t}v - p_m$. In general, the retailer is closer to the consumers than the manufacturer, we have $t_m > t_e$. It implies that $e^{\beta \Delta t} > 1$ and $0 < e^{-\beta \Delta t} < 1$.

Next, we discuss the demand functions of the retailer and the manufacturer under the two different channel strategies.

Table 1 Summary of notations

Notation	Description
U_m	The utility of consumers buying per unit product from the online direct channel
U_e	The utility of consumers buying per unit product from the online retail channel
U_t	The utility of consumers buying per unit product from the offline retail channel
Π_r	The profit of a retailer
Π_m	The profit of a manufacturer
p_m	The online direct selling price offered by a manufacturer to a consumer
p_e	The online retail price offered by a retailer to a consumer
p_t	The offline retail price offered by a retailer to a consumer
λ_e	The profits earned by a retailer from selling per unit product through the online retail channel
λ_t	The profits earned by a retailer from selling per unit product through the offline retail channel
q_m	The quantity demanded of a product in the online direct channel
q_e	The quantity demanded of a product in the online retail channel
q_t	The quantity demanded of a product in the offline retail channel
t_m	The delivery lead time in the online direct channel
t_e	The delivery lead time in the online retail channel
w	The wholesale price charged by a manufacturer to a retailer
v	The consumption value of per unit product
β	Consumers' delivery lead time preference coefficient

3.2 Model formulation

Scenario 1: Retailer adopts the single online retail channel strategy

We assume that the utilities of the consumers purchasing products from the online retail channel and the online direct channel are $U_{e1} = e^{\beta \Delta t}v - p_{e1}$ and $U_{m1} = e^{-\beta \Delta t}v - p_{m1}$, respectively, where subscript 1 represents the Scenario 1.

When $U_{m1} > 0$ and $U_{e1} \geq U_{m1}$, the consumers will choose online retail channel, i.e. $v \geq e^{-\beta \Delta t}p_{e1}$ and $v \geq \frac{p_{e1} - p_{m1}}{e^{\beta \Delta t} - e^{-\beta \Delta t}}$. Similarly, when $U_{m1} \geq 0$ and $U_{m1} > U_{e1}$, the consumers will choose online direct channel, i.e. $v \geq e^{\beta \Delta t}p_{m1}$ and $v \leq \frac{p_{e1} - p_{m1}}{e^{\beta \Delta t} - e^{-\beta \Delta t}}$. Here, the condition $\frac{p_{e1} - p_{m1}}{e^{\beta \Delta t} - e^{-\beta \Delta t}} \geq e^{\beta \Delta t}p_{m1}$ should be satisfied. In summary, the demand functions of the online retail channel and the online direct channel can be written as follow:

$$q_{e1} = 1 - \frac{p_{e1} - p_{m1}}{e^{\beta\Delta t} - e^{-\beta\Delta t}} \tag{1}$$

$$q_{m1} = \frac{p_{e1} - p_{m1}}{e^{\beta\Delta t} - e^{-\beta\Delta t}} - e^{\beta\Delta t} p_{m1} \tag{2}$$

Scenario 2: Retailer adopts the dual retail channels strategy

The utilities of the consumers purchasing products from the offline retail channel, the online retail channel, and the online direct channel are denoted by $U_{t2} = v - p_{t2}$, $U_{e2} = e^{\beta\Delta t} v - p_{e2}$, and $U_{m2} = e^{-\beta\Delta t} v - p_{m2}$, respectively, where subscript 2 represents the Scenario 2.

When $U_{t2} \geq 0$, $U_{t2} \geq U_{e2}$, and $U_{t2} \geq U_{m2}$, the consumers will choose offline retail channel. Here, we have $v \geq p_{t2}$, $v \leq \frac{p_{t2}-p_{e2}}{1-e^{\beta\Delta t}}$, and $v \geq \frac{p_{t2}-p_{m2}}{1-e^{-\beta\Delta t}}$. Moreover, the condition $\frac{p_{t2}-p_{e2}}{1-e^{\beta\Delta t}} > p_{t2}$ should be satisfied.

When $U_{e2} \geq U_{t2}$, and $U_{e2} \geq U_{m2}$, the consumers will choose online retail channel. It implies that $v \geq e^{-\beta\Delta t} p_{e2}$, $v \geq \frac{p_{t2}-p_{e2}}{1-e^{\beta\Delta t}}$, and $v \geq \frac{p_{e2}-p_{m2}}{e^{\beta\Delta t}-e^{-\beta\Delta t}}$.

When $U_{m2} \geq 0$, $U_{m2} \geq U_{t2}$, and $U_{m2} \geq U_{e2}$, the consumers will choose online direct channel. Here, we have $v \geq e^{\beta\Delta t} p_{m2}$, $v \leq \frac{p_{t2}-p_{m2}}{1-e^{-\beta\Delta t}}$, and $v \leq \frac{p_{e2}-p_{m2}}{e^{\beta\Delta t}-e^{-\beta\Delta t}}$. In addition, the following conditions should be satisfied: $\frac{p_{t2}-p_{m2}}{1-e^{-\beta\Delta t}} \geq e^{\beta\Delta t} p_{m2}$ and $\frac{p_{e2}-p_{m2}}{e^{\beta\Delta t}-e^{-\beta\Delta t}} \geq e^{\beta\Delta t} p_{m2}$.

In summary, the demand function of the offline retail channel, the online retail channel, and the online direct channel can be written as follow:

$$q_{t2} = \frac{p_{t2} - p_{e2}}{1 - e^{\beta\Delta t}} - \frac{p_{t2} - p_{m2}}{1 - e^{-\beta\Delta t}} \tag{3}$$

$$q_{e2} = 1 - \frac{p_{t2} - p_{e2}}{1 - e^{\beta\Delta t}} \tag{4}$$

$$q_{m2} = \frac{p_{t2} - p_{m2}}{1 - e^{-\beta\Delta t}} - e^{\beta\Delta t} p_{m2} \tag{5}$$

3.3 Equilibrium outcomes

Scenario 1: Retailer adopts the single online retail channel strategy

In Scenario 1, the profit of the manufacturer can be written as:

$$\Pi_{m1} = w_1 \left(1 - \frac{w_1 + \lambda_{e1} - p_{m1}}{e^{\beta\Delta t} - e^{-\beta\Delta t}}\right) + p_{m1} \left(\frac{w_1 + \lambda_{e1} - p_{m1}}{e^{\beta\Delta t} - e^{-\beta\Delta t}} - e^{\beta\Delta t} p_{m1}\right) \tag{6}$$

According to Eq. 6, the Hesse matrix of Π_{m1} on p_{m1} and w_1 can be obtained as $H(\Pi_{m1}) = \frac{1}{e^{\beta\Delta t}-e^{-\beta\Delta t}} \begin{bmatrix} -2e^{2\beta\Delta t} & 2 \\ 2 & -2 \end{bmatrix}$. Since $\frac{\partial \Pi_{m1}^2}{\partial {p_{m1}}^2} = -\frac{2e^{2\beta\Delta t}}{e^{\beta\Delta t}-e^{-\beta\Delta t}} < 0$ and $|H(\Pi_{m1})| >$, $H(\Pi_{m1})$ is a negative definite matrix. It implies that Π_{m1} has a unique maximum about p_{m1} and w_1.

Let $\partial\Pi_{m1}/\partial p_{m1} = 0$ and $\partial\Pi_{m1}/\partial w_1 = 0$. The reaction function of the manufacturer can be written as $p_{m1} = e^{-\beta\Delta t}/2$ and $w_1 = \left(e^{\beta\Delta t} - \lambda_{e1}\right)/2$.

In Scenario 1, the profit of the retailer can be written as:

$$\Pi_{r1} = \lambda_{e1}(1 - \frac{w_1 + \lambda_{e1} - p_{m1}}{e^{\beta\Delta t} - e^{-\beta\Delta t}}) \tag{7}$$

After substituting the reaction function of the manufacturer into Eq. 7, the second derivative of Π_{r1} on λ_{e1} is given as follows $\partial^2\Pi_{r1}/\partial{\lambda_{e1}}^2 = e^{-\beta\Delta t} - e^{\beta\Delta t} < 0$. It means that Π_{r1} has a unique maximum on λ_{e1}.

Let $\partial\Pi_{r1}/\partial\lambda_{e1} = 0$. The optimal pricing decision for the retailer and the manufacturer can be obtained as follows:

$$p_{e1}^{*} = \frac{3}{4}e^{\beta\Delta t} - \frac{1}{4}e^{-\beta\Delta t} \tag{8}$$

$$p_{m1}^{*} = \frac{e^{-\beta\Delta t}}{2} \tag{9}$$

The according optimal profits for the retailer and the manufacturer can be obtained as follows:

$$\Pi_{r1}^{*} = \frac{1}{8}\left(e^{\beta\Delta t} - e^{-\beta\Delta t}\right) \tag{10}$$

$$\Pi_{m1}^{*} = \frac{1}{16}\left(e^{\beta\Delta t} - 3e^{-\beta\Delta t}\right) \tag{11}$$

Scenario 2: Retailer adopts the dual retail channel strategy

In Scenario 2, the profit of the manufacturer can be written as:

$$\Pi_{m2} = w_2\left(1 - \frac{\lambda_{t2} + w_2 - p_{m2}}{1 - e^{-\beta\Delta t}}\right) + p_{m2}\left(\frac{\lambda_{t2} + w_2 - p_{m2}}{1 - e^{-\beta\Delta t}} - e^{\beta\Delta t}p_{m2}\right) \tag{12}$$

According to Eq. 12, the Hesse matrix of Π_{m2} on p_{m2} and w_2 can be obtained as $H(\Pi_{m2}) = \frac{1}{1-e^{-\beta\Delta t}}\begin{bmatrix} -2e^{\beta\Delta t} & 2 \\ 2 & -2 \end{bmatrix}$.

Since $\partial^2\Pi_{m2}/\partial {p_{m2}}^2 = -2e^{\beta\Delta t}/\left(1 - e^{-\beta\Delta t}\right) < 0$ and $|H(\Pi_{m2})| > 0$, $H(\Pi_{m2})$ is a negative definite matrix, which means Π_{m2} has a unique maximum on p_{m2} and w_2.

Let $\partial\Pi_{m2}/\partial p_{m2} = 0$ and $\partial\Pi_{m2}/\partial w_2 = 0$; hence, the reaction function of the manufacturer can be denoted as $p_{m2} = e^{-\beta\Delta t}/2$ and $w_2 = (1 - \lambda_{t2})/2$.

In Scenario 2, the profit of the retailer can be written as:

$$\Pi_{r2} = \lambda_{t2}\left(\frac{\lambda_{t2} - \lambda_{e2}}{1 - e^{\beta\Delta t}} - \frac{\lambda_{t2} + w_2 - p_{m2}}{1 - e^{-\beta\Delta t}}\right) + \lambda_{e2}\left(1 - \frac{\lambda_{t2} - \lambda_{e2}}{1 - e^{\beta\Delta t}}\right) \tag{13}$$

After substituting the reaction function of the manufacturer into Eq. 13, the Hessian matrix of Π_{r2} on λ_{t2} and λ_{e2} can be obtained as $H(\Pi_{r2}) = -\frac{1}{1-e^{\beta\Delta t}}\begin{bmatrix} -\left(e^{\beta\Delta t} + 2\right) & 2 \\ 2 & -2 \end{bmatrix}$.

Since $\partial^2\Pi_{r2}/\partial {\lambda_{t2}}^2 = \left(e^{\beta\Delta t} + 2\right)/\left(1 - e^{\beta\Delta t}\right) < 0$ and $|H(\Pi_{r2})| > 0$, $H(\Pi_{r2})$ is a negative definite matrix, which means Π_{r2} has a unique maximum about λ_{t2} and λ_{e2} . Let $\partial\Pi_{r2}/\partial\lambda_{t2} = 0$ and $\partial\Pi_{r2}/\partial\lambda_{e2} = 0$, we can get $\lambda_{t2}^{*} = \frac{e^{-\beta\Delta t}\left(-1+e^{\beta\Delta t}\right)}{2}$ and $\lambda_{e2}^{*} = \frac{-e^{-\beta\Delta t}+e^{\beta\Delta t}}{2}$.

Therefore, the optimal pricing strategies for the retailer and the manufacturer can be represented as follows, respectively:

$$p_{t2}^{*} = \frac{3}{4} - \frac{e^{-\beta\Delta t}}{4} \tag{14}$$

$$p_{e2}^{*} = \frac{1}{4}\left(1 - e^{-\beta\Delta t} + 2e^{\beta\Delta t}\right) \tag{15}$$

$$p_{m2}^{*} = \frac{e^{-\beta\Delta t}}{2} \tag{16}$$

Accordingly, the optimal profit for the retailer and the manufacturer can be obtained as follows:

$$\Pi_{r2}^{*} = \frac{1}{8}\left(2e^{\beta\Delta t} - e^{-\beta\Delta t} - 1\right) \tag{17}$$

$$\Pi_{m2}^{*} = \frac{1}{16}\left(1 + 3e^{-\beta\Delta t}\right) \tag{18}$$

4. Analysis and discussion of results

In this section, we firstly investigate the impact of consumer delivery time preferences on the profit and optimal pricing strategies of the retailers and manufacturers under the two channel structures. Then, we explore the retailer's optimal channel strategy and its impact on the manufacturer, and try to coordinate the conflict between the retailer and the manufacturer in the retailer's channel selection.

Proposition 1: When the retailer adopts the single online retail channel strategy (Scenario 1), we have:

(1) The optimal pricing in the online retail channel is positively related to consumer preference for delivery lead time;
(2) The optimal pricing in the online direct channel is negatively related to consumer preference for delivery lead time;
(3) The optimal profit of the retailer is positively related to consumer preference for delivery lead time;
(4) The optimal profit of the manufacturer is positively related to consumer preference for delivery lead time.

Proof of Proposition 1:

(1) From Eq. 8, we can get $\frac{\partial p_{e1}^*}{\partial \beta} = \frac{1}{4}(3e^{\beta \Delta t} + e^{-\beta \Delta t})\Delta t > 0$. Hence, p_{e1}^* is the monotonically increasing function of β.
(2) Similarly, due to $\frac{\partial p_{m1}^*}{\partial \beta} = -\frac{e^{-\beta \Delta t}\Delta t}{2} < 0$, p_{m1}^* decreases monotonically with β.
(3) From Eq. 10, we can get $\frac{\partial \Pi_{r1}^*}{\partial \beta} = \frac{1}{8}(e^{\beta \Delta t} + e^{-\beta \Delta t})\Delta t > 0$. Hence, Π_{r1}^* is the monotonically increasing function of β.
(4) Similarly, due to $\frac{\partial \Pi_{m1}^*}{\partial \beta} = \frac{1}{16}(e^{\beta \Delta t} + 3e^{-\beta \Delta t})\Delta t > 0$, Π_{m1}^*increases monotonically with β.

Proposition 1(1) indicates that the optimal pricing in the online retail channel increases as β increases. The higher the value of β, the shorter the delivery lead time of products required by consumers, which leads to an increase in deliver costs. Therefore, the online retail price increases accordingly. Moreover, Proposition 1(3) shows that with the increase of online channel price, the profit of the retailer will increase correspondingly. In contrast, Proposition 1(2) indicates that the optimal pricing of online direct channel decreases as β increases. Considering that manufacturers are at a disadvantage compared with the retailers in terms of spatial distance to consumers, manufacturers need to lower the online direct selling price to improve their market competitiveness. This price adjustment may lead to a decline in the profit of the manufacturer as shown in Proposition 1(4).

Proposition 2: When the retailer adopts the dual retail channels strategy (Scenario 2), we have:

(1) The optimal pricing in the offline retail channel is positively related to consumer preference for delivery lead time.
(2) The optimal pricing in the online retail channel is positively related to consumer preference for delivery lead time.
(3) The optimal pricing in the online direct channel is negatively related to consumer preference for delivery lead time.
(4) The optimal profit of the retailer is positively related to consumer preference for delivery lead time.
(5) The optimal profit of the manufacturer is negatively related to consumer preference for delivery lead time.

Proof of Proposition 2:

(1) From Eq. 14, we can get $\frac{\partial p_{t2}^*}{\partial \beta} = \frac{1}{4}e^{-\beta \Delta t}\Delta t > 0$. Hence, p_{t2}^* is the monotonically increasing function of β.

(2) Similarly, due to $\frac{\partial p_{e2}^*}{\partial \beta} = \frac{1}{4}(e^{-\beta \Delta t} + 2e^{\beta \Delta t})\Delta t > 0$, p_{e2}^* increases monotonically with β.

(3) Due to $\frac{\partial p_{m2}^*}{\partial \beta} = -\frac{1}{2}e^{-\beta \Delta t}\Delta t < 0$, p_{m2}^* decreases monotonically with β.

(4) From Eq. 17, we can get $\frac{\partial \Pi_{r2}^*}{\partial \beta} = \frac{1}{8}(2e^{\beta \Delta t} + e^{-\beta \Delta t})\Delta t > 0$. Hence, Π_{r2}^* is the monotonically increasing function of β.

(5) Similarly, due to $\frac{\partial \Pi_{m2}^*}{\partial \beta} = -\frac{3}{16}e^{-\beta \Delta t}\Delta t < 0$, Π_{m2}^* decreases monotonically with β.

Propositions 2(1) and 2(2) indicate that the optimal pricing in the offline retail channel and the online retail channel increases as β increases**.** Considering that retailers have an inherent advantage in the delivery lead time of products compared with manufacturers, Proposition 2(4) shows that retailers can increase profits by increasing offline retail prices and online retail prices with the increase of β. In contrast, Proposition 2(3) shows that the optimal pricing in the online direct channel decreases with the increase of β. Although manufacturers may obtain more profits from retailers as β increases, Proposition 2(5) shows that the additional profits are not enough to offset the decline in profits from theirs online direct channel.

Proposition 3: The optimal pricing in the online retail channel is higher than that in the offline retail channel and online direct channel under manufacturer encroachment considering consumer preference for delivery lead time.

Proof of Proposition 3:

When the retailer adopts the single online retail channel strategy, we have $p_{e1}^* - p_{m1}^* = \frac{3}{4}e^{\beta \Delta t} - \frac{1}{4}e^{-\beta \Delta t} - \frac{1}{2}e^{-\beta \Delta t} = \frac{3}{4}(e^{\beta \Delta t} - e^{-\beta \Delta t}) > 0$. When the retailer adopts the dual retail channels strategy, we have $p_{e2}^* - p_{t2}^* = \frac{1}{4}(1 - e^{-\beta \Delta t} + 2e^{\beta \Delta t}) - \frac{1}{4}(3 - e^{-\beta \Delta t}) = \frac{1}{2}(e^{\beta \Delta t} - 1) > 0$, and $p_{e2}^* - p_{m2}^* = \frac{1}{4}(1 - e^{-\beta \Delta t} + 2e^{\beta \Delta t}) - \frac{1}{2}e^{-\beta \Delta t} = \frac{1}{4}(1 + 2e^{\beta \Delta t} - 3e^{-\beta \Delta t}) > 0$. To sum up, Proposition 3 Q.E.D.

Proposition 3 shows that retailers can set online retail price higher than offline retail prices and online direct selling price considering consumer preference for delivery lead time under manufacturer encroachment. This finding is contrary to previous findings that online retail price should be lower than offline retail price to improve market competitiveness.

Proposition 4: Considering consumer preference for delivery lead time under manufacturer encroachment, we have:

(1) The profit of the retailer from adopting the dual retail channels strategy is greater than its profit from adopting the single online retail channel strategy.

(2) The profit margin of the retailer from adopting the dual retail channels strategy and the single online retail channel strategy is positively related to β.

Proof of Proposition 4:

(1) From Eq. 10 and Eq. 17, we can get
$\Pi_{r2}^* - \Pi_{r1}^* = \frac{1}{8}(2e^{\beta \Delta t} - e^{-\beta \Delta t} - 1) - \frac{1}{8}(e^{\beta \Delta t} - e^{-\beta \Delta t}) = \frac{1}{8}(e^{\beta \Delta t} - 1) > 0$.

(2) From Eq. 10 and Eq. 17, we can get $\frac{\partial (\Pi_{r2}^* - \Pi_{r1}^*)}{\partial \beta} = \frac{1}{8}e^{\beta \Delta t}\Delta t > 0$. Hence, $\Pi_{r2}^* - \Pi_{r1}^*$ is the monotonically increasing function of β.

Proposition 5: Considering consumer preference for delivery lead time under manufacturer encroachment, we have:

(1) When $\beta \in \{0 < \beta < \frac{\ln 3}{\Delta t}\}$, the profit of the manufacturer when the retailer adopts the dual retail channels strategy is higher than its profit when the retailer adopts the single online retail channel strategy.

(2) When $\beta \in \{\frac{\ln 3}{\Delta t} < \beta < 1\}$, the profit of the manufacturer when the retailer adopts the dual retail channels strategy is lower than its profit when the retailer adopts the single online retail channel strategy.

Proof of Proposition 5:

(1) From Eq. 11 and Eq. 18, we can get
$\Pi_{m2}^* - \Pi_{m1}^* = \frac{1}{16}(3e^{-\beta\Delta t} + 1) - \frac{1}{16}(e^{\beta\Delta t} - 3e^{-\beta\Delta t}) = \frac{1}{16}(1 + 6e^{-\beta\Delta t} - e^{\beta\Delta t})$
Let $\Pi_{m2}^* - \Pi_{m1}^* > 0$, we have $0 < \beta < \frac{\ln 3}{\Delta t}$.

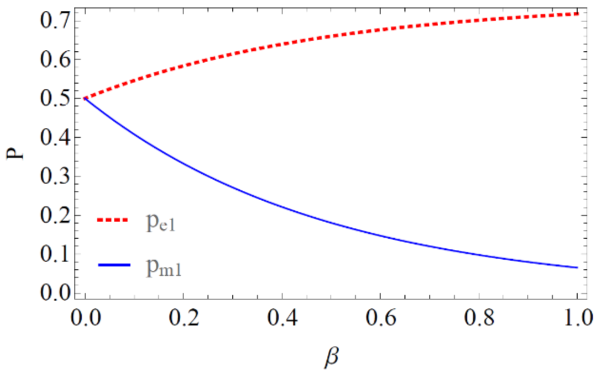
(2) Similarly, let $\Pi_{m2}^* - \Pi_{m1}^* < 0$, we have $\frac{\ln 3}{\Delta t} < \beta < 1$.

Proposition 4 shows that the retailer can gain more profits from dual retail channels strategy than the single online retail channel strategy considering consumer preference for delivery lead time. Therefore, the dual retail channels strategy is the better choice for the retailer than the single online retail channel strategy. The higher the value of β, the larger the profit margin of the retailer between the two channel strategies. However, Proposition 5 shows that the optimal retail channel selection for the manufacturer is uncertain. When the value of β is greater than some threshold $\frac{\ln 3}{\Delta t}$, the single online retail channel strategy is the best choice for the manufacturer. Conversely, when the value of β is less than some threshold $\frac{\ln 3}{\Delta t}$, the dual retail channels strategy is the best choice for the manufacturer.

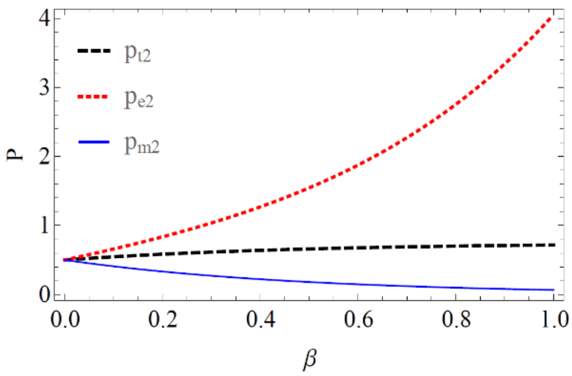
Numerical simulation

The following numerical simulations are used to analyze the impact of β on the optimal pricing and profits of the retailer and the manufacturer. For the convenience of discussion, we assume $\Delta t = 2$.

Firstly, we analyze the impact of β on the optimal pricing of the retailer and the manufacturer. As shown in Fig. 2a, when the retailer adopts a single online retail channel strategy, the optimal pricing in the online retail channel supply chain is positively related to β, whereas the optimal pricing in the online direct channel supply chain is negatively related to β. As shown in Fig. 2b, when the retailer adopts the dual retail channels strategy, the optimal pricing in the offline retail channel and online retail channel have a positive correlation with β, whereas the optimal pricing in the online direct channel shows a negative correlation with β. It is worth noting that β has a significant impact on the optimal pricing in the online retail channel when the retailer adopts the dual retail channels strategy. As shown in Fig. 2b, the retailer can set higher online retail prices than offline retail prices and online direct selling prices with the increase of β in the dual retail channels supply chain.



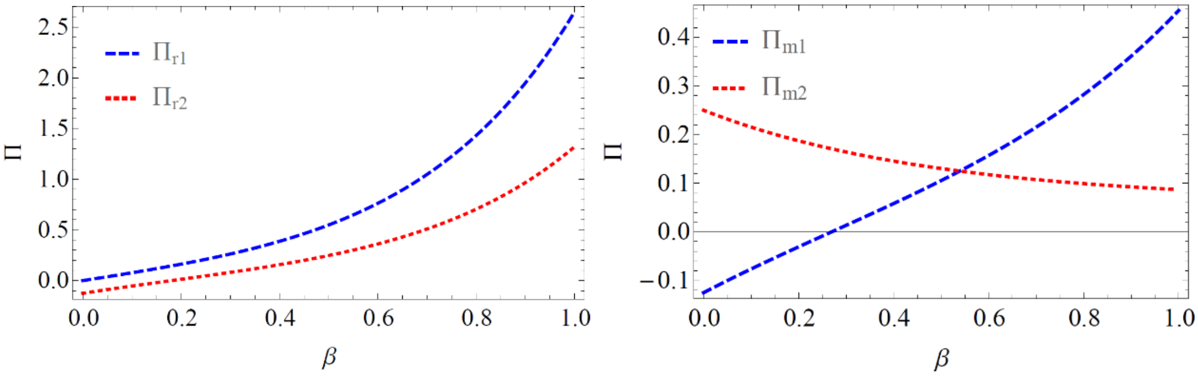
a) Single online retail channel supply chain



b) Dual retail channels supply chain

Fig. 2 Impact of β on optimal pricing ($\Delta t = 2$)

Secondly, we analyze the impact of β on the profit of the retailer and the manufacturer. It can be seen from Fig. 3a that retailer's profit in the dual retail channels supply chain and the single online retail channel supply chain is positively related to β, and that the retailer's profit in the dual retail channels supply chain is always higher than that of the single online retail channel supply chain, which means that dual retail channels strategy is the optimal channel choice for the retailer. Meanwhile, it can be seen from Fig. 3b that manufacturer's profit in the single online retail channel supply chain is positively related to β, whereas manufacturer's profit in the dual retail channels supply chain is negatively related to β, and that the dual retail channels strategy is the optimal choice for the manufacturer only when β is less than $\frac{ln\,3}{2}$. Additionally, it can be seen from Fig. 3 that there is a conflict between the retailer and the manufacturer in the optimal channel choice of the retailer when β is greater than $\frac{ln\,3}{2}$.



a) Impact on the profit of the retailer b) Impact on the profit of the manufacturer

Fig. 3 Impact of β on profit ($\Delta t = 2$)

Supply chain coordination

A comparative analysis of Proposition 4 and Proposition 5 reveals that a conflict exists between the retailer and the manufacturer as regards to the optimal channel choice of the retailer when β is greater than $\frac{ln\,3}{\Delta t}$. A large number of studies show that supply chain members can resolve the conflict of channel selection through coordination at different stages of supply chain decision [27]. In this section, we attempt to coordinate the conflict by using a compensation-based whole price contract and examine whether the retailer and the manufacturer can reach an agreement on the optimal channel choice of the retailer.

We assume that the coordination strategy is feasible if the two conditions are satisfied: 1) the retailer's profit from adopting the dual retail channels is greater than the profit from the single offline retail channel; 2) when the retailer adopts the dual retail channels, the profit of the manufacturer is not less than its profit when the retailer adopts the single online retail channel.

<u>Proposition 6:</u> In a retailer-led dual-channel supply chain, retailers and manufacturers can use a compensation-based whole price contract to coordinate the conflict regarding the optimal channel choice of the retailer to achieve a win–win scenario.

Proof of Proposition 6:

Assume that the contract (w, ρ) stipulates that the retailer shares the proportion of profit $\rho (0 < \rho < 1)$ with the manufacturer after sales. The decision-making problems of the retailer and the manufacturer under this contract can be written as:

$$\begin{cases} \max\limits_{\lambda_{t2},\lambda_{e2}} (\Pi_{r2}) = (1-\rho)[\lambda_{t2}(\frac{\lambda_{t2}-\lambda_{e2}}{1-e^{\beta \Delta t}} - \frac{\lambda_{t2}+w_2-p_{m2}}{1-e^{-\beta \Delta t}}) + \lambda_{e2}(1-\frac{\lambda_{t2}-\lambda_{e2}}{1-e^{\beta \Delta t}})] \\ s.t.\ \Pi_{r2}^* > \Pi_{r1}^* \end{cases} \tag{19}$$

and

$$\begin{cases} \max\limits_{p_{m2},w_2}(\Pi_{m2}) = w_2(1-\frac{\lambda_{t2}+w_2-p_{m2}}{1-e^{-\beta\Delta t}}) + p_{m2}(\frac{\lambda_{t2}+w_2-p_{m2}}{1-e^{-\beta\Delta t}} - e^{\beta\Delta t}p_{m2}) \\ \quad + \rho[\lambda_{t2}(\frac{\lambda_{t2}-\lambda_{e2}}{1-e^{\beta\Delta t}} - \frac{\lambda_{t2}+w_2-p_{m2}}{1-e^{-\beta\Delta t}}) + \lambda_{e2}(1-\frac{\lambda_{t2}-\lambda_{e2}}{1-e^{\beta\Delta t}})] \\ s.t.\ \Pi^*_{m2} > \Pi^*_{m1} \end{cases} \tag{20}$$

The solution of Eq. 19 and Eq. 20 can be obtained by using the backyard induction.

$$p^*_{t2} = \frac{3}{4} - \frac{1}{4e^{\beta\Delta t}} \tag{21}$$

$$p^*_{e2} = \frac{1+2e^{\beta\Delta t}-e^{-\beta\Delta t}}{4} \tag{22}$$

$$p^*_{m2} = \frac{e^{-\beta\Delta t}}{2} \tag{23}$$

$$w^*_2 = \frac{1+e^{-\beta\Delta t}+\rho\left(e^{-\beta\Delta t}-3\right)}{4(1-\rho)} \tag{24}$$

$$\Pi^*_{r2} = \frac{2(1-\rho)\left(1-e^{-\beta\Delta t}\right)+e^{\beta\Delta t}-1}{8} \tag{25}$$

$$\Pi^*_{m2} = \frac{4\rho\left(e^{\beta\Delta t}-1\right)+3e^{-\beta\Delta t}+1}{16} \tag{26}$$

We can obtain $\rho \in \{\frac{1}{4} \leq \rho < \frac{1}{2}\}$ by solving the inequalities $\begin{cases} \Pi^*_{r2} > \Pi^*_{r1} \\ \Pi^*_{m2} > \Pi^*_{m1} \end{cases}$, i.e. the inequalities have at least one solution, which means that in contract (w, ρ), the retailer and the manufacturer agree on the optimal channel choice of the retailer. Therefore, the supply chain coordination can be reached by using a compensation-based whole price contract.

Proposition 6 shows that the retailer who chooses dual retail channels strategy can reach a consensus with the manufacturer by sharing part of the profit with the manufacturer after sales. The profit of the retailer is reduced after sharing, but they remain higher than those from the single retail channel strategy. Moreover, dual retail channels strategy becomes the optimal retail channel choice for the manufacturer after it obtains profit sharing.

5. Conclusion

The following conclusions were obtained considering consumer preference for delivery lead time under manufacturer encroachment in the retailer-led dual-channel supply chain:

- The dual retail channels strategy is the optimal channel choice for the retailers. Our numerical studies show that the profit margins that the retailer obtains from dual retail channels supply chain and single online retail channel supply chain will increase as consumers' delivery lead time preference coefficient increases.
- The optimal pricing of online retail channel and offline retail channel are positively related to consumers' delivery lead time preference coefficient, whereas the optimal pricing of online direct channel is negatively related to consumers' delivery lead time preference coefficient. Our numerical studies show that consumers' delivery lead time preference coefficient has a particularly significant impact on the optimal pricing of single online retail channel.
- The optimal pricing in the online retail channel is higher than that in the offline retail channel and online direct channel. Thus, a retailer can set online retail prices higher than its offline retail prices and the manufacturer's online direct selling price.

- Although the optimal channel selection of the retailer may reduce the profit of the manufacturer, the retailer and the manufacturer can adopt a compensation-based whole price contract to coordinate the conflict brought by the optimal channel choice of the retailer.

Several interesting topics can be explored for further research. In this study, we assumed that consumer preference for delivery lead time is determined. In practice, consumer preference for delivery lead time is heterogeneous and varies greatly due to different products purchased. For example, consumers may have a stronger delivery lead time preference for fresh and perishable products and a weaker preference for durable goods. In the future, studying the pricing and channel choice of the retailer in the dual-channel supply chain will be sensible in the case of uncertain consumer preference for delivery lead time.

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