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Research Article

Pricing Decisions of a Supply Chain with Multichannel Retailer under Fairness Concerns

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With the rapid development of the Internet, many traditional retailers have built their online channels. The fairness concern may play an important role in a dual-channel supply chain with a multichannel retailer. This paper establishes a Stackelberg game model in which a manufacturer produces and sells products through direct online channel and a retailer sells directly to consumers through online and offline channels. The manufacturer's fairness concern (advantageous inequity) and the retailer's fairness concern (disadvantageous inequity) are considered. Four scenarios are investigated: no fairness concern (NF), the retailer fairness concern (RF), the manufacturer fairness concern (MF), and both the manufacturer and the retailer fairness concern (MRF). The theoretical analysis shows that if the manufacturer's advantageous inequity concern is low, the profit of the whole supply chain in the MRF scenario is the greatest. Otherwise, the supply chain profit in the NF or RF scenario is the greatest. That is, the manufacturer's and the retailer's fairness concern may increase the profit of the supply chain. This study also finds that the manufacturer's advantageous inequity concern can increase the social welfare. The retailer should not concern about fairness if the manufacturer has high fairness concern. Besides, this paper shows that the manufacturer's selling price cannot be affected by the fairness concern. Adjusting the wholesale price is the only thing that the manufacturer can do to reduce disadvantageous or advantageous inequity. In the RF scenario, the role of the retailer's disadvantageous inequity concern is to reallocate the supply chain profit. Our findings provide some managerial insights on the pricing decision when the multichannel retailer and the manufacturer consider the fairness.

1. Introduction

With rapid development of Internet, more and more manufacturers, such as Cisco, IBM, Estee Lauder, and Haier, have begun to sell directly through online channels. Due to the increasing customer flow online and market competitiveness coming from manufacturers, some traditional retailers, such as War-Mart, Tesco, Costco Gome, and Suning, began to establish online selling channels in addition to the traditional "Brick-and-Mortar" channels. Multichannel supply chain emerges as a popular commercial mode. For example, Haier, as a well-known manufacturer of household electrical appliances, developed its online channel (http://www.shunguang.com/). On the other hand, some traditional retailers, which sell appliances of Haier in their own physical stores, began to establish online stores in order to reach different customer segments. A typical example is Suning. As a leading Chinese brick-and-mortar home electronics retailer, Suning launched its official online store (https://www.suning.com/) in 2010. The appearance of multichannel retailers has a profound impact on the traditional dual-channel supply chain in which a manufacturer sells through online channel and a retailer with physical store. This makes the traditional dual-channel structures more complex than ever. The opening of the online channel may increase the retailer's sales and income. However, it may increase the retailer's operational cost, and the channel competition may become fierce due to the online channel. The research studies on the dual-channel or multichannel supply chain with multichannel retailer mainly investigate the channel selection problem [1–3]. Therefore, it is important to understand the impact of the retailer's multichannel choice on the pricing decisions and the supply chain performance.

Fairness concern is a hot topic in the field of behavior operations. Research studies have verified that fairness concern plays an important role in supply chain management. In a supply chain, if the retailer feels that the manufacturer unfairly shares more supply chain profit, he may retaliate by raising retail price in order to reduce the manufacturer's share of the supply chain profit. On the other hand, if the manufacturer thinks that he unfairly shares more profit, he may volunteer to reduce the wholesale price in order to increase the retailer's share of the supply chain profit. The research studies on fairness concern mainly focus on the supply chain coordination [4–6], contract design [7, 8], and the impact of fairness concern on supply chain performance [9, 10]. To the best of our knowledge, few research studies investigate the interaction between the manufacturer's fairness concern and the retailer's fairness concern in a dual-channel supply chain with a multichannel retailer. There are two types of fairness concerns: peer-induced fairness and distributional fairness [7]. A retailer exhibits peer-induced fairness concerns when his own profit is behind that of a peer retailer interacting with the same supplier. A retailer exhibits distributional fairness when his supplier's share of total profit is larger than his own. In our paper, we only consider distributional fairness. Thus, the "fairness concern" mentioned in our paper is actually "distributional fairness concern." This paper introduces different members' fairness concerns into the dual-channel supply chain in which the retailer has two channels: online channel and offline channel. Four scenarios are considered: (1) no fairness model (NF); (2) the retailer fairness concern model (RF); (3) the manufacturer fairness concern model (MF); and (4) both the manufacturer and the retailer fairness concern model (MRF). The questions this paper trying to solve are as follows:

(1) How do the fairness concern and the proportion of the retailer's online sales affect the pricing decisions when the retailer in a dual-channel supply chain sells products through the online and offline channels?

(2) What is the interaction between the manufacturer's fairness concern and the retailer's fairness concern?

(3) How does different members' fairness concern affect the supply chain performance and the social welfare?

To solve above questions, this paper establishes a model in which a manufacturer produces and sells products through a direct channel and a retailer sells products through online and offline channels. The manufacturer or the retailer may consider fairness. Therefore, four different models are developed in the paper: NF, RF, MF, and MRF. The manufacturer is the leader of the Stackelberg game and first makes the wholesale price decision and the selling price decision, and then the retailer, as the follower, makes the retail price decision. By solving the Stackelberg game problem under different scenarios, we find that the retailer's fairness concern has no impact on the selling price and the retail price decisions. However, the wholesale price decision is affected by the retailer's fairness concern behavior. The wholesale price in the RF or MF or MRF scenario is lower than that in the NF scenario. That is, either the manufacturer's fairness concern or the retailer's fairness concern makes the manufacturer set a small wholesale price. Moreover, we also find that the proportion of the retailer's online sales does affect the wholesale price and retail price decisions. Finally, by comparing the profits in different scenarios, we find that the profit difference of the manufacturer or the retailer between in the RF scenario and in the MF scenario depends on the extents of the manufacturer's fairness concern and the retailer's fairness concern. If the manufacturer less concerns about the fairness, then the supply chain profit in the MRF scenario is the largest. The fairness concern increases the social welfare. When the manufacturer concerns the fairness very much, the retailer's fairness concern benefits the manufacturer, but hurts the supply chain profit.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature. Model description is introduced in Section 3. Section 4 analyzes the benchmark model in which there is no fairness concern. In Section 5, three cases are investigated: the retailer concerns fairness, the manufacturer considers fairness, both the manufacturer and the retailer concern fairness. The comparison of different fairness concern cases is done in Section 6. Numerical example is provided in Section 7. Finally, we summarize key findings and discuss the directions for future research in Section 8.

2. Literature Review

The research on the multichannel or dual-channel supply chain has been rich. A comprehensive review of dual-channel supply chains can be found in Tsay and Agrawal [11] and Cai et al. [12]. However, the retailer's multichannel problem in a dual-channel supply chain still needs to be deeply investigated. Our study is also related to studies that focus on the fairness concern in a supply chain. Thus, we will mainly summarize the research studies on the dual-channel supply chain and the fairness concern.

There are a large number of research studies on the traditional dual-channel supply chain in which a manufacturer has an online channel and the retailer has a physical store channel. These research studies on the dual-channel supply chain focus on channel selection [13–16], channel coordination [13, 17–20], the pricing and other decisions optimization [21–27], and channel competition [28–30]. A comprehensive review of dual-channel supply chains can be found in Tsay and Agrawal [11] and Cai et al. [12]. Chiang et al. [31] conceptualize the impact of customer acceptance of a direct channel on supply chain design. After that, research studies focus on the channel selection and the coordination of the dual-channel supply chain. Cai et al. [13] investigate the impact of channel structure on the supplier, the retailer, and the entire supply chain with and without coordination. Cao et al. [32] investigate the wholesale contract design problem in a dual-channel supply chain where the retailer's cost is private information. Yu et al. [33] study the impact of supply chain power structure in terms of market power and retail channel dominance on a manufacturer's optimal distribution channel strategy. Matsui [14] studies the optimal wholesale and retail prices set in a multichannel supply chain which comprises a manufacturer and two retailers.

Some existing studies consider the retailer's multichannel issue in supply chain fields. Chen and Chen [1] study how the money-back guarantee affects the retailer's channel selection when the retailer has a chance to introduce an online channel. Wang et al. [2] investigate the channel selection and pricing strategy in a supply chain where a multichannel retailer is the leader and a manufacturer sells two differentiated products through his direct channel and the retail channel. Hsiao and Chen [3] investigate the online channel introduction problem of the manufacturer and the retailer. Zhang et al. [15] investigate a retailer's channel structure choice and pricing decisions in a supply chain with a manufacturer and a retailer. However, the above research studies focus on the channel selection or channel introduction problem. Our work complements these studies by identifying the impact of the fairness concern on the pricing decisions and supply chain performance when the retailer has both online channel and offline channel in a dual-channel supply chain.

In terms of the literature on fairness concern in the single-channel supply chain, Cui et al. [4] are the first to model fairness concerns in the context of supply chain channel coordination. Their model could be stemmed from the inequity aversion proposed by Fehr and Schmidt [34], and they designed wholesale price contract with the linear demand to coordinate channel members. Caliskan-Demirag et al. [5] extend the demand assumption of Cui et al. [4] by considering a nonlinear demand and reveal that the coordination can be achieved under their setting with less stringent conditions to when only retailer is fairness-concerned. Du et al. [35] consider fairness concerns for the supplier and the manufacturer with sustainable green technology innovation development and find that fairness concerns can promote and coordinate the supply chain members to invest more on their sustainable green technology. Various types of supply chains begin to take account of fairness such as cooperative advertising [36], private information [8, 37], logistics service supply chain [38], and sustainable supply chain [39]. Chen et al. [40] formulate the retailer's fairness-concerned utility function, and then develop a two-echelon supply chain model to study the combined impacts of fairness concerns and buyback guarantee financing on equilibrium strategies and supply chain performance.

Some authors try to investigate the impact of the fairness on dual-channel supply chain operation. Choi and Messinger [10] consider a two-manufacturer/one-retailer supply chain over repeated periods of interaction, and they find that the supply chain members tend to choose similar margin levels, and profits tend to be more fairly divided than noncooperative, game-theoretic, supply chain models predict. Ho et al. [7] investigate the interaction between distributional and peer-induced fairness in the one-supplier/two-retailer supply chain. Nie and Du [6] consider a dual channel consisting of one supplier and two retailers, and they all concern fairness. Li and Li [41] consider a dual-channel supply chain where a supplier with a direct channel acts as the leader and a retailer is the follower with fairness concerns. They find that channel efficiency grows with increasing customer loyalty to the retail channel and falls with increase in the retailer's fairness concern. Zhang and Ma [42] find with the increase in the retailer's fair concern coefficient, the total profits in two models both decrease while the total profits gap between two models gets better. Liu and Yu [43] consider that a supply chain is dominated by retailer and study how one channel member's fairness concern affects the coordination. Their investigation is based on different degrees of trust between the channel members, and finds that the supply chain could be coordinated by constant markup pricing contract when the members have the same degree of trust. Liu et al. [44] consider free-ride behavior, rebuild the linear demand function considering free-riding behavior, and modify the pricing model based on channel fairness. However, few research studies consider the impact of the fairness concerns in a dual-channel supply chain in which the retailer has both online and offline channels. Our paper also investigates how the different members' fairness concerns affect the pricing decisions and supply chain performance. We choose part of some classical research studies which focus on fairness concern or dual-channel supply chain to highlight the contributions of this paper (see Table 1).

The contributions of this research are summarized as follows. Firstly, although there are a large number of studies focusing on the dual-channel, few studies consider the retailer's online channel. A few studies on multichannel retailer focus on the channel selection problem, assuming that the members seek maximum profit. Our work considers the supply chain participators' fairness concern and the retailer's online sales effort. Secondly, this paper investigates the impact of the different fairness members' fairness concern on the pricing decision and supply chain performance. The interaction between the manufacturer's fairness concern and the retailer's fairness concern is explored in our paper. It complements the existing studies on the fairness concern in the supply chain field. Specially, our theoretical analysis shows that if the manufacturer's fairness concern is weak, the manufacturer's and the retailer's fairness concern increase the supply chain profit. However, if the manufacturer cares about the fairness very much, then the retailer's fairness concern will hurt the supply chain profit and the social welfare. Finally, our results can provide some managerial insights for managers or decision makers. For instance, the manufacturer or the retailer does not need to worry about the fairness concern's influence on the selling price decision. The reason is that the manufacturer's selling price decision is not affected by the fairness concerns. If the manufacturer cares about the fairness concern very much, the retailer's fairness concern will benefit the manufacturer but hurt the retailer.

Table 1: The literature positioning of this paper.

Research	Traditional dual-channel supply chain	Multichannel retailer	Manufacturer fairness concern	Retailer fairness concern	Both manufacturer and retailer fairness concern
Cai et al. [13] Matsui [14] Cattani et al. [21] Dzyabura and Jagabathula [23]	✓	×	×	×	×
Chen and Chen [1] Wang et al. [2]; Hsiao and Chen [3]	×	✓	×	×	×
Cui et al. [4] Caliskan et al. [5] Katok et al. [8]	×	×	×	✓	✓
Ho et al. [7] Nie and Du [6]	✓	×	×	✓	×
This paper	✓	✓	✓	✓	✓

3. The Model

Consider a dual-channel supply chain where a manufacturer (he) produces and sells the products both through a direct channel to consumers at a selling price P_{m} and through a retailer (she) at a wholesale price w. However, the retailer can sell the products online and in her physical store at a selling price P_{r} (we use the superscript "r" and "m" to denote the retailer and the manufacturer, respectively). Thus, the retailer has two channels: online channel and offline channel (see Figure 1). In practice, some retailers set the same selling price for the online and offline channels, such as Gome, Suning, and so on. Following the studies of Yue and Liu [45], Huang and Swaminathan [46], Hua et al. [22], Chen et al. [17], and Matsui [47], the demand functions of the retailer and the manufacturer are as follows:

$$\begin{aligned} q(P_{\mathrm{r}}, P_{\mathrm{m}}) &= \lambda a - bP_{\mathrm{r}} + dP_{\mathrm{m}}, \\ Q(P_{\mathrm{r}}, P_{\mathrm{m}}) &= (1-\lambda)a - bP_{\mathrm{m}} + dP_{\mathrm{r}}. \end{aligned} \tag{1}$$

In this model, we can think of a as a parameter giving the total potential market size (if prices were all 0), and λ can be thought of as retailer's underlying market share. Thus, λa is the demand for the retailer if all prices are zero, while $(1-\lambda)a$ is the demand for the manufacturer. $b(>0)$ represents manufacturer or retailer's demand sensitivity to its own retail price. d is used to capture channel competitive effects, and $d < b$. A large value of d corresponds to switching customers who are very sensitive to differences between prices.

Given the total demand of the retailer q, the retailer can sell these quantities through the online and offline channels. Let τ $(0 \le \tau \le 1)$ represent the percentage of online sales in total sales of the retailer. The total quantity of the product sold through the online channel is τq, while the retailer sells $(1-\tau)q$ product through the offline channel. The retailer can exert some efforts to increase the sales in the online channel. For instance, the retailer can encourage consumers to purchase the product through the online channel by advertising. The cost of the effort can be $C_{\mathrm{E}}\tau^2$, where C_{E} is the cost coefficient of the effort. The unit sales costs in the online channel and the offline channel are C_1 and C_2, respectively. Table 2 summarizes the main symbols and notations used in this paper.

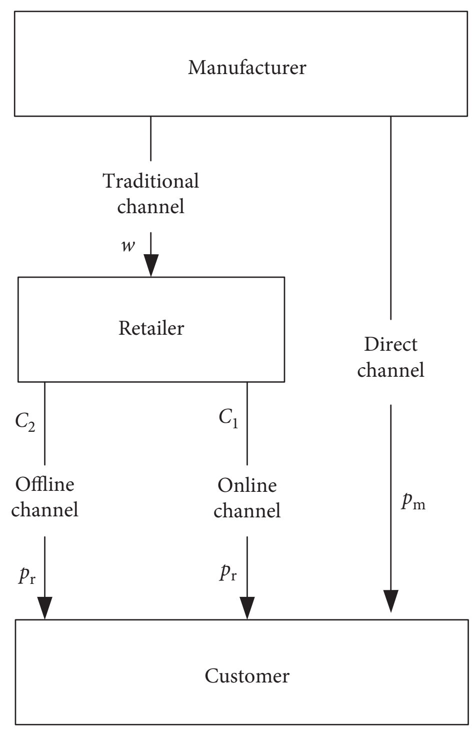


Figure 1: The supply chain configuration.

The assumptions of our paper are as follows:

(1) The manufacturer has sufficient production capacity to meet demands in the direct and retail channels [48].

(2) The retailer's unit sales cost in the offline channel is more than that in the online channel, i.e., $C_1 < C_2$.

(3) The manufacturer or the retailer may not be fairness neutral. That is, the manufacturer or the retailer has a social preference for distribution fairness. As such, the manufacturer or the retailer cares not only about his or her own profit but also about his/her profit relative to the other participators. He or she incurs a

Table 2: Symbol and notations.

Parameters	
C_1	Unit sale cost of the retailer's online channel
C_2	Unit sale cost of the retailer's offline channel
C_E	The cost coefficient of the retailer's effort (e.g., advertising)
a	Total potential market size
b	Coefficient of the price elasticity of demand
d	Cross-price sensitive parameter, which captures the channel competitive effect
λ	The retailer's underlying market share and the manufacturer's is $1-\lambda$
q	The retailer's market demand
Q	The manufacturer's market demand
τ	The percentage of online sales in the retailer's market demand
γ	The disadvantageous inequity concern parameters
β	The advantageous inequity concern parameters
Decision variables	
p_r	Retail price set by the retailer
p_m	Selling price set by the manufacturer
w	Wholesale price set by the manufacturer
Performance measures	
π_r	Profit of the retailer
π_m	Profit of the manufacturer
u_i	Utility of the retailer ($i = r$)/the manufacturer ($i = m$)

disutility of making less than the other one. Therefore, there are three scenarios considered in our paper: retailer fairness concern (RF), manufacturer fairness concern (MF), and both of them fairness concern (MRF). We use o, s, and os to denote the three scenarios, respectively.

(4) The manufacturer, as the leader, plays the Stackelberg game with the retailer [17, 26, 49, 50]. The reason is that the manufacturer may have more bargaining power than the retailer because he has its own channel. The manufacturer first makes the wholesale price w and selling price P_m, and then the retailer determines her retail price P_r.

4. Benchmark: No Fairness (NF)

Without consideration of fairness concerns, supply chain members make decisions to maximize their profits. Firstly, the manufacturer decides the wholesale price and the online direct selling price. Considering the manufacturer's decision, the retailer makes her retail price.

In this scenario, the retailer's profit can be written as

$$\pi_r(P_r, P_m, w) = \pi_r^1 + \pi_r^2, \tag{2}$$

where π_r^1 is the profit coming from the online channel and $\pi_r^1 = (P_r - w - C_1)\tau q - C_E\tau^2$. π_r^2 is the retailer's profit earned from the offline channel and $\pi_r^2 = (P_r - w - C_2)(1-\tau)q$. Thus, we have

$$\pi_r(P_r, P_m, w) = [P_r - w - (C_2 - \Delta\tau)]q - C_E\tau^2, \tag{3}$$

where $\Delta = C_2 - C_1$.

The manufacturer's profit can be written as

$$\pi_m(P_r, P_m, w) = P_m Q + wq. \tag{4}$$

By backward induction, we obtain Proposition 1. Proofs of all propositions and lemmas in the paper are provided in the Appendix.

Proposition 1. *In the NF scenario, the optimal wholesale price and direct selling price of the manufacturer are* $w^* = -(C_2 - \Delta\tau)/2 + ((1-\lambda)ad + \lambda ab)/(2(b^2 - d^2))$, $P_m^* = ((1-\lambda)ab + \lambda ad)/(2(b^2-d^2))$, *respectively. ie optimal retail price of the retailer is* $P_r^* = (1/4)(C_2 - \Delta\tau) + (\lambda a(3b^2 - d^2) + 2(1-\lambda)abd)/(4b(b^2-d^2))$.

From Proposition 1, we can find that the proportion of online sales τ has an impact on the wholesale price decision and the retail price decision. However, the manufacturer's selling price is not affected by the retailer's proportion of her online sales. Proposition 1 also indicates that the unit cost of the retailer's online sales affects the wholesale price and retail price decisions. This implies that the retailer's online channel will influence the manufacturer's behavior by changing his wholesale price decision. The manufacturer's direct channel is not affected.

Lemma 1. P_r^* *decreases in* τ *but increases in* C_2*;* w^* *increases in* τ *but decreases in* C_2.

Lemma 1 shows that the retail price of the retailer is a decreasing function of the proportion of her online sales, while the wholesale price increases as the proportion of the retailer's online sales increases. As the unit cost of the retailer's offline sales increases, the retail price increases, but the wholesale price decreases. The selling price cannot be affected by τ and C_2. As C_2 increases, the retailer benefits from a lower wholesale price and the increase of the retail price, but hurts by the decrease of the sales. However, the benefit is more than the harm, so the retailer increases her retail price as the unit cost of offline sales increases.

Lemma 2

(i) $\pi_m^* > \pi_r^*$.

(ii) π_m^* *increases in* τ*. If* $C_E > (\Delta(-bC_2 + a\lambda + b\Delta\tau))/(16\tau)$*, then* π_r^* *decreases in* τ*; otherwise, if* $C_E < (\Delta(-bC_2 + a\lambda + b\Delta\tau))/(16\tau)$*, then* π_r^* *increases in* τ.

Lemma 2 (i) indicates that in the NF scenario, the profit of the manufacturer is greater than that of the retailer. That is, he shares more supply chain profit than the retailer. This is intuitive because the manufacturer is the leader, making decision first. The first-move advantage can help him share more profit than the retailer. Lemma 2 (ii) indicates that the manufacturer's profit increases as the proportion of the retailer's online sales increase. However, the retailer's profit decreases in the proportion of the retailer's online sales τ, when C_E is high. This indicates that the increase of τ may hurt the retailer's profit, but it always benefits the manufacturer. The reason may be that the advantage of the increase of the wholesale price outweighs the disadvantage of the retailer's retail price decrease.

5. Fairness Concern Model

5.1. Retailer Fairness Model (RF). We follow the same fairness capture model as Ho et al. [7], Nie and Du [6], and Haitao Cui et al. [4]. The retailer's utility is

$$u_{\mathrm{r}}(P_{\mathrm{r}}) = \pi_{\mathrm{r}} - f = \pi_{\mathrm{r}} - \gamma(\pi_{\mathrm{m}} - \pi_{\mathrm{r}})^{+} - \beta(\pi_{\mathrm{r}} - \pi_{\mathrm{m}})^{+}, \quad (5)$$

where $\gamma > \beta$ and $0 < \beta < 1$.

If the retailer's profit is lower than the equitable payoff, a disadvantageous inequity occurs, resulting in disutility for the retailer. However, if her profit is higher than the equitable payoff, an advantageous inequity occurs. Let π_{m} be the equitable payoff. γ and β are the disadvantageous inequity and advantageous inequity concern parameters, respectively. The greater γ (or β) is, the more the retailer is concerned about the disadvantageous (or advantageous) inequity (the manufacturer's profit is more than that of the retailer in the benchmark model; the retailer is always behind the manufacturer in terms of profitability). We use the superscript "o" to denote the optimal solutions in the RF scenario.

Based on the obtained optimal profits of the manufacturer and the retailer in the benchmark model (without fairness concerns), the profit of the manufacturer is much more than that of the retailer. Besides, $\pi_{\mathrm{m}} - \pi_{\mathrm{r}}$ increases in C_{E}; thus, $\pi_{\mathrm{m}} - \pi_{\mathrm{r}} > 0$ when C_{E} is enough high. Therefore, the utility function of the fairness-concerned retailer is $u_{\mathrm{r}}(P_{\mathrm{r}}) = \pi_{\mathrm{r}} - \gamma(\pi_{\mathrm{m}} - \pi_{\mathrm{r}})$. The following propositions are obtained by backward solving.

Proposition 2

(i) In the RF scenario, the optimal retail price of the retailer is

$$P_{\mathrm{r}}^{\mathrm{o}^*} = \frac{dP_{\mathrm{m}}^{\mathrm{o}} + a(1+\gamma)\lambda + b(1+\gamma)(C_2 - \Delta\tau) + b(1+2\gamma)w^{\mathrm{o}}}{2b(1+\gamma)}. \quad (6)$$

(ii) $P_{\mathrm{r}}^{\mathrm{o}^*}$ is decreasing in τ but increases in γ.

Proposition 2 (i) shows that the disadvantageous inequity affects the retailer's pricing decision. Given P_{m} and w, the retailer cares more about the disadvantageous inequity, and she will set a higher retail price (Proposition 2 (ii)). The increase of the retail price may hurt the retail's profit but may reduce the profit gap between the manufacturer and the retailer. Proposition 2 (ii) indicates that the retail price decreases as the proportion of the retailer's online sales increases.

Proposition 3. *In the RF scenario, the manufacturer's optimal wholesale price and direct selling price are*

$$w^{\mathrm{o}^*} = \frac{\lambda a\left[(1+\gamma)b^2 + \gamma d^2\right]}{2b(2\gamma+1)(b^2-d^2)} + \frac{(1-\lambda)ad}{2(b^2-d^2)} - \frac{(1+\gamma)(C_2 - \Delta\tau)}{2(2\gamma+1)},$$

$$P_{\mathrm{m}}^{\mathrm{o}^*} = \frac{(1-\lambda)ab + \lambda ad}{2(b^2-d^2)}, \quad (7)$$

respectively.

From the Proposition 3, we find that the wholesale price is affected by the retailer's fairness care behavior, but the manufacturer's selling price has no relationship with the fairness concern. Considering the retailer's behavior in the RF scenario, the manufacturer tries to adjust his wholesale price rather than his selling price. From Proposition 1 and Proportion 3, we find that $P_{\mathrm{m}}^{\mathrm{o}^*} = P_{\mathrm{m}}^{*}$ *and* $P_r^* = P_{\mathrm{r}}^{\mathrm{o}^*}$. Therefore, the adjustment of the wholesale price makes the retailer's retail price decision have no relationship with the retailer's fairness concern. The manufacturer uses his first-move advantage to reduce the impact of the retailer's fairness concern on the channel competition.

Lemma 3

(i) In the RF scenario, w^{o^*} decreases in γ but increases in τ.

(ii) $\pi_{\mathrm{m}}^{\mathrm{o}^*}$ decreases in γ but increases in τ; $\pi_{\mathrm{r}}^{\mathrm{o}^*}$ increases in γ, but decreases in τ when $C_{\mathrm{E}} > \Delta(1+4r)(\lambda a - b(C_2 - \Delta\tau))/(16\tau(1+2\gamma))$.

Lemma 3 (i) shows that in the RF scenario, the wholesale price decreases as the disadvantage inequity parameter γ increases. That is, if the retailer cares more about the disadvantage inequity, the manufacturer will set a lower wholesale price. The manufacturer's wholesale price increases as the proportion of the retailer's online sales increase. Because the retail price decreases in τ (Proposition 2 (ii)) and increases in w, a high wholesale price the manufacturer sets can reduce the increase of the demand in the retailer's online and offline channels. Lemma 3 (ii) shows that the profit of the manufacturer decreases as the retailer's fairness concern increases, but increases as the proportion of the retailer's online sales. The profit of the retailer in the RF scenario increases as the retailer's fairness concern increases. If the C_{E} is high, the retailer's profit decreases in the proportion of the retailer's online sales.

5.2. Retailer Fairness Model (MF). In the scenario, the optimization object of the retailer is profit maximization, while the manufacturer makes decisions to maximize his utility. Similar to the scenario in which the retailer considers fairness, we establish the optimization object of the manufacturer by introducing the reference point of the other's profit to describe the utility function of the fairness preference. The manufacturer's equity aversion utility function is expressed as follows:

$$u_{\mathrm{m}}(P_{\mathrm{m}}, w) = \pi_{\mathrm{m}} - f = \pi_{\mathrm{m}} - \gamma(\pi_{\mathrm{r}} - \pi_{\mathrm{m}})^{+} - \beta(\pi_{\mathrm{m}} - \pi_{\mathrm{r}})^{+}. \quad (8)$$

Based on the obtained optimal profits of the manufacturer and the retailer in the benchmark model (without fairness concerns), the profit of the manufacturer is much more than that of the retailer. Therefore, the utility function of the fairness-concerned retailer is $u_{\mathrm{m}}(P_{\mathrm{m}}, w) = \pi_{\mathrm{m}} - \beta(\pi_{\mathrm{m}} - \pi_{\mathrm{r}})$.

We use the superscript "s" to denote the optimal decisions of this case. The following theorems are obtained by backward solving.

Proposition 4. *In the MF scenario, the manufacturer's optimal wholesale price and direct selling price are*

$$w^{s^*} = \frac{(1-2\beta)(C_2-\Delta\tau)}{3\beta-2} + \frac{2\lambda ab^2(2\beta-1)+\beta\lambda ad^2}{2b(b^2-d^2)(3\beta-2)} + \frac{ad(1-\lambda)}{2(b^2-d^2)}, \tag{9}$$

$$P_m^{s^*} = \frac{(1-\lambda)ab+\lambda ad}{2(b^2-d^2)}.$$

The optimal retail price of the retailer is

$$P_r^{s^*} = \frac{(1-\beta)(C_2-\Delta\tau)}{2(2-3\beta)} + \frac{\lambda a\left[(3-5\beta)b^2+(2\beta-1)d^2\right]}{2b(d^2-b^2)(3\beta-2)} + \frac{ad(1-\lambda)}{2(b^2-d^2)}. \tag{10}$$

Proposition 4 indicates that the manufacturer's wholesale price and the retailer's retail price are affected by the manufacturer's advantageous inequity concern, which is inconsistent with the RF scenario. The manufacturer's selling price keeps unchanged.

Lemma 4

(i) w^{s^*} or $P_r^{s^*}$ decreases in β.

(ii) P_r^s is decreasing in τ. w^{s^*} decreases in τ when $\beta<0.5$ but increases in τ when $\beta>0.5$.

Lemma 4 (i) shows that if the manufacturer cares more about his advantageous inequity, he will set a lower wholesale price, and the retailer will set a lower retail price. The retailer benefits from a low wholesale price, but the manufacturer's profit is hurt by the low wholesale price and the demand decrease is caused by the low retail price. The manufacturer's advantageous inequity feeling is reduced by setting a low wholesale price. When the retailer benefits more from the decrease in the retail price than the increase in the demand, the retailer will decrease her retail price. Lemma 4 (ii) indicates that the retail price decreases as the proportion of the retailer's online sales increases. However, the wholesale price increases in τ when $\beta>0.5$ but decreases in τ if $\beta<0.5$. If $\beta=0.5$, the wholesale price decision has no relationship with τ. In this case, only the retail price is affected by τ.

Lemma 5. *In the MF scenario, the retailer's profit is increasing in the manufacturer's advantageous inequity concern parameter β, but the manufacturer's profit is decreasing in β.*

Lemma 5 shows that if the manufacturer cares more about the advantageous inequity, then the retailer's profit will become higher, but the manufacturer's profit will become lower. The reduction of the manufacturer's profit is helpful to eliminate his advantageous inequity.

5.3. Both Manufacturer and Retailer Fairness Model (MRF). In the scenario, both the manufacturer and the retailer concern about the fairness. The manufacturer first makes wholesale price and selling price decisions to maximize his utility. Considering the manufacturer's decisions, the retailer makes the retail price decision by maximizing her utility.

Similar to the scenario in which the retailer or the manufacturer considers fairness, we establish the optimization objects of the manufacturer and the retailer by introducing the other's profit as the fairness reference point to describe the retailer or the manufacturer's fairness preferences utility function. The manufacturer and the retailer's equity aversion utility functions are expressed as follows:

$$\begin{aligned} u_m(P_m,w) &= \pi_m-\gamma(\pi_r-\pi_m)^+-\beta(\pi_m-\pi_r)^+, \\ u_r(P_r) &= \pi_r-\gamma(\pi_m-\pi_r)^+-\beta(\pi_r-\pi_m)^+, \end{aligned} \tag{11}$$

respectively.

Based on the obtained optimal profits of the manufacturer and the retailer in the benchmark model (without fairness concerns), the profit of the manufacturer is much more than that of the retailer. Therefore, the utility function of the fairness-concerned retailer is $u_r(P_r)=\pi_r-\gamma(\pi_m-\pi_r)$. The utility function of the fairness-concerned manufacturer is $u_m(P_m,w)=\pi_m-\beta(\pi_m-\pi_r)$.

We use the superscript "os" to denote the optimal decisions of this case. The following proposition is obtained by backward solving.

Proposition 5. *In the MRF scenario, the manufacturer's optimal wholesale price and direct selling price are*

$$P_m^{os^*} = \frac{(1-\lambda)ab+\lambda ad}{2(b^2-d^2)},$$

$$w^{os^*} = \frac{ad(1-\lambda)}{2(b-d)(b+d)} + \frac{(-1+2\beta)(1+\gamma)^2(C_2-\Delta\tau)}{(1+2\gamma)(2-3\beta+2(1-\beta)\gamma)} - \frac{a\lambda\left[2b^2(-1+2\beta)(1+\gamma)^2-d^2(\beta+2\gamma(1+\gamma))\right]}{2b(b-d)(b+d)(1+2\gamma)(2-3\beta+2(1-\beta)\gamma)}. \tag{12}$$

The optimal retail price of the retailer is

$$P_r^{os^*} = \frac{ad(1-\lambda)}{2(b-d)(b+d)} + \frac{(1-\beta+\gamma)(C_2-\Delta\tau)}{2(2-3\beta+2(1-\beta)\gamma)} - \frac{a\lambda\left[b^2(\beta(5+4\gamma)-3(1+\gamma))-d^2(-1+2\beta)(1+\gamma)\right]}{2b(b-d)(b+d)(2-3\beta+2(1-\beta)\gamma)}. \tag{13}$$

Proposition 5 shows that in the MRF scenario, the manufacturer's optimal selling price is equal to that in the RF, MF, or NF scenario. That is, the manufacturer's selling price decision is not affected by the retailer and the manufacturer's fairness concern. We can also find that the manufacturer's wholesale price decision and the retailer's retail price decision are affected by both the retailer's disadvantageous inequity and the manufacturer's advantageous inequity.

Lemma 6

(i) $P_r^{os^*}$ *or* w^{os^*} *decreases in* β.

(ii) If $\beta > 0.5$, *then* $P_r^{os^*}$ *or* w^{os^*} *increases in* γ; otherwise, if $\beta < 0.5$, *then* $P_r^{os^*}$ *or* w^{os^*} *decreases in* γ.

(iii) If $\beta > 0.5$, *then* w^{os^*} *decreases in* τ; *otherwise, if* $\beta < 0.5$, *then* w^{os^*} *increases in* τ. *If* $\beta > 2(1+\gamma)/(3+2\gamma)$, *then* $P_r^{os^*}$ *increases in* τ; *otherwise,* $P_r^{os^*}$ *decreases in* τ.

Lemma 6 (i) indicates that the optimal retail price or the optimal wholesale price decreases as the manufacturer cares more about the advantageous inequity. However, the impact of the retailer's fairness on the optimal wholesale price and the optimal retail price depends on the manufacturer's advantageous inequity (Lemma 6 (ii)). If the manufacturer cares more about the advantageous inequity, the optimal wholesale price or the optimal retail price increases in the retailer's disadvantageous inequity parameter γ. This result implies the interaction between the manufacturer's fairness concern and the retailer's fairness concern. Lemma 6 (iii) shows that the relationship between the proportion of the retailer's online sales and the wholesale price decision depends on the manufacturer and the retailer's fairness concern. If the manufacturer more concerns about the advantageous inequity, the wholesale price decreases in the proportion of the retailer's online sales, while the retail price increases in the proportion of the retailer's online sales, τ. Compared with Lemma 4, we can find that the impact of the fairness concern on the wholesale price and the retail price decisions in the MRF scenario is different from that in the MF scenario.

Lemma 7

(i) $\pi_r^{os^*}$ *increases in* β; $\pi_m^{os^*}$ *decreases in* β.

(ii) If $\beta > 0.5$, *then* $\pi_r^{os^*}$ *decreases in* γ, *and* $\pi_m^{os^*}$ *increases in* γ; *otherwise, if* $\beta < 0.5$, *then* $\pi_r^{os^*}$ *increases in* γ, *and* $\pi_m^{os^*}$ *decreases in* γ.

Lemma 7 (i) shows that in the MRF scenario, the retailer's profit increases in β, while the manufacturer's profit decreases in β. This is consistent with Lemma 5. That is, if the manufacturer cares more about the advantageous inequity, the manufacturer will share less supply chain profit to reduce his advantageous inequity, whereas the retailer will share more supply chain profit to reduce her disadvantageous inequity. Lemma 7 (ii) indicates that if the manufacturer's fairness concern is very high, then the retailer's profit decreases in γ, while the manufacturer's profit increases in γ, which is not consistent with Lemma 3. This implies that the manufacturer's fairness concern affects the impact of the retailer's fairness concern on their profits. However, the retailer's fairness concern does not have impact on the impact of the manufacturer's fairness concern on their profits. The reason may be that if $\beta > 0.5$, the wholesale price increases in γ, which benefits the manufacturer.

6. Comparison of Different Fairness Concerns

In this section, we compare the optimal retail prices, direct selling prices, wholesale prices, demand quantities, and profits in different scenarios.

Proposition 6

(i) $w^{o^*} < w^*$, $w^{s^*} < w^*$, *and* $w^{os^*} < w^*$.

(ii) $w^{os^*} < w^{o^*}$. If $\beta > 0.5$, *then* $w^{s^*} < w^{os^*} < w^{o^*}$; *if* $\beta_1 < \beta \leq 0.5$, *then* $w^{os^*} \leq w^{s^*} < w^{o^*}$; *and if* $\beta \leq \beta_1$, *then* $w^{os^*} < w^{o^*} \leq w^{s*}$, *where* $\beta_1 = 2\gamma/(5\gamma+1)$.

(iii) $P_m^* = P_m^{o^*} = P_m^{s^*} = P_m^{os^*}$; $P_r^* = P_r^{o^*} > P_r^{s^*}$; *and* $P_r^{os^*} < P_r^*$. *If* $\beta > 0.5$, *then* $P_r^{os^*} > P_r^{s^*}$; *otherwise,* $P_r^{os^*} \leq P_r^{s^*}$.

Proposition 6 (i) indicates that the wholesale price in the RF or MF or MRF scenario is smaller than that in the NF scenario. That is, to reduce the advantageous inequity of the manufacturer or the disadvantageous inequity of the retailer, the manufacturer determines a low wholesale price. Proposition 6 (ii) shows that the optimal wholesale price in the MRF scenario is smaller than that in the RF scenario. If the manufacturer's advantageous inequity concern is high, then the optimal wholesale price in the MF scenario is the lowest. The optimal wholesale price in the MRF is the lowest when the manufacturer's advantageous inequity concern is low. That is, the retailer's disadvantageous inequity concern increases the wholesale price when the manufacturer's advantageous inequity concern is high. However, when the manufacturer's advantageous inequity concern is low, the retailer's disadvantageous inequity can lead to a low wholesale price.

Proposition 6 (iii) shows that the manufacturer's selling price decision is not affected by the fairness concern. The retailer's retail price decision in the RF scenario is not influenced by the fairness concern. Proposition 6 (iii) also indicates that the retail price in the RF or NF scenario is higher than that in the MF or MRF scenario. That is, the manufacturer's fairness concern results in a low retail price. The extent of the manufacturer's fairness concern also has an impact on the relationship between the retail price in the MRF scenario and that in the MF scenario. Specially, the retail price in the MRF scenario is higher than that in the MF scenario when the manufacturer cares more about the advantageous inequity.

Proposition 7

(i) $q = q^o < q^s$ *and* $q^{os} > q^o$; *if* $\beta > 0.5$, *then* $q^{os} < q^s$; *otherwise,* $q^{os} \geq q^s$.

(ii) $Q = Q^o > Q^s$; $Q^o > Q^{os}$; *if* $\beta > 0.5$, *then* $Q^{os} > Q^s$; *otherwise,* $Q^{os} \leq Q^s$.

(iii) $Q^{os} + q^{os} > (Q+q) = Q^o + q^o$ *and* $Q^s + q^s > (Q+q)$. *If* $\beta > 0.5$, *then* $Q^{os} + q^{os} < (Q^s + q^s)$; *otherwise,* $Q^{os} + q^{os} \geq (Q^s + q^s)$.

Proposition 7 (i) indicates that the amount of the product sold through the retailer's online and offline channels in the NF scenario equals that in the RF scenario. That is, the retailer's fairness concern has no impact on her sales. Proposition 7 (i) also shows that the manufacturer's fairness concern makes the retailer sell more products. The reason is that the manufacturer's advantageous inequity concern leads to a low retail price, while the selling price keeps the same in the four scenarios. Besides, the retailer's online and offline sales in the MF scenario are greater than that in the MRF scenario when the manufacturer's advantageous inequity concern is high. That is, if the manufacturer cares more about the advantageous inequity, the retail's disadvantageous inequity will make her sell less products.

Proposition 7 (ii) shows that the amount of the product sold through the manufacturer's online channel in the NF scenario equals to that in the RF scenario. The reason is that the retail price and the selling price in the RF scenario are equal to that in the NF scenario. That is, the retailer's fairness concern has no impact on the retail price and selling price decisions. The manufacturer's online sales are reduced due to the manufacturer's fairness concern. Considering Proposition 7 (i), we can find that the manufacturer's advantageous inequity concern increases the retailer's sales but decreases the manufacturer's sales. If the manufacturer's advantageous inequity concern is high, the retailer's fairness concern increases the manufacturer's sales. That is, the manufacturer benefits from the retailer's fairness concern but the retailer hurts when the manufacturer cares about the advantageous inequity very much.

Proposition 7 (iii) indicates that the total sale of the supply chain in the MRF or MF scenario is greater than that in the NF or RF scenario. This shows that the manufacturer's advantageous inequity concern can increase the social welfare. We can also find that the retailer's disadvantageous inequity concern hurts the social welfare when the manufacturer's advantageous inequity concern is high.

Proposition 8

(i) $\pi_r^{o^*} > \pi_r^*$, $\pi_r^{s^*} > \pi_r^*$, *and* $\pi_r^{os^*} > \pi_r^{o^*}$; *if* $8\gamma + \beta(-4 + 5\beta + 4(-8 + 7\beta)\gamma) > 0$, *then* $\pi_r^{o^*} > \pi_r^{s^*}$; *otherwise,* $\pi_r^{o^*} \le \pi_r^{s^*}$.

(ii) $\pi_m^{o^*} < \pi_m^*$, $\pi_m^{s^*} < \pi_m^*$, *and* $\pi_m^{os^*} < \pi_m^{o^*}$; *if* $4\gamma - 12\beta\gamma + \beta^2(-1 + 7\gamma) < 0$, *then* $\pi_m^{o^*} > \pi_m^{s^*}$; *otherwise,* $\pi_m^{o^*} \le \pi_m^{s^*}$.

(iii) $\Pi_C^{o^*} = \Pi_C^*$ *and* $\Pi_C^{os^*} \ge \Pi_C^{s^*}$; *If* $\beta > \beta_2$, *then* $\Pi_C^{o^*} > \Pi_C^{os^*} \ge \Pi_C^{s^*}$. *If* $(4/7) < \beta \le \beta_2$, *then* $\Pi_C^{os^*} \ge \Pi_C^{o^*} > \Pi_C^{s^*}$, *where* $\beta_2 = 4(1 + \gamma)/(6\gamma + 7)$. *If* $\beta \le (4/7)$, *then* $\Pi_C^{os^*} \ge \Pi_C^{s^*} \ge \Pi_C^{o^*}$.

Note that $\Pi_C^* = \pi_m^* + \pi_r^*$, $\Pi_C^{o^*} = \pi_m^{o^*} + \pi_r^{o^*}$, $\Pi_C^{s^*} = \pi_m^{s^*} + \pi_r^{s^*}$ *and* $\Pi_C^{os^*} = \pi_m^{os^*} + \pi_r^{os^*}$.

Proposition 8 indicates that the retailer's profit in the RF or MF scenario is larger than that in the NF scenario (Proposition 8 (i)). The manufacturer's profit in the RF or MF scenario is smaller than that in the NF scenario (Proposition 8 (ii)). This implies that the fairness concern can help to reallocate the supply chain profit. The manufacturer's advantageous inequity concern and the retailer's disadvantageous inequity concern have different impacts on the results, which depends on γ and β (Proposition 8 (i) and (ii)). Proposition 8 (i) indicates that the retailer's profit in the MRF scenario is higher than that in the RF scenario. This implies that the manufacturer's fairness concern benefits the retailer. Proposition 8 (ii) shows that the manufacturer's profit in the RF scenario is higher than that in the MRF scenario. That is, the manufacturer's fairness concern may hurt his own profit.

Proposition 8 (iii) shows that the total profit of the supply chain in the RF scenario is equal to that in the NF scenario. That is, the retailer's advantageous inequity does not increase or decrease the profit of the supply chain, but reallocates it. The supply chain profit in the MRF scenario is greater than that in the MF scenario. It implies that the retailer's fairness concern may have positive relationship with the supply chain profit. Proposition 8 (iii) also indicates that if $\beta > \beta_2$, then supply chain profit in the NF or RF scenario is the largest one. However, if $\beta \le \beta_2$, the wholesale supply chain profit in the MRF scenario is greater than that in the RF or MF or NF scenario. This implies that the manufacturer's advantageous inequity concern and the retailer's disadvantageous inequity concern may increase the whole supply chain profit when the extent of the manufacturer's advantageous inequity concern is not so high.

7. Numerical Example

In this section, we investigate the impact of certain key parameters on the profits of both the manufacturer and the retailer. Referring to some studies on the dual-channel supply chain [13, 26, 40], we set the parameters and run our models for various input parameters. However for expositional brevity, we will report the results for the following dataset unless otherwise stated: $a = 1$, $\lambda = 0.5$, $\tau = 0.5$, $C_E = 0.03$, $C_2 = 0.02$ $C_1 = 0.01$, $b = 1$, and $d = 0.6$. To assure the existence of optimal solutions, we set $\beta < 0.62$.

7.1. Effect of the Manufacturer's Fairness Concern on Profits. Let $\gamma = 0.6$. The condition under which the demand cannot be negative is $\beta < 0.62$. Since $\beta < \gamma$, we let $\beta \in (0, 0.6)$.

Figure 2 indicates that the retailer's profit increases as the manufacturer's fairness concern increases in the RF and MRF scenarios. The retailer's profit in the MF scenario is more likely to be the largest as the manufacturer's fairness concern increases. That is, if the manufacturer cares very much about fairness, the retailer's fairness concern hurts her own profit. This is because that although the retailer benefits from the low wholesale price due to the manufacturer's fairness concern, the decrease in the retail price hurts the retailer. When the manufacturer's fairness concern is low, the MRF will be the best for the retailer. The reason is that the retailer benefits from the low wholesale price decrease due to the manufacturer's fairness concern. Besides, the disadvantage of decrease in the retail price outweighs the advantage of the increase in the demand.

Figure 3 shows that the manufacturer's profit decreases as his fairness concern increases. The manufacturer partially shares his profit by setting a low wholesale price. Figure 3 also illustrates that for the manufacturer, the MF is the best if his fairness concern is low, while RF is the best if his fairness concern is high. Compared with the result shown in Figure 2, we find that the manufacturer and the retailer have different choices for the fairness concern. The manufacturer does not hope both of them concern fairness.

Figure 4 indicates that the profit of the supply chain in the MF or MRF scenario first increases and then decreases as the manufacturer's fairness concern increases. That is, there exists an optimal fairness concern for the manufacturer. MRF is the best for the supply chain. The result that RF is the best (from Proposition 8) does not exist. The reason is that the demand is negative when β is high enough. Therefore, from the perspective of the supply chain, MRF is the best. This implies that although the fairness concern of both the manufacturer and the retailer may hurt their profit, it benefits the whole supply chain. The fairness concern can be a method to coordinate the supply chain.

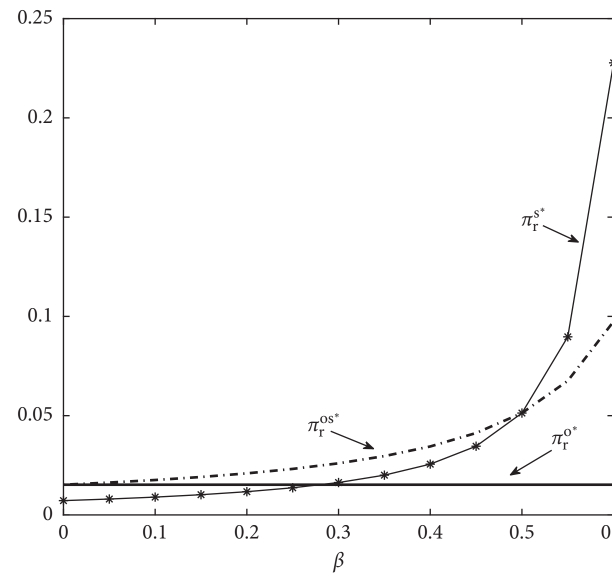


Figure 2: The impact of β on $\pi_r^{o^*}$, $\pi_r^{s^*}$, and $\pi_r^{os^*}$.

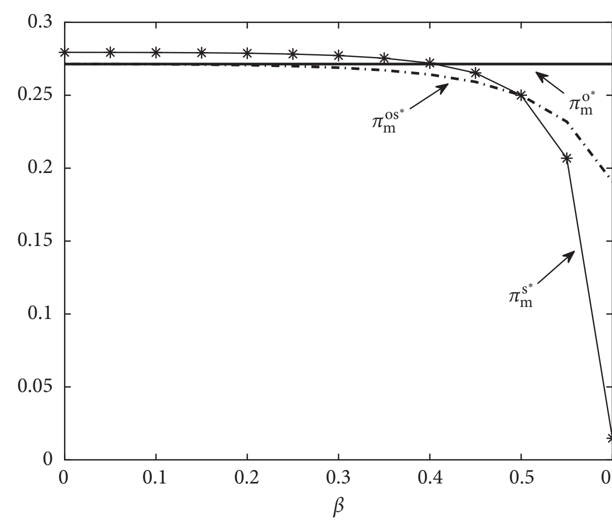


Figure 3: The impact of β on $\pi_m^{o^*}$, $\pi_m^{s^*}$, and $\pi_m^{os^*}$.

7.2. Effect of the Retailer's Fairness Concern on Profits. Next, we discuss how the retailer's fairness concern affects the profits of different participants. The parameters stay the same.

Figure 5(a) indicates that if β is low, the retailer's profit in the MRF or RF scenario increases as the retailer's fairness concern increases. The retailer benefits from the manufacturer's low wholesale price (see Lemma 3). Figure 5(a) also shows that the retailer always prefers MRF as the retailer's fairness concern increases when the manufacturer's fairness concern is low. However, if the manufacturer's fairness concern is high, MF is the best choice for the retailer (Figure 5(b)). The retailer's profit in the MRF scenario decreases as the retailer's fairness concern increases (Figure 5(b)). This is because that when the manufacturer's fairness concern is high, the whole price or the retail price increases as the retailer's fairness concern (see Lemma 6 (ii)), which hurts the retailer's profit. The retailer's profit in the RF scenario keeps stable as the retailer's fairness concern increases. The retailer's fairness concern has no impact on pricing decisions of the manufacturer and the retailer. This reduces the influence of the retailer's fairness concern on the channel operation, which further causes that RF is the worst scenario for the retailer.

Figure 6(a) illustrates that for the manufacturer, MF is the best when the manufacturer's fairness concern , β, is low. However, if the manufacturer's fairness concern is high, RF is the best for the manufacturer (Figure 6(b)). The reason is that in the RF scenario, only the wholesale price is affected by the retailer's fairness concern. In the MRF scenario, in addition to the wholesale price, the retailer's retail price increases as the retailer's fairness concern. Although the manufacturer benefits both from the high wholesale price and the demand increase in the direct channel, the wholesale price in the RF scenario is higher than that in the MRF scenario when the manufacturer's fairness concern is high (Proposition 6 (ii)). The benefits from the high wholesale price in the RF scenario outweigh that from the high wholesale price and the demand increase, so RF is the best for the manufacturer when his fairness concern is high. This implies that the wholesale price plays a more important role in the dual-channel management than other factors, such as the retail price. Figure 6 also shows that if the manufacturer's fairness concern is low, the manufacturer's profit in the MR or MRF scenario dramatically decreases as the retailer's fairness concern increases. If the manufacturer's fairness concern is high, the retailer's fairness concern has little impact on the manufacturer's profit.

Figure 7 indicates that for the supply chain, MRF is the best. This result is consistent with that shown in Figure 4. Figure 7 also shows that the supply chain's profit in the RF scenario stays the same as the retailer's fairness concern increases. This indicates that the fairness concern has no impact on the supply chain's total profit in the RF scenario. The role of the fairness concern is to reallocate the supply chain profit. However, in the MRF scenario, we find that the supply chain's profit increases as the retailer's fairness concern increases. That is, the supply chain benefits from the retailer's fairness concern.

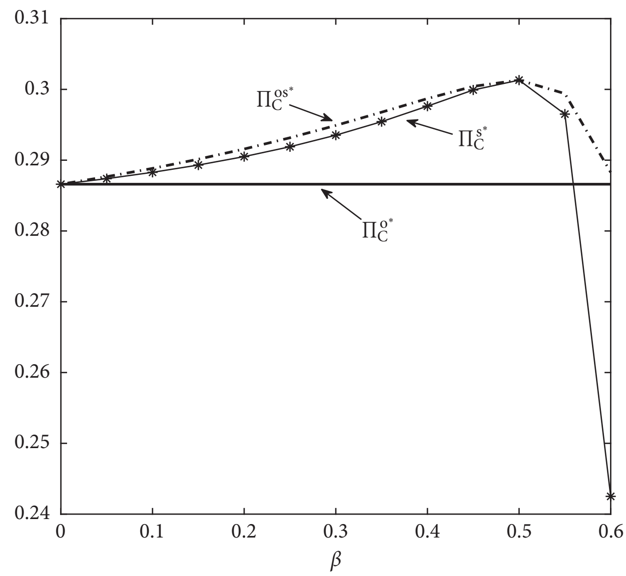


FIGURE 4: The impact of β on $\Pi_C^{o^*}$, $\Pi_C^{s^*}$, and $\Pi_C^{os^*}$.

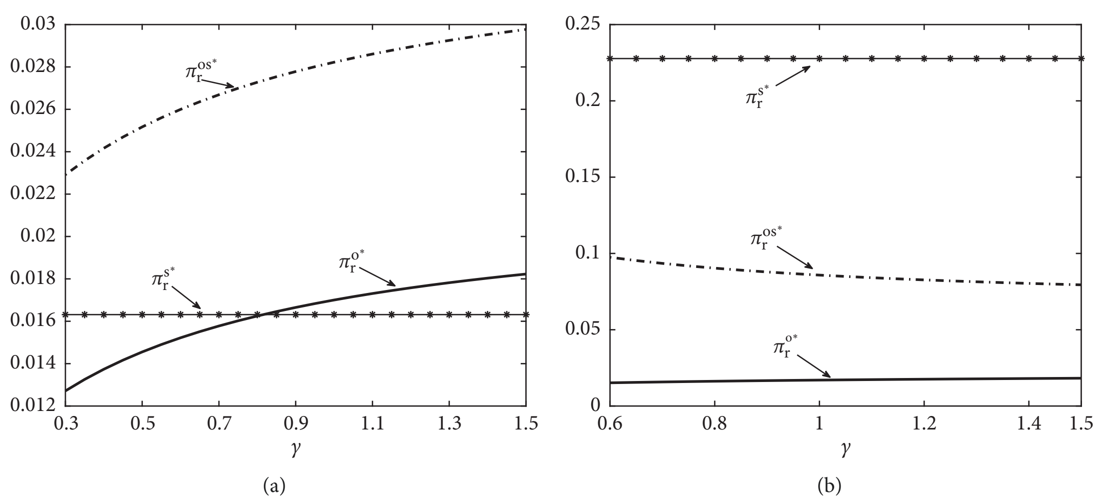


FIGURE 5: The impact of γ on $\pi_r^{o^*}$, $\pi_r^{s^*}$, and $\pi_r^{os^*}$. (a) $\beta = 0.3$. (b) $\beta = 0.6$.

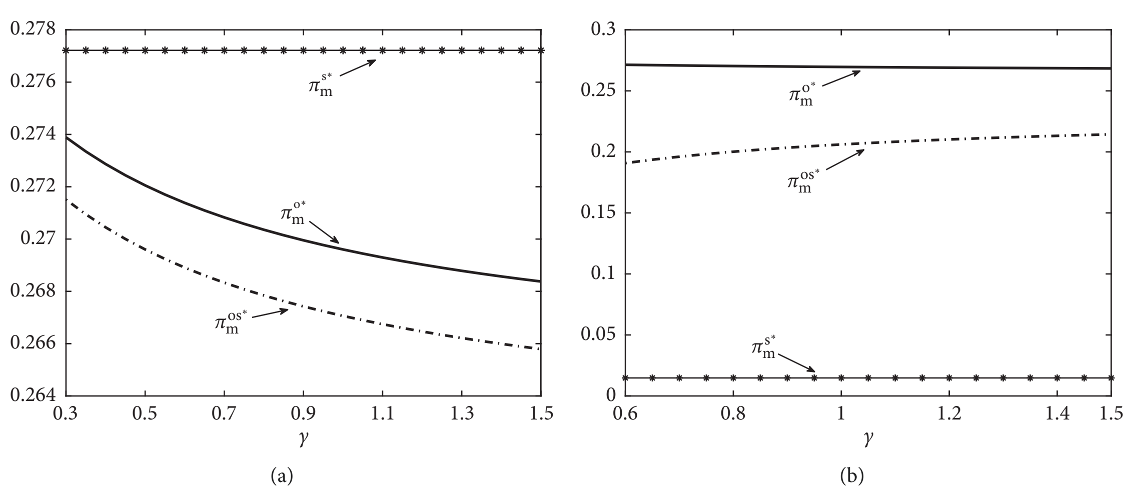


FIGURE 6: The impact of γ on $\pi_m^{o^*}$, $\pi_m^{s^*}$, and $\pi_m^{os^*}$. (a) $\beta = 0.3$. (b) $\beta = 0.6$.

8. Management Insights and Conclusions

A retailer in a dual-channel supply chain may sell products through the online and offline channels. The complex structure of the supply chain may make the pricing decisions difficult due to the consideration of more factors. On the other hand, for the supply chain with long-term cooperation, the fairness concern may play an important role in a dual-channel supply chain. Under this background, we consider the question of how the fairness concern and the proportion of the retailer's online sales affect the pricing decisions when the retailer has online and offline channels. The manufacturer's fairness concern may influence the retailer's fairness concern. Thus, this research also investigates the interaction between the manufacturer's fairness concern and the retailer's fairness concern. Finally, we consider the problem from the performance, studying how supply chain members' fairness concern affects supply chain performance and social welfare. In the section, we summarize the main findings and managerial insights of the paper and conclude this paper with a discussion of several limitations of current model.

8.1. Management Insights. This paper develops a supply chain which consists of a manufacturer and a retailer. The manufacturer produces and sells products through his own online channel and the traditional channel with a retailer. The retailer in a dual-channel supply chain also sells products through two channels: online channel and offline channel. Four models are established: NF model, RF model, MF model, and MRF model. The manufacturer, as the leader, plays the Stackelberg game with the retailer.

From the analysis results, some implications can be derived for both manufacturers and retailers, as follows:

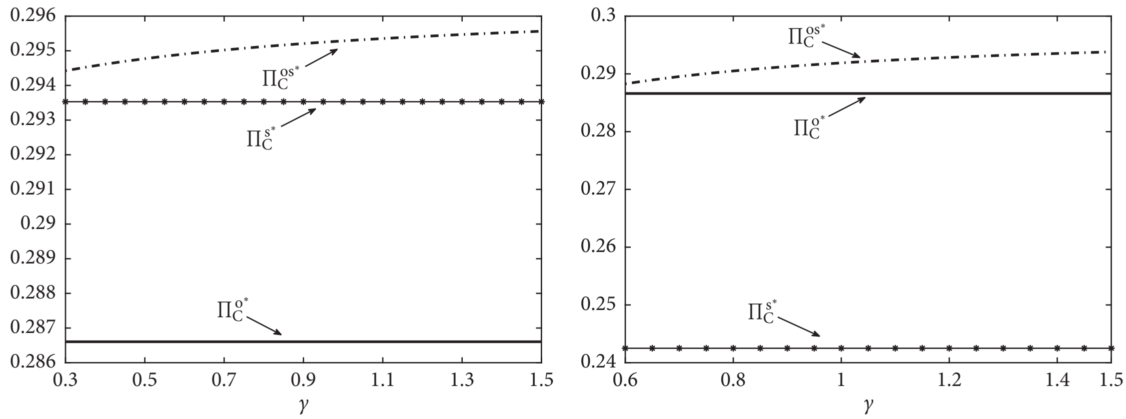
(1) The paper provides some guidelines on pricing decisions for multichannel supply chain members with fairness concerns. The manufacturer will set a low wholesale price to reduce the advantageous inequity of the manufacturer or the disadvantageous inequity of the retailer. The wholesale price is lower in the MRF scenario than that in the RF scenario. This means that the manufacturer's advantageous inequity concern benefits the retailer. Besides, we find that the manufacturer's selling price decision is not affected by the fairness concern. That is, adjusting the wholesale price is the only thing that the manufacturer can do to reduce disadvantageous or advantageous inequity. However, the retailer's disadvantageous inequity concern leads to a high wholesale price when the manufacturer's advantageous inequity concern is high. This implies that if the manufacturer cares advantageous inequity very much, it is better for the retailer not to concern her disadvantageous inequity.

(2) Fairness concerns have a significant impact on the market demand. The demand of the manufacturer or the retailer in the RF scenario equals to that in the NF scenario. This implies that if only the retailer concerns about disadvantageous inequity, the demands in the traditional and direct channels keep the same, although the wholesale price is adjusted. We can know that the manufacturer's fairness concern plays a more important role than the retailer's. The manufacturer's fairness concern increases the retailer's demand and the social welfare, but reduces his own demand. This implies that the manufacturer's fairness concern reduces his market share. Besides, if the manufacturer cares more about the advantageous inequity, the retailer's disadvantageous inequity will enhance the manufacturer's demand, but will reduce the retailer's demand and hurt the social welfare.

(3) We also examine the impact of fairness concerns on the performance of the manufacturer and the retailer. According to Proposition 8, we find that the retailer's profit in the MRF scenario is higher than that in the RF scenario, but the manufacturer's profit is lower. The supply chain profit in the RF scenario is equal to that in the NF scenario, which indicates that the retailer's advantageous inequity does not increase or decrease the profit of the supply chain, but reallocates it. We also find that if the manufacturer's advantageous inequity concern is not so high, and the retailer's fairness concern will lead to an increase in the performance of the supply chain. However, if the manufacturer has a relatively high fairness concern, the supply chain performance is likely to be worse off.

8.2. Limitation and Future Research. This study can be extended in the following aspects in the future research. Firstly, as mentioned in Section 3, we use a linear demand function to describe the market demand of the product. In the future study, we can expand the demand function to nonlinear forms. Second, this research assumes that supply chain members are completely information symmetric. However, in practice, it is difficult for a manufacturer and a retailer to share information with each other. For example, the manufacturer may hide his fairness concern information or provide wrong information to the retailer. For example, the manufacturer may pretend to concerning about fairness very much, causing that the scenario, MF, appears. The profit of the manufacturer with low fairness concern in the MF scenario is the highest. The retailer also has incentive to hide her information on fairness concentration. In addition to the information on fairness concern, the unit sales cost or the percentage of online sales is also private information. It would be very interesting to investigate how the information asymmetry affects the equilibrium results and how to deal with the information problem.

Other limitations of our model setting include the manufacturer's capacity constraint and capital constraint.



(a) (b)

Figure 7: The impact of γ on $\Pi_C^{o^*}$, $\Pi_C^{s^*}$, and $\Pi_C^{os^*}$. (a) $\beta = 0.3$. (b) $\beta = 0.6$.

We assume that the demand is certain in our model. How about if the demand is uncertain? Besides, we consider that retailer sets the same price in the online and offline channels. The different prices can be set in different channels. This may make the analysis extraordinarily complex.

Appendix

Proof of Proposition 1. The profit function of the retailer:

$$\pi_r = (\lambda a - bP_r + dP_m)[P_r - w - (C_2 - \Delta\tau)] - C_E\tau^2. \tag{A.1}$$

Taking the first order derivative of π_r with respect to P_r, we have

$$\begin{aligned}\frac{\partial \pi_r}{\partial P_r} &= \lambda a - 2bP_r + b(w + C_2 - \Delta\tau) + dP_m = 0,\\ P_r(P_m, w) &= \frac{d}{2b}P_m + \frac{\lambda a}{2b} + \frac{1}{2}(w + C_2 - \Delta\tau).\end{aligned} \tag{A.2}$$

Then, take the second order derivative of π_r with respect to P_r, $(\partial^2\pi_r/\partial P_r^2) = -2b < 0$. Therefore, we can verify the concavity of the profit function, and the profit of the retailer has the optimal decision. We take the expression of $P_r(P_m, w)$ into the profit of the manufacturer $\pi_m(P_r, P_m, w)$:

$$\begin{aligned}\pi_m(P_m, w) = {} & \frac{d^2 - 2b^2}{2b}P_m^2 + \left[(1-\lambda)a + \frac{\lambda a d}{2b} + \frac{d(C_2 - \Delta\tau)}{2}\right]P_m \\ & + dwP_m - \frac{1}{2}bw^2 + \frac{1}{2}[\lambda a - b(C_2 - \Delta\tau)]w.\end{aligned} \tag{A.3}$$

We need to verify the concavity of the profit function of the manufacturer. The Hessian matrix of the objective function is

$$\begin{aligned} H &= \begin{bmatrix} \dfrac{\partial^2\pi_m}{\partial w^2} & \dfrac{\partial^2\pi_m}{\partial w\,\partial P_m} \\ \dfrac{\partial^2\pi_m}{\partial P_m \partial w} & \dfrac{\partial^2\pi_m}{\partial P_m^2} \end{bmatrix} = \begin{bmatrix} -b & d \\ d & \dfrac{d^2 - 2b^2}{b} \end{bmatrix}, \\ &\frac{\partial^2\pi_m}{\partial w^2} < 0, \\ &\frac{\partial^2\pi_m}{\partial P_m^2} < 0, \\ &\frac{\partial^2\pi_m}{\partial w\,\partial P_m} = b, \\ &H = 2(b-d)(b+d) > 0. \end{aligned} \tag{A.4}$$

Therefore, the Hessian matrix is negative definite, and the objective function is jointly concave on (P_m, w).

Take the first order derivative of $\pi_m(P_m, w)$ with respect to P_m and w, respectively; then, we have

$$\begin{aligned}\frac{\partial \pi_m}{\partial P_m} &= -\frac{2b^2 - d^2}{b}P_m + \left(1 - \frac{2b - d}{2b}\lambda\right)a + \frac{1}{2}(2w + C_2 - \Delta\tau),\\ \frac{\partial \pi_m}{\partial w} &= \frac{1}{2}\left(2\,dP_m + \alpha\lambda - b(C_2 - \Delta\tau + 2\,w)\right).\end{aligned} \tag{A.5}$$

Let $\partial\pi_m/\partial P_m = 0$ and $\partial\pi_m/\partial w = 0$, then we have

$$\begin{aligned}P_m^* &= \frac{(1-\lambda)ab + \lambda a d}{2(b^2 - d^2)},\\ w^* &= -\frac{1}{2}(C_2 - \Delta\tau) + \frac{(1-\lambda)ad + \lambda a b}{2(b^2 - d^2)}.\end{aligned} \tag{A.6}$$

Based on that, the optimal-directed selling price and the optimal retail price can also be obtained.

Substituting P_m^* and w^* into $P_r(P_m^*, w^*)$, we obtain the optimal retail price of the retailer:

$$P_r^* = \frac{1}{4}(C_2 - \Delta\tau) + \frac{\lambda a(3b^2 - d^2) + 2(1-\lambda)abd}{4b(b^2 - d^2)}. \tag{A.7}$$

□

Proof of Lemma 1. Taking the first order derivative of P_{r}^{*}, P_{m}^{*}, and w^{*} with respect to τ, respectively, we have

$$\begin{aligned}\frac{\partial w^{*}}{\partial \tau}&=\frac{c_2-c_1}{2}>0,\\ \frac{\partial P_{\mathrm{m}}^{*}}{\partial \tau}&=0,\\ \frac{\partial P_{\mathrm{r}}^{*}}{\partial \tau}&=-\frac{c_2-c_1}{4}<0.\end{aligned}\tag{A.8}$$

□

Proof of Lemma 2. Substituting P_{r}^{*}, P_{m}^{*}, and w^{*} into π_{r} and π_{m}, we have

$$\begin{aligned}\pi_{\mathrm{r}}^{*}&=\frac{[\lambda a-b(C_2-\Delta\tau)]^2}{16b}-C_{\mathrm{E}}\tau^2,\\ \pi_{\mathrm{m}}^{*}&=\frac{2a^2[(1-\lambda)b+\lambda d]^2}{8b(b^2-d^2)}+\frac{[b(C_2-\Delta\tau)-\lambda a]^2}{8b}.\end{aligned}\tag{A.9}$$

Since

$$\pi_{\mathrm{m}}^{*}-\pi_{\mathrm{r}}^{*}=\frac{2a^2[(1-\lambda)b+\lambda d]^2}{8b(b^2-d^2)}+\frac{[b(C_2-\Delta\tau)-\lambda a]^2}{16b}+C_{\mathrm{E}}\tau^2>0,\tag{A.10}$$

we have $\pi_{\mathrm{m}}^{*}>\pi_{\mathrm{r}}^{*}$.

$$\frac{\partial \pi_{\mathrm{r}}^{*}}{\partial \tau}=-\frac{\Delta((C_2-\Delta\tau)b-a\lambda)+16C_{\mathrm{E}}\tau}{8}>0.\tag{A.11}$$

If $C_{\mathrm{E}}>(\Delta(-bC_2+a\lambda+b\Delta\tau)/16\tau)$, then $(\partial\pi_{\mathrm{r}}^{*}/\partial\tau)<0$; otherwise, if $C_{\mathrm{E}}<(\Delta(-bC_2+a\lambda+b\Delta\tau)/16\tau)$, then $(\partial\pi_{\mathrm{r}}^{*}/\partial\tau)<0$.

$$\frac{\partial \pi_{\mathrm{m}}^{*}}{\partial \tau}=\frac{\Delta((\Delta\tau-C_2)b+a\lambda)}{4}>0.\tag{A.12}$$

□

Proof of Propositions 2 and 3. Taking the first order derivative of $u_{\mathrm{r}}^{\mathrm{o}}$ with respect to $P_{\mathrm{r}}^{\mathrm{o}}$, we have

$$\begin{aligned}\frac{\partial u_{\mathrm{r}}^{\mathrm{o}}}{\partial P_{\mathrm{r}}^{\mathrm{o}}}&=(1+\gamma)[\lambda a+b(w+C_2-\Delta\tau)]+\gamma bw\\ &\quad-2(1+\gamma)bP_{\mathrm{r}}+dP_{\mathrm{m}}.\end{aligned}\tag{A.13}$$

Then, take the second order derivative of $u_{\mathrm{r}}^{\mathrm{o}}$ with respect to $P_{\mathrm{r}}^{\mathrm{o}}$, $\partial^2u_{\mathrm{r}}/\partial P_{\mathrm{r}}^2=-2b(1+\gamma)<0$. Therefore, we can verify the concavity of the profit function, and the profit of the retailer has the optimal decision.

Let $\partial u_{\mathrm{r}}^{\mathrm{o}}/\partial P_{\mathrm{r}}^{\mathrm{o}}=0$, then we have

$$\begin{aligned}P_{\mathrm{r}}^{\mathrm{o}}(P_m,w)&=\frac{dP_{\mathrm{m}}}{2(1+\gamma)b}+\frac{\lambda a}{2b}+\frac{1}{2}(w+C_2-\Delta\tau)+\frac{\gamma w}{2(1+\gamma)},\\ \frac{dP_{\mathrm{r}}^{\mathrm{o}}}{d\gamma}&=\frac{bw-dP_{\mathrm{m}}}{2b(1+\gamma)^2}>0.\end{aligned}\tag{A.14}$$

We take the expression of $P_{\mathrm{r}}^{\mathrm{o}}(P_{\mathrm{m}},w)$ into the profit of the manufacturer $\pi_{\mathrm{m}}^{\mathrm{o}}$:

$$\begin{aligned}\pi_{\mathrm{m}}^{\mathrm{o}}(P_{\mathrm{m}},w)&=\frac{[d^2-2b^2(1+\gamma)]P_{\mathrm{m}}^2+[2ab(1-\lambda)+\lambda ad+bd(C_2-\Delta\tau)](1+\gamma)P_{\mathrm{m}}}{2b(1+\alpha)}\\ &\quad+\frac{2bd(1+2\gamma)P_{\mathrm{m}}w+[\lambda ab-b^2(C_2-\Delta\tau)]w-b^2(1+2\gamma)w^2}{2b(1+\gamma)}.\end{aligned}\tag{A.15}$$

We need to verify the concavity of the profit function of the manufacturer. The Hessian matrix of the objective function is

$$\begin{aligned}H^{\mathrm{o}}&=\begin{bmatrix}\dfrac{\partial^2\pi_{\mathrm{m}}}{\partial w^2} & \dfrac{\partial^2\pi_{\mathrm{m}}}{\partial w\,\partial P_{\mathrm{m}}}\\ \dfrac{\partial^2\pi_{\mathrm{m}}}{\partial P_{\mathrm{m}}\partial w} & \dfrac{\partial^2\pi_{\mathrm{m}}}{\partial P_{\mathrm{m}}^2}\end{bmatrix}=\begin{bmatrix}-\dfrac{b(2\gamma+1)}{\gamma+1} & \dfrac{d(2\gamma+1)}{\gamma+1}\\ \dfrac{d(2\gamma+1)}{\gamma+1} & \dfrac{d^2}{b(\gamma+1)}-2b\end{bmatrix},\\ &\frac{\partial^2\pi_m}{\partial w^2}<0,\\ &\frac{\partial^2\pi_{\mathrm{m}}}{\partial P_{\mathrm{m}}^2}<0,\\ &\frac{\partial^2\pi_{\mathrm{m}}}{\partial w\,\partial P_{\mathrm{m}}}>0,\\ H^{\mathrm{o}}&=\frac{2b^2(2\alpha+1)^2-d^2}{(\gamma+1)}=\frac{2(b-d)(b+d)(1+2\gamma)}{1+\gamma}>0.\end{aligned}\tag{A.16}$$

Therefore, the Hessian matrix is negative definite, and the objective function is jointly concave on (P_{m},w).

Taking the first order derivative of $\pi_{\mathrm{m}}^{\mathrm{o}}$ with respect to $P_{\mathrm{m}}^{\mathrm{o}}$, we have

$$\begin{aligned}\frac{\partial \pi_{\mathrm{m}}^{\mathrm{o}}}{\partial P_{\mathrm{m}}^{\mathrm{o}}}&=\frac{2d^2-2b^2(2\alpha+2)}{(2\alpha+2)b}P_{\mathrm{m}}+\frac{(2\alpha+1)}{(\alpha+1)}dw\\ &\quad+(1-\lambda)a+\frac{\lambda ad}{2b}+\frac{d}{2}(C_2-\Delta\tau).\end{aligned}\tag{A.17}$$

Let $\partial\pi_{\mathrm{m}}^{\mathrm{o}}/\partial P_{\mathrm{m}}^{\mathrm{o}}=0$ and $\partial\pi_{\mathrm{m}}^{\mathrm{o}}/\partial w^{\mathrm{o}}=0$, we can obtain the optimal direct selling price and wholesale price:

$$\begin{aligned}P_{\mathrm{m}}^{\mathrm{o}}&=\frac{(1-\lambda)ab+\lambda ad}{2(b^2-d^2)},\\ w^{\mathrm{o}}&=\frac{\lambda a[(1+\gamma)b^2+\gamma d^2]}{2b(2\gamma+1)(b^2-d^2)}+\frac{(1-\lambda)ad}{2(b^2-d^2)}-\frac{(1+\gamma)(C_2-\Delta\tau)}{2(2\gamma+1)}.\end{aligned}\tag{A.18}$$

Substituting P_m^o and w^o into P_r^o, we obtain the optimal retail price of the retailer:

$$P_r^o = \frac{1}{4}\left(C_2 - \Delta\tau\right) + \frac{\lambda a\left(3b^2 - d^2\right) + 2\left(1-\lambda\right)abd}{4b\left(b^2 - d^2\right)}. \tag{A.19}$$

□

Proof of Lemma 3

$$\begin{aligned}
\frac{\partial w^{o^*}}{\partial \tau} &= \frac{(1+\gamma)}{2(2\gamma+1)}\left(C_2 - C_1\right) > 0,\\
\frac{\partial P_m^{o^*}}{\partial \tau} &= 0,\\
\frac{\partial P_r^{o^*}}{\partial \tau} &= -\frac{1}{4}\left(C_2 - C_1\right) < 0,\\
\frac{\partial w^{o^*}}{\partial \gamma} &= \frac{b\left(C_2 - \Delta\tau\right) - \lambda a}{2b\left[(2\gamma+1)\right]^2}.
\end{aligned} \tag{A.20}$$

Since the demand must not be negative, we have $\lambda a - b(C_2 - \Delta\tau) > 0$.

Thus, we have $\partial w^{o^*}/\partial\gamma < 0$.

Substituting $P_r^{o^*}$, w^{o^*}, and $P_m^{o^*}$ into π_r^o and π_m^o, we have

$$\begin{aligned}
\pi_r^{o*} &= \frac{(4\gamma+1)\left[\lambda a - b\left(C_2 - \Delta\tau\right)\right]^2}{16b(2\gamma+1)} - C_E\tau^2,\\
\pi_m^{o^*} &= \frac{\left[b\left(C_2 - \Delta\tau\right) - \lambda a\right]^2(1+\gamma)}{8b(2\gamma+1)} + \frac{a^2\left[(1-\lambda)b + \lambda d\right]^2}{4b\left(b^2-d^2\right)},\\
\frac{\partial \pi_r^{o*}}{\partial \tau} &= \frac{\Delta(1+4\gamma)\left[\lambda a - b\left(C_2 - \Delta\tau\right)\right] - 16C_e(1+2\gamma)\tau}{8+16\gamma} > 0.
\end{aligned} \tag{A.21}$$

Thus, if $C_e > \Delta(1+4r)(\lambda a - b(C_2 - \Delta\tau))/16\tau(1+2\gamma)$, then $\partial\pi_r^{o^*}/\partial\tau < 0$; otherwise, if $C_e < \Delta(1+4r)(\lambda a - b(C_2 - \Delta\tau))/16\tau(1+2\gamma)$, $\partial\pi_r^{o^*}/\partial\tau > 0$.

$$\begin{aligned}
\frac{\partial \pi_m^{o*}}{\partial \tau} &= \frac{2b\left[\lambda a - b\left(C_2 - \Delta\tau\right)\right]\left(C_2 - C_1\right)(\gamma+1)}{8b(2\gamma+1)} > 0,\\
\frac{\partial \pi_r^{o*}}{\partial \gamma} &= \frac{\left[\lambda a - b\left(C_2 - \Delta\tau\right)\right]^2 32b}{\left[16b(2\gamma+1)\right]^2} > 0,\\
\frac{\partial \pi_m^{o*}}{\partial \gamma} &= \frac{-8b\left[\lambda a - b\left(C_2 - \Delta\tau\right)\right]^2}{\left[8b(2\gamma+1)\right]^2} < 0,
\end{aligned} \tag{A.22}$$

□

Proof of Proposition 4. The profit function of the retailer is

$$\pi_r^s = \left(\lambda a - bP_r + dP_m\right)\left[P_r - w - \left(C_2 - \Delta\tau\right)\right] - C_E\tau^2. \tag{A.23}$$

Then, take the second order derivative of π_r^s with respect to π_r^s, $\partial^2\pi_r^s/\partial P_r^2 = -2b < 0$. Therefore, we can verify the concavity of the profit function, and the profit of the retailer has the optimal decision. By taking the first order derivative of π_r^s with respect to P_r^s, we have

$$\begin{aligned}
\frac{\partial \pi_r^s}{\partial P_r} &= \lambda a - 2bP_r + b\left(w + C_2 - \Delta\tau\right) + dP_m = 0,\\
P_r^s\left(P_m, w\right) &= \frac{d}{2b}P_m + \frac{\lambda a}{2b} + \frac{1}{2}\left(w + C_2 - \Delta\tau\right).
\end{aligned} \tag{A.24}$$

We take the expression of $P_r^s(P_m, w)$ into the utility function of the manufacturer u_m:

$$\begin{aligned}
u_m^s\left(P_m, w\right) = {} & \left[4b^2(\beta-1) + d^2(2-\beta)\right]P_m^2 + 3b^2\beta w^2\\
& + 2b(2\beta-1)\left[b\left(C_2 - \Delta\tau\right) + \lambda a\right]w\\
& + \Big[4ab(1-\lambda)(1-\beta) + 2bd\left(C_2 - \Delta\tau\right)(1-2\beta)\\
& + 2bdw(2-3\beta) + 2\lambda ad\Big]P_m\\
& + b^2\beta\left(C_2 - \Delta\tau\right)^2 - 2\lambda ab\beta\left(C_2 - \Delta\tau\right) + \lambda^2a^2\beta^2\\
& - 4b\beta C_E\tau^2.
\end{aligned} \tag{A.25}$$

We need to verify the concavity of the utility function of the manufacturer. The Hessian matrix of the objective function is

$$\begin{aligned}
H^s &= \begin{bmatrix} \dfrac{\partial^2 u_m^s}{\partial w^2} & \dfrac{\partial^2 u_m^s}{\partial w\,\partial P_m} \\[2ex] \dfrac{\partial^2 u_m^s}{\partial P_m \partial w} & \dfrac{\partial^2 u_m^s}{\partial P_m^2} \end{bmatrix}\\
&= \begin{bmatrix} \left(\dfrac{3\beta}{2} - 1\right)b & d\left(1 - \dfrac{3\beta}{2}\right) \\[2ex] d\left(1 - \dfrac{3\beta}{2}\right) & \dfrac{d^2(2-\beta) - 4b^2(1-\beta)}{2b} \end{bmatrix}.
\end{aligned} \tag{A.26}$$

Let $(\partial^2 u_m^s/\partial w^2) < 0$, we have $\beta < (2/3)$. Thus,

$$\begin{aligned}
&\frac{\partial^2 u_m}{\partial w\,\partial P_m} > 0,\\
&\frac{\partial^2 u_m}{\partial P_m^2} = \frac{d^2(2-\beta) - 4b^2(1-\beta)}{2b} < \frac{d^2(2-\beta) - 4d^2(1-\beta)}{2b}\\
&\qquad = \frac{d^2(3\beta-2)}{2b} < 0.
\end{aligned} \tag{A.27}$$

$H^s = (b-d)(b+d)(-1+\beta)(-2+3\beta) > 0$. Therefore, the objective function is jointly concave.

Taking the first order derivative of $u_m^s(P_m, w)$ with respect to P_m, we can obtain the optimal direct selling price:

$$P_{\mathrm{m}}^{\mathrm{s}}(w)=\frac{2ab(\beta-1)(1-\lambda)+bd(2\beta-1)(C_2-\Delta\tau)+bdw(3\beta-2)-\lambda ad}{4(\beta-1)b^2+(2-\beta)d^2}. \tag{A.28}$$

Taking the first order derivative of $u_{\mathrm{m}}^{\mathrm{s}}(P_{\mathrm{m}},w)$ with respect to w, we have the optimal wholesale price:

$$w^{\mathrm{s}}=\frac{(1-2\beta)(C_2-\Delta\tau)}{3\beta-2}+\frac{2\lambda ab^2(2\beta-1)+\beta\lambda ad^2}{2b(b^2-d^2)(3\beta-2)}+\frac{ad(1-\lambda)}{2(b^2-d^2)}. \tag{A.29}$$

Substituting $P_{\mathrm{m}}^{\mathrm{s}}$ and w^{s} into $P_{\mathrm{r}}^{\mathrm{s}}$, we have

$$P_{\mathrm{r}}^{\mathrm{s}}=\frac{(1-\beta)(C_2-\Delta\tau)}{2(2-3\beta)}+\frac{\lambda a[(3-5\beta)b^2+(2\beta-1)d^2]}{2b(d^2-b^2)(3\beta-2)}+\frac{ad(1-\lambda)}{2(b^2-d^2)}. \tag{A.30}$$

□

Proof of Lemma 4. Since $\beta<(2/3)$, we have $\partial P_{\mathrm{r}}^{\mathrm{s}}/\partial\tau=(\beta-1)(C_2-C_1)/(2(2-3\beta))<0$, $\partial P_{\mathrm{m}}^{\mathrm{s}}/\partial\tau=0$, $\partial w^{\mathrm{s}}/\partial\tau=(2\beta-1)(C_2-C_1)/(3\beta-2)$. If $\beta<(1/2)$, $(\partial w^{\mathrm{s}^*}/\partial\tau^{\mathrm{s}})>0$; otherwise, if $\beta>(1/2)$, then $(\partial w^{\mathrm{s}^*}/\partial\tau^{\mathrm{s}})<0$.

Since $\beta<(2/3)$, we have $\partial P_{\mathrm{r}}^{\mathrm{s}}/\partial\beta=-(\lambda a+b(C_2-\Delta\tau))/(2b(3\beta-2)^2)<0$, $\partial P_{\mathrm{m}}^{\mathrm{s}}/\partial\beta=0$, and $\partial w^{\mathrm{s}}/\partial\beta=(b(C_2-\Delta\tau)-\lambda a)/(b(3\beta-2)^2)<0$. □

Proof of Lemma 5. By taking the optimal wholesale price $w^{\mathrm{s}}=(1-2\beta)(C_2-\Delta\tau)/(3\beta-2)+(2\lambda ab^2(2\beta-1)+\beta\lambda ad^2)/(2b(b^2-d^2)(3\beta-2))+ad(1-\lambda)/(2(b^2-d^2))$, the optimal retail price $P_{\mathrm{r}}^{\mathrm{s}}=(1-\beta)(C_2-\Delta\tau)/(2(2-3\beta))+\lambda a[(3-5\beta)b^2+(2\beta-1)d^2]/(2b(d^2-b^2)(3\beta-2))+ad(1-\lambda)/(2(b^2-d^2))$, and the optimal demand of the retailer $q^{\mathrm{s}}=[\lambda a-b(C_2-\Delta\tau)](\beta-1)/(6\beta-4)$ into the profit function of the retailer $\pi_{\mathrm{r}}(P_{\mathrm{r}},P_{\mathrm{m}},w)=q[P_{\mathrm{r}}-w-(C_2-\Delta\tau)]-C_{\mathrm{E}}\tau^2$, we obtain the retailer's optimal profit.

By taking the optimal wholesale price $w^{\mathrm{s}}=(1-2\beta)(C_2-\Delta\tau)/(3\beta-2)+(2\lambda ab^2(2\beta-1)+\beta\lambda ad^2)/(2b(b^2-d^2)(3\beta-2))+ad(1-\lambda)/(2(b^2-d^2))$, the optimal direct selling price $P_{\mathrm{m}}^{\mathrm{s}}=((1-\lambda)ab+\lambda ad)/(2(b^2-d^2))$, and the optimal demand of the manufacturer $Q^{\mathrm{s}}=a(1-\lambda)/2+d(\beta-1)(C_2-\Delta\tau)/(2(3\beta-2))+(2\beta-1)\lambda ad/((3\beta-2)2b)$, we obtain the manufacturer's optimal profit.

$$\pi_{\mathrm{r}}^{\mathrm{s}}=\frac{(\beta-1)^2[b(C_2-\Delta\tau)-\lambda a]^2}{4b(3\beta-2)^2}-C_{\mathrm{e}}\tau^2,$$

$$\pi_{\mathrm{m}}^{\mathrm{s}}=\frac{(2\beta-1)(\beta-1)[b(C_2-\Delta\tau)-\lambda a]^2}{2b(3\beta-2)^2}+\frac{a[ab(\lambda-1)-\lambda ad]}{4(d^2-b^2)}. \tag{A.31}$$

By taking the first order derivative of $\pi_{\mathrm{r}}^{\mathrm{s}}$ and $\pi_{\mathrm{m}}^{\mathrm{s}}$ with respect to β, we have

$$\frac{\partial\pi_{\mathrm{r}}^{\mathrm{s}}}{\partial\beta}=\frac{(\beta-1)[\lambda a-b(C_2-\Delta\tau)]^2}{2b(3\beta-2)^3}>0,$$
$$\frac{\partial\pi_{\mathrm{m}}^{\mathrm{s}}}{\partial\beta}=\frac{\beta(b(C_2-\Delta\tau)-\lambda a)^2}{2b(-2+3\beta)^3}<0. \tag{A.32}$$

□

Proof of Proposition 5. Taking the first order derivative of $u_{\mathrm{r}}^{\mathrm{os}}$ with respect to P_{r}, we have

$$\frac{\partial u_{\mathrm{r}}^{\mathrm{os}}}{\partial P_{\mathrm{r}}}=(1+\gamma)[\lambda a+b(w+C_2-\Delta\tau)]+\gamma bw-2(1+\gamma)bP_{\mathrm{r}}+dP_{\mathrm{m}}. \tag{A.33}$$

Then, take the second order derivative of $u_{\mathrm{r}}^{\mathrm{so}}$ with respect to P_{r}, $\partial^2u_{\mathrm{r}}^{\mathrm{os}}/\partial P_{\mathrm{r}}^2=-2b(1+\gamma)<0$. Therefore, we can verify the concavity of the profit function, and the profit of the retailer has the optimal decision.

Let $\partial u_{\mathrm{r}}^{\mathrm{os}}/\partial P_{\mathrm{r}}=0$, then we have

$$P_{\mathrm{r}}^{\mathrm{os}}(P_{\mathrm{m}},w)=\frac{dP_{\mathrm{m}}}{2(1+\gamma)b}+\frac{\lambda a}{2b}+\frac{1}{2}(w+C_2-\Delta\tau)+\frac{\gamma w}{2(1+\gamma)},$$
$$\frac{dP_{\mathrm{r}}^{\mathrm{o}}}{d\gamma}=\frac{bw-dP_{\mathrm{m}}}{2b(1+\gamma)^2}>0. \tag{A.34}$$

Substituting $P_{\mathrm{r}}^{\mathrm{o}}(P_{\mathrm{m}},w)$ into the utility of the manufacturer $u_{\mathrm{m}}^{\mathrm{os}}$, we have the Hessian matrix of the objective function as follows:

$$H^{os} = \begin{bmatrix} \dfrac{\partial^2 u_m^{os}}{\partial w^2} & \dfrac{\partial^2 u_m^{os}}{\partial w \partial P_m} \\ \dfrac{\partial^2 u_m^{os}}{\partial P_m \partial w} & \dfrac{\partial^2 u_m^{os}}{\partial P_m^2} \end{bmatrix} == \begin{bmatrix} \dfrac{b(1+2\gamma)(-2+3\beta+2(-1+\beta)\gamma)}{2(1+\gamma)^2} & -\dfrac{d(1+2\gamma)(-2+3\beta+2(-1+\beta)\gamma)}{2(1+\gamma)^2} \\ -\dfrac{d(1+2\gamma)(-2+3\beta+2(-1+\beta)\gamma)}{2(1+\gamma)^2} & 2b(-1+\beta) - \dfrac{d^2\beta}{2b(1+\gamma)^2} + \dfrac{d^2}{b+b\gamma} \end{bmatrix}. \tag{A.35}$$

Since $\beta < (2/3)$, we have $3\beta - 2 - 2(1-\beta)\gamma < 0$. Thus, $(\partial^2 u_m^{os}/\partial w^2) < 0$

$$\frac{\partial^2 u_m^{os}}{\partial P_m \partial w} = \frac{\partial^2 u_m^{os}}{\partial w \partial P_m} > 0,$$
$$\frac{\partial^2 u_m^{os}}{\partial P_m^2} = 2b(-1+\beta) - \frac{d^2\beta}{2b(1+\gamma)^2} + \frac{d^2}{b+b\gamma}. \tag{A.36}$$

$\partial^2 u_m^{os}/\partial P_m^2$ is increasing in β because $-d^2 + 4b^2(1+\gamma)^2 > 0$.

Since $\beta < (2/3)$, we have $\partial^2 u_m^{os}/\partial P_m^2|_{\beta=2/3} 2b(1+\gamma)^2 = (2/3)(-2b^2(1+\gamma)^2 + d^2(2+3\gamma))$.

Because $-2(1+\gamma)^2 > (2+3\gamma)$ and $b > d$, we have $\partial^2 u_m^{os}/\partial P_m^2|_{\beta=2/3} < 0$. Thus, we have $(\partial^2 u_m^{os}/\partial P_m^2) < 0$.

$$H^{os} = \frac{(b-d)(b+d)(1-\beta)(1+2\gamma)(2-3\beta+2(1-\beta)\gamma)}{(1+\gamma)^2} > 0. \tag{A.37}$$

Therefore, the Hessian matrix is negative definite, and the objective function is jointly concave on (P_m, w).

Let $\partial u_m^{os}/\partial P_m = 0$ and $\partial u_m^{os}/\partial w = 0$, we have

$$P_m^{os} = \frac{(1-\lambda)ab + \lambda ad}{2(b^2 - d^2)},$$
$$w^{os} = \frac{ad(1-\lambda)}{2(b-d)(b+d)} + \frac{(-1+2\beta)(1+\gamma)^2(C_2 - \Delta\tau)}{(1+2\gamma)(2-3\beta+2(1-\beta)\gamma)} - \frac{a\lambda\left[2b^2(-1+2\beta)(1+\gamma)^2 - d^2(\beta + 2\gamma(1+\gamma))\right]}{2b(b-d)(b+d)(1+2\gamma)(2-3\beta+2(1-\beta)\gamma)},$$
$$P_r^{os} = \frac{ad(1-\lambda)}{2(b-d)(b+d)} + \frac{(1-\beta+\gamma)(C_2 - \Delta\tau)}{2(2-3\beta+2(1-\beta)\gamma)} - \frac{a\lambda\left[b^2(\beta(5+4\gamma) - 3(1+\gamma)) - d^2(-1+2\beta)(1+\gamma)\right]}{2b(b-d)(b+d)(2-3\beta+2(1-\beta)\gamma)}. \tag{A.38}$$

□

Proof of Lemma 6. $dw^{os}/d\beta = (1+\gamma)^2(-a\lambda + b(C_2 - \Delta\tau))/(b(-2+3\beta+2(-1+\beta)\gamma)^2) < 0$ because $-a\lambda + b(C_2 - \Delta\tau) < 0$.

$$\frac{dw^{os}}{d\gamma} = \frac{2(2\beta-1)(1-\beta+\gamma)(1+\gamma)(a\lambda - b(C_2 - \Delta\tau))}{b(1+2\gamma)^2(-2+3\beta+2(-1+\beta)\gamma)^2}. \tag{A.39}$$

If $(1/2) < \beta < (2/3)$, then $(dw^{os}/d\gamma) > 0$; otherwise, if $\beta < (1/2)$, then $(dw^{os}/d\gamma) < 0$.

$$\frac{dP_r^{os}}{d\beta} = -\frac{(1+\gamma)(1+2\gamma)(a\lambda - b(C_2 - \Delta\tau))}{2b(-2+3\beta+2(-1+\beta)\gamma)^2} < 0,$$
$$\frac{dP_r^{os}}{d\gamma} = \frac{\beta(-1+2\beta)(a\lambda - b(C_2 - \Delta\tau))}{2b(-2+3\beta+2(-1+\beta)\lambda)^2}. \tag{A.40}$$

Thus, if $(1/2) < \beta < (2/3)$, then $(dP_r^{os}/d\gamma) > 0$; otherwise, if $\beta < (1/2)$, then $(dP_r^{os}/d\gamma) < 0$.

$$\frac{dw^{os}}{d\tau} = \frac{(1-2\beta)\Delta(1+\gamma)^2}{(1+2\gamma)(2-3\beta+2(1-\beta)\gamma)}. \tag{A.41}$$

Thus, if $(1/2) < \beta < (2/3)$, then $(dw^{os}/d\tau) < 0$; otherwise, if $\beta < (1/2)$, then $(dw^{os}/d\tau) > 0$.

$$\frac{dP_r^{os}}{d\tau} = \frac{\Delta(1-\beta+r)}{-4(1+\gamma)+\beta(6+4\gamma)}. \tag{A.42}$$

If $\beta > 2(1+\gamma)/(3+2\gamma)$, then $(dP_{\mathrm{r}}^{\mathrm{os}}/d\tau) > 0$; otherwise, if $\beta < 2(1+\gamma)/(3+2\gamma)$, then $(dw^{\mathrm{os}}/d\tau) < 0$. □

Proof of Lemma 7

$$\frac{d\pi_{\mathrm{r}}^{\mathrm{os}}}{d\gamma} = -\frac{(1-2\beta)\left(\beta(4+(3-2\gamma)\gamma)+2\beta^2(-1+\gamma+2\gamma^2)-2(1+\gamma)^2\right)(1+\gamma)(a\lambda-b(C_2-\Delta\tau))^2}{2b(1+2r)^2(2-3\beta+2(1-\beta)\gamma)^3}. \tag{A.43}$$

Let $X = \beta(4+(3-2\gamma)\gamma)+2\beta^2(\gamma+1)(2\gamma-1)-2(1+\gamma)^2$.

$$\frac{d^2X}{d\gamma^2} = 4(-1+\beta)(1+2\beta) < 0, \tag{A.44}$$

so we let $dX/d\gamma = 0$

Then, we have $\gamma = (4-3\beta-2\beta^2)/(-4-4\beta+8\beta^2)$.

Substituting $\gamma = (4-3\beta-2\beta^2)/(-4-4\beta+8\beta^2)$ into X, we have $X = (1-2\beta)^2\beta(8-9\beta)/(8(\beta-1)(2\beta+1)) < 0$.

Therefore, we have if $(1/2) < \beta < (2/3)$, then $d\pi_r^{\mathrm{os}}/d\gamma < 0$; otherwise, if $\beta < (1/2)$, then $(d\pi_{\mathrm{r}}^{\mathrm{os}}/d\gamma) > 0$.

$$\begin{aligned}
\frac{d\pi_{\mathrm{r}}^{\mathrm{os}}}{d\beta} &= \frac{(1-\beta)(1+\gamma)^2(1+2\gamma)(a\lambda-b(C_2-\Delta\tau))^2}{2b(2-3\beta+2(1-\beta)\gamma)^3} > 0,\\
\frac{d\pi_{\mathrm{m}}^{\mathrm{os}}}{d\beta} &= -\frac{\beta(1+\gamma)^2(1+2\gamma)(a\lambda-b(C_2-\Delta\tau))^2}{2b(2-3\beta+2(1-\beta)\gamma)^3} < 0,\\
\frac{d\pi_{\mathrm{m}}^{\mathrm{os}}}{d\gamma} &= \frac{(-1+2\beta)(1+\gamma)\left(2(1+\gamma)^2-\beta(1+\gamma)(5+2\gamma)+\beta^2(4+6\gamma+4\gamma^2)\right)(a\lambda-b(C_2-\Delta\tau))^2}{2b(1+2\gamma)^2(2-3\beta+2(1-\beta)\gamma)^3}.
\end{aligned} \tag{A.45}$$

Let

$$\begin{aligned}
Y &= 2(1+\gamma)^2-\beta(1+\gamma)(5+2\gamma)+2\beta^2\left(2+3\gamma+2\gamma^2\right),\\
\frac{d^2Y}{d\beta^2} &= 8+4\gamma(3+2\lambda) > 0.
\end{aligned} \tag{A.46}$$

Let $dY/d\beta = 0$, we have $\beta = (1+\gamma)(5+2\gamma)/(8+4\gamma(3+2\gamma))$.

Substituting $\beta = (1+\gamma)(5+2\gamma)/(8+4\gamma(3+2\gamma))$ into Y, we have $Y = 7(1+\gamma)^2(1+2\gamma)^2/(8(2+\gamma(3+2\gamma))) > 0$.

Thus, we have $Y > 0$.

Therefore, we have if $(1/2) < \beta < (2/3)$, then $(d\pi_{\mathrm{m}}^{\mathrm{os}}/d\gamma) > 0$; otherwise, if $\beta < (1/2)$, then $(d\pi_{\mathrm{m}}^{\mathrm{os}}/d\gamma) < 0$. □

Proof of Proposition 6. $w^{\mathrm{o}^*} - w^* = \gamma[b(C_2-\Delta\tau)-\lambda a]/(2b(2\gamma+1))$. Since $(C_2-\Delta\tau) < p_{\mathrm{r}}$, and $b(C_2-\Delta\tau)-\lambda a < 0$, we obtain $w^{\mathrm{o}^*} < w^*$.

$$w^{\mathrm{s}^*} - w^* = \frac{\beta[\lambda a - b(C_2-\Delta\tau)]}{2b(3\beta-2)}. \tag{A.47}$$

Since $\lambda a - b(C_2-\Delta\tau) > 0$ and $\beta < (2/3)$, we get $w^{\mathrm{s}^*} < w^*$.

$$w^{\mathrm{o}^*} - w^{\mathrm{s}^*} = \frac{(\beta-2\gamma+5\gamma\beta)(a\lambda-b(C_2-\Delta\tau))}{2b(2-3\beta)(1+2\gamma)}. \tag{A.48}$$

Since $\beta < (2/3)$ and $b(C_2-\Delta\tau)-\lambda a < 0$, we have if $\beta > 2\gamma/(1+5\gamma)$, then $w^{\mathrm{o}^*} > w^{\mathrm{s}^*}$; otherwise, $w^{\mathrm{o}^*} \le w^{\mathrm{s}^*}$.

$$\begin{aligned}
w^{\mathrm{os}} - w &= -\frac{(\beta+2\gamma(1+\gamma))(a\lambda-b(C_2-\Delta\tau))}{2b(1+2\gamma)(2-3\beta+2(1-\beta)\gamma)} < 0,\\
w^{\mathrm{os}} - w^{\mathrm{o}^*} &= -\frac{k(1+r)(a\lambda-b(C_2-\Delta\tau))}{2b(2-3\beta+2(1-\beta)\gamma)} < 0,\\
w^{\mathrm{os}} - w^{\mathrm{s}^*} &= \frac{(-1+2\beta)\gamma(2(1+\gamma)-\beta(2+\gamma))(a\lambda-b(C_2-\Delta\tau))}{b(2-3\beta)(1+2\gamma)(2-3\beta+2(1-\beta)\gamma)}.
\end{aligned} \tag{A.49}$$

Since $\beta(2+\gamma)-2(1+\gamma) < 0$, we have if $(1/2) < \beta < (2/3)$, then $w^{\mathrm{os}} > w^{\mathrm{s}^*}$, otherwise, if $\beta \le (1/2)$, then $w^{\mathrm{os}} \le w^{\mathrm{s}^*}$.

Since $2\gamma/(1+5\gamma) < (1/2)$, we have if $(1/2) < \beta$, then $w^{\mathrm{os}} > w^{\mathrm{s}^*}$ and $w^{\mathrm{o}^*} > w^{\mathrm{s}^*}$, that is, $w^{\mathrm{s}^*} < w^{\mathrm{os}^*} < w^{\mathrm{o}^*}$ because $w^{\mathrm{os}^*} < w^{\mathrm{o}^*}$.

If $2\gamma/(1+5\gamma) < \beta \le (1/2)$, then $w^{\mathrm{os}} \le w^{\mathrm{s}^*}$ and $w^{\mathrm{o}^*} > w^{\mathrm{s}^*}$, that is, $w^{\mathrm{os}} \le w^{\mathrm{s}^*} < w^{\mathrm{o}^*}$.

If $\beta \le 2\gamma/(1+5\gamma)$, then we have $w^{\mathrm{os}} \le w^{\mathrm{s}^*}$ and $w^{\mathrm{o}*} \le w^{\mathrm{s}^*}$, that is, $w^{\mathrm{os}^*} < w^{\mathrm{o}^*} \le w^{\mathrm{s}^*}$ because $w^{\mathrm{os}^*} < w^{\mathrm{o}^*}$.

It is easy to find that $P_{\mathrm{m}}^* = P_{\mathrm{m}}^{\mathrm{o}^*} = P_{\mathrm{m}}^{\mathrm{s}^*} = P_{\mathrm{m}}^{\mathrm{os}^*}$ and $P_{\mathrm{r}}^* = P_{\mathrm{r}}^{\mathrm{o}^*}$.

$$P_{\mathrm{r}}^* - P_{\mathrm{r}}^{\mathrm{s}^*} = \frac{\beta}{4b(3\beta-2)}\left(b(C_2-\Delta\tau)-a\lambda\right) \tag{A.50}$$

Since $\beta < (2/3)$ and $b(C_2-\Delta\tau)-\lambda\alpha < 0$, we can have $P_{\mathrm{r}}^* > P_{\mathrm{r}}^{\mathrm{s}^*}$.

$$P_r^{os} - P_r^* = -\frac{\beta(1+2\gamma)(a\lambda - b(C_2-\Delta\tau))}{4b(2-3\beta+2(1-\beta)\gamma)} < 0,$$
$$P_r^{os} - P_r^{s^*} = \frac{\beta(-1+2\beta)\gamma(a\lambda - b(C_2-\Delta\tau))}{2b(2-3\beta)(2-3\beta+2(1-\beta)\gamma)}. \quad (A.51)$$

Thus, if $(1/2) < \beta < (2/3)$, then $P_r^{os} > P_r^{s^*}$; otherwise, $P_r^{os} \le P_r^{s^*}$. □

Proof of Proposition 7. The optimal demand quantities of the manufacturer in the three cases are:

(1) Without fairness concerns

$$q = \frac{1}{4}[\lambda a - b(C_2-\Delta\tau)]. \quad (A.52)$$

(2) With retailer's fairness concern

$$q^o = \frac{1}{4}[\lambda a - b(C_2-\Delta\tau)]. \quad (A.53)$$

(3) With manufacturer's fairness concern

$$q^s = \frac{(\beta-1)}{6\beta-4}[\lambda a - b(C_2-\Delta\tau)]. \quad (A.54)$$

Since $q^s/q = (\beta-1)/(6\beta-4) = ((4\beta-4)/(6\beta-4)) > 1$, we can get $q < q^s$.

The optimal demand quantities of the manufacturer in the three cases are as follows:

(1) Without fairness concerns

$$Q = \frac{1}{4}[2(1-\lambda)a + d(C_2-\Delta\tau)] + \frac{\lambda ad}{4b}. \quad (A.55)$$

(2) With retailer's fairness concern

$$Q^o = \frac{1}{4}[2(1-\lambda)a + d(C_2-\Delta\tau)] + \frac{\lambda ad}{4b}. \quad (A.56)$$

(3) With manufacturer's fairness concern

$$Q^s = \frac{1}{2}a(1-\lambda) + \frac{d(\beta-1)(C_2-\Delta\tau)}{2(3\beta-2)} + \frac{(2\beta-1)\lambda ad}{(3\beta-2)2b},$$
$$Q^s - Q = \frac{\beta d}{4b(3\beta-2)}[a\lambda - b(C_2-\Delta\tau)]. \quad (A.57)$$

Since $\beta < (2/3)$ and $b(C_2-\Delta\tau) - \lambda\alpha < 0$, we can obtain $Q > Q^s$.

$$q^{os} - q^s = \frac{\beta(1-2\beta)\gamma(a\lambda - b(C_2-\Delta\tau))}{2(-2+3\beta)(-2+3\beta+2(-1+\beta)\gamma)}. \quad (A.58)$$

If $(1/2) < \beta < (2/3)$, then $q^{os} < q^s$; otherwise, $q^{os} \ge q^s$.

$$q^{os} - q^o = \frac{\beta(1+2\gamma)(a\lambda - b(C_2-\Delta\tau))}{8(1+\gamma) - 4\beta(3+2\gamma)}. \quad (A.59)$$

Since $2(1+\gamma)/(3+2\gamma) > (2/3) > \beta$, we have $q^{os} > q^o$.

$Q^{os} - Q^o = d\beta(1+2\gamma)(a\lambda - b(C_2-\Delta\tau))/(4b(-2+3\beta+2(-1+\beta)\gamma)) < 0$. Thus, we have $Q^{os} < Q^o$.

$$Q^{os} - Q^s = \frac{d\beta(-1+2\beta)\gamma(a\lambda - b(C_2-\Delta\tau))}{2b(-2+3\beta)(-2+3\beta+2(-1+\beta)\gamma)}. \quad (A.60)$$

If $(1/2) < \beta < (2/3)$, then $Q^{os} > Q^s$; otherwise, $Q^{os} \le Q^s$.

$$Q^{os} + q^{os} - (Q^s + q^s) = \frac{(b-d)\beta(1-2\beta)\gamma(a\lambda - b(C_2-\Delta\tau))}{2b(-2+3\beta)(-2+3\beta+2(-1+\beta)\gamma)}. \quad (A.61)$$

If $(1/2) < \beta < (2/3)$, then $Q^{os} + q^{os} < (Q^s + q^s)$; otherwise, $Q^{os} + q^{os} \ge (Q^s + q^s)$.

$$Q^{os} + q^{os} - (Q+q) = \frac{(b-d)\beta(1+2\gamma)(a\lambda - b(C_2-\Delta\tau))}{4b(2-3\beta+2(1-\beta)\gamma)} > 0. \quad (A.62)$$

Thus, we have $Q^{os} + q^{os} > (Q+q)$.

$$Q^s + q^s - (Q+q) = \frac{(b-d)\beta(a\lambda - b(C_2-\Delta\tau))}{4b(2-3\beta)} > 0. \quad (A.63)$$

That is, $Q^s + q^s > (Q+q)$. □

Proof of Proposition 8. The optimal profits of the retailer in the three cases are as follows:

(1) Without fairness concerns

$$\pi_r = \frac{[\lambda a - b(C_2-\Delta\tau)]^2}{16b} - C_E\tau^2. \quad (A.64)$$

(2) With retailer's fairness concern

$$\pi_r^o = \frac{(4\alpha+1)[\lambda a - b(C_2-\Delta\tau)]^2}{16b(2\alpha+1)} - C_E\tau^2. \quad (A.65)$$

(3) With manufacturer's fairness concern

$$\pi_r^s = \frac{(\beta-1)^2[b(C_2-\Delta\tau) - \lambda a]^2}{4b(3\beta-2)^2} - C_e\tau^2. \quad (A.66)$$

Because $-C_E\tau^2$ is the same part of the every profit function, we omit it and compare the remaining parts as follows:

$$\overline{\pi}_r = \frac{[\lambda a - b(C_2-\Delta\tau)]^2}{16b},$$
$$\overline{\pi}_r^o = \frac{(4\alpha+1)[\lambda a - b(C_2-\Delta\tau)]^2}{16b(2\alpha+1)}, \quad (A.67)$$
$$\overline{\pi}_r^s = \frac{(\beta-1)^2[b(C_2-\Delta\tau) - \lambda a]^2}{4b(3\beta-2)^2}.$$

Since $\overline{\pi}_r^o/\overline{\pi}_r = (4\alpha+1)/(2\alpha+1) > 1$, we get $\pi_r^o > \pi_r$.

We assume that $s = \overline{\pi}_r^s/\overline{\pi}_r = 4(1-\beta)^2/(3\beta-2)^2$. When $\beta < (2/3)$, $((1-\beta)^2/(3\beta-2)^2) > (1/4)$. Therefore, $s > 1$. We get $\pi_r^s > \pi_r$.

$$\pi_r^o - \pi_r^s = \frac{(8\gamma + \beta(-4+5\beta+4(-8+7\beta)\gamma))(\lambda a - b(C_2 - \Delta\tau))^2}{16(2-3\beta)^2(b+2b\gamma)}. \tag{A.68}$$

If $8\gamma + \beta(-4+5\beta+4(-8+7\beta)\gamma) > 0$, then $\pi_r^o > \pi_r^s$; otherwise, $\pi_r^o \leq \pi_r^s$.

$$\pi_r^{os} - \pi_r^o = -\frac{\beta(1+2\gamma)(-4+5\beta+4(-1+\beta)\gamma)(\lambda a - b(C_2-\Delta\tau))^2}{16b(-2+3\beta+2(-1+\beta)\gamma)^2}. \tag{A.69}$$

Let $x = -4+5\beta+4(-1+\beta)\gamma$, then $dx/d\beta = 5+4\gamma > 0$. Since $x|_{\beta=0} = -4-4\gamma < 0$ and $x|_{\beta=2/3} = -(2/3)(1+2\gamma) < 0$, we have $x < 0$, that is, $\pi_r^{os} > \pi_r^o$.

That is, $\beta > 4(1+\gamma)/(5+4\gamma)$, then $\pi_r^{os} - \pi_r^o < 0$; otherwise, $\pi_r^{os} - \pi_r^o \geq 0$.

$$\pi_m - \pi_m^o = \frac{\gamma(\lambda a - b(C_2-\Delta\tau))^2}{8(b+2b\gamma)} > 0,$$

$$\pi_m - \pi_m^s = \frac{\beta^2(\lambda a - b(C_2-\Delta\tau))^2}{8b(2-3\beta)^2} > 0,$$

$$\pi_m^o - \pi_m^s = -\frac{\left(4\gamma - 12\beta\gamma + \beta^2(-1+7\gamma)\right)(\lambda a - b(C_2-\Delta\tau))^2}{8(2-3\beta)^2(b+2b\gamma)}. \tag{A.70}$$

Thus, if $4\gamma - 12\beta\gamma + \beta^2(-1+7\gamma) < 0$, then $\pi_m^o > \pi_m^s$; otherwise, $\pi_m^o \leq \pi_m^s$.

$\pi_m^{os} - \pi_m^o = -\beta^2(1+\gamma)(1+2\gamma)(\lambda a - b(C_2-\Delta\tau))^2/(8b(-2+3\beta+2(-1+\beta)\gamma)^2) < 0$, that is, $\pi_m^{os} < \pi_m^o$.

We also can find that $\pi_m + \pi_r - (\pi_m^o + \pi_r^o) = 0$.

$$\pi_m + \pi_r - \left(\pi_m^s + \pi_r^s\right) = \frac{\beta(-4+7\beta)(\lambda a - b(C_2-\Delta\tau))^2}{16b(2-3\beta)^2}. \tag{A.71}$$

Thus, if $\beta > (4/7)$, then $\pi_m + \pi_r > (\pi_m^s + \pi_r^s)$; otherwise, $\pi_m + \pi_r \leq \pi_m^s + \pi_r^s$.

$$\pi_m^{os} + \pi_r^{os} - \left(\pi_m^o + \pi_r^o\right) = -\frac{\beta(1+2\gamma)(-4(1+\gamma)+\beta(7+6\gamma))(a\lambda - b(C_2-\Delta\tau))^2}{16b(-2+3\beta+2(-1+\beta)\gamma)^2}. \tag{A.72}$$

If $\beta > 4(1+\gamma)/(7+6\gamma)$, then $\pi_m^{os} + \pi_r^{os} < (\pi_m^o + \pi_r^o)$; otherwise, $\pi_m^{os} + \pi_r^{os} \geq (\pi_m^o + \pi_r^o)$.

$$\pi_m^{os} + \pi_r^{os} - \left(\pi_m^s + \pi_r^s\right) = -\frac{(1-2\beta)^2\beta\gamma(-4(1+\gamma)+\beta(6+5\gamma))(a\lambda - b(C_2-\Delta\tau))^2}{6b(-2+3\beta+2(-1+\beta)\gamma)^2}. \tag{A.73}$$

Thus, if $\beta > 4(1+\gamma)/(6+5\gamma)$, then $\pi_m^{os} + \pi_r^{os} < (\pi_m^s + \pi_r^s)$; otherwise, $\pi_m^{os} + \pi_r^{os} \geq (\pi_m^s + \pi_r^s)$.

Let $\Pi_C^s = \pi_m^s + \pi_r^s$, $\Pi_C^{os} = \pi_m^{os} + \pi_r^{os}$ and $\Pi_C^o = \pi_m^o + \pi_r^o$.

if $\beta > (4/7)$, then $\Pi_C > \Pi_C^s$; otherwise, $\Pi_C \leq \Pi_C^s$.

If $\beta > 4(1+\gamma)/(7+6\gamma)$, then $\Pi_C^{os} < \Pi_C$; otherwise, $\Pi_C^{os} \geq \Pi_C$.

if $\beta > 4(1+\gamma)/(6+5\gamma)$, then $\Pi_C^{os} < \Pi_C^s$; otherwise, $\Pi_C^{os} \geq \Pi_C^s$.

Since $4(1+\gamma)/(6+5\gamma) > (2/3) > (1+\gamma)/(7+6\gamma) > (4/7)$, we have if $4(1+\gamma)/(7+6\gamma) < \beta \leq (2/3)$, then we have $\Pi_C^{os} \geq \Pi_C^s$, $\Pi_C^{os} < \Pi_C$ and $\Pi_C > \Pi_C^s$, that is, $\Pi_C > \Pi_C^{os} \geq \Pi_C^s$.

If $(4/7) < \beta \leq 4(1+\gamma)/(7+6\gamma)$, then we have $\Pi_C^{os} \geq \Pi_C^s$, $\Pi_C^{os} \geq \Pi_C$ and $\Pi_C > \Pi_C^s$, that is, $\Pi_C^{os} \geq \Pi_C > \Pi_C^s$.

If $\beta \leq (4/7)$, then we have $\Pi_C \leq \Pi_C^s$, $\Pi_C^{os} \geq \Pi_C$ and $\Pi_C^{os} \geq \Pi_C^s$, that is, $\Pi_C^{os} \geq \Pi_C^s \geq \Pi_C$. □

Data Availability

All data generated or analyzed during this study are included in this paper. The authors are willing to share the implementation scripts in the form of some MATLAB m-files with the interested reader.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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