RAIRO-Oper. Res. 58 (2024) 4437–4475
https://doi.org/10.1051/ro/2024148

RAIRO Operations Research
www.rairo-ro.org

MODELS FOR DUAL-CHANNEL REMANUFACTURING SUPPLY CHAIN WITH REFERENCE PRICE EFFECT UNDER STATIC AND DYNAMIC GAMES

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Abstract. With the diversity of shopping styles, reference prices have become a consideration in consumers' purchasing decisions. It is critical to understand how manufacturers and retailers make optimal decisions based on consumer behavior. To this end, we develop a manufacturer-led Stackelberg (M-Stackelberg) game model to investigate the impact of consumer proportion, reference price effect (RPE), and the channel preference coefficient on the decision of the remanufacturing supply chain (RSC) in dual-channel structures. Through comparing different game scenario models, we find that when the reference price coefficient is relatively small, the optimal decisions for the manufacturer and the retailer are the same regardless of whether the RPE is considered. The manufacturer and E-tailer always benefit from RPE, while the traditional retailer (T-retailer) is uncertain. The numerical analysis revealed that the profits of supply chain members are inversely proportional to the proportion of consumers. The smaller the proportion of primary consumers, the more favorable the supply chain. In particular, the higher the channel preference coefficient, the higher the profits of the manufacturer and E-tailer, while the lower the benefit of the T-retailer. Further, in the dynamic game, the total supply chain profit is highest when the T-retailer prices earlier than the E-tailer.

Mathematics Subject Classification. 35J20, 35J25, 35J60.

Received March 13, 2023. Accepted July 21, 2024.

1. Introduction

Remanufacturing is the process of disassembling a used product, and its parts are repaired, replaced, or restored and used to produce a new product [1]. Several studies have shown that remanufacturing plays an essential role in the market by saving costs, benefiting the environment, and increasing corporate profit [2–5]. Recently, countries have made great efforts to recycle used resources. For instance, China released the 14th Five-Year Plan for Circular Economy Development in 2021 on product recycling, which is conducive

Keywords. Dual-channel supply chain, remanufacturing, reference price effect, pricing strategy, game theory.

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to promote the recycling of used products and recycled resources. In addition, European countries and the United States have implemented product recycling and disposal programs to prevent e-waste from polluting the environment. Recycling used products is vital for conserving market resources and can create great value. For example, Hewlett-Packard and Epson saved 65% of remanufacturing costs by recycling used products [6]. While previous studies have emphasized that remanufacturing can bring significant benefits to firms, it is worthwhile for researchers to further whether remanufacturing will bring lasting benefits to companies. On the one hand, early studies have shown that remanufacturing offers significant benefits to companies. For example, in 2011, the value of all remanufactured products produced in the United States amounted to $43 billion [7, 8]. On the other hand, studies have found that many companies have adopted sustainable remanufacturing business models in an environment of uncertain benefits due to continued public concern and pressure from resource scarcity. Examples include Kodak, Xerox, Robert Bosch Tool, Black and Decker, Apple, Boeing, and Caterpillar [9–11]. Besides, Dell, Lenovo, and Canon have conducted trade-in activities in their remanufacturing practices [4]. However, despite the many benefits that remanufacturing brings to firms, the quality of remanufactured products remains a concern for consumers. Consumers are less willing to pay for and value remanufactured products than new ones. Consumers have different buying attitudes towards new (used) products. Therefore, it is crucial to consider consumers' buying behavior in the RSC when studying product pricing decisions.

In addition, the rapid development of the Internet and advances in information technology have enabled companies to choose one more channel to sell their products to relieve the pressure on inventories and seek more profits. As traditional marketing channels such as brick-and-mortar shops flourished, new business models such as Internet e-commerce channels emerged in the late 20th century. Several companies are exploring new marketing channels to gain more market share and profits. For example, Apple, Nike, IBM, Dell, Sony, and Estee Lauder have added internet channels to their existing retail channels [12, 13]. Apparently, multi-channel sales have become a new and popular trend. Apple sells iPhones and other products through various channels, including telephone service providers, the Apple online store, and other retailers (*e.g.*, Sam's Club, Walmart, Best Buy). Multi-channel selling can generate profits for a company. However, providing consumers with product information through multiple channels can influence their buying behavior. Various real-life factors, including reference price, income level, gender, and age, can influence consumer purchase behavior. The reference price is one of the most crucial reference indications. Relevant studies have proved that reference price influences consumers' purchasing decisions. The reference price is a benchmark consumers perceive based on past product prices and plays a decisive role in consumers' decisions on the final purchase. Consumers assess whether the current price is high or low by comparing it with the current price; if the actual price is lower than the reference price, consumers feel a gain; if the actual price is higher than the reference price, consumers feel a loss [14, 15]. Empirical investigation has shown that reference prices affect consumer demand for many products, such as coffee and orange juice [16]. Therefore, it is necessary to consider consumer behavior and multi-channel choice when studying product decisions in the RSC. Reference behavior is also common in real life. For example, in the case of electronic products, consumers could easily identify online prices through electronic retail (e-retail) channels to compare offline prices, thus creating a reference role. Firms have realized the impact of reference prices on business decisions and would like to use RPE to increase profits. However, it is uncertain whether the reference price brings gains or losses to firms. Based on these facts, this paper integrates RPE and dual channel selling into RSC to address the following questions. What is the ideal strategy for supply chain members in the context of static and dynamic games, and how does RPE affect the optimal strategies of the manufacturer and retailers? How does the optimal profit change when considering RPE? How do consumer proportion and channel coefficients affect supply chain members? All of these issues are important for supply chain members. First, the manufacturer can access reference prices to make optimal pricing decisions. Second, it is necessary for traditional and online retailers to fully understand the impact of reference price effects on their margins and demand. Third, different proportions of consumers and channel preferences may inevitably lead to changes in the profitability of RSC members. However, previous research on dual-channel supply chains has not addressed these issues well.

To address the above issues, first, we consider a scenario in which the manufacturer, acting as a Stackelberg leader, determines the optimal wholesale price by analyzing the response functions of a T-retailer and an

E-tailer in a dual-channel RSC to maximize profit. This supply chain structure is commonly found in previous literature [17–19]. Second, consumers are categorized into two types: replacement consumers (R-consumers), *i.e.*, consumers who own obsolete products and buy new products by selling them, and primary consumers (P-consumers), *i.e.*, consumers who do not own obsolete products and buy new products directly. Similar consumer classifications have been studied in earlier literature works [4, 17]. We focused on durable goods because of their high recycling value, such as electronics, which have received extensive attention in previous studies [14, 17]. Third, based on reality, we consider that retailers have different channel power, while most prior work focuses on the same channel power [20]. Retailers set the best retail price based on the optimal wholesale price to maximize profits according to different pricing timing. Motivated by these facts, this paper constructs a dual-channel RSC with traditional retail (t-retail) and e-retail channels under RPE, *i.e.*, the manufacturer distributes its products through a T-retailer and an E-tailer. Three main strategies are considered to study the impact of RPE on pricing strategies in the dual-channel RSC: MS, ME, and ML. MS, ME, and ML, respectively, mean that the manufacturer sets the wholesale price first. Then, the T-retailer decides the retail price simultaneously, earlier, and later than the E-tailer. Based on the above hypotheses, this study mainly investigates the impact of consumer heterogeneity and different pricing timing on game players through a two-channel RSC under RPE.

Some findings and contributions are summarized. Through the model analysis, we find that consumer proportion, channel preference, and reference price parameters are key factors that affect the optimal decision of supply chain members. The results show that the lower the proportion of P-consumers, the more favorable the supply chain members are. The reference price parameter within a certain range favors the profits of the manufacturer and E-tailer over the benefit of the T-retailer. The profits of the manufacturer and E-tailer are proportional to the channel preference coefficient. The contributions are reflected in the following aspects: First, this paper considers the reference price factor in a dual-channel RSC model for the first time. Second, unlike previous literature, the article divides the market into P-consumers and R-consumers and considers both static and dynamic games between the T-retailer and E-tailer under the M-Stackelberg game model.

The rest of this paper is organized as follows. Section 2 reviews the literature most closely related to this study. In Section 3, model assumptions, consumer behavior, and game sequence are established. Sections 4 and 5 discuss the model setup. The analysis and numerical examples are presented in Section 6. Section 7 provides conclusions, limitations, and future research. All proofs are collected in Appendix A.

2. Literature review

In this section, there are three main streams of relevant literature to our research: remanufacturing, dual-channel supply chains, and reference price effects.

2.1. Remanufacturing

A growing number of studies have provided comprehensive reviews of remanufacturing or closed-loop supply chains (CLSCs) [21–23]. Consumer behavior has attracted a great deal of attention from scholars who are researching remanufacturing operations management research. Particularly, many scholars have extensively studied the impact of consumer behavior on remanufacturing pricing decisions. Debo *et al.* [24] explored the issues of joint pricing and production technology choice faced by manufacturers when introducing remanufactured products in markets consisting of heterogeneous consumers. Atasu *et al.* [1] focused on the impact of green segmentation, OEM competition, and the product life cycle on the market demand of primary and green consumers. They found that remanufacturing can be an effective marketing strategy in a competitive environment, enabling manufacturers to defend their market share through price discrimination. Ma *et al.* [17] examined the impact of government consumer subsidies on a dual-channel CLSC by considering primary and replacement consumers. Their study showed that the manufacturer and the retailer, as well as consumers purchasing new products, benefited from the subsidies to varying degrees, while E-tailers were uncertain. Abbey *et al.* [25] investigated consumer perceptions of remanufactured products in CLSCs. They found that consumers held strongly negative views of remanufactured products; however, green consumers and those who perceived remanufactured products as green generally found them more attractive. Ma *et al.* [26] proposed a remanufacturing model with dual reference effects of trade-in, considering both consumer perceptions of the new product and perceptions of the functionality of the remanufactured product. They found that the manufacturer's profit decreases continuously with the increase of the reference quality parameter and increases rapidly with the increase of the reference price parameter. Recently, Zhou *et al.* [5] considered consumer heterogeneity through the perspective of consumer education. They developed a game model consisting of a manufacturer and a supplier to research the influence of consumer education on CLSC decisions. They found that the supply chain could benefit from moderate consumer education, but the manufacturer may abandon remanufacturing due to higher wholesale prices. It is not hard to find that significant progress has been made in remanufacturing pricing decisions based on the above studies in the primary literature. However, none of these studies have addressed the effect of heterogeneous consumers on the dual RSC structure under RPE. In other words, previous studies on the decision-making behavior of heterogeneous consumers in the RSC have not received extensive attention.

2.2. Dual-channel supply chains

Over the past few decades, pricing strategies and channel power structures in dual-channel supply chains have attracted much attention in the literature. Chiang *et al.* [27] developed a pricing game model with only one independent retailer and one manufacturer. Their work showed that increasing direct channels may not always be unfavorable to the retailer. Several studies have focused on channel power structures, such as Dumrongsiri *et al.* [28], Almehdawe and Mantin [29], Choi *et al.* [20], Chen *et al.* [30], and Zheng *et al.* [31]. Specifically, Dumrongsiri *et al.* [28] studied the dual-channel pricing problem where consumers choose to buy based on price and service quality. They found that the marginal cost differences between channels play an essential role in determining the existence of a dual-channel equilibrium. Almehdawe and Mantin [29] studied a supply chain comprising a single manufacturer and multiple retailers. They examined the performance of manufacturer-led and retailer-led supply chains separately and showed that the retailer-led reduces wholesale prices. Choi *et al.* [20] built a CLSC framework consisting of a retailer, a recycler, and a manufacturer and examined the performance of CLSC under different channel power structures. By comparison, they found that retailer led CLSC structure was the most effective. Chen *et al.* [30] analyzed the impact of free and bundled channels' power structures on pricing and selection decisions. They found that firms with higher channel power will be more profitable. From the perspective that the manufacturer and retailers have the same decision-making power, Jafari *et al.* [18] considered a two-channel supply chain with one manufacturer and multiple retailers. They developed a Nash game model to determine prices under decentralized and centralized models. Zheng *et al.* [31] investigated the symmetric and asymmetric channel power structures by considering independent retail and direct sales channels with pricing decision problems under centralized and decentralized models. They found that the channel power structure significantly impacted the efficiency of CLSC. Yang *et al.* [32] examined the impact of online consumer reviews on pricing decisions and profits in dual-channel retailing and Internet channels. They found that consumer reviews on the centralized channel may increase or lower the direct price but always lower retail prices. Fan *et al.* [33] developed a game-theoretic model of the supply chain under the t-retail channel and dual-channel structure to explore the optimal channel choice for trade-ins, discussing whether and when the manufacturer adopts a collection delegation policy. The findings revealed that collection delegation always benefits the manufacturer but can occasionally harm the retailer. Different from previous research, we focus on the pricing decision problem of a manufacturer and two retailers by integrating consumer behavior and different game decisions of supply chain members.

2.3. Reference price effects

Prior studies on RPE dating back to 1989. Previous literature has provided valuable insights and guidance on durable goods pricing, and these studies have often abstracted an important behavioral concept, RPE, which has been validated by empirical research [34]. Lattin *et al.* [16] developed a model to test the effects of price reference effects and promotion reference effects on brand choice behavior. The results showed that promotions

TABLE 1. Comparison of main relevant literature with our study.

Related studies	WTP	CLSC/ RSC	Dual-channel	Pricing timing	RPE	Strategies
Ma *et al.* [17]	✓	✓	✓	×	×	CB, GCS, M-S, Rs-SG
Zhang *et al.* [14]	×	×	×	×	✓	Hamiltonian, M-S
Lin [41]	×	×	✓	×	✓	Price promotion, M-S
Matsui *et al.* [45]	×	×	✓	✓	×	M-S, Rs-VN, Rs-DG
Cao *et al.* [44]	✓	×	×	×	✓	Bayesian demand learning
Ma *et al.* [26]	✓	✓	×	×	✓	CB, Trade-in
Wang *et al.* [15]	✓	×	✓	×	✓	R-S, Rs-SG
Yang *et al.* [32]	✓	×	✓	×	×	Online consumer reviews,M-S
Zhou *et al.* [5]	✓	✓	×	×	×	Consumer education, Supplier-lead
Our study	✓	✓	✓	✓	✓	CB, M-S, Rs-SG,Rs-DG

Notes. GCS: Government consumption subsidy; CB: Consumer behavior; M-S: Manufacturer-led Stackelberg; R-S: Retailer-lead Stackelberg; Rs-DG: Retailers-Dynamic Game; Rs-SG: Retailers-Static Game.

had a significant reference effect on consumers. Kopalle *et al.* [35] investigated the effect of reference prices on firms' optimal dynamic policies under the assumptions of retailer brand groups and oligopolistic brand groups. Mazumdar *et al.* [36] provided a detailed review of the formation of reference prices and their impact on various purchase decisions. Based on the above studies, previous papers on reference prices have focused on dynamic prices, inventory decisions, and advertising [37–41]. Popescu and Wu [37] addressed the dynamic pricing problem in a monopolistic market environment; they found that the optimal price converges to a constant steady-state price. Kopalle *et al.* [38] examined the impact of RPE household-level heterogeneity on retailers' pricing policies. They discovered that households differ significantly in terms of the impact of gains and losses. Zhang *et al.* [39] proposed a model of dynamic cooperative advertising in a manufacturer–retailer supply chain under RPE. Their study showed that the stable reference price was usually higher than the market price because the intensity of advertising affects the consumer's reference price. Zhang *et al.* [14] studied bilateral monopoly supply chains under RPE. The findings revealed that the more sensitive consumers were to RPE, the more loyal they were to products in centralized or decentralized channels. Lin [41] proposed a model of consumer price promotion with RPE, and the findings indicated that optimal price promotions are beneficial to the manufacturer, the retailer, and the consumers. Wang [42] explored the dynamic pricing problem of a seller's monopoly under RPE with consumers arriving in heterogeneous periods. The results demonstrated that the optimal pricing strategy may no longer be asymptotically constant, and the periodic pricing strategy may be optimal. Wang [43] studied the problem of pricing optimization for consumer choice models under RPE. Their research showed that incorporating reference prices into the choice model can significantly improve consumer choice behavior's goodness-of-fit and prediction accuracy. Cao *et al.* [44] established a Bayesian dynamic programming model and found that ignoring RPE leads to a substantial loss of revenue. Wang *et al.* [15] incorporated RPE into the Hotelling model to study the competitive pricing strategies of both online and offline. They found that online and offline retailers prefer to use their prices as a reference.

The aforementioned studies on RPE in supply chain decisions are numerous; however, few address consumer behavior and RPE in the dual-channel RSC. Hence, our study integrates consumer behavior and RPE to explore the impact of these factors on pricing decisions and profits in a dual RSC. Table 1 compares our study with other related work.

3. The model

In this work, under RPE, a dual-channel RSC is considered to consist of a manufacturer and two retailers, where the manufacturer is the leader, and the retailers are followers. Retailers can control not only the level

TABLE 2. Notations.

Notation	Description
Parameters	
p_t	Retail price from the T-retailer (decision variable)
p_e	Retail price from the E-tailer (decision variable)
w	Wholesale price from the manufacturer (decision variable)
p_s	Acquisition price
c	Cost of the new product
c_t	Cost of the t-retail product
c_e	Cost of the e-retail product
$\emptyset$	Proportion of primary consumers, $0 < \emptyset < 1$
U_{xy}^N, U_{xy}	Consumers' utility without RPE or with RPE
q^N, q	Total demand without RPE or with RPE
v	Valuation of products by customers
δ	Consumer preferences for the e-retail channel
μ	Magnitude of the RPE when perceiving a gain
ρ	Magnitude of the RPE when perceiving a loss
$\pi_{Re}^{Ni}, \pi_{Re}^{i}$	Profit of the E-tailer without RPE or with RPE
$\pi_{Rt}^{Ni}, \pi_{Rt}^{i}$	Profit of the T-retailer without RPE or with RPE
$\pi_{M}^{Ni}, \pi_{M}^{i}$	Profit of the manufacturer without RPE or with RPE
Indexes	
x	Subscript, denoting the retailer type, where $x = T, E$
y	Subscript, denoting consumers type, where $y = 1, 2$
i	Superscript, denoting the order of decisions, where $i = E, S, L$
$*$	Superscript, denoting optimal solutions

of the retail price but also pricing timing. The manufacturer sells products to P-consumers and R-consumers through traditional retail and online channels. The problem description and assumptions are presented in Sections 3.1 and 3.2 describes consumer behavior in detail. Section 3.3 introduces the sequence of game events. Table 2 lists the variables included in the model. Let E, S, and L denote that T-retailer sets the retail price earlier than, simultaneously with, and later than the price by the E-tailer, respectively. The framework of the RSC model is shown in Figure 1. The manufacturer is assumed to sell to different retailers at the same wholesale price. Previous literature on MS/OR is divided into two categories: price discrimination and no-price discrimination. Most of the literature argues that there is no price discrimination [17,46], and they believe that manufacturers should offer the same wholesale price to different retailers for two possible reasons, one is legal constraints, such as the Robinson–Patman Act. Another reason is the potential to reduce operating costs. Only a small body of literature has considered price discrimination, *e.g.*, Ingene and Parry [47]. Our study assumes that the manufacturer sells to different retailers at the same wholesale price, considers the interaction between competing retailers, and focuses on the effect of reference prices on members of the remanufacturing supply chain based on a dual-channel model. On the one hand, the impact of the manufacturer and retailer decisions under different pricing models is explored, and on the other hand, the impact of reference price effects on consumer surplus is investigated. Therefore, based on the above assumption, it is reasonable for the manufacturer to sell

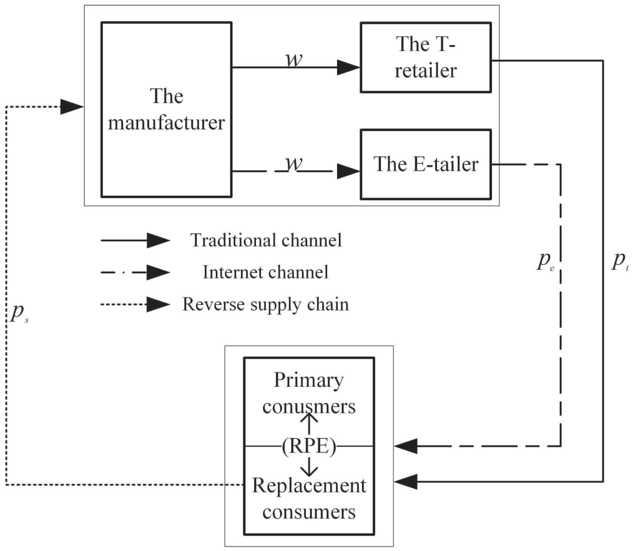

FIGURE 1. Framework of the model.

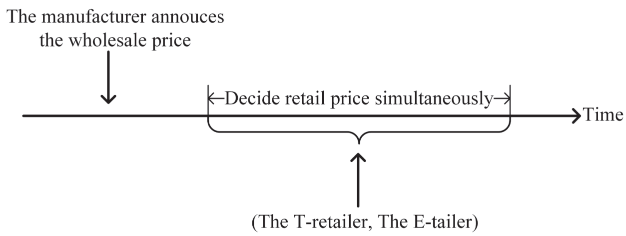

FIGURE 2. The sequence of events in the static game about the T-retailer and the E-tailer (MS).

products to different retailers at the same wholesale price. Figures 2 and 3 depict the decision-making flow of game events in the supply chain.

3.1. Problem descriptions and assumptions

In this subsection, we focus on pricing decisions considering RPE in several scenarios based on the sequence of events illustrated in Figures 2 and 3. In the M-Stackelberg game, there are static and dynamic games among game members, depending on the level of retailer channel power [45]. Our motivation for considering three scenarios is to determine the optimal strategies for the manufacturer and retailers to respond to changes in channel power under RPE.

First, we consider a single product in a single period market. Obsolete products are recycled into remanufactured products with identical value as new products, in line with Dumrongsiri *et al.* [28] and Chen *et al.* [48]. Moreover, we assume p_s as an exogenous variable that does not affect product demand. Previous studies on the acquisition price of obsolete products have included endogenous variables, *e.g.*, Fan *et al.* [33], and exogenous variables, *e.g.*, Savaskan *et al.* [49] and Ma *et al.* [17]. p_s is considered as the exogenous factor. On the one hand, this study focuses on the effect of reference price effects on the prices of new products and the profitability of supply chain members. On the other hand, due to space constraints, the price and demand for new products are

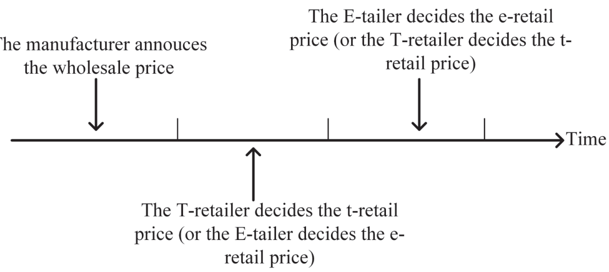

FIGURE 3. The sequence of events in the dynamic game about the T-retailer and the E-tailer (ME or ML).

focused on exploring how the competitive pricing behavior of retailers affects the optimal decisions of supply chain members. Further, most previous studies focusing on remanufacturing have considered the acquisition price of obsolete products as an exogenous variable. This is true, for example, for consumer goods (*e.g.*, cameras, ink cartridges) with low salvage values and for which there is no secondary market [50]. In real life, home appliances are easily obsolete. Most used appliances can only be recycled, and both have similar values. For simplicity, we assume that the used products are identical, which is consistent with the research of Ma *et al.* [17]. Second, following a large body of literature (*e.g.*, [3, 31, 41]), we assume supply chain members are risk-neutral and rational. Supply chain members are information-symmetric and profit-seeking. Third, we consider that there are two types of consumers in the market (primary and replacement consumers); similar assumptions have been used in many studies, *e.g.*, Ma *et al.* [17] and He *et al.* [3]. Fourth, two sales channels are considered in the market, *i.e.*, the T-retail channel and the e-retail channel, to sell products to consumers, and such dual channels have been widely studied [17]. Besides, consistent with Wang *et al.* [15], we assume that the cost of the t-retail channel is higher than that of e-retail, *i.e.*, $c_t > c_e$. Finally, it is reasonable to assume that RPE exists in the market. As evidenced by previous studies [35, 40, 41], which examined and discussed in detail the impact of the reference price effect on consumer purchasing behavior. These studies have consistently demonstrated that consumers are influenced by price reference points when making purchase decisions. To be specific, factors such as a product's historical price, advertised price, retail price, or competitor's price can be referred to as reference prices. Consumers compare these reference prices with the current market price of a product to assess its current value. The utility caused by RPE can be characterized as $U_{Ri} = \mu(r - p_i)^+ - \rho(p_i - r)^+$, $i = t, e$. U_{Rt} represents the utility generated by the reference price effect on the traditional channel, U_{Re} represents the utility generated by the reference price effect on the Internet channel, where

$$(r - p_i)^+ = \begin{cases} r - p_i, & r - p_i > 0 \\ 0, & r - p_i \leq 0 \end{cases},$$

which is consistent with studies of Kopalle *et al.* [35], Wang *et al.* [15] and Wang *et al.* [43]. r means the reference price, and p_i denotes the actual retail price, μ and ρ represent the magnitude of consumers' perceived gains and perceived losses, respectively.

3.2. Consumer behavior

In this subsection, we consider that consumers are heterogeneous with respect to their willingness to pay v which is assumed to be uniformly distributed between 0 and 1, and the total market size is normalized to 1 (*e.g.*, [3, 5, 17, 27, 31]). The value of the parameter δ is called the consumer acceptance of the e-retail channel, where $0 < \delta < 1$. Higher δ means higher acceptance. This hypothesis is reasonable. The reason why a consumer receives a lower valuation of the online channel ($\delta < 1$) is that consumers cannot easily touch, feel, and try products the products when shopping online, whereas traditional retail stores have more experience in after-sales service [15]. Specifically, several empirical studies by Chiang *et al.* [27] and Luo *et al.* [51] showed that consumers prefer traditional retail stores to e-retail channels. For many products, customer acceptance is lower in the e-retail channel than in the retail channel. For example, consumers are less willing to pay for books and consumer electronics in the e-retail channel than in the traditional retail channel. For a P-consumer, purchasing a new product in two channels without RPE yields a net utility $U_{T1}^N = v - p_t$ and $U_{E1}^N = \delta v - p_e$, respectively. If $U_{T1}^N > U_{E1}^N$, $U_{T1}^N > 0$, P-consumers prefer to buy products from the t-retail channel. q_{T1}^N, q_{E1}^N represent the demand of P-consumers in t-retail and e-retail channels, respectively. The demand function can be characterized as $q_{T1}^N = \emptyset \int_{\max\{p_t, \frac{p_t-p_e}{1-\delta}\}}^1 1\,\mathrm{d}v$. We assume that the t-retail price is higher than the e-retail price, *i.e.*, $p_e < \delta p_t$, as confirmed by empirical studies (*e.g.*, [52,53]). Thus, $q_{T1}^N = \emptyset \int_{\frac{p_t-p_e}{1-\delta}}^1 1\,\mathrm{d}v$. Also, to ensure the demand is non-negative, $\delta < 1 - p_t + p_e$. Then, the constraints are obtained as follow, $\frac{p_t}{p_e} < \delta < 1 - p_t + p_e$. If $U_{E1}^N > U_{T1}^N$, $U_{E1}^N > 0$, P-consumers are more willing to buy products from the e-retail channel. Then, $q_{E1}^N = \emptyset \int_{\frac{p_e}{\delta}}^{\frac{p_t-p_e}{1-\delta}} 1\,\mathrm{d}v$. Similarly, for R-consumers, purchasing a new product in two channels without RPE generates a net utility, $U_{T2}^N = v - p_t + p_s$ and $U_{E2}^N = \delta v - p_e + p_s$, respectively. The demand function of R-consumers, $q_{T2}^N = (1-\emptyset)(1 - \frac{p_t-p_e}{1-\delta})$ and $q_{E2}^N = (1-\emptyset)(\frac{p_t-p_e}{1-\delta} - \frac{p_e-p_s}{\delta})$, q_{T2} and q_{E2} are the demands of R-consumers in dual channels. Then, the demand of both channels can be derived as follows.

$$q_T^N = q_{T1}^N + q_{T2}^N = 1 - \frac{p_t - p_e}{1-\delta} \tag{1}$$

$$q_E^N = q_{E1}^N + q_{E2}^N = \frac{p_t - p_e}{1-\delta} - \frac{p_e}{\delta} + (1-\emptyset)\frac{p_s}{\delta} \tag{2}$$

$$q^N = q_T^N + q_E^N = 1 - \frac{p_e}{\delta} + (1-\emptyset)\frac{p_s}{\delta}. \tag{3}$$

Moreover, demands of the P-consumers and R-consumers under no RPE are $q_P^N = q_{T1}^N + q_{E1}^N = \emptyset(1 - \frac{p_e}{\delta})$ and $q_R^N = q_{T2}^N + q_{E2}^N = (1-\emptyset)(1 - \frac{p_e-p_s}{\delta})$, respectively. Under RPE scenarios, since $U_{Rt} = \mu(r - p_t)^+ - \rho(p_t - r)^+$, $U_{Re} = \mu(r - p_e)^+ - \rho(p_e - r)^+$, for a P-consumer, purchasing a new product in both channels will yield a net utility $U_{T1} = v - p_t + U_{Rt}$ and $U_{E1} = \delta v - p_e + U_{Re}$, while for a R-consumer, $U_{T2} = v - p_t + p_s + U_{Rt}$ and $U_{E2} = \delta v - p_e + p_s + U_{Re}$. We assume that when the product is available in both channels, consumers prefer the t-retail price as the reference price before making a purchase decision, *i.e.*, $r = p_t$, thus, $U_{Rt} = 0$, $U_{Re} = \mu(p_t - p_e)$.

Similar to the above case (without RPE), the functions for demand are as follows. $q_{T1} = \emptyset(1 - \frac{(1+\mu)(p_t-p_e)}{1-\delta})$, $q_{E1} = \emptyset(\frac{(1+\mu)(p_t-p_e)}{1-\delta} - \frac{p_e-\mu(p_t-p_e)}{\delta})$, $q_{T2} = (1-\emptyset)(1 - \frac{(1+\mu)(p_t-p_e)}{1-\delta})$, $q_{E2} = (1-\emptyset)(\frac{(1+\mu)(p_t-p_e)}{1-\delta} - \frac{p_e-p_s-\mu(p_t-p_e)}{\delta})$. Therefore, with the RPE scenarios, the demand results for two channels are as follows.

$$q_T = q_{T1} + q_{T2} = 1 - \frac{(1+\mu)(p_t - p_e)}{1-\delta} \tag{4}$$

$$q_E = q_{E1} + q_{E2} = \frac{(1+\mu)(p_t - p_e)}{1-\delta} - \frac{p_e - \mu(p_t - p_e)}{\delta} + (1-\emptyset)\frac{p_s}{\delta} \tag{5}$$

$$q = q_T + q_E = 1 - \frac{p_e - \mu(p_t - p_e)}{\delta} + (1-\emptyset)\frac{p_s}{\delta}. \tag{6}$$

Besides, the demand of P-consumers and R-consumers under RPE, $q_P = q_{T1} + q_{E1} = \emptyset(1 - \frac{p_e-\mu(p_t-p_e)}{\delta})$ and $q_R = q_{T2} + q_{E2} = (1-\emptyset)(1 - \frac{p_e-p_s-\mu(p_t-p_e)}{\delta})$.

To ensure a positive demand for the product, that is, $q_T^N > 0$, $q_E^N > 0$, $q_T > 0$ and $q_E > 0$, then $\delta \in (\frac{p_e}{p_t}, 1 - (1+\mu)(p_t - p_e))$ holds.

3.3. Sequence of game

The model structure considered in this study includes a manufacturer, a T-retailer, and an E-tailer. The manufacturer sells new products through the t-retail and e-retail channels. Consumers can purchase products from both channels but only buy one, as described in Figure 1. The upstream members of the supply chain could recycle the obsolete product from R-consumers at a price p_s. The M-Stackelberg game is used to model the game between the manufacturer and retailers, and the static and dynamic games are used to model the game between T-retailer and E-tailer; the game sequence is illustrated in Figures 2 and 3. Scenario MS: The manufacturer sets the wholesale price w, and then the T-retailer and E-tailer observe the wholesale price and simultaneously decide the retail prices (p_t, p_e). Scenario ME: The manufacturer first sets the wholesale price w, and the T-retailer observes the wholesale price and sets the t-retail price $p_t(w)$, and then, the E-tailer observes the decision of the T-retailer and determines the e-retail price $p_e(w, p_t)$. Scenario ML: The manufacturer sets the wholesale price w first, the E-tailer observes the wholesale price, then sets the e-retail price $p_e(w)$, and finally, the T-retailer observes the decision of the E-tailer and determines the t-retail price $p_t(w, p_e)$. We compare and analyze how the optimal decisions of the supply chain members with and without RPE change under the three games mentioned above by using the no-RPE scenario as the benchmark model.

4. Benchmark models without RPE

In this section, we consider a dual-channel RSC without or with RPE, where one manufacturer determines the wholesale price, and one t-retailer and one e-retailer decide the retail price. For convenience, the subscript M denotes the manufacturer, R_t denotes the T-retailer, and R_e denotes the E-tailer. All models in the study are denoted by symbols: model-M^{NS}, model-M^{NE}, model-M^{NL}, model-M^S, model-M^E, model-M^L, which represent retailers pricing at the same time, the T-retailer pricing earlier or later than E-tailer, respectively. The superscript N indicates that there is no RPE.

In Section 4.1, the optimal strategies of the three strategies under the benchmark model are explored. In Section 4.2, a comparison of the optimal equilibria of the different strategies under the RPE is analyzed.

4.1. Model description without RPE

In this subsection, the profit functions of the manufacturer and the retailers can be formulated as.

$$\pi_M^N(w) = \left(q_T^N + q_E^N\right)(w - c) \tag{7}$$

$$\pi_{Rt}^N(p_t) = q_T^N(p_t - w - c_t) \tag{8}$$

$$\pi_{Re}^N(p_e) = q_E^N(p_e - w - c_e). \tag{9}$$

Specifically, if retailers are in a dynamic game, pricing times would differ, *i.e.*, pricing decisions are interdependent. If the game is static, the decision between retailers does not affect each other. Let $\mathcal{L}$ represents the model type, $\mathcal{L} = \{M^{NS}, M^{NE}, M^{NL}\}$.

4.2. Equilibrium of dual RSC models under different scenarios

Combined equations (1)–(3) and (7)–(9), the following theorem are drawn.

Theorem 4.1. *Under model-$\mathcal{L}$, the optimal wholesale price, t-retail price, e-retail price, demands, and profits are as follows.*

Scenario MS (Model-M^{NS})

$w^{NS^*} = \frac{A_1}{2(\delta+2)}$, $p_t^{NS^*} = \frac{B_1}{2(\delta+2)(\delta-4)}$, $p_e^{NS^*} = \frac{C_1}{2(\delta-2)}$, $q_T^{NS^*} = \frac{D_1}{2(\delta-1)(\delta+2)(\delta-4)}$, $q_E^{NS^*} = \frac{E_1}{\delta(\delta-1)(\delta+2)(\delta-4)}$, $q_P^{NS^*} = \frac{F_1}{2\delta(\delta-4)}$, $q_R^{NS^*} = \frac{G_1}{2\delta(\delta-4)}$, $q^{NS^*} = \frac{H_1}{2\delta(\delta-4)}$, $\pi_M^{NS^*} = \frac{(A_1-2(\delta+2)c)H_1}{4\delta(\delta+2)(\delta-4)}$, $\pi_{R_t}^{NS^*} = \frac{(B_1-(\delta-4)A_1-2(\delta+2)(\delta-4)c_t)D_1}{4(\delta-1)(\delta+2)^2(\delta-4)^2}$, $\pi_{R_e}^{NS^*} = \frac{((\delta+2)C_1-(\delta-2)A_1-2(\delta-2)(\delta+2)c_e)E_1}{2\delta(\delta-1)(\delta-2)(\delta+2)^2(\delta-4)}$.

TABLE 3. Compare for model-$\mathcal{L}$ and model-$\mathcal{R}$.

	w^* $L>S>E$	p_t^* $S<L<E$	p_e^* $S<E<L$	q_T^* $E<S<L$
No RPE	–	$\emptyset \in (\max(0,\emptyset_1),1)$	$\emptyset \in (0,\min(\emptyset_2,1))$	$\emptyset \in (\max(0,\emptyset_3),\min(\emptyset_4,1))$
RPE	–	$\emptyset \in (\max(0,\emptyset_{t1}),\min(\emptyset_{t2},1))$	$\emptyset \in (0,\min(\emptyset_{e1},\emptyset_{e2},1))$	$\emptyset \in (\max(0,\emptyset_{T1}),\min(\emptyset_{T2},1))$
	q_E^* $L<S<E$	q_P^* $S>E>L$	q_R^* $S>E>L$	q^* $S>E>L$
No RPE	$\emptyset \in (0,\min(\emptyset_5,\emptyset_6,1))$	$\emptyset \in (\max(0,\emptyset_7),\min(\emptyset_8,1))$	$\emptyset \in (0,\min(\emptyset_9,\emptyset_{10},1))$	$\emptyset \in (0,\min(\emptyset_{11},\emptyset_{12},1))$
RPE	$\emptyset \in \min(0,\min(\emptyset_{E1},\emptyset_{E2},1))$	$\emptyset \in (\max(0,\emptyset_{P1}),\min(\emptyset_{P2},1))$	$\emptyset \in (\max(0,\emptyset_{R1}),\min(\emptyset_{R2},1))$	$\emptyset \in (\max(0,\emptyset_{q1}),\min(\emptyset_{q2},1))$

Notes. $L>S>E$ denotes model-M^L (model-M^{NL}) greater than model-M^S (model-M^{NS}) greater than model-M^E (model-M^{NE}), others similar.

Scenario ME (Model-M^{NE})

$w^{NE^*} = \frac{A_2}{2(\delta^2-\delta-4)}$, $p_t^{NE^*} = \frac{B_2}{4(\delta-2)(\delta^2-\delta-4)}$, $p_e^{NE^*} = \frac{C_2}{8(\delta-2)}$,$q_T^{NE^*} = \frac{D_2}{8(\delta-1)(\delta^2-\delta-4)}$, $q_E^{NE} = \frac{E_2}{8\delta(\delta-1)(\delta-2)(\delta^2-\delta-4)}$, $q_P^{NE^*} = \frac{F_2}{8\delta(\delta-2)}$, $q_R^{NE^*} = \frac{G_2}{8\delta(\delta-2)}$, $q^{NE^*} = \frac{H_2}{8\delta(\delta-2)}$, $\pi_M^{NE^*} = \frac{(A_2-2c(\delta^2-\delta-4))H_2}{16\delta(\delta-2)(\delta^2-\delta-4)}$, $\pi_{R_t}^{NE^*} = \frac{(B_2-2(\delta-2)A_2-4(\delta-2)(\delta^2-\delta-4)c_t)D_2}{32(\delta-1)(\delta-2)(\delta^2-\delta-4)^2}$, $\pi_{R_e}^{NE^*} = \frac{((\delta^2-\delta-4)C_2-4(\delta-2)A_2-8(\delta-2)(\delta^2-\delta-4)c_e)E_2}{64(\delta-1)(\delta-2)^2(\delta^2-\delta-4)^2}$.

Scenario ML (Model-M^{NL})

$w^{NL^*} = \frac{A_3}{4}$, $p_t^{NL^*} = \frac{B_3}{8(\delta-2)}$, $p_e^{NL^*} = \frac{C_3}{4(\delta-2)}$, $q_T^{NL^*} = \frac{D_3}{8(\delta-1)(\delta-2)}$, $q_E^{NL^*} = \frac{E_3}{8\delta(\delta-1)}$, $q_P^{NL^*} = \frac{F_3}{4\delta(\delta-2)}$, $q_R^{NL^*} = \frac{G_3}{4\delta(\delta-2)}$, $q^{NL^*} = \frac{H_3}{4\delta(\delta-2)}$, $\pi_M^{NL^*} = \frac{(A_3-4c)H_3}{16\delta(\delta-2)}$, $\pi_{R_t}^{NL^*} = \frac{(B_3-2(\delta-2)A_3-8(\delta-2)c_t)D_3}{64(\delta-1)(\delta-2)^2}$, $\pi_{R_e}^{NL^*} = \frac{(C_3-(\delta-2)A_3-4(\delta-2)c_e)E_3}{32\delta(\delta-1)(\delta-2)}$.

The symbols in the values are given in Appendix A.

By comparing the results in Theorem 4.1, we have the following proposition.

Proposition 4.1. *Under benchmark models, the following relationships of prices and demands hold if and only if the value of $\emptyset$ satisfies the threshold shown in Table 3,*

(i) $w^{NL^*} > w^{NS^*} > w^{NE^*}$, $p_t^{NS^*} < p_t^{NL^*} < p_t^{NE^*}$, $p_e^{NS^*} < p_e^{NE^*} < p_e^{NL^*}$.
(ii) $q_T^{NE^*} < q_T^{NS^*} < q_T^{NL^*}$, $q_E^{NL^*} < q_E^{NS^*} < q_E^{NE^*}$, $q_P^{NS^*} > q_P^{NE^*} > q_P^{NL^*}$, $q_R^{NS^*} > q_R^{NE^*} > q_R^{NL^*}$, $q^{NS^*} > q^{NE^*} > q^{NL^*}$.

Proposition 4.1 provides the relationship between the decision variables in the three models, depending on the proportion of P-consumers in the three cases, which may be higher or lower. In contrast, the wholesale price is independent on $\emptyset$, implying that the proportion has no direct effect on the manufacturer's pricing strategy. When the value of $\emptyset$ satisfies the threshold given in Table 3, the total market demand is highest under the MS scenario. Under benchmark models, to ensure the expressions behave well, let $\chi_i^{SE} = i^{NS^*} - i^{NE^*}$, χ is only used to distinguish the RPE case. In addition, we also study the effect of the channel coefficient on the decision variables (see Figs. 4 and 5). Figures 4 and 5 illustrate that as δ increases, $\chi_i^{SE} > 0$, $\chi_j^{SE} < 0$, $i = w$, q_T, q_P, q_R, q; $j = p_e$, q_E; $\chi_\vartheta^{EL} > 0$, $\chi_\nu^{EL} < 0$, $\vartheta = p_t$, q_E, q_P, q_R, q; $\nu = w$, p_e, q_T; $\chi_\kappa^{SL} > 0$, $\chi_l^{SL} < 0$, $\kappa = q_E$, q_P, q_R, q; $l = w$, p_t, p_e, q_T. To be specific, from Figure 4, $\chi_w^{SE}(\delta) > 0$, $\chi_w^{SL}(\delta) < 0$, $\chi_w^{EL}(\delta) < 0$, that means for the wholesale price, scenario ML is greater than scenario MS greater than scenario ME. For p_t, scenario ME is greater than scenario ML greater than scenario MS; for p_e, scenario ML is greater than scenario ME greater than scenario MS. The results suggest that the optimal retail price is the highest when retailers have an active pricing advantage. Moreover, we observe that the changing trend in demand differs from the price. Figure 5 depicts the ME strategy has the lowest demand in the t-retail channel and the highest demand in the e-retail channel; however, the opposite is true for the ML strategy, indicating that consumers prefer the channel with lower prices. The MS strategy has the lowest retail price and the highest demand compared to the other two strategies. This is because, in a situation where there is no RPE, the retail price level determines the demand

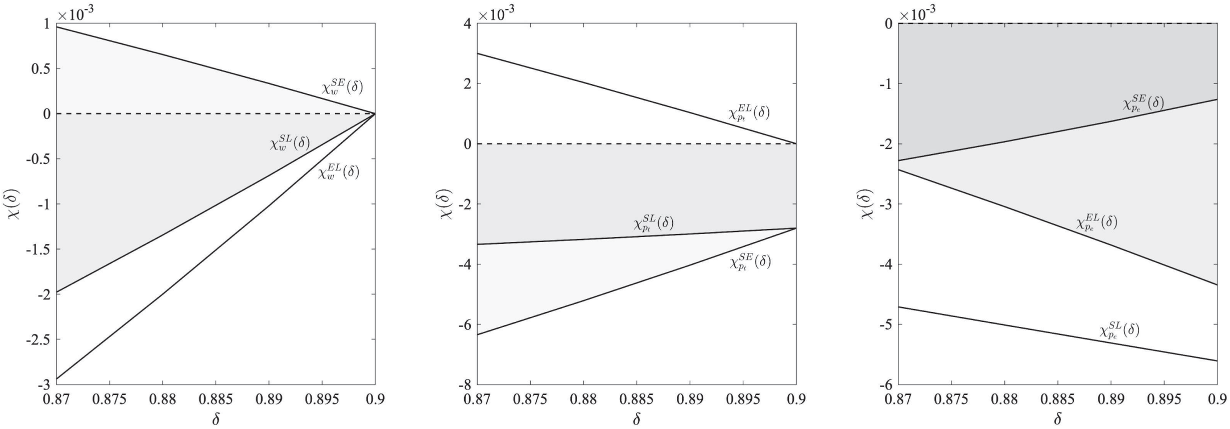

FIGURE 4. Prices comparison without RPE ($c = 0.4$, $c_t = 0.2$, $c_e = 0.1$, $\emptyset = 0.5$, $p_s = 0.05$).

TABLE 4. Compare for the manufacturer's profit.

	Scenario comparison	Feasible region ($\emptyset$)
Without RPE	$\pi_M^{NS^*} > \pi_M^{NE^*} > \pi_M^{NL^*}$	$\left(0, \min\left(1 - \frac{-\xi_1+\sqrt{\xi_1^2-4\delta^2\xi_0\xi_2}}{2\delta^2\xi_2 p_s}, 1\right)\right) \cup \left(\max\left(1 - \frac{-\xi_1-\sqrt{\xi_1^2-4\delta^2\xi_0\xi_2}}{2\delta^2\xi_2 p_s}, 0\right), 1\right)$
		$\cap\left(0, \min\left(1 - \frac{-\xi_4+\sqrt{\xi_4^2-4\xi_3\xi_5}}{2\xi_5 p_s}, 1\right)\right) \cup \left(\max\left(1 - \frac{-\xi_4-\sqrt{\xi_4^2-4\xi_3\xi_5}}{2\xi_5 p_s}, 0\right), 1\right)$
RPE	$\pi_M^{S^*} > \pi_M^{E^*} > \pi_M^{L^*}$	$\left(0, \min\left(1 - \frac{-\widetilde{\xi_1}+\sqrt{\widetilde{\xi_1}^2-4(\mu+1)\widetilde{\xi_0}\widetilde{\xi_2}}}{2(1+\mu)\widetilde{\xi_2} p_s}, 1\right)\right) \cup \left(\max\left(1 - \frac{-\widetilde{\xi_1}-\sqrt{\widetilde{\xi_1}^2-4(\mu+1)\widetilde{\xi_0}\widetilde{\xi_2}}}{2(1+\mu)\widetilde{\xi_2} p_s}, 0\right), 1\right)$
		$\cap\left(0, \min\left(1 - \frac{-\widetilde{\xi_4}+\sqrt{\widetilde{\xi_4}^2-4(\delta+\mu)\widetilde{\xi_3}\widetilde{\xi_5}}}{2(\delta+\mu)\widetilde{\xi_5} p_s}, 1\right)\right) \cup \left(\max\left(1 - \frac{-\widetilde{\xi_4}-\sqrt{\widetilde{\xi_4}^2-4(\delta+\mu)\widetilde{\xi_3}\widetilde{\xi_5}}}{2(\delta+\mu)\widetilde{\xi_5} p_s}, 0\right), 1\right)$

Notes. The symbols in the values are given in Appendix A.

amount. The lower the retail price, the higher the consumer demand, and therefore the higher demand for the lower-priced channel.

Proposition 4.2. *When RPE is not considered, if the value of the proportion of P-consumers is not high or low, the MS strategy is optimal for the manufacturer, the E-tailer prefers the ME strategy, and the T-retailer prefers the ML strategy.*

Proposition 4.2 shows that when the appropriate threshold for the value $\emptyset$ is satisfied in Tables 4–6 (the values are provided in Appendix A), different optimal strategic choices arise between the manufacturer and retailers. When the above conditions are satisfied, the manufacturer prefers the MS strategy, and the ML strategy is most unfavorable to the manufacturer without considering RPE. For retailers, dynamic sequential game decisions are always more profitable than simultaneous decisions under certain conditions. One possible reason is that the roles of the two retailers are asymmetric, giving one retailer a first-mover advantage to gain more profit by choosing a greater demand. Interestingly, the optimal decision outcome of the supply chain members within a certain threshold differs from previous studies [45], *i.e.*, for both retailers, the retailer with the first-mover advantage is less profitable than the second-mover advantage. Clearly, as the threshold value $\emptyset$ changes, the optimal decision of the supply chain members changes accordingly. This means the optimal decision is not unique and depends on the threshold level of $\emptyset$.

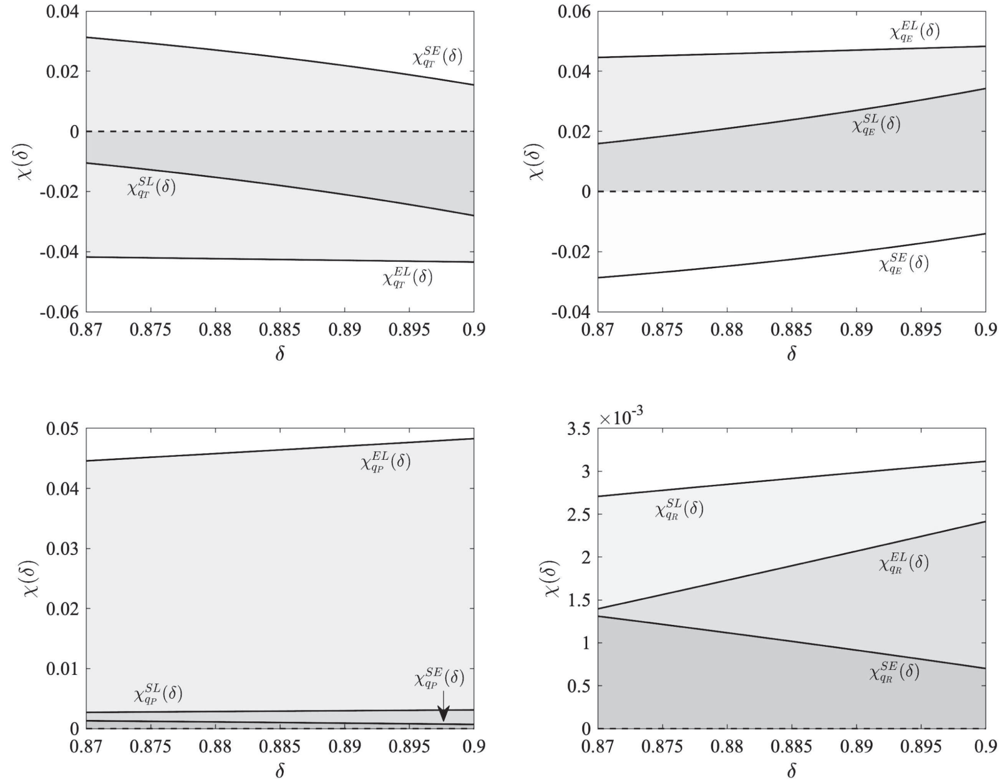

FIGURE 5. Demands comparison without RPE ($c = 0.4$, $c_t = 0.2$, $c_e = 0.1$, $\emptyset = 0.5$, $p_s = 0.05$).

TABLE 5. Compare for the profit of the T-retailer.

	Scenario comparison	Feasible region ($\emptyset$)
Without RPE	$\pi_{R_t}^{NS^*} < \pi_{R_t}^{NE^*} < \pi_{R_t}^{NL^*}$	$\left(0, \min\left(1 - \frac{-\nu_1+\sqrt{\nu_1^2-4\nu_0\nu_2(\delta-1)^2}}{2\nu_2(\delta-1)^2 p_s}, 1\right)\right) \cup \left(\max\left(1 - \frac{-\nu_1-\sqrt{\nu_1^2-4\nu_0\nu_2(\delta-1)^2}}{2\nu_2(\delta-1)^2 p_s}, 0\right), 1\right)$
		$\cap\left(0, \min\left(1 - \frac{-\nu_4+\sqrt{\nu_4^2-8\delta\nu_3\nu_5}}{4\delta\nu_5 p_s}, 1\right)\right) \cup \left(\max\left(1 - \frac{-\nu_4+\sqrt{\nu_4^2-8\delta\nu_3\nu_5}}{4\delta\nu_5 p_s}, 0\right), 1\right)$
RPE	$\pi_{R_t}^{S^*} < \pi_{R_t}^{E^*} < \pi_{R_t}^{L^*}$	$\left(0, \min\left(1 - \frac{-\widetilde{\nu_1}+\sqrt{\widetilde{\nu_1}^2-4(1+\mu)\widetilde{\nu_0}\widetilde{\nu_2}}}{2(1+\mu)\widetilde{\nu_2} p_s}, 1\right)\right) \cup \left(\max\left(1 - \frac{-\widetilde{\nu_1}-\sqrt{\widetilde{\nu_1}^2-4(1+\mu)\widetilde{\nu_0}\widetilde{\nu_2}}}{2(1+\mu)\widetilde{\nu_2} p_s}, 0\right), 1\right)$
		$\cap\left(0, \min\left(1 - \frac{-\widetilde{\nu_4}+\sqrt{\widetilde{\nu_4}^2-4(1+\mu)(\delta-1)\widetilde{\nu_3}\widetilde{\nu_5}}}{2(1+\mu)(\delta+\mu)\widetilde{\nu_5} p_s}, 1\right)\right) \cup \left(\max\left(1 - \frac{-\widetilde{\nu_4}-\sqrt{\widetilde{\nu_4}^2-4(1+\mu)(\delta-1)\widetilde{\nu_3}\widetilde{\nu_5}}}{2(1+\mu)(\delta+\mu)\widetilde{\nu_5} p_s}, 0\right), 1\right)$

Notes. The symbols in the values are given in Appendix A.

5. MODELS WITH RPE

In this section, RPE is considered from the perspective of consumer purchasing behavior. Three scenarios (MS, ME, ML) are proposed in a dual RSC with RPE.

Table 6. Compare for the profit of the E-tailer.

	Scenario comparison	Feasible region ($\emptyset$)
Without RPE	$\pi_{R_e}^{NS^*} < \pi_{R_e}^{NL^*} < \pi_{R_e}^{NE^*}$	$\left(\max\left(1-\frac{-\vartheta_1+\sqrt{\vartheta_1^2-16\vartheta_0\vartheta_2}}{8\vartheta_2 p_s},0\right),\min\left(1-\frac{-\vartheta_1-\sqrt{\vartheta_1^2-16\vartheta_0\vartheta_2}}{8\vartheta_2 p_s},1\right)\right)\cap$
		$\left(\max\left(1-\frac{-\vartheta_4+\sqrt{\vartheta_4^2-4(\delta-1)^2\vartheta_3\vartheta_5}}{2(\delta-1)^2 p_s},0\right),\min\left(1-\frac{-\vartheta_4-\sqrt{\vartheta_4^2-4(\delta-1)^2\vartheta_3\vartheta_5}}{2(\delta-1)^2 p_s},1\right)\right)$
RPE	$\pi_{R_e}^{S^*} < \pi_{R_e}^{L^*} < \pi_{R_e}^{E^*}$	$\left(0,\min\left(1-\frac{-\widetilde{\vartheta_1}+\sqrt{\widetilde{\vartheta_1}^2-16(1+\mu)^2\widetilde{\vartheta_0}\widetilde{\vartheta_2}}}{8(1+\mu)^2\widetilde{\vartheta_2}p_s},1\right)\right)\cup\left(\max\left(1-\frac{-\widetilde{\vartheta_1}-\sqrt{\widetilde{\vartheta_1}^2-16(1+\mu)^2\widetilde{\vartheta_0}\widetilde{\vartheta_2}}}{8(1+\mu)^2\widetilde{\vartheta_2}p_s},0\right),1\right)$
		$\cap\left(0,\min\left(1-\frac{-\widetilde{\vartheta_4}+\sqrt{\widetilde{\vartheta_4}^2-4(1+\mu)\widetilde{\vartheta_3}\widetilde{\vartheta_5}}}{2(1+\mu)\widetilde{\vartheta_5}p_s},1\right)\right)\cup\left(\max\left(1-\frac{-\widetilde{\vartheta_4}-\sqrt{\widetilde{\vartheta_4}^2-4(1+\mu)\widetilde{\vartheta_3}\widetilde{\vartheta_5}}}{2(1+\mu)\widetilde{\vartheta_5}p_s},0\right),1\right)$

Notes. The symbols in the values are given in Appendix A.

Table 7. Optimal solutions in the models for $\mathcal{R} = \{M^S, M^E, M^L\}$.

	Model-M^S	Model-M^E	Model-M^L
w^*	$\frac{A_1^R}{2(\mu+1)(\delta+2)}$	$\frac{A_2^R}{2(\delta^2-(1+\mu)\delta-3\mu-4)}$	$\frac{A_3^R}{4(\mu+1)((1+\delta)\mu+2)}$
p_t^*	$\frac{B_1^R}{2(\delta+2)(\delta-3\mu-4)}$	$\frac{B_2^R}{4(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)}$	$\frac{B_3^R}{-8(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)}$
p_e^*	$\frac{C_1^R}{2(\mu+1)(\delta+2)(\delta-3\mu-4)}$	$\frac{C_2^R}{8(1+\mu)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)}$	$\frac{C_3^R}{-4(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)}$
q_T^*	$\frac{D_1^R}{2(\delta-1)(\delta+2)(\delta-3\mu-4)}$	$\frac{D_2^R}{-8(\delta-1)(\delta^2-(1+\mu)\delta-3\mu-4)}$	$\frac{D_3^R}{-8(\delta-1)(\delta-\mu-2)((1+\delta)\mu+2)}$
q_E^*	$\frac{E_1^R}{\delta(\delta-1)(\delta+2)(\delta-3\mu-4)}$	$\frac{E_2^R}{8\delta(\delta-1)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)}$	$\frac{E_3^R}{8\delta(1+\mu)(\delta-1)((1+\delta)\mu+2)}$
q_P^*	$\frac{F_1^R}{2\delta(\delta-3\mu-4)}$	$\frac{F_2^R}{-8\delta(\delta-\mu-2)}$	$\frac{F_3^R}{-8\delta(1+\mu)(\delta-\mu-2)}$
q_R^*	$\frac{G_1^R}{2\delta(\delta-3\mu-4)}$	$\frac{G_2^R}{-8\delta(\delta-\mu-2)}$	$\frac{G_3^R}{-8\delta(1+\mu)(\delta-\mu-2)}$
q^*	$\frac{H_1^R}{2\delta(\delta-3\mu-4)}$	$\frac{H_2^R}{-8\delta(\delta-\mu-2)}$	$\frac{H_3^R}{-8\delta(1+\mu)(\delta-\mu-2)}$
π_M^*	$\frac{(A_1^R-2c(\mu+1)(\delta+2))H_1^R}{4\delta(\mu+1)(\delta+2)(\delta-3\mu-4)}$	$\frac{(A_2^R-2c(\delta^2-(1+\mu)\delta-3\mu-4))H_2^R}{-16\delta(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)}$	$\frac{(A_3^R-4c(\mu+1)((1+\delta)\mu+2))H_3^R}{-32\delta(\delta-\mu-2)((1+\delta)\mu+2)(1+\mu)^2}$
$\pi_{R_t}^*$	$\frac{D_1^R((\mu+1)B_1^R-(\delta-3\mu-4)A_1^R-2c_t(\delta+2)(\mu+1)(\delta-3\mu-4))}{4(\delta-1)(\mu+1)(\delta+2)^2(\delta-3\mu-4)^2}$	$\frac{D_2^R(B_2^R-2(\delta-\mu-2)A_2^R-4c_t(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4))}{-32(\delta-1)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)^2}$	$\frac{D_3^R(B_3^R+2(\delta-\mu-2)A_3^R+8c_t(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2))}{64(\delta-1)(1+\mu)(\delta-\mu-2)^2((1+\delta)\mu+2)^2}$
$\pi_{R_e}^*$	$\frac{E_1^R(C_1^R-(\delta-3\mu-4)A_1^R-2c_e(\delta+2)(\mu+1)(\delta-3\mu-4))}{2\delta(\delta-1)(\mu+1)(\delta+2)^2(\delta-3\mu-4)^2}$	$\frac{E_2^R(C_2^R-4(1+\mu)(\delta-\mu-2)A_2^R-8c_e(1+\mu)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4))}{64\delta(\delta-1)(1+\mu)(\delta-\mu-2)^2(\delta^2-(1+\mu)\delta-3\mu-4)^2}$	$\frac{E_3^R(C_3^R+(\delta-\mu-2)A_3^R+4c_e(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2))}{-32\delta(\delta-1)(1+\mu)^2(\delta-\mu-2)((1+\delta)\mu+2)^2}$

5.1. Model description with RPE

In this subsection, the profit functions for manufacturers and retailers are expressed as follows.

$$\pi_M(w) = (q_T + q_E)(w - c) \tag{10}$$

$$\pi_{Rt}(p_t) = q_T(p_t - w - c_t) \tag{11}$$

$$\pi_{Re}(p_e) = q_E(p_e - w - c_e). \tag{12}$$

Equation (10) reflects the manufacturer's profit comprising wholesale price minus cost multiplied by total demand, equation (11) indicates that the traditional T-retailer's profit consists of retail price minus wholesale price minus cost multiplied by demand in the traditional channel, and equation (12) presents that the E-tailer's profit consists of retail price minus wholesale price minus cost multiplied by demand in the electronic channel. $\mathcal{R}$ represents the model type, $\mathcal{R} = \{M^S, M^E, M^L\}$.

5.2. Equilibrium decisions with RPE under different scenarios

Using backward induction and game theory, the following equilibrium solution is derived. The detailed parsing process is shown in Appendix A.

Theorem 5.1. *In model-$\mathcal{R}$, the optimal results for decision variables, demands, and profits are summarized in Table 7.*

By comparing the results of Theorem 5.1, the conclusion of Proposition 5.1 is drawn.

Proposition 5.1. *For $\mathcal{R} = \{M^S, M^E, M^L\}$, the following relationships of prices and demands holds,*

(i) $w^{L^*} > w^{S^*} > w^{E^*}$*;* $p_t^{S^*} < p_t^{L^*} < p_t^{E^*}$*, if and only if* $\max(0, \emptyset_{t1}) < \emptyset < \min(\emptyset_{t2}, 1)$*;* $p_e^{S^*} < p_e^{E^*} < p_e^{L^*}$*, if and only if* $0 < \emptyset < \min\{\emptyset_{e1}, \emptyset_{e2}, 1\}$.

(ii) $q_T^{E^*} < q_T^{S^*} < q_T^{L^*}$, $q_E^{L^*} < q_E^{S^*} < q_E^{E^*}$, $q_P^{S^*} > q_P^{E^*} > q_P^{L^*}$, $q_R^{S^*} > q_R^{E^*} > q_R^{L^*}$, $q^{S^*} > q^{E^*} > q^{L^*}$*, if and only if* $\emptyset$ *is satisfied in Table 3.*

The relationship between wholesale price and retail price in three cases depends on the threshold of $\emptyset$. From Figure 6, when δ is less than δ_1, $p_t^{S^*} < p_t^{L^*} < p_t^{E^*}(\delta_1^-)$, when δ is greater than δ_1, $p_t^{S^*} < p_t^{E^*} < p_t^{L^*}(\delta_1^+)$. Near δ_1, $w^{E^*} < w^{S^*} < w^{L^*}(\delta_0^-)$,$w^{L^*} < w^{S^*} < w^{E^*}(\delta_0^-)$.This implies that the optimal wholesale and retail prices are directly related to the channel coefficients and the proportion of consumers. It is found that the MS strategy has the lowest retail price and the highest total demand when there are neither too many nor too few consumers who do not own the obsolete product. Comparing the results of the distribution channel studies shows that the demand under the MS strategy is in the middle of the level, neither too high nor too low. Thus, the proportion of P-consumers is at different intervals, leading to different optimal decisions. A detailed analysis of the impact of the proportion of P-consumers on the profitability of supply chain members is given in the numerical analysis in Section 6.

Proposition 5.2. *When the proportion of P-consumers is at a certain threshold, no higher or lower, then* $\pi_M^{S^*} > \pi_M^{E^*} > \pi_M^{L^*}$, $\pi_{R_t}^{S^*} < \pi_{R_t}^{E^*} < \pi_{R_t}^{L^*}$, $\pi_{R_e}^{S^*} < \pi_{R_e}^{L^*} < \pi_{R_e}^{E^*}$.

The comparative analysis of the equilibrium results of the three strategies changes when RPE is considered in the model, especially for the E-tailer's profit. From Figure 7, not far from the level of δ_2, we find that, $\pi_{R_e}^{S^*} < \pi_{R_e}^{L^*} < \pi_{R_e}^{E^*}(\delta_2^-)$, $\pi_{R_e}^{S^*} < \pi_{R_e}^{E^*} < \pi_{R_e}^{L^*}(\delta_2^+)$. The effect of the channel preference coefficient on the E-tailer's profit level is notable. Higher channel levels lead the E-tailer to choose the ML strategy. This is because channel preference is sensitive to consumers' purchase decisions. The higher the channel preference, the higher the sales. Under the ML strategy, the E-tailer has a first-mover pricing advantage and uses higher channel preference to increase sales and profits. As μ increases to some degree, the prices and demands of the three strategies change, which causes the profit level of the e-tailer to change. In addition, the optimal strategy of the manufacturer and retailer is the same as those in benchmark models. This means that when considering RPE in the supply chain, the level of the channel coefficient would result in subtle changes in the wholesale and t-retail prices in the three decisions. The change in sales volume could be negligible, leaving the choice of the optimal decision for the profit level of the manufacturer and the t-retailer. Besides, μ can increase the comparative area of the three strategies within a constrained setting. Therefore, some insights can be gained. The optimal strategy for the manufacturer and retailers depends on the P-consumers' proportion. The proportion of P-consumers will be determined from the value of δ, μ and the price of the obsolete product.

Corollary 5.1. *Under RPE, the total supply chain profit of the ME strategy is the highest.*

The result can be derived from Proposition 5.2. Although the optimal options of the manufacturer and the retailers are different, the E-tailer's profit and the supply chain's total profit are the highest under strategy ME. As can be seen in Figure 8, the total profit is the lowest under ML strategy. The total profit under strategy MS is very close to that of strategy ME. The optimal strategy for the manufacturer and retailers depends on

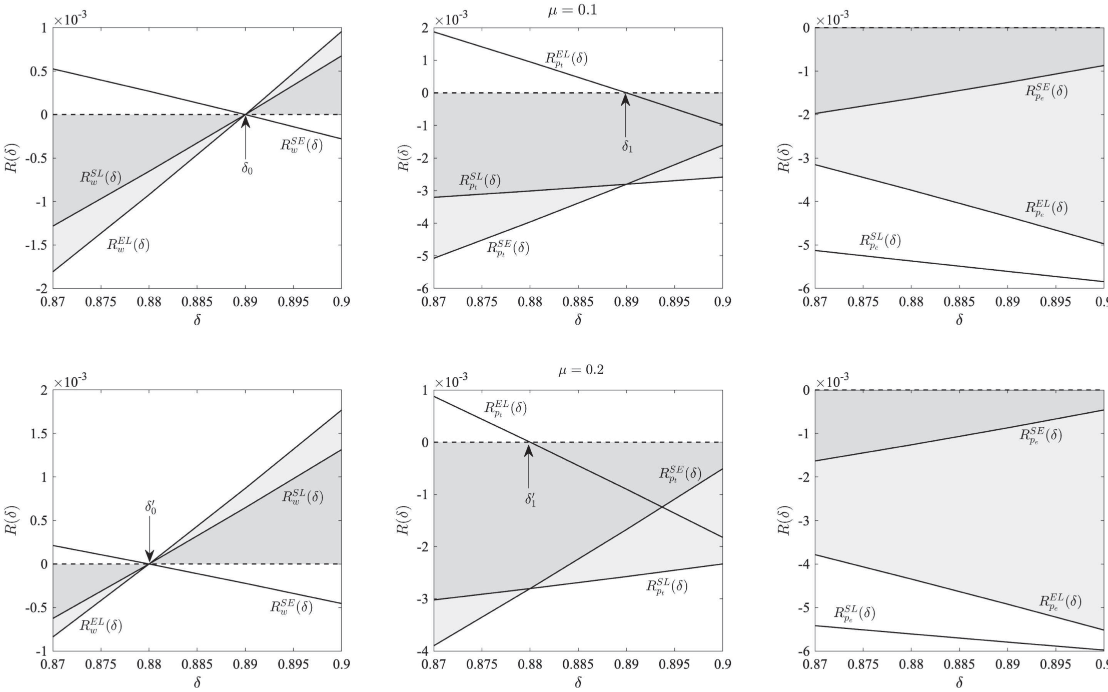

FIGURE 6. Prices comparison with RPE ($c = 0.4$, $c_t = 0.2$, $c_e = 0.1$, $\emptyset = 0.5$, $p_s = 0.05$).

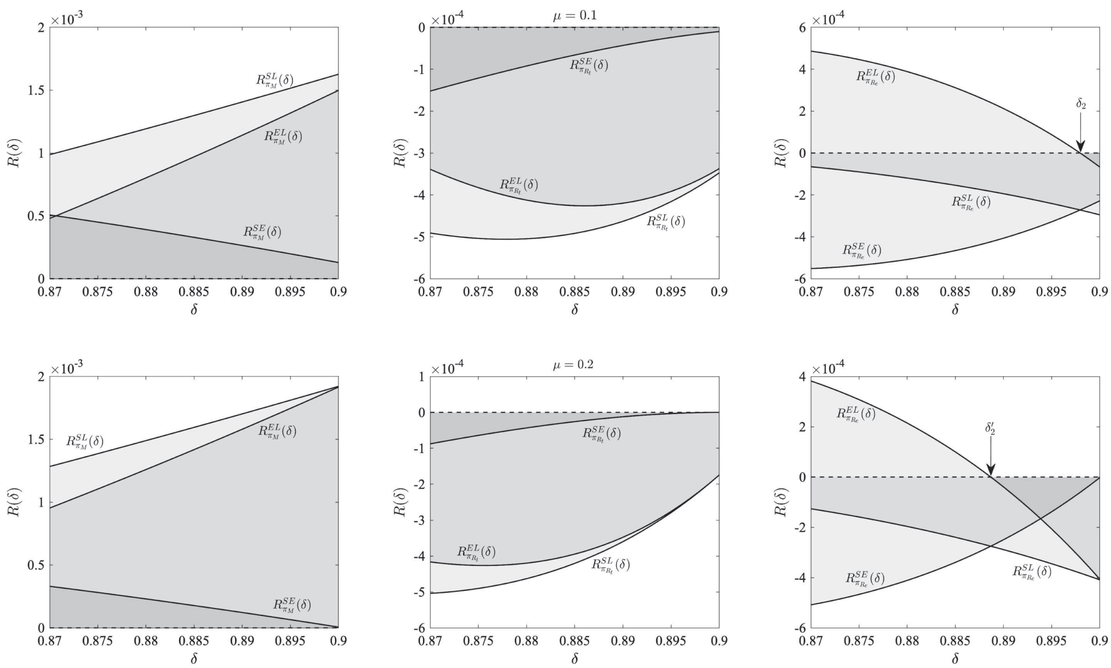

FIGURE 7. Profits comparison with RPE ($c = 0.4$, $c_t = 0.2$, $c_e = 0.1$, $\emptyset = 0.5$, $p_s = 0.05$).

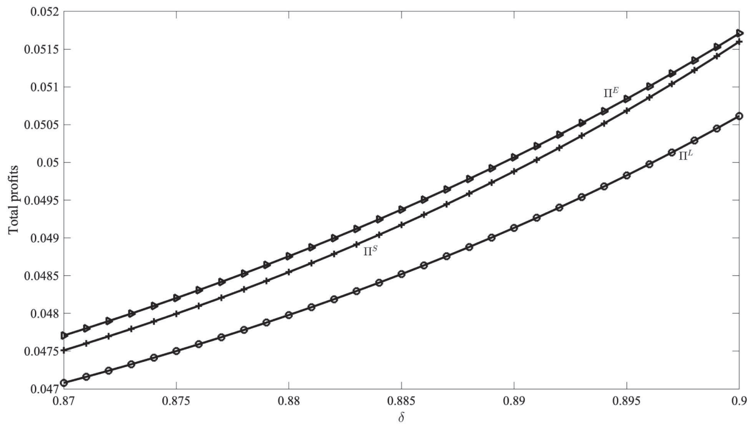

FIGURE 8. Total profits with RPE ($c = 0.4$, $c_t = 0.2$, $c_e = 0.1$, $\emptyset = 0.5$, $p_s = 0.05$, $\mu = 0.1$).

the proportion of P-consumers. If the proportion of P-consumers is neither too high nor too low. In that case, the optimal strategy for total supply chain profit is the ME strategy, *i.e.*, the T-retailer pricing earlier than the E-tailer. Under the MS strategy, the manufacturer earns the highest profit but does not make retailers choose the MS strategy by coordinating contracts because by calculation, we find that a reasonable payment function F, would not be found satisfying $F \in [\pi_{R_t}^{L^*} + \pi_{R_e}^{E^*} - \pi_{R_t}^{S^*} - \pi_{R_e}^{S^*}, \pi_M^{S^*} - \max\{\pi_M^{E^*}, \pi_M^{L^*}\}]$. Thus, the manufacturer and retailers have different optimal strategies, and it is possible to negotiate the distribution of profits among supply chain members if the strategy with the highest total profit in RSC is chosen.

Proposition 5.3. *Under the precondition that* $\mu > \max(0, \frac{A_1^R}{(A_1^R)'_\mu} - 1)$,*the wholesale price* w^{S^*} *increase in* μ, *(i.e.,* $\frac{\partial w^{S^*}}{\partial \mu} > 0$*);* $\mu > \max(0, \frac{A_2^R}{(A_2^R)'_\mu} - \frac{4-\delta^2+\delta}{\delta+3})$, *the wholesale price* w^{E^*} *increase in* μ, *(i.e.,* $\frac{\partial w^{E^*}}{\partial \mu} > 0$*);* $\mu > \max(0, \frac{3(1+\delta)A_3^R - (3+\delta)(A_3^R)'_\mu + \sqrt{(3(1+\delta)A_3^R - (3+\delta)(A_3^R)'_\mu)^2 - 8(1+\delta)(A_3^R)'_\mu(2(A_3^R)'_\mu - 3(1+\delta)A_3^R)}}{2(1+\delta)(A_3^R)'_\mu})$,*the wholesale price* w^{L^*} *increase in* μ, *(i.e.,* $(\frac{\partial w^{L^*}}{\partial \mu} > 0)$*).* $(A_3^R)'_\mu$ *denotes the first-order partial derivative of* A_3^R *with respect to* μ.

Proposition 5.3 illustrates that w increases with μ in three cases when μ exceeds a certain level. As μ increases, the wholesale price increases faster. When μ meets a certain threshold, the increase in wholesale price under the MS strategy is even more significant (see Fig. 9). The reason is that the reference price has a very strong influence on the manufacturer's decision. When the reference price parameter is higher, the optimal wholesale price also increases, thus affecting other variables. In other words, it is wise to consider the influence of the reference price appropriately for the manufacturer. In the following numerical study, optimal profits are explained in more detail.

Proposition 5.4. (i) *When* $\{\mu \in R^+ \mid B_1^R < \frac{(\delta-3\mu-4)(B_1^R)'_\mu}{-3}\}$,$\{\mu \in R^+ \mid B_2^R > \frac{-(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)(B_2^R)'_\mu}{(\delta^2-(1+\mu)\delta-3\mu-4)+(\delta-\mu-2)(\delta+3)}\}$, $\{\mu \in R^+ \mid B_3^R > \frac{-(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)(B_3^R)'_\mu}{-((\delta-\mu-2)((1+\delta)\mu+2)+(1+\mu)(-((1+\delta)\mu+2)+(\delta-\mu-2)(1+\delta)))}\}$ *holds, the retail price* p_t^{o*} *decreases in* μ, *(i.e.,* $\frac{\partial p_t^{o*}}{\partial \mu} < 0$*); otherwise increase.*

(ii) *When* $\{\mu \in R^+ \mid \frac{(\mu+1)(\delta+2)(\delta-3\mu-4)(C_1^R)'_\mu}{(\delta+2)(\delta-3\mu-4)-3(\delta+2)(\mu+1)} < C_1^R\}$, $\{\mu \in R^+ \mid C_2^R < \frac{(1+\mu)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)(C_2^R)'_\mu}{(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)+(1+\mu)(-(\delta^2-(1+\mu)\delta-3\mu-4)-(3+\delta)(\delta-\mu-2))}\}$, $\{\mu \in R^+ \mid C_3^R < \frac{(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)(C_3^R)'_\mu}{(\delta-\mu-2)((1+\delta)\mu+2)+(1+\mu)(-((1+\delta)\mu+2)+(\delta-\mu-2)(1+\delta))}\}$ *holds, the retail price* p_e^{o*} *increases in* μ, *(i.e.,* $\frac{\partial p_e^{o*}}{\mu}$*). Where* $o = S, E, L$.

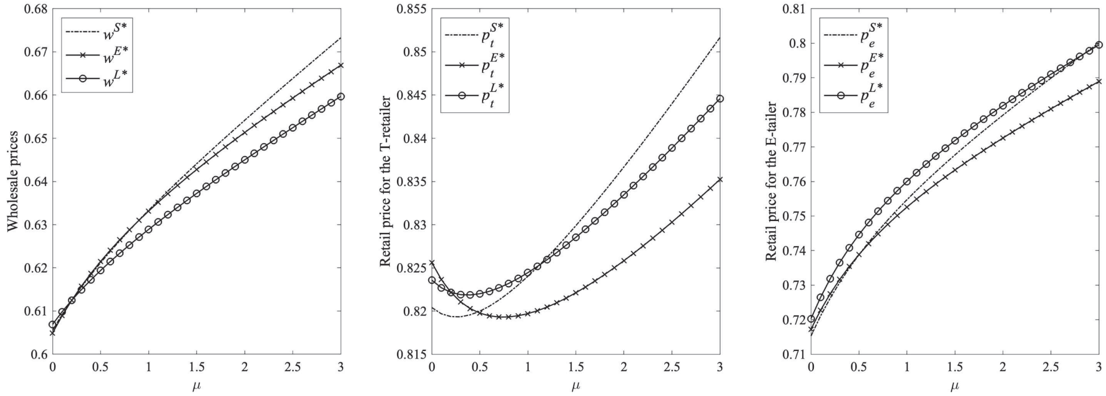

FIGURE 9. The impact of μ on the wholesale price and retail prices ($c = 0.4$, $c_t = 0.2$, $c_e = 0.1$, $\emptyset = 0.5$, $p_s = 0.05$, $\delta = 0.88$).

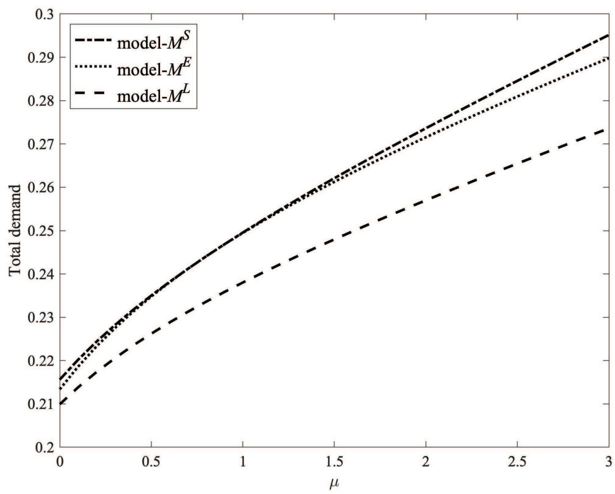

FIGURE 10. The impact of μ on the total demand ($c = 0.4$, $c_t = 0.2$, $c_e = 0.1$, $\emptyset = 0.5$, $p_s = 0.05$, $\delta = 0.88$).

When the reference price parameter is within the above-aggregated range, it is observed that the t-retail price decreases with the increase of the reference price parameter. However, the t-retail price increases with the reference price parameter after a critical value. Within a given range, the e-retail price increases with μ. As μ increases, the t-retail price increases fastest under the MS strategy, while the e-retail price increases fastest under the ML strategy. Under the ME strategy, the t-retail and e-retail prices increase slowly as μ increases. Moreover, when the effect of μ is considered, we find that the optimal retail price of the T-retailer prefers the ME strategy over the ML strategy. In contrast, the E-tailer favors the ML strategy over the ME strategy over the MS strategy. In other words, the first mover decision works when retailers make decisions without considering the effect of the reference price factor. However, the first mover advantage does not work when the reference price factor is considered.

Proposition 5.5. *When the set* $\{\mu \in R^+ \mid H_1^R > \frac{(\delta-3\mu-4)(H_1^R)'_\mu}{-3}\}$ *holds,* q^{S^*} *increase in* μ, *(i.e.,* $\frac{\partial q^{S^*}}{\partial \mu} > 0$*); when the set* $\{\mu \in R^+ \mid H_2^R < -(\delta-\mu-2)(H_2^R)'_\mu\}$ *holds,* q^{E^*} *increase in* μ, *(i.e.,* $\frac{\partial q^{E^*}}{\partial \mu} > 0$*); when the set* $\{\mu \in R^+ \mid H_3^R < \frac{(1+\mu)(\delta-\mu-2)(H_3^R)'_\mu}{(\delta-\mu-2)(1+\mu)}\}$ *holds,* q^L*increase in* μ, *(i.e.,* $\frac{\partial q^{L^*}}{\partial \mu} > 0$*).*

From Proposition 5.5, we find that the total demand under the three strategies increases with the reference price parameter. The same trend is reflected in the manufacturer's wholesale price. In particular, q^{S^*} increases rapidly with μ, while q^{L^*} increases slowly (see Fig. 10). This is because the reference price parameter has an extreme effect on the wholesale and retail prices. Under the MS strategy, the wholesale and t-retail prices increase sharply as μ increases, while the price of the E-tailer decreases and then increases. For consumers, the manufacturer sets higher wholesale prices regardless of whether they own the old product; as consumers become more sensitive to reference behavior due to the perceived benefit effect, t-retail and e-retail prices increase. This is consistent with previous research [35]. This implies that an increase in customer reference price behavior allows the manufacturer and retailers to increase profits by raising prices.

Proposition 5.6. *(i) Under the model-$\mathcal{R}$, when* μ *satisfies the set* $\{\mu \in R^+ \mid f_M^o > 0\}$, *the profit of the manufacturer increases in* μ. *(ii) Under the model-$\mathcal{R}$, when* μ *satisfies the set* $\{\mu \in R^+ \mid f_{R_t}^o < 0\}$, $\{\mu \in R^+ \mid f_{R_e}^o > 0\}$, *the profit of the T-retailer decreases in* μ, *while the profit of the E-tailer increases.* f_M^o, $f_{R_t}^o$ *and* $f_{R_e}^o$ *are given by* (A.9)–(A.17) *in Appendix A.*

According to Proposition 5.6, when μ is small enough, the reference price reduces the profit of the T-retailer. As μ gradually increases to a certain level, the reference price increases the profit of the T-retailer (see Fig. 11). In the MS strategy, the profit of the T-retailer decreases fastest. Conversely, in the ML strategy, the profit of the T-retailer decreases slowly as the reference price parameter increases. As μ becomes progressively larger, retailers' profits change inversely, and the first-mover advantage of pricing comes into play. The reference price increases the profit for the E-tailer, and the manufacturer's profit follows the same trend. When μ satisfies $\{\mu \in R^+ \mid f_M^o > 0\}$, $\{\mu \in R^+ \mid f_{R_t}^o < 0\}$, $\{\mu \in R^+ \mid f_{R_e}^o > 0\}$, μ hardly affects the manufacturer's optimal profit decision. However, for the E-tailer, the profit changes the opposite way for a T-retailer. μ is small enough that profits grow fastest when the E-tailer prices later than the T-retailer, but as μ increases, the E-tailer's profit grows fastest under the ML strategy. This is because the RPE plays a dominant role in consumer behavior decisions, affecting demands and profits. The higher μ is, the more sensitive consumers are to reference prices. This suggests that retailers need to fully understand the impact of RPE on profits and make the best decision. Therefore, we can draw some management insights. A lower reference price parameter does not change the optimal strategy of supply chain members with or without reference prices. The optimal strategy depends on the game sequence between the manufacturer and retailers.

6. Analyses

This section discusses the impact of the parameters in the model (the reference price coefficient, channel coefficient, and consumer proportion) on prices, consumer surplus, and profits.

6.1. Scenarios comparison

In this subsection, we discuss model-M^{NS} and model-M^S, and other cases are similar. Comparing the optimal results in Theorem 4.1 and Table 7, the following corollary can be drawn.

Corollary 6.1. *When* $\max(0, \Theta_2, \Theta_3, \Theta_4) < \mu < \Theta_1$ *holds,* $w^{S^*} > w^{NS^*}$; $p_t^{S^*} < p_t^{NS^*}$; $p_e^{NS^*} < p_e^{S^*}$; $\pi_M^{S^*} > \pi_M^{NS^*}$; *when* $\{\mu \in R^+ \mid \Theta_5 > 0, \Theta_6 < 0\}$ *holds,* $\pi_{R_t}^{S^*} < \pi_{R_t}^{NS^*}$; $\pi_{R_e}^{NS^*} < \pi_{R_e}^{S^*}$.

$\Theta_1 = \frac{A_1^R}{A_1} - 1$; $\Theta_2 = \frac{(4-\delta)(B_1^R - B_1)}{3B_1}$, $\Theta_3 = \frac{\delta - 7 + \sqrt{(\delta-7)^2 + 12(\delta - 4 - \frac{(\delta-2)C_1^R}{(\delta+2)C_1})}}{6}$, $\Theta_4 = \frac{\Theta - \sqrt{\Theta^2 - 12(A_1 - 2c(\delta+2))H_1((A_1^R - 2c(\delta+2))(\delta-4)H_1^R - (A_1 - 2c(\delta+2))(\delta-4)H_1)}}{6(A_1 - 2C(\delta+2))H_1}$, $\Theta_5 = (\delta - 4)^2 D_1^R((\mu + 1)B_1^R - (\delta -$

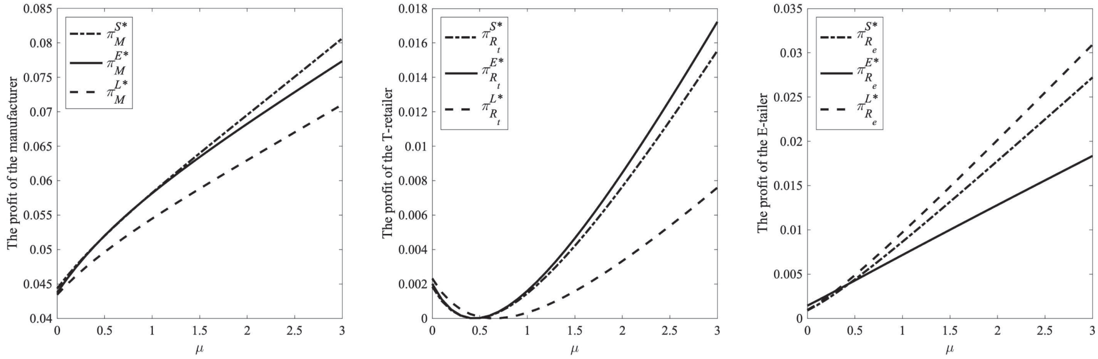

FIGURE 11. The impact of μ on the profits of the manufacturer, T-retailer, and E-tailer ($c = 0.4$, $c_t = 0.2$, $c_e = 0.1$, $\emptyset = 0.5$, $p_s = 0.05$, $\delta = 0.88$).

$3\mu - 4)A_1^R - 2c_t(\delta + 2)(\mu + 1)(\delta - 3\mu - 4)) - (\mu + 1)(\delta - 3\mu - 4)^2(B_1 - (\delta - 4)A_1 - 2(\delta + 2)(\delta - 4)c_t)D_1$, $\Theta_6 = E_1^R(C_1^R - (\delta - 3\mu - 4)A_1^R - 2c_e(\delta + 2)(\mu + 1)(\delta - 3\mu - 4))(\delta - 2)(\delta - 4) - (\mu + 1)(\delta - 3\mu - 4)^2((\delta + 2)C_1 - (\delta - 2)A_1 - 2(\delta - 2)(\delta + 2)c_e)E_1$. *Where* $\Theta = (\delta - 7)A_1 - 2c(\delta + 2))H_1 + 2c(\delta + 2)(\delta - 4)H_1^R$.

Corollary 6.1 shows that when $\max(0, \Theta_2, \Theta_3, \Theta_4) < \mu < \Theta_1$, the wholesale price, e-retail price, and manufacturer's profit are all greater for the model with RPE than for the one without RPE, while the opposite is true for the t-retail price. When $\{\mu \in R^+ \mid \Theta_5 > 0, \Theta_6 < 0\}$ holds, the T-retailer with RPE is less profitable than the one without RPE, while the E-tailer's profit is the opposite. This suggests that reference price behavior affects the decisions of supply chain members. When μ is at a specific bounded level, the behavior is beneficial to the manufacturer and the E-tailer but harmful to the T-retailer. This implies that RPE significantly increases the profits of the manufacturer and the E-tailer.

Besides, Figure 12 displays that as the channel coefficient increases, the profits of the manufacturer and E-tailer increase, while the profit of the T-retailer decreases. Particularly, to illustrate the effect of P-consumers proportion on the RSC, the level of $\emptyset$ greater or less than 0.5 is given by numerical analysis. From Figure 10, it can be observed that when $\emptyset = 0.3$, the optimal wholesale price, retail price, and profit are higher than when $\emptyset = 0.7$. Therefore, lowering the proportion of P-consumers will benefit supply chain members. However, under the RPE condition, neither a high nor a low proportion of P consumers is enough to make up for the profit lost by the T-retailer due to RPE.

6.2. Numerical examples and analyses

In this subsection, we discuss model-M^{NS} and model-M^S, and other cases are similar. Comparing the optimal results in Theorem 4.1 and Table 7, the following corollary can be drawn.

To better understand the effects of the reference price coefficient, channel coefficient, and consumer proportion on the profits of the manufacturer, retailers, and consumers, numerical analyses are established in this research. The parameter values in the numerical experiments of this study remain largely consistent with earlier work [17, 26].

6.2.1. The impacts of RPE and primary consumer proportion on firms

On the basis of the above propositions, the cases of ME and ML are identical to the analysis above. In brief, RPE plays a different role in the decision of the manufacturer and the two retailers under different μ settings. In addition, from the left to right of the fifth Figure 12, there is a reduced tendency in the profits of the T-retailer as the proportion of consumers increases. This is because q_T is not directly related to $\emptyset$ as shown in equations (1) and (4). The higher the value $\emptyset$, the lower the price. As the reference price parameter increases, Figure 12

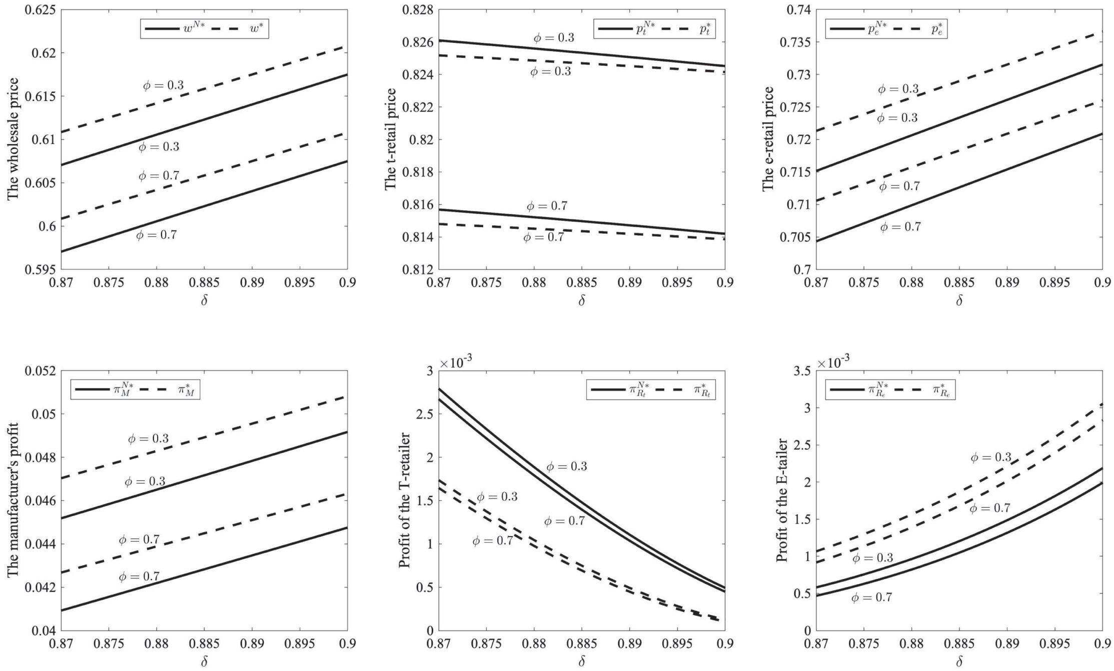

FIGURE 12. The effect of δ and $\emptyset$ on variables under Scenario MS ($c = 0.4$, $c_t = 0.2$, $c_e = 0.1$, $p_s = 0.05$, $\mu = 0.1$).

shows a similar trend to the second subplot of Figure 11, *i.e.*, the higher the proportion of consumers, the lower the profit of the T-retailer. This means that more primary or replacement consumers would not affect sales at T-retailer, regardless of how the proportion changes. As shown in Figure 11, when μ gradually increases within a specific range, the profits of the manufacturer and E-tailer increase with the reference price parameter. In contrast, the profit of the T-retailer shows the opposite trend. This finding is contrary to the study of Wang *et al.* [15], which showed that retailers prefer to use their own prices as the reference price, whereas our study indicates that the profit of the T-retailer decreases with the increase of the reference price parameter when the price of the T-retailer is used as the reference price. Between $\emptyset = 0.3$ and $\emptyset = 0.7$, the profit of the t-retailer keeps a small distance and slowly decreases (see Fig. 13). The profits of the manufacturer and retailers are higher when the proportion of P-consumers is low due to the greater consumer preference for the electronic channel. For example, in common applications, certain goods are targeted explicitly with marketing strategies to attract specific groups of people and increase demand, thus increasing profits. The suggestion given in this study is that to maximize the benefits, the firm attracts more R-consumers by developing appropriate strategies.

6.2.2. *The impacts of RPE and consumer proportion and channel coefficient on consumer surplus*

This subsection discusses the impact of the related parameters on consumer surplus. Based on the difference between the value of the product and the price the customer is willing to pay, the consumer surplus for benchmark models is calculated as follows.

$$CS^N = \int_{\frac{p_t - p_e}{1-\delta}}^{1} (v - p_t)\,\mathrm{d}v + \int_{\frac{p_e}{\delta}}^{\frac{p_t - p_e}{1-\delta}} (\delta v - p_e)\,\mathrm{d}v + (1-\emptyset)\int_{\frac{p_e - p_s}{\delta}}^{\frac{p_e}{\delta}} (\delta v - p_e)\,\mathrm{d}v + (1-\emptyset)\int_{\frac{p_e - p_s}{\delta}}^{1} p_s\,\mathrm{d}v. \quad (13)$$

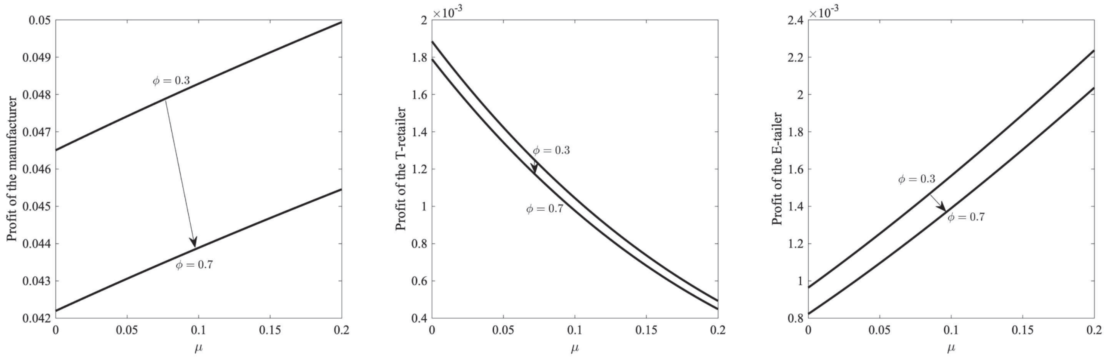

FIGURE 13. Profits with different consumers proportion ($c = 0.4$, $c_t = 0.2$, $c_e = 0.1$, $p_s = 0.05$, $\delta = 0.88$).

From equation (13) and Theorem 4.1, it yields,

$$CS^N = \frac{(1+2(1-\emptyset)p_s - 2p_t)\delta^2 + (2p_t + 2p_e p_t - p_t^2 - 1 + p_s(2p_e - p_s + 2)(\emptyset - 1))\delta - p_e^2 - p_s(2p_e - p_s)(\emptyset - 1)}{2\delta(\delta - 1)}.$$

The consumer surplus with RPE models is given,

$$\begin{aligned} CS = &\int_{\frac{(1+\mu)(p_t-p_e)}{1-\delta}}^{1} (v - p_t)\,\mathrm{d}v + \int_{\frac{p_e-\mu(p_t-p_e)}{\delta}}^{\frac{(1+\mu)(p_t-p_e)}{1-\delta}} (\delta v - p_e + \mu(p_t - p_e))\,\mathrm{d}v \\ &+ (1-\emptyset)\int_{\frac{p_e-p_s-\mu(p_t-p_e)}{\delta}}^{\frac{p_e-\mu(p_t-p_e)}{\delta}} (\delta v - p_e + \mu(p_t - p_e))\,\mathrm{d}v + (1-\emptyset)\int_{\frac{p_e-p_s-\mu(p_t-p_e)}{\delta}}^{1} p_s\,\mathrm{d}v. \end{aligned} \tag{14}$$

According to equation (14) and Table 7, it is concluded that,

$$\begin{aligned} CS = &((2(1-\emptyset)p_s - 2p_t + 1)\delta^2 + (2p_t + 2p_e p_t - 2\mu p_t^2 - p_t^2 + 2\mu p_e p_t - 1 \\ &+ p_s(\emptyset - 1)(2p_e - p_s + 2\mu(p_e - p_t) + 2)\delta - \mu^2 p_t^2 - 2\mu p_e^2 - p_e^2 + 2\mu^2 p_e p_t \\ &+ 2\mu p_e p_t - p_s(\emptyset - 1)(2p_e - p_s + 2\mu(p_e - p_t))))/(2\delta(\delta - 1)). \end{aligned}$$

The optimal consumer surplus is shown in Table A.1 in Appendix A. Figure 14 illustrates that under the MS strategy, the highest consumer surplus is found for the model with no RPE or a smaller μ.

Corollary 6.2. *Comparing the three strategies, consumer surplus is highest under RPE when the T-retailer and E-tailer are in the static game.*

Corollary 6.2 indicates that R_C^{SL}, R_C^{EL}, and R_C^{SE} are more than zero as μ and δ increase (see the three subplots of Fig. 14). This suggests that the consumer surplus under the MS strategy is the highest regardless of whether RPE is considered. When μ varies very little, RPE hardly affects the level of consumer surplus. Further, Figure 15 explores that consumer surplus is higher under RPE when the proportion of P-consumers reaches 0.3. By comparing α_1 and α_2, α_3 and α_4, α_5 and α_6, consumer surplus increases with the reference price coefficient at roughly the same rate of growth but not with the proportion of P-consumers. The fastest growth is in the MS strategy. This means MS has a higher consumer surplus when the proportion of P consumers is small. The possible reason is that R-consumers can partially offset the cost of obsolete products when they rebuy new products. The market is more attractive to R-consumers, so a large proportion of R-consumers is

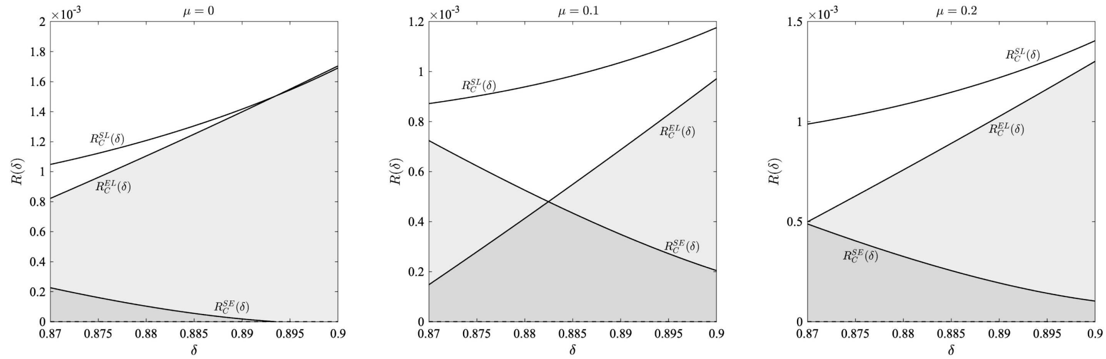

FIGURE 14. Consumer surplus comparison ($c = 0.4$, $c_t = 0.2$, $c_e = 0.1$, $\emptyset = 0.5$, $p_s = 0.05$).

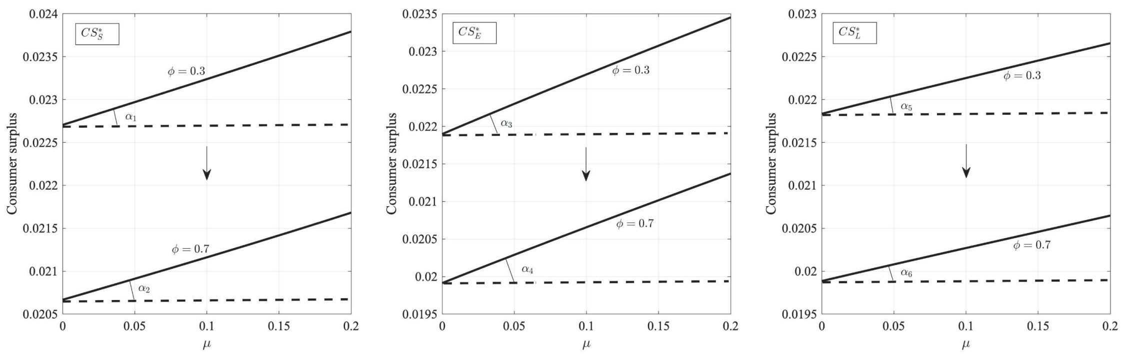

FIGURE 15. Consumer surplus with different consumers proportion ($c = 0.4$, $c_t = 0.2$, $c_e = 0.1$, $p_s = 0.05$, $\delta = 0.88$).

most favorable to supply chain members (including the manufacturer, retailers, and consumers). When the reference price parameter increases, it is detrimental to the profit of the T-retailer. Initially, the T-retailer may lower prices to compete for more demand. When electronic channel preference declines due to perceived losses, the E-tailer will lower prices accordingly to seek demand. The T-retailer will then raise prices to increase the reference price, and the overall benefit to the supply chain will increase as consumers are willing to pay a higher price for the product due to the perceived gain.

6.3. Rationale and insights

Based on the above findings, the study provides some rationale from a game theory perspective and some management insights from an operations research and management perspective.

6.3.1. Rationale

This subsection discusses the impact of the related parameters on consumer surplus. Based on the difference between the value of the product and the price the customer is willing to pay, the consumer surplus for benchmark models is calculated as follows.

Combined with previous work on non-cooperative game theory in the OR/MS literature (*e.g.*, [45, 54–59]), a mechanism is revealed for the rationale of the findings by the research. In Matsui's [45] study, "strategic complements" and "strategic substitutes" are common. Strategic complements refer to the fact that if one player adopts a more (less) aggressive strategy, other players will also adopt a more (less) aggressive strategy, *i.e.*, there is a positive correlation between the strategic variables decided by the players. Strategic substitutes refer to the fact that when one player increases his/her strategic variable, the other player decreases his/her strategic variable. That is, there is a negative correlation between variables characterized by strategic substitutes. The existing literature suggests that prices set by multiple firms in price competition are strategic complements, while quantities determined in quantity competition are strategic substitutes [54]. Since we consider price competition (Bertrand competition), the strategic variable (price) is a strategic complement. Strategic complements are used in price competition to explore the intuition behind the results through pricing sequences. The study finds that sequence S yields the highest profit for the manufacturer and the highest consumer surplus. As shown in Propositions 4.2 and 5.2, the sequence generates the highest profit for the manufacturer. Due to the different structures of the dual-channel supply chain explored, this result differs from that of a peer paper [45], which showed that the highest profits are made under sequence E. This is because, in sequence S, p_t and p_e have no strategic impact on the manufacturer, who is the leader of the game and decides about w on based on the price response function. The retailer simultaneously makes decisions on prices, resulting in $p_t(w)$ and $p_e(w)$, which are replaced in the manufacturer's expected profit, and p_t and p_e no longer appear. The expected profit of the T-retailer and the E-tailer depends on the level of wholesale prices. Therefore, under the S sequence, the manufacturer can predict the retailer's pricing level well and has a definite strategic advantage.

Second, considering the sequence E. The pricing sequences of the T-retailer and the E-tailer are different; when the T-retailer sets the retail channel price p_t at the early stage, the E-tailer calculates by backward induction, and then slightly lower p_e to gain a larger share of the market. This puts pressure on the T-retailer to maintain a high price (higher than the price in sequence S) to avoid the very low price from the E-tailer. As a result, the prices of the manufacturer and retailers are higher than the price levels in the simultaneous movement game. In sequence E, the T-retailer, as the party that first decides the retail price, has an incentive to raise the price, but this also ignores the fact that competitors compete for more demand by lowering the retail price. As shown in Proposition 4.1(ii), in sequence E, the T-retailer has the smallest demand. As a result, the first-moving play is not dominant in the pricing strategy. This is because the later mover is concerned that the first mover has the upper hand in the pricing sequence, thus, lower the price to compete for more advantage in the demand market. Therefore, the strategic effect is counterproductive in terms of the strategic behavior of the retailers; that is, the aggressive strategy of one player reduces its own profit but increases the profit of its competitors. The results suggest that the first mover does not dominate the pricing strategy because of late-mover advantage, which is consistent with Gal-Or's [55] and Amir's [59]. Moreover, the same is true for the L sequence. When retailers have the same pricing sequence, the retailer will choose to lower the retail price due to the fear that the other player will lower the price to compete for more markets. This also verifies Proposition 5.1(ii) that demand is not the highest. The reason is that market demand is affected by prices and consumer preferences such as channel acceptance. Therefore, the results show that the demand for simultaneous games is at an intermediate level, *i.e.*, $q_T^{E^*} < q_T^{S^*} < q_T^{L^*}$, $q_E^{L^*} < q_E^{S^*} < q_E^{E^*}$. A higher price in sequence E will reduce the sales volume in the channel, thereby reducing the manufacturer's profit. In order to minimize the decline in sales volume, the manufacturer must lower the wholesale price w^{E^*} below w^{S^*} to attract retailers to increase sales, hence $w^{E^*} < w^{S^*} < w^{L^*}$ holds. It is worth noting that since the reference price coefficient has little influence on the demand function, see equations (3) and (6), the decision of the game theory members is more or less the same as that of the benchmark model, even if the model takes into account the reference price effect.

This study deals with the price competition problem of retailers and is the first application of strategic complements to a remanufacturing dual-channel supply chain with RPE. It can be observed no analytical difficulties are encountered, although the model may have some computational complexity. Considering the profit difference under different decision sequences, as shown in Figure 7, as the channel preference increases, the profit difference $R_{\pi_M}^{SL}$ of the sequences S and L decreases, and the profit difference $R_{\pi_M}^{EL}$ decreases in sequences E and L and the profit difference $R_{\pi_M}^{SE}$ between S sequence and E sequence increases, suggesting that there is a potential effect of the channel coefficient on market demand. This also hints at a competitive situation among retailers, *i.e.*, retailers do not capture the largest market share despite lowering each other's prices. The profit of the T-retailer will be negatively affected when consumers prefer electronic channels. Under sequence E, the profit of the E-tailer is the highest. As the channel preference increases, the demand for the electronic channel will increase. In contrast, the demand for the T-retailer will be harmed, and to minimize the decrease in sales, the T-retailer will increase the price in sequence E. Therefore, as the channel coefficient increases, the profits of the T-retailer will increase slightly, and the profit of the E-tailer will decrease slightly so that the profit difference $R^{SL}_{\pi_M}$ and $R^{EL}_{\pi_M}$ will decrease. Since the profit of sequence S is not affected by p_t and p_e , the profit is slightly stable. Thus, $R^{SE}_{\pi_M}$ will increase. Overall, the channel coefficient has little effect on the manufacturer's profit strategy within a certain range, so $\pi_M^{S^*} > \pi_M^{E^*} > \pi_M^{L^*}$ holds.

6.3.2. Insights

From the above discussion of results and parameter sensitivity, the managerial and academic insights can be drawn as follows.

Insights 1. The profits of the manufacturer and the E-tailer are positively proportional to the channel coefficient, and profits could be increased by improving channel preference, such as increasing consumers' willingness to online e-retail shopping. Meanwhile, the T-retailer is inversely proportional and may lower price to capture more demand. It is suggested that firms consider the influence of reference prices in their decisions, with relatively low reference price parameters favoring supply chain members. Supply chain members could adjust strategies according to consumer behavior (reference prices) to gain more marginal. To maximize profits, companies need to lower the reference price threshold by reducing the wholesale price.

Insights 2. The optimal profit decisions of the members in the game theory depend on the different pricing timing of the retailers. It is suggested that the manufacturer makes decisions to adjust the wholesale price appropriately according to the pricing behavior of retailers so as to equilibrate the profits of the members.

Insights 3. Profits and consumer surplus are inversely proportional to the proportion of primary consumers. The profitability of the supply chain members depends on the threshold value of μ. When the reference price parameter is relatively low, the profits of the manufacturer and retailers are relatively higher. Therefore, the manufacturer can offer more discounts to R-consumers, then the proportion of customers who do not own the obsolete product will be relatively small; as a result, the supply chain members will gain more profit.

7. Conclusions

This study constructs a dual-channel supply chain consisting of a manufacturer, a T-retailer, and an E-tailer in a market where there are only primary and replacement consumers to explore the influence of reference price behavior on the dual-channel RSC decisions. We consider the M-Stackelberg game, in which there are static and dynamic game situations for retailers and analyze the game process using game theory and backward induction. The following conclusions and insights are drawn based on the optimal equilibrium results by comparing important correlation results and sensitivity analyses to parameters.

Based on static and dynamic game choices and taking into account RPE, six different equilibrium outcomes are derived. Some findings are found. First, the proportional interval of P-consumers determines the optimal decision choice whether RPE is considered. Second, the optimal strategy of the manufacturer and retailers differ. The optimal choice of the manufacturer is the MS strategy, the T-retailer is the ML strategy, and the E-tailer is the ME strategy. The total profit of the supply chain is highest under the ME strategy. Under the MS strategy, the manufacturer cannot balance retailers' profits through a revenue-sharing contract. Third, the reference price parameter is relatively small and does not affect the optimal choice of the manufacturer and the retailer. However, as the reference price parameter increases, the profits of the manufacturer and E-tailer increase while the returns of the T-retailer decrease. Additionally, the game between a manufacturer and two competing retailers is explored from the perspective of a non-cooperative game. Previous studies believed the first mover has more decision advantages in the dual-channel price competition. However, our findings suggest that the second mover has a decision advantage for retailers. This provides more possibilities for decisions in competitive games with different channels. Several insights are obtained. First, the profits of supply chain members are inversely proportional to the proportion of primary consumers. The lower the proportions, the higher the profit. Second, the reference price plays a dominant role for supply chain members, and decision-makers can take advantage of consumers' perceived gain and perceived loss psychology to set reasonable wholesale and retail prices. For example, the analysis in this paper suggests that, due to the role of the reference price, the T-retailer can reduce the price first and then increase the retail price to increase the demand and improve the profit. Third, the level of channel preference coefficient affects the demand of the dual-channel; the higher the preference of the e-retail channel is, the more harmful it is to the T-retailer, so it is suggested that the T-retailer needs to make more efforts to attract more consumers to choose the t-retail channel.

Limitations and future research are as follows. Although this research yielded many interesting results and insights. However, this paper remains shortcomings and limitations. First, the article assumes that t-retail prices are used as the reference price; actually, using online retailer's prices as the reference price would lead to different findings. Second, the supply chain structure considered in this study is one manufacturer and two retailers. In real life, a manufacturer may face many retailers, and as a future research direction, a supply chain structure with multiple retailers in a multi-channel environment can be considered. Third, the study considers the remanufactured supply chain, where there is no difference between new and remanufactured products in terms of function and role. As a future direction of concern, some interesting results can be found by considering reference quality effects between the new and remanufactured products within the context of the limited rationality of the game participants.

Appendix A.

Let $A_1 = (-c_t + c + (1-\emptyset)p_s + 3)\delta + 2(-c_e + c + (1-\emptyset)p_s)$
$B_1 = 2((1-\emptyset))p_s + 2)\delta^2 - (c_t + 2c_e + 3c + (1-\emptyset))p_s + 5)\delta - 2(4c_t - c_e + 3c + 5(1-\emptyset))p_s + 4)$
$C_1 = 2\delta^2 + (-c_t - c + 3(1-\emptyset)p_s - 5)\delta - 2(c_e + c + 3(1-\emptyset)p_s)$
$D_1 = (c_t + c - (1-\emptyset)p_s - 1)\delta^2 + (c_t + c - (1-\emptyset)p_s - 7)\delta - 2(4c_t - 3c_e + c - (1-\emptyset)p_s - 4)$
$E_1 = -\delta^3 + (c_e + c - (1-\emptyset)p_s + 2)\delta^2 + (3c_t - 2c_e + c - (1-\emptyset)p_s - 1)\delta - 2(c_e + c - (1-\emptyset)p_s)$
$F_1 = \emptyset((c_t + c - 3(1-\emptyset)p_s - 3)\delta + 2(c_e + c + 3(1-\emptyset)p_s))$
$G_1 = (1-\emptyset)(((c_t + c) + (3\emptyset - 1)p_s - 3)\delta + 2((c_e + c) - (1 + 3\emptyset)p_s))$
$H_1 = (c_t + c - (1-\emptyset)p_s - 3)\delta + 2(c_e + c - (1-\emptyset)p_s)$
$A_2 = (-c_t + c + (1-\emptyset)p_s + 2)\delta^2 + (2c_t - c_e - c - (1-\emptyset)p_s - 6)\delta + 4(c_e - c - (1-\emptyset)p_s)$
$B_2 = (c_t + c + 3(1-\emptyset)p_s + 6)\delta^3 + (-c_t - 3c_e - 4c - 8(1-\emptyset)p_s - 20)\delta^2 + (-10c_t + 9c_e - c - 7(1-\emptyset)p_s + 6)\delta + 4(4c_t - c_e + 3c + 5(1-\emptyset)p_s + 4)$
$C_2 = (c_t + c - (1-\emptyset)p_s + 6)\delta^2 + (-2c_t + c_e - c + 9(1-\emptyset)p_s - 10)\delta - 4(c_e + c + 3(1-\emptyset)p_s)$
$D_2 = (-c_t - c + (1-\emptyset)p_s + 2)\delta^3 + (3c_t - c_e + 2c - 2(1-\emptyset)p_s)\delta^2 + 3(2c_t - c_e + c - (1-\emptyset)p_s - 6)\delta - 4(4c_t - 3c_e + c - (1-\emptyset)p_s - 4)$
$E_2 = (-c_t - c + (1-\emptyset)p_s - 6)\delta^4 + (-c_t + 7c_e + 6c - 6(1-\emptyset)p_s + 24)\delta^3 + (18c_t - 23c_e - 5c + 5(1-\emptyset)p_s - 26)\delta^2 + 8(-3c_t + c_e - 2c + 2(1-\emptyset)p_s + 1)\delta + 16(c_e + c - (1-\emptyset)p_s)$
$F_2 = \emptyset((-c_t - c + (1-\emptyset)p_s + 2)\delta^2 + (2c_t - c_e + c - 9(1-\emptyset)p_s - 6)\delta + 4(c_e + c + 3(1-\emptyset)p_s))$
$G_2 = (1-\emptyset)((-c_t - c + (1-\emptyset)p_s + 2)\delta^2 + (2c_t - c_e + c - (1 - 9\emptyset)p_s - 6)\delta + 4(c_e + c - (1 + 3\emptyset)p_s))$
$H_2 = (-c_t - c + (1-\emptyset)p_s + 2)\delta^2 + (2c_t - c_e + c - (1-\emptyset)p_s - 6)\delta + 4(c_e + c - (1-\emptyset)p_s)$
$A_3 = -\delta^2 + (-c_t + c_e + 3)\delta + 2(-c_e + c + (1-\emptyset)p_s)$
$B_3 = -\delta^3 + (-c_t + c_e + 4)\delta^2 + (5c_t - 3c_e + 2c + 6(1-\emptyset)p_s + 1)\delta - 2(4c_t - c_e + 3c + 5(1-\emptyset)p_s + 4)$
$C_3 = 3\delta^2 + (-c_t + c_e + 4(1-\emptyset)p_s - 5)\delta - 2(c_e + c + 3(1-\emptyset)p_s)$
$D_3 = -\delta^3 + (-c_t + c_e + 6)\delta^2 + (7c_t - 5c_e + 2c - 2(1-\emptyset)p_s - 13)\delta + 2(-4c_t + 3c_e - c + (1-\emptyset)p_s + 4)$
$E_3 = \delta^3 + (c_t - c_e - 2)\delta^2 + (-3c_t + c_e - 2c + 2(1-\emptyset)p_s + 1)\delta + 2(c_e + c - (1-\emptyset)p_s)$
$F_3 = \emptyset(\delta^2 + (c_t - c_e - 4(1-\emptyset)p_s - 3)\delta + 2(c_e + c + 3(1-\emptyset)p_s))$
$G_3 = (1-\emptyset)(\delta^2 + (c_t - c_e + 4\emptyset p_s - 3)\delta + 2(c_e + c - (1 + 3\emptyset)p_s))$
$H_3 = \delta^2 + (c_t - c_e - 3)\delta + 2(c_e + c - (1-\emptyset)p_s)$

$A_1^R = ((c-c_t+(1-\emptyset)p_s)(1+\mu)+2\mu+3)\delta+2(c-c_e+(1-\emptyset)p_s)+\mu(1+2c-3c_e+c_t-\mu c_e+\mu c_t+2(1-\emptyset)p_s)$
$B_1^R = 2((1-\emptyset)p_s+2)\delta^2-(c_t+2c_e+3c+(1-\emptyset)p_s+\mu(6+3c+2c_e+c_t+3(1-\emptyset)p_s)+5)\delta-2(4c_t-c_e+3c+5(1-\emptyset)p_s+4)+\mu((-3\mu-11)c_t+(3\mu+5)c_e-6c-6(1-\emptyset)p_s-3)$
$C_1^R = 2\delta^3+((1+\mu)(-c_t-c+3(1-\emptyset)p_s)-1)\delta^2+(-2(c_t+c_e+2c+5)-\mu(2c_t+7c+5c_e+6\mu+3(1-\emptyset)(1+\mu)p_s+3\mu(c+c_e)+12))\delta-4(c_e+c+3(1-\emptyset)p_s)-2\mu(3c_t+2c_e+5c+9(1-\emptyset)p_s+3)-3\mu^2(c_t(3+\mu)-c_e(1+\mu)+2c+2(1-\emptyset)p_s+1)$
$D_1^R = (-2\mu+(1+\mu)((c_t+c)-(1-\emptyset)p_s)-1)\delta^2+(c_t+c-(1-\emptyset)p_s+\mu((1+\mu)c_e-\mu c_t+c-(1-\emptyset)p_s-5)-7)\delta-2(4c_t-3c_e+c-(1-\emptyset)p_s-4)+\mu(-13c_t+11c_e-2c+2(1-\emptyset)p_s+5\mu(c_e-c_t)+7)$
$E_1^R = -\delta^3+((1+\mu)(c_e+c-(1-\emptyset)p_s)+2+\mu)\delta^2+(3c_t-2c_e+c-(1-\emptyset)p_s+\mu(-2+c-4c_e+5c_t-(1-\emptyset)p_s-2\mu(c_e-c_t))-1)\delta-2(c_e+c-(1-\emptyset)p_s)+\mu((1+\mu)c_t-(3+\mu)c_e-2c+2(1-\emptyset)p_s+1)$
$F_1^R = \emptyset((c_t+c-3(1-\emptyset)p_s-\mu(2-c-c_t)-\mu(1-\emptyset)p_s-3)\delta+2(c_e+c+3(1-\emptyset)p_s)+\mu(-c_t+3c_e+2c+4(1-\emptyset)p_s+\mu(c_e-c_t)-1))$
$G_1^R = (1-\emptyset)((c_t+c-(1-3\emptyset)p_s-3+\mu(c_t+c-2-(1-\emptyset)p_s))\delta+2(c_e+c-2(1+3\emptyset)p_s)+\mu(-c_t+3c_e+2c-2(1+2\emptyset)p_s+\mu(c_e-c_t)-1))$
$H_1^R = ((1+\mu)(c_t+c-(1-\emptyset)p_s)-2\mu-3)\delta-\mu(1+\mu)c_t+(\mu+1)(\mu+2)c_e+2c(1+\mu)-\mu-2(1-\emptyset)(1+\mu)p_s$
$A_2^R = (-c_t+c+(1-\emptyset)p_s+2)\delta^2+(2c_t-c_e-c-(1-\emptyset)p_s-\mu(-2c_t+c_e+c+2+(1-\emptyset)p_s)+6)\delta+4(c_e-c-(1-\emptyset)p_s)-\mu((2+\mu)c_t-(5+\mu)c_e+3c+2+3(1-\emptyset)p_s)$
$B_2^R = (c_t+c+3(1-\emptyset)p_s+6)\delta^3+(-c_t-3c_e-8(1-\emptyset)p_s-4c-20-\mu(3c_e+3c+5(1-\emptyset)p_s)+10)\delta^2+(-10c_t+9c_e-c-7(1-\emptyset)p_s+6+\mu(-(12+3\mu)c_t+(14+5\mu)c_e+2c+8+2c\mu+4\mu-2(1-\emptyset)(1-\mu)p_s))\delta+4(4c_t-c_e+3c+5(1-\emptyset)p_s+4)+\mu((2\mu^2+13\mu+26)c_t-(2\mu^2+7\mu+9)c_e+(4+6c)\mu+17c+18+(6\mu+23)(1-\emptyset)p_s)$
$C_2^R = (c_t+c-(1-\emptyset)p_s+6)\delta^4+(-3c_t+c_e-2c+10(1-\emptyset)p_s+\mu(-c_t+c_e+8(1-\emptyset)p_s)-16)\delta^3+(-2c_t-5c_e-7c-17(1-\emptyset)p_s-\mu(-(1+3\mu)c_t+(13+8\mu)c_e+(14+5c)\mu+40+12c+(11\mu+28)(1-\emptyset)p_s+14))\delta^2+(8c_t+8c-24(1-\emptyset)p_s+\mu(-(7\mu^2+21\mu+8)c_t+(11\mu^2+31\mu+20)c_e+2(1-\emptyset)(2\mu^2-\mu-14)p_s+(4c+8)\mu^2+(32+10c)\mu+12c+64)+40)\delta+16c_e+16c+48(1-\emptyset)p_s+\mu((4\mu^3+23\mu^2+42\mu+24)c_t+(-4\mu^3-11\mu^2+\mu+24)c_e+(1-\emptyset)(12\mu^2+61\mu+96)p_s+(12c+8)\mu^2+(43c+30)\mu+48c+24)$
$D_2^R = (c_t+c-(1-\emptyset)p_s-2)\delta^3-(3c_t-c_e+2c-2(1-\emptyset)p_s-\mu(-2c_t+c_e-c+2+(1-\emptyset)p_s))\delta^2-(3(2c_t-c_e+c-6-(1-\emptyset)p_s)-\mu(-(4-\mu)c_t+(2-\mu)c_e-2c+8+2(1-\emptyset)p_s))\delta+4(4c_t-3c_e+c-4-(1-\emptyset)p_s)+\mu((7\mu+22)c_t-(7\mu+19)c_e+3c-10-3(1-\emptyset)p_s)$
$E_2^R = (-c_t-c+(1-\emptyset)p_s-6)\delta^4+(-c_t+7c_e+6c+24-6(1-\emptyset)p_s+\mu(-3c_t+7c_e+4c+8-4(1-\emptyset)p_s))\delta^3+(18c_t-23c_e-5c-26+5(1-\emptyset)p_s-\mu(-(27+9\mu)c_t+(12\mu+35)c_e+(3c+2)\mu+8c+16-(1-\emptyset)(8+3\mu)p_s))\delta^2+8(-3c_t+c_e-2c+2(1-\emptyset)p_s+1)\delta+\mu((-5\mu^2-23\mu-40)c_t+(5\mu^2+17\mu+20)c_e+(8-6c)\mu-20c+16+2(1-\emptyset)(3\mu+10)p_s)\delta+16(c_e+c-(1-\emptyset)p_s)+\mu((-3\mu^2-10\mu-8)c_t+(3\mu^2+19\mu+32)c_e+(9c-6)\mu+24c-8-(1-\emptyset)(9\mu+24)p_s)$
$F_2^R = \emptyset((c_t+c-2-(1-\emptyset)p_s)\delta^2-(2c_t-c_e+c-6-9(1-\emptyset)p_s)\delta+\mu(-2c_t+c_e-c+2+(1-\emptyset)p_s)\delta-4(c_e+c+3(1-\emptyset)p_s)+\mu((2+\mu)c_t-(5+\mu)c_e-3c+2-5(1-\emptyset)p_s))$
$G_2^R = (1-\emptyset)((c_t+c-2-(1-\emptyset)p_s)\delta^2-(2c_t-c_e+c-6+(1-9\emptyset)p_s)\delta+\mu(-2c_t+c_e-c+2+(1-\emptyset)p_s)\delta-4(c_e+c-(1+3\emptyset)p_s)+\mu((2+\mu)c_t-(5+\mu)c_e-3c+2+(3+5\emptyset)p_s))$
$H_2^R = (c_t+c-2-(1-\emptyset)p_s)\delta^2-(2c_t-c_e+c-6-(1-\emptyset)p_s)\delta+\mu(-2c_t+c_e-c+2+(1-\emptyset)p_s)\delta-4(c_e+c-(1-\emptyset)p_s)+\mu((2+\mu)c_t-(5+\mu)c_e-3c+2+3(1-\emptyset)p_s)$
$A_3^R = (-\mu-2)\delta^2+(-2c_t+2c_e+6+\mu(-(5+3\mu)c_t+(3+\mu)c_e+(2c+3)\mu+2c+7+2(1-\emptyset)(1+\mu)p_s))\delta+4(-c_e+c+(1-\emptyset)p_s)+\mu((\mu^2+3\mu+2)c_t-(\mu^2+5\mu+8)c_e+(2c+1)\mu+6c+2+2(1-\emptyset)(3+\mu)p_s)$
$B_3^R = (3\mu+2)\delta^3+(2c_t-2c_e-8+\mu((\mu+3)c_t-(5+3\mu)c_e-(2c+11)\mu-2c-22-6(1-\emptyset)(1+\mu)p_s))\delta^2+(-10c_t+6c_e-4c-2-12(1-\emptyset)p_s)\delta+\mu(-(5\mu^2+10\mu+19)c_t+(5\mu^2+18\mu+19)c_e+17+(4c+6)\mu^2+(8c+22)\mu-c_t\mu^2+4(\mu^2+2\mu-2)(1-\emptyset)p_s)\delta+16c_t-4c_e+12c+16+20(1-\emptyset)p_s+\mu(-(2\mu^3+11\mu^2+21\mu+16)c_e+(2\mu^3+15\mu^2+39\mu+42)c_t+(2+4c)\mu^2+(18c+13)\mu+26c+26+(38+22\mu+4\mu^2)(1-\emptyset)p_s)$
$C_3^R = -2\mu\delta^3+\mu((2+2\mu)c_t-(2+2\mu)c_e-3\mu-3-4(1+\mu)(1-\emptyset)p_s)\delta^2-6\delta^2+(2c_t-2c_e-8(1-\emptyset)p_s+10)\delta+\mu(-(1+\mu^2+4\mu)c_t+(3\mu^2+8\mu+3)c_e+(2c+3)\mu^2+(4c+10)\mu+2c+11+2(\mu-1)(\mu+3)(1-\emptyset)p_s)\delta+4(c_e+c+3(1-\emptyset)p_s)+\mu((\mu^3+6\mu^2+11\mu+6)c_t-(\mu^3+4\mu^2+3\mu-4)c_e+(1+2c)\mu^2+(8c+5)\mu+10c+6+2(1-\emptyset)(\mu^2+6\mu+11)p_s)$
$D_3^R = (2-\mu)\delta^3+(-2c_e+2c_t-12+\mu(-(1+3\mu)c_t-(1-\mu)c_e+(3-2c)\mu-2c+2(1-\emptyset)(1+\emptyset)p_s))\delta^2-(14c_t-10c_e+4c-26-4(1-\emptyset)p_s)\delta+\mu(-(-\mu^2+2\mu+17)c_t+(-\mu^2+2\mu+13)c_e+2\mu-4c+19+4(1-\emptyset)p_s)\delta-4(-4c_t+3c_e-c+4+(1-\emptyset)p_s)+\mu((3\mu^2+17\mu+30)c_t-(3\mu^2+15\mu+24)c_e+(2c-5)\mu+6c-18-2(1-\emptyset)(3+\mu)p_s)$

$E_3^R = (3\mu+2)\delta^3 + 2(c_t - c_e - 2)\delta^2 + \mu((\mu+3)c_t - (3\mu+5)c_e - (1+2c)\mu - 2c - 8 + 2(1-\emptyset)(1+\mu)p_s)\delta^2 + 2(-3c_t + c_e - 2c + 2(1-\emptyset)p_s + 1)\delta + \mu(-(3\mu^2+10\mu+13)c_t + (3\mu^2+10\mu+9)c_e + 2\mu - 4c + 7 + 4(1-\emptyset)p_s)\delta + 4(c_e + c - (1-\emptyset)p_s) + \mu(-(\mu^2+3\mu+2)c_t + (\mu^2+5\mu+8)c_e + (2c-1)\mu + 6c - 2 - 2(1-\emptyset)(3+\mu)p_s)$
$F_3^R = \emptyset((-\mu-2)\delta^2 - 2(c_t - c_e - 3 - 4(1-\emptyset)p_s)\delta + \mu(-(3\mu+5)c_t + (\mu+3)c_e + (3-2c)\mu - 2c + 7 + 2(5+\mu)(1-\emptyset)p_s)\delta - 4(c_e + c + 3(1-\emptyset)p_s) + \mu((\mu^2+3\mu+2)c_t - (\mu^2+5\mu+8)c_e + (1-2c)\mu - 6c + 2 - 6(3+\mu)(1-\emptyset)p_s))$
$G_3^R = (1-\emptyset)((-\mu-2)\delta^2 - 2(c_t - c_e + 4\emptyset p_s - 3)\delta + \mu(-(3\mu+5)c_t + (3+\mu)c_e + (3-2c)\mu - 2c + 7 + 2p_s(1+\mu-\emptyset(5+\mu)))\delta - 4(c_e + c - (1+3\emptyset)p_s) + \mu((\mu^2+3\mu+2)c_t - (\mu^2+5\mu+8)c_e + (1-2c)\mu - 6c + 2 + 2(3+\mu)(1+3\emptyset)p_s))$
$H_3^R = -(\mu+2)\delta^2 + 2(-c_t + c_e + 3)\delta + \mu(-(3\mu+5)c_t + (\mu+3)c_e + (3-2c)\mu - 2c + 7 + 2(1+\mu)(1-\emptyset)p_s)\delta + 4(-c_e - c + (1-\emptyset)p_s) + \mu(-(\mu^2+5\mu+8)c_e + (\mu^2+3\mu+2)c_t + (1-2c)\mu - 6c + 2 + 2(3+\mu)(1-\emptyset)p_s)$

Proof of Theorem 4.1. Combining the KKT optimal conditions, the optimization problem in equations (7)–(9) is solved using backward induction as follows.

Model-M^{NS}

$$\begin{cases} \max \pi_M^N(w \mid p_t, p_e) = \max\big(q_T^N + q_E^N\big)(w-c) \\ \text{s.t.} \begin{cases} p_t^* \in \arg\max \pi_{R_t}^N(p_t \mid w, p_e) \\ p_e^* \in \arg\max \pi_{R_e}^N(p_e \mid w, p_t) \\ p_e < \delta p_t, \delta < 1 - p_t + p_e. \end{cases} \end{cases} \tag{A.1}$$

Jointing the concavity of equation (A.1) and the first order condition, using the backward induction technique, the decision is made simultaneously by the manufacturer as the leader and the retailer as the follower. First, maximizing equations (8) and (9) with respect to p_t and p_e, combining equations (1)–(3), we obtain the first-order derivatives as follows,

$$\frac{\partial \pi_{R_t}^N}{\partial p_t} = \frac{p_t - w - c_t}{\delta - 1} + 1 - \frac{p_t - p_e}{1-\delta} \tag{A.2}$$

$$\frac{\partial \pi_{R_e}^N}{\partial p_e} = \left(\frac{1}{\delta-1} - \frac{1}{\delta}\right)(p_e - w - c_e) + \frac{p_t - p_e}{1-\delta} - \frac{p_e}{\delta} + (1-\emptyset)\frac{p_s}{\delta}\cdot \tag{A.3}$$

By solving $\frac{\partial \pi_{R_t}^N}{\partial p_t} = 0$, $\frac{\partial \pi_{R_e}^N}{\partial p_e} = 0$, we get $p_t^{NS^*}(w)$, $p_e^{NS^*}(w)$. Putting $p_t^{NS^*}(w)$, $p_e^{NS^*}(w)$ into equation (7), and with respect to w by solving $\frac{\partial \pi_M^N}{\partial w} = 0$, we get w^{NS^*}. Then, we have $p_t^{NS^*}$ and $p_e^{NS^*}$. Further, we can get $q_T^{NS^*}$, $q_E^{NS^*}$, $q_P^{NS^*}$, $q_R^{NS^*}$, q^{NS^*}, $\pi_M^{NS^*}$, $\pi_{R_t}^{NS^*}$, $\pi_{R_e}^{NS^*}$.

Model-M^{NE}

$$\begin{cases} \max \pi_M^N(w \mid p_t, p_e) = \max\big(q_T^N + q_E^N\big)(w-c) \\ \text{s.t. } p_t^* \in \arg\max \pi_{R_t}^N(p_t \mid w, p_e) \\ \begin{cases} \max \pi_{R_t}^N(p_t \mid w, p_e) = \max q_T^N(p_t - w - c_t) \\ \text{s.t.} \begin{cases} p_e^* \in \arg\max \pi_{R_e}^N(p_e \mid w, p_t) \\ p_e < \delta p_t, \delta < 1 - p_t + p_e. \end{cases} \end{cases} \end{cases} \tag{A.4}$$

In this scenario, the manufacturer acts as the leader, the T-retailer pricing earlier than the E-tailer. From equation (A.4), we have $p_e^{NE^*}(p_t, w)$. Putting $p_e^{NE^*}(p_t, w)$ into equation (8), with respect to p_t by solving $\frac{\partial \pi_{R_t}^N}{\partial p_t} = 0$. we can get $p_t^{NE^*}(w)$. Putting $p_t^{NE^*}(w)$ into $p_e^{NE^*}(p_t, w)$, we get $p_e^{NE^*}(w)$. Putting $p_t^{NE^*}(w)$, $p_e^{NE^*}(w)$ into equation (7), we can get w^{NE^*}. Then, all results are obtained.

Model-M^{NL}:

$$\begin{cases} \max \pi_M^N(w \mid p_t, p_e) = \max\bigl(q_T^N + q_E^N\bigr)(w-c) \\ \text{s.t. } p_e^* \in \arg\max \pi_{R_e}^N(p_e \mid w, p_t) \\ \begin{cases} \max \pi_{R_e}^N(p_e \mid w, p_t) = \max q_E^N(p_e - w - c_e) \\ \text{s.t.} \begin{cases} p_t^* \in \arg\max \pi_{R_t}^N(p_t \mid w, p_e) \\ p_e < \delta p_t, \delta < 1 - p_t + p_e. \end{cases} \end{cases} \end{cases} \tag{A.5}$$

In this scenario, the manufacturer as the leader, the T-retailer pricing later than the E-tailer. From equations (A.2), (A.5), we have $p_t^{NL^*}(p_e, w)$. Put $p_t^{NL^*}(p_e, w)$ into equation (9), with respect to p_e by solving $\frac{\partial \pi_{R_e}^N}{\partial p_e} = 0$.we can get $p_e^{NL^*}(w)$. Put $p_e^{NL^*}(w)$ into $p_t^{NL^*}(p_e, w)$, we get $p_t^{NL^*}(w)$. Put $p_t^{NL^*}(w)$ into $p_e^{NL^*}(p_t, w)$, we get $p_e^{NL^*}(w)$. Putting $p_t^{NL^*}(w)$, $p_e^{NL^*}(w)$ into equation (7), we can get w^{NL^*}. Then, all results are obtained. $\square$

Proof of Proposition 4.1. To simplify the analysis, $(c_e - c_t + 1 - \delta) > 0$ is considered. $\widetilde{K_i^R}$ denotes K_i^R does not contain any monomials related to $\emptyset$, where $K = B, C, D, E, F, i = 1, 2, 3$.

From Theorem 4.1, we have $w^{NL^*} > w^{NS^*} > w^{NE^*}$.

Because $\delta(\delta^3 - 4\delta^2 + 7\delta - 8)(c_e - c_t + 1 - \delta) < 0$, then, $p_t^{NS^*} < p_t^{NL^*} < p_t^{NE^*}$ if and only if $1 > \emptyset > \max(0, \emptyset_1)$, where $\emptyset_1 = 1 - \frac{\delta^3 - (5 - c_t + c_e)\delta^2 + 2(2c_e - 3c_t - c + 5)\delta - 4c - 4c_e}{-2p_s(\delta+2)}$; $p_e^{NS^*} < p_e^{NE^*} < p_e^{NL^*}$, if and only if $0 < \emptyset < \max(\emptyset_2, 1)$, where $\emptyset_2 = 1 - \frac{\delta((c_t+c)\delta - c_e - c)}{(\delta^2 - \delta + 18)p_s}$. $q_T^{NE^*} < q_T^{NS^*} < q_T^{NL^*}$, if and only if $\emptyset \in (\max(0, \emptyset_3), \min(\emptyset_4, 1))$, where $\emptyset_3 = 1 - \frac{(2 - c_t - c)\delta^4 + (c_t - c_e)\delta^3 + (8c_t - c_e + 7c - 10)\delta^2 + (2c_e + 2c - 24)\delta - 8c + 24c_e - 32c_t + 32}{-(\delta+2)(\delta-1)(\delta^2 - \delta - 4)p_s}$.

$\emptyset_4 = 1 - \frac{\delta^4 + (c_t - c_e - 8)\delta^3 + (7c_e - 5c_t + 2c + 13)\delta^2 + (10c_t - 8c_e + 2c - 6)\delta - 4c_e - 4c}{2p_s(\delta-1)(\delta+2)}$; $q_E^{NL^*} < q_E^{NS^*} < q_E^{NE^*}$, if and only if $\emptyset \in (0, \min(\emptyset_5, \emptyset_6, 1))$, where $\emptyset_5 = 1 - \frac{\delta^4 + (c_e - c_t + 4)\delta^3 + (2c - 3c_e + 5c_t - 5)\delta^2 + 2(c + c_t + 1)\delta - 4c_e - 4c}{2p_s(\delta+2)(\delta-1)}$, $\emptyset_6 = 1 - \frac{(c + c_t - 2)\delta^4 + (c_e - c_t + 4)\delta^3 + (-7c - 3c_e - 4c_t - 14)\delta^2 + 2(9c_e - c - 10c_t + 30)\delta + 8(c - 5c_e + 6c_t - 8)}{(\delta-1)(\delta+2)(\delta^2 - \delta - 4)p_s}$. $q_P^{NS^*} > q_P^{NE^*} > q_P^{NL^*}$, if and only if $\emptyset \in (\max(0, \emptyset_7), \min(\emptyset_8, 1))$, where $\emptyset_7 = 1 - \frac{(c + c_t)\delta - c_e - c}{p_s(\delta^2 - \delta + 6)}$, $\emptyset_8 = 1 - \frac{(c + c_t - 2)\delta + c_e - 2c_t - c + 2}{p_s(\delta - 1)}$. $q_R^{NS^*} > q_R^{NE^*} > q_R^{NL^*}$, if and only if $\emptyset \in (0, \min(\emptyset_9, \emptyset_{10}, 1))$, where $\emptyset_9 = 1 + \frac{\delta((c + c_t - 2)\delta + c_e - c + 2)}{(1 - \delta)p_s}$, $\emptyset_{10} = 1 + \frac{(-c_t - c)\delta + c_e + c}{(\delta - 1)p_s}$, $q^{NS^*} > q^{NE^*} > q^{NL^*}$, if and only if $\emptyset \in (0, \min(\emptyset_{11}, \emptyset_{12}, 1))$, where $\emptyset_{11} = 1 - \frac{(c + c_t - 2)\delta + c_e - 2c_t - c + 2}{(\delta - 1)p_s}$, $\emptyset_{12} = 1 - \frac{(c + c_t)\delta - c_e - c}{(\delta - 1)p_s}$. $\square$

Proof of Proposition 4.2. Note $\xi_0 = (\delta^2 - \delta - 4)(4(\delta - 2)(\widetilde{A_1} - 2(\delta + 2)c)\widetilde{H_1} - (\delta + 2)(\delta - 4)(\widetilde{A_2} - 2c(\delta^2 - \delta - 4))\widetilde{H_2})$, $\xi_1 = (\delta + 2)(\delta^2 - \delta - 4)(4(\delta - 2)(\widetilde{H_1} - \widetilde{A_1} + 2(\delta + 2)c) - (\delta - 4)(\widetilde{H_2} + \widetilde{A_2} - 2c(\delta^2 - \delta - 4)))$, $\xi_2 = -(\delta - 1)(\delta + 2)(\delta^2 - \delta - 4)$, $\xi_3 = (\widetilde{A_2} - 2c(\delta^2 - \delta - 4))\widetilde{H_2} - (\delta^2 - \delta - 4)(\widetilde{A_3} - 4c)\widetilde{H_3}$, $\xi_4 = (\delta^2 - \delta - 4)(\widetilde{A_2} - 2c(\delta^2 - \delta - 4) + \widetilde{H_2} - 2(\widetilde{H_3} - \widetilde{A_3} + 4c))$, $\xi_5 = \delta(\delta - 1)(\delta^2 - \delta - 4)$.

From $\pi_M^{NS^*} - \pi_M^{NE^*} > 0$, we have $\delta^2\xi_2(1 - \emptyset)^2 p_s^2 + \xi_1(1 - \emptyset)p_s + \xi_0 < 0$.

Then, $1 - \emptyset > \frac{-\xi_1 + \sqrt{\xi_1^2 - 4\delta^2\xi_0\xi_2}}{2\delta^2\xi_2 p_s}$, or $1 - \emptyset < \frac{-\xi_1 - \sqrt{\xi_1^2 - 4\delta^2\xi_0\xi_2}}{2\delta^2\xi_2 p_s}$.

From $\pi_M^{NE^*} - \pi_M^{NL^*} > 0$, we have $\xi_5(1 - \emptyset^2 p_s^2 + \xi_4(1 - \emptyset)p_s + \xi_3 > 0$. Then, $1 - \emptyset < \frac{-\xi_4 - \sqrt{\xi_4^2 - 4\xi_3\xi_5}}{2\xi_5 p_s}$, or $1 - \emptyset > \frac{-\xi_4 + \sqrt{\xi_4^2 - 4\xi_3\xi_5}}{2\xi_5 p_s}$.

From $\pi_{R_t}^{NS^*} - \pi_{R_t}^{NE^*} < 0$, we have, $\nu_0 + \nu_1(1 - \emptyset)p_s + \nu_2(\delta - 1)^2((1 - \emptyset)p_s)^2 < 0$, where $\nu_0 = 8(\delta - 2)(\delta^2 - \delta - 4)^2(\widetilde{B_1} - (\delta - 4)\widetilde{A_1} - 2(\delta + 2)(\delta - 4)c_t)\widetilde{D_1} - (\delta + 2)^2(\delta - 4)^2(\widetilde{B_2} - 2(\delta - 2)\widetilde{A_2} - 4(\delta - 2)(\delta^2 - \delta - 4)c_t)\widetilde{D_2}$, $\nu_1 = (\delta^2 - \delta - 4)(8(\delta - 2)(\delta^2 - \delta - 4)(\delta^2 + \delta - 2)(-\widetilde{B_1} + (\delta - 4)\widetilde{A_1} + 2(\delta + 2)(\delta - 4)c_t + \widetilde{D_1}) - (\delta - 1)(\delta + 2)^2(\delta - 4)^2(\widetilde{B_2} - 2(\delta - 2)\widetilde{A_2} - 4(\delta - 2)(\delta^2 - \delta - 4)c_t + \widetilde{D_2}))$. $\nu_2 = -\delta^2(\delta + 2)^2(\delta - 1)^2(\delta^2 - \delta - 4)^2$. Then, $1 - \emptyset > \frac{-\nu_1 + \sqrt{\nu_1^2 - 4\nu_0\nu_2(\delta - 1)^2}}{2\nu_2(\delta - 1)^2 p_s}$, $1 - \emptyset < \frac{-\nu_1 - \sqrt{\nu_1^2 - 4\nu_0\nu_2(\delta - 1)^2}}{2\nu_2(\delta - 1)^2 p_s}$.

From $\pi_{R_t}^{NE^*} - \pi_{R_t}^{NL^*} < 0$, we have $\nu_3 + \nu_4(1 - \emptyset)p_s + 2\delta\nu_5((1 - \emptyset)p_s)^2 > 0$, where $\nu_3 = 2(\delta - 2)(\widetilde{B_2} - 2(\delta - 2)\widetilde{A_2} - 4(\delta - 2)(\delta^2 - \delta - 4)c_t)\widetilde{D_2} - (\delta^2 - \delta - 4)^2(\widetilde{B_3} - 2(\delta - 2)\widetilde{A_3} - 8(\delta - 2)c_t)\widetilde{D_2}$, $\nu_4 = 2(\delta - 2)(\delta^3 - 2\delta^2 - 3\delta +$

$4)(\widetilde{B_2}-2(\delta-2)\widetilde{A_2}-4(\delta-2)(\delta^2-\delta-4)c_t+\widetilde{D_2})-2(1-\delta)(\delta^2-\delta-4)^2(\widetilde{B_3}-2(\delta-2)\widetilde{A_3}-8(\delta-2)c_t-\widetilde{D_3})$, $\nu_5=(\delta-1)^2(\delta^2-\delta-4)^2$.

Then, $1-\emptyset>\frac{-\nu_4+\sqrt{\nu_4^2-8\delta\nu_3\nu_5}}{4\delta\nu_5 p_s}$, $1-\emptyset<\frac{-\nu_4-\sqrt{\nu_4^2-8\delta\nu_3\nu_5}}{4\delta\nu_5 p_s}$.

From $\pi_{R_e}^{NS^*}-\pi_{R_e}^{NL^*}<0$, we have $\vartheta_0+\vartheta_1(1-\emptyset)p_s+4\vartheta_2((1-\emptyset)p_s)^2>0$, where $\vartheta_0=16((\delta+2)\widetilde{C_2}-(\delta-2)\widetilde{A_1}-2(\delta-2)(\delta+2)c_e)\widetilde{E_1}-(\delta+2)^2(\delta-4)(\widetilde{C_3}-(\delta-2)\widetilde{A_3}-4(\delta-2)c_e)\widetilde{E_3}$, $\vartheta_1=16((-\delta^2-\delta+2)((\delta+2)\widetilde{C_1}-(\delta-2)\widetilde{A_1}-2(\delta-2)(\delta+2)c_e)+2(\delta+2)(\delta-2)\widetilde{E_1})-2(\delta-1)(\delta+2)^2(\delta-4)(C_3-(\delta-2)\widetilde{A_3}-4(\delta-2)c_e+\widetilde{E_3})$, $\vartheta_2=-(\delta-1)(\delta+2)^2(\delta^2+3\delta-12)$.

Then, $1-\emptyset>\frac{-\vartheta_1-\sqrt{\vartheta_1^2-16\vartheta_0\vartheta_2}}{8\vartheta_2 p_s}$,$1-\emptyset<\frac{-\vartheta_1+\sqrt{\vartheta_1^2-16\vartheta_0\vartheta_2}}{8\vartheta_2 p_s}$.

From $\pi_{R_e}^{NL^*}-\pi_{R_e}^{NE^*}<0$, we have $\vartheta_3+\vartheta_4(1-\emptyset)p_s+\vartheta_5(\delta-1)^2((1-\emptyset)p_s)^2>0$. Where $\vartheta_3=2(\delta-2)(\delta^2-\delta-4)^2(\widetilde{C_3}-(\delta-2)\widetilde{A_3}-4(\delta-2)c_e)\widetilde{E_3}-\delta((\delta^2-\delta-4)\widetilde{C_2}-4(\delta-2)\widetilde{A_2}-8(\delta-2)(\delta^2-\delta-4)c_e)\widetilde{E_2}$, $\vartheta_4=(\delta-1)(\delta^2-\delta-4)(4(\delta-2)(\delta^2-\delta-4)(\widetilde{C_3}-(\delta-2)\widetilde{A_3}-4(\delta-2)c_e+\widetilde{E_3})+\delta(\delta-4)((\delta^2-\delta-4)\widetilde{C_2}-4(\delta-2)\widetilde{A_2}-8(\delta-2)(\delta^2-\delta-4)c_e-\widetilde{E_2}))$, $\vartheta_5=(\delta^2-\delta-4)^2(8(\delta-2)+\delta(\delta-4)^2)$.

Then, $1-\emptyset>\frac{-\vartheta_4-\sqrt{\vartheta_4^2-4(\delta-1)^2\vartheta_3\vartheta_5}}{2(\delta-1)^2\vartheta_5 p_s}$, $1-\emptyset<\frac{-\vartheta_4+\sqrt{\vartheta_4^2-4(\delta-1)^2\vartheta_3\vartheta_5}}{2(\delta-1)^2\vartheta_5 p_s}$. □

Proof of Theorem 5.1. Model-M^S

$$\begin{cases}\max\pi_M(w\mid p_t,p_e)=\max(q_T+q_E)(w-c)\\ \text{s.t.}\begin{cases}p_t^*\in\arg\max\pi_{R_t}(p_t\mid w,p_e)\\ p_e^*\in\arg\max\pi_{R_e}(p_e\mid w,p_t)\\ p_e<\delta p_t,\delta<1-(1+\mu)(p_t-p_e).\end{cases}\end{cases} \tag{A.6}$$

Model-M^E

$$\begin{cases}\max\pi_M(w\mid p_t,p_e)=\max(q_T+q_E)(w-c)\\ \text{s.t. } p_t^*\in\arg\max\pi_{R_t}(p_t\mid w,p_e)\\ \begin{cases}\max\pi_{R_t}(p_t\mid w,p_e)=\max q_T(p_t-w-c_t)\\ \text{s.t.}\begin{cases}p_e^*\in\arg\max\pi_{R_e}(p_e\mid w,p_t)\\ p_e<\delta p_t,\delta<1-(1+\mu)(p_t-p_e).\end{cases}\end{cases}\end{cases} \tag{A.7}$$

Model-M^L

$$\begin{cases}\max\pi_M(w\mid p_t,p_e)=\max(q_T+q_E)(w-c)\\ \text{s.t. } p_e^*\in\arg\max\pi_{R_e}(p_e\mid w,p_t)\\ \begin{cases}\max\pi_{R_e}(p_e\mid w,p_t)=\max q_E(p_e-w-c_e)\\ \text{s.t.}\begin{cases}p_t^*\in\arg\max\pi_{R_t}(p_t\mid w,p_e)\\ p_e<\delta p_t,\delta<1-(1+\mu)(p_t-p_e).\end{cases}\end{cases}\end{cases} \tag{A.8}$$

By analyzing equations (A.6)–(A.8), the proof process is similar to Theorem 4.1 and won't be repeated. □

Proof of Proposition 5.1. Considering $\delta-\mu>0$, because $\emptyset<1-\frac{-(\delta-\mu)(\delta+\mu)((c_e-c_t)(1+\mu)+1-\delta)}{6\mu(\delta+2)(1+\mu)p_s}<1$, $\delta(2+\mu)(\delta+\mu)((c_e-c_t)(1+\mu)+1-\delta)>0$, we have $w^{L^*}>w^{S^*}>w^{E^*}$;
when $\emptyset>1-\frac{-2(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)\widetilde{B_2^R}-(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)\widetilde{B_3^R}}{4p_s(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)(4\delta^2-(\mu-1)\mu\delta-4)}=\emptyset_{t1}$,
$\emptyset<1-\frac{-4(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)\widetilde{B_1^R}-(\delta+2)(\delta-3\mu-4)\widetilde{B_3^R}}{2p_s(1+\mu)(2+(1+\delta)\mu)(\delta^3+(1+\mu)\delta^2+\mu\delta-22\mu+18\delta-40)}=\emptyset_{t2}$, $p_t^{S^*}<p_t^{L^*}<p_t^{E^*}$.

When $\emptyset < 1 - \frac{4(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)\widetilde{C_1^R}-(\delta+2)(\delta-3\mu-4)\widetilde{C_2^R}}{-p_s(\delta-1)(\delta+2)(\delta+\mu)^2(\delta^2-(1+\mu)\delta-3\mu-4)} = \emptyset_{e1}$,
$\emptyset < 1 - \frac{(1+\delta)\mu+2)\widetilde{C_2^R}+2(\delta^2-(1+\mu)\delta-3\mu-4)\widetilde{C_3^R}}{-(\delta-1)(\delta+\mu)((1+\delta)\mu+2)(\delta^2-(1+\mu)\delta-3\mu-4)p_s} = \emptyset_{e2}$, $p_e^{S^*} < p_e^{E^*} < p_e^{L^*}$.

When $\emptyset > 1 - \frac{(\delta+2)(\delta-3\mu-4)\widetilde{D_2^R}+4(\delta^2-(1+\mu)\delta-3\mu-4)\widetilde{D_1^R}}{p_s(\delta+2)(\delta^4+2(\mu-1)\delta^3-(7\mu^2+8\mu+3)\delta^2-(14\mu^2+16\mu-4)\delta+3\mu^2+4\mu)} = \emptyset_{T1}$,
$\emptyset < 1 - \frac{-4(\delta-\mu-2)((1+\delta)\mu+2)\widetilde{D_1^R}-(\delta+2)(\delta-3\mu-4)\widetilde{D_3^R}}{-2p_s(1+\mu)(\delta+2)(\delta-1)((1+\delta)\mu+2)(\delta+\mu)} = \emptyset_{T2}$, $q_T^{E^*} < q_T^{S^*} < q_T^{L^*}$.

When $\emptyset < 1 - \frac{(\delta-1)(\delta+2)(\delta-3\mu-4)\widetilde{E_3^R}-8(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)\widetilde{E_1^R}}{2p_s(1-\delta)(\delta+2)(1+\mu)((1+\delta)\mu+2)(\delta^2+(\mu-1)\delta-4\mu^2-9\mu-4)} = \emptyset_{E1}$,
$\emptyset < 1 - \frac{8(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)\widetilde{E_1^R}-(\delta+2)(\delta-3\mu-4)\widetilde{E_2^R}}{p_s(\delta+2)(\delta-1)(\delta+\mu)^2(\delta^2-(1+\mu)\delta-3\mu-4)} = \emptyset_{E2}$, $q_E^{L^*} < q_E^{S^*} < q_E^{E^*}$.

When $\emptyset > 1 - \frac{((c_t+c-2)\delta+(c_e-c_t)\mu+c_e-c-2c_t+2)}{p_s(\delta-1)} = \emptyset_{P1}$, $\emptyset < 1 - \frac{(1+\mu)\widetilde{F_2^R}-\widetilde{F_3^R}}{p_s((1+\mu)\delta^2+(\mu^2-13)\delta-\mu^2-\mu)} = \emptyset_{P2}$,
$q_P^{S^*} > q_P^{E^*} > q_P^{L^*}$.

When $\emptyset > \frac{(\delta+\mu)((((c_t+c)(1+\mu)-\mu)\delta-(c_e+c)\mu-c_e-c+\mu)-p_s(\mu-\delta-(1+\mu)\delta^2-(1+\delta)\mu^2-2\delta\mu+8)}{p_s(1+\mu)(17\delta-\mu+\delta\mu+\delta^2)} = \emptyset_{R1}$,
$\emptyset < \frac{(\delta-\mu)(\delta+\mu)((-c_t-c+2)\delta-(c_e-c_t)\mu-c_e+c+2c_t-2)-(8\mu+6\delta\mu+\delta\mu^2-\delta^2-\delta^3-\mu^2+16)p_s}{p_s(\delta^3+17\delta^2-\delta\mu^2-54\delta\mu-96\delta+24\mu+48)} = \emptyset_{R2}$, $q_R^{S^*} > q_R^{E^*} > q_R^{L^*}$.

When $\emptyset > 1 - \frac{(\delta+\mu)(((c_t+c)(1+\mu)-\mu)\delta-(c_e+c)\mu-c_e-c+\mu)}{(1+\mu)(\delta^2-(1-\mu)\delta+5\mu)p_s} = \emptyset_{q1}$,
$\emptyset < 1 - \frac{(\delta-\mu)(\delta+\mu)^2((-c_t-c+2)\delta-(c_e-c_t)\delta-c_e+c+2c_t-2)}{-p_s(\delta^3-\delta^2-\mu^2\delta+6\mu\delta-17\mu^2-24\mu)} = \emptyset_{q2}$, $q^{S^*} > q^{E^*} > q^{L^*}$. □

Proof of Proposition 5.2. From $\pi_M^{S^*} - \pi_M^{E^*} > 0$, we have $\widetilde{\xi_0} + \widetilde{\xi_1}(1-\emptyset)p_s + (\mu+1)\widetilde{\xi_2}((1-\emptyset)p_s)^2 > 0$, then $1-\emptyset < \frac{-\widetilde{\xi_1}-\sqrt{\widetilde{\xi_1}^2-4(\mu+1)\widetilde{\xi_0}\widetilde{\xi_2}}}{2(1+\mu)\widetilde{\xi_2}p_s}$, or $1-\emptyset > \frac{-\widetilde{\xi_1}+\sqrt{\widetilde{\xi_1}^2-4(\mu+1)\widetilde{\xi_0}\widetilde{\xi_2}}}{2(1+\mu)\widetilde{\xi_2}p_s}$, where $\widetilde{\xi_0} = -4(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)(\widetilde{A_1^R}-2c(\mu+1)(\delta+2))\widetilde{H_1^R}-(\mu+1)(\delta+2)(\delta-3\mu-4)(\widetilde{A_2^R}-2c(\delta^2-(1+\mu)\delta-3\mu-4))\widetilde{H_2^R}$, $\widetilde{\xi_1} = (\mu+1)(\delta+2)(\delta^2-(1+\mu)\delta-3\mu-4)(4(\delta-\mu-2)(\widetilde{A_1^R}-2c(\mu+1)(\delta+2)-\widetilde{H_1^R})+(\delta-3\mu-4)(\widetilde{A_2^R}-2c(\delta^2-(1+\mu)\delta-3\mu-4)-\widetilde{H_2^R}))$, $\widetilde{\xi_2} = (\delta-1)(\delta+2)(\delta-\mu)(\delta+\mu)(\delta^2-(1+\mu)\delta-3\mu-4)$.

From $\pi_M^{E^*} - \pi_M^{L^*} > 0$, we have $(1+\mu)^2\widetilde{\xi_5}((1-\emptyset)p_s)^2 + \widetilde{\xi_4}(1-\emptyset)p_s + \widetilde{\xi_3} < 0$, then $1-\emptyset < \frac{-\widetilde{\xi_4}-\sqrt{\widetilde{\xi_4}^2-4(\delta+\mu)\widetilde{\xi_3}\widetilde{\xi_5}}}{2(\delta+\mu)\widetilde{\xi_5}p_s}$, $1-\emptyset > \frac{-\widetilde{\xi_4}+\sqrt{\widetilde{\xi_4}^2-4(\delta+\mu)\widetilde{\xi_3}\widetilde{\xi_5}}}{2(\delta+\mu)\widetilde{\xi_5}p_s}$, where $\widetilde{\xi_3} = 2((1+\delta)\mu+2)(1+\mu)^2(\widetilde{A_2^R}-2c(\delta^2-(1+\mu)\delta-3\mu-4))\widetilde{H_2^R} - (\delta^2-(1+\mu)\delta-3\mu-4)(\widetilde{A_3^R}-4c(\mu+1)((1+\delta)\mu+2))\widetilde{H_3^R}$, $\widetilde{\xi_4} = (\delta^2-(1+\mu)\delta-3\mu-4)(2((1+\delta)\mu+2)(1+\mu)^2(-\widetilde{A_2^R}+2c(\delta^2-(1+\mu)\delta-3\mu-4)+\widetilde{H_2^R})-(2\mu((1+\mu)\delta+3+\mu)+4)(\widetilde{A_3^R}-4c(\mu+1)((1+\delta)\mu+2)+\widetilde{H_3^R})$, $\widetilde{\xi_5} = -2(\delta-1)((1+\delta)\mu+2)(\delta^2-(1+\mu)\delta-3\mu-4)(1+\mu)^2$.

From $\pi_{R_t}^{S^*} - \pi_{R_t}^{E^*} < 0$, we have $\widetilde{\nu_0} + \widetilde{\nu_1}(1-\emptyset)p_s + (1+\mu)\widetilde{\nu_2}((1-\emptyset)p_s)^2 > 0$, where $\widetilde{\nu_0} = -8(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)^2((\mu+1)\widetilde{B_1^R}-(\delta-3\mu-4)\widetilde{A_1^R}-2(\delta+2)(\mu+1)(\delta-3\mu-4)c_t)\widetilde{D_1^R}-(1+\mu)(\delta+2)^2(\delta-3\mu-4)^2(\widetilde{B_2^R}-2(\delta-\mu-2)\widetilde{A_2^R}-4(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)c_t)\widetilde{D_2^R}$, $\widetilde{\nu_1} = (1+\mu)(\delta^2-(1+\mu)\delta-3\mu-4)(\delta+2)^2(8(1+\mu)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)(\delta-1)^2((\mu+1)\widetilde{B_1^R}-(\delta-3\mu-4)\widetilde{A_1^R}-2(\delta+2)(\mu+1)(\delta-3\mu-4)c_t+\widetilde{D_1^R})+(\delta-3\mu-4)^2(\widetilde{B_2^R}-2(\delta-\mu-2)\widetilde{A_2^R}-4(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)c_t-\widetilde{D_2^R}))$, $\widetilde{\nu_2} = (\delta+2)^2(\delta-1)^2(\delta^2-(1+\mu)\delta-3\mu-4)^2(8(\mu+1)(\delta-\mu-2)+(\delta-3\mu-4)^2)$.

Then, $1-\emptyset > \frac{-\widetilde{\nu_1}+\sqrt{\widetilde{\nu_1}^2-4(1+\mu)\widetilde{\nu_0}\widetilde{\nu_2}}}{2(1+\mu)\widetilde{\nu_2}p_s}$, $1-\emptyset < \frac{-\widetilde{\nu_1}-\sqrt{\widetilde{\nu_1}^2-4(1+\mu)\widetilde{\nu_0}\widetilde{\nu_2}}}{2(1+\mu)\widetilde{\xi_2}p_s}$.

From $\pi_{R_t}^{E^*} - \pi_{R_t}^{L^*} < 0$, we have $\widetilde{\nu_3} + \widetilde{\nu_4}(1-\emptyset)p_s + (1+\mu)(\delta-1)\widetilde{\nu_5}((1-\emptyset)p_s)^2 < 0$, where $\widetilde{\nu_3} = 2(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)^2(\widetilde{B_2^R}-2(\delta-\mu-2)\widetilde{A_2^R}-4(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)c_t)\widetilde{D_2^R}+(\delta^2-(1+\mu)\delta-3\mu-4)^2(\widetilde{B_3^R}+2(\delta-\mu-2)\widetilde{A_3^R}+8(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)c_t)\widetilde{D_3^R}$, $\widetilde{\nu_4} = 2(1+\mu)((1+\delta)\mu+2)^2(\delta^2-(1+\mu)\delta-3\mu-4)(-\widetilde{B_2^R}+2(\delta-\mu-2)\widetilde{A_2^R}+4(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)c_t+\widetilde{D_2^R})+2(1+\mu)(\delta-1)^2(\delta^2-(1+\mu)\delta-3\mu-4)(\widetilde{B_3^R}+2(\delta-\mu-2)\widetilde{A_3^R}+8(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)c_t-\widetilde{D_3^R}))$, $\widetilde{\nu_5} = -2(\delta-1)^2((1+\delta)\mu+2)^2(\delta^2-(1+\mu)\delta-3\mu-4)^2$.

Then, $1-\emptyset > \frac{-\widetilde{\nu_4}+\sqrt{\widetilde{\nu_4}^2-4(1+\mu)(\delta-1)\widetilde{\nu_3}\widetilde{\nu_5}}}{2(1+\mu)(\delta+\mu)\widetilde{\nu_5}p_s}$, $1-\emptyset < \frac{-\widetilde{\nu_4}-\sqrt{\widetilde{\nu_4}^2-4(1+\mu)(\delta-1)\widetilde{\nu_3}\widetilde{\nu_5}}}{2(1+\mu)(\delta+\mu)\widetilde{\nu_5}p_s}$.

From $\pi_{R_e}^{S^*}-\pi_{R_e}^{L^*}<0$, we have $\widetilde{\vartheta_0}+(\widetilde{\vartheta_1}(1-\emptyset)p_s+4\widetilde{\vartheta_2}((1-\emptyset)p_s)^2>0$, where $\widetilde{\vartheta_0}=-16(\mu+1)(\delta-\mu-2)((1+\delta)\mu+2)^2(\widetilde{C_1^R}-(\delta-3\mu-4)\widetilde{A_1^R}-2(\delta+2)(\mu+1)(\delta-3\mu-4)c_e)\widetilde{E_1^R}-(\delta+2)^2(\delta-3\mu-4)^2(\widetilde{C_3^R}+(\delta-\mu-2)\widetilde{A_3^R}+4(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)c_e)\widetilde{E_3^R}$, $\widetilde{\vartheta_1}=4(\delta+2)(\delta-1)(1+\mu)^2((1+\delta)\mu+2)^2(-4(\delta-\mu-2)(-(\widetilde{C_1^R}-(\delta-3\mu-4)\widetilde{A_1^R}-2(\delta-3\mu-4)c_e)+2\widetilde{E_1^R})-(\delta-1)(\delta+2)(\delta-3\mu-4)^2(\widetilde{C_3^R}+(\delta-\mu-2)\widetilde{A_3^R}+4(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)c_e-\widetilde{E_3^R}))$, $\widetilde{\vartheta_2}=(\delta-1)^2(\delta+2)^2(\delta+\mu)^2((1+\delta)\mu+2)^2$.

Then, $1-\emptyset>\frac{-\widetilde{\vartheta_1}+\sqrt{\widetilde{\vartheta_1}^2-16(1+\mu)^2\widetilde{\vartheta_0}\widetilde{\vartheta_2}}}{8(1+\mu)^2\widetilde{\vartheta_2}p_s}$, $1-\emptyset<\frac{-\widetilde{\vartheta_1}-\sqrt{\widetilde{\vartheta_1}^2-16(1+\mu)^2\widetilde{\vartheta_0}\widetilde{\vartheta_2}}}{8(1+\mu)^2\widetilde{\vartheta_2}p_s}$.

From $\pi_{R_e}^{L^*}-\pi_{R_e}^{E^*}<0$, we have, $\widetilde{\vartheta_3}+\widetilde{\vartheta_4}(1-\emptyset)p_s+\widetilde{\vartheta_5}((1-\emptyset)p_s)^2<0$, where $\widetilde{\vartheta_3}=2(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)^2(\widetilde{C_3^R}+(\delta-\mu-2)\widetilde{A_3^R}+4(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)c_e)\widetilde{E_3^R}+(1+\mu)((1+\delta)\mu+2)^2(\widetilde{C_2^R}-4(1+\mu)(\delta-\mu-2)\widetilde{A_2^R}-8(1+\mu)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)c_e)\widetilde{E_2^R}$, $\widetilde{\vartheta_4}=(1+\mu)((1+\delta)\mu+2)(4(\delta-1)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)^2(\widetilde{C_3^R}+(\delta-\mu-2)+\widetilde{A_3^R}+4(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)c_e-\widetilde{E_3^R})+((1+\delta)\mu+2)((\delta-1)(\delta-3\mu-4)(\delta^2-(1+\mu)\delta-3\mu-4)(\widetilde{C_2^R}-4(1+\mu)(\delta-\mu-2)\widetilde{A_2^R}-8(1+\mu)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)c_e)-(\delta^4-(4\mu+6)\delta^3+(3\mu^2+8\mu+5)\delta^2+(30\mu^2+44\mu+16)\delta-24\mu^3-81\mu^2-72\mu-16)\widetilde{E_2^R}))$, $\widetilde{\vartheta_5}=(\delta-1)(\delta^2-(1+\mu)\delta-3\mu-4)((1+\delta)\mu+2)^2(-8(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)(1+\mu)(\delta-1)-(\delta-3\mu-4)(\delta^4-(4\mu+6)\delta^3+(3\mu^2+8\mu+5)\delta^2+(30\mu^2+44\mu+16)\delta-24\mu^3-81\mu^2-72\mu-16))$.

Then, $1-\emptyset>\frac{-\widetilde{\vartheta_4}+\sqrt{\widetilde{\vartheta_4}^2-4(1+\mu)\widetilde{\vartheta_3}\widetilde{\vartheta_5}}}{2(1+\mu)\widetilde{\vartheta_5}p_s}$, $1-\emptyset<\frac{-\widetilde{\vartheta_4}-\sqrt{\widetilde{\vartheta_4}^2-4(1+\mu)\widetilde{\vartheta_3}\widetilde{\vartheta_5}}}{2(1+\mu)\widetilde{\vartheta_5}p_s}$. □

Proof of Corollary 5.1. Obviously, from Propositions 4.2 and 5.1, we can get the result. □

Proof of Proposition 5.3. When $A_1^R<(\mu+1)\frac{\partial A_1^R}{\partial\mu}$, $\frac{\partial w^{S^*}}{\partial\mu}=\frac{\partial(\frac{A_1^R}{2(\mu+1)(\delta+2)})}{\partial\mu}=\frac{2(\mu+1)(\delta+2)(A_1^R)'_\mu-2(\delta+2)A_1^R}{(2(\mu+1)(\delta+2))^2}>0$, then $\frac{\partial A_1^R}{\partial\mu}>0$, $\mu>\frac{A_1^R}{(A_1^R)'_\mu}-1$, $\mu>\max\{0,\frac{A_1^R}{(A_1^R)'_\mu}-1\}$.

When $A_2^R<\frac{-(\delta^2-(1+\mu)\delta-3\mu-4)\frac{\partial A_2^R}{\partial\mu}}{\delta+3}$, $\frac{\partial w^{E^*}}{\partial\mu}=\frac{\partial(\frac{A_2^R}{2(\delta^2-(1+\mu)\delta-3\mu-4)})}{\partial\mu}=\frac{2(\delta^2-(1+\mu)\delta-3\mu-4)\frac{\partial A_2^R}{\partial\mu}+2(\delta+3)A_2^R}{(2(\delta^2-(1+\mu)\delta-3\mu-4))^2}<0$, then $\frac{\partial A_2^R}{\partial\mu}<0$, $\mu>\frac{A_2^R}{(A_2^R)'_\mu}-\frac{4-\delta^2+\delta}{\delta+3}$.

When $\frac{\partial A_3^R}{\partial\mu}<0$, then $\frac{\partial w^{L^*}}{\partial\mu}=\frac{\partial(\frac{A_3^R}{4(\mu+1)((1+\delta)\mu+2)})}{\partial\mu}=\frac{4(\mu+1)((1+\delta)\mu+2)\frac{\partial A_3^R}{\partial\mu}-(4((1+\delta)\mu+2)+4(\mu+1)(1+\delta))A_3^R}{(4(\mu+1)((1+\delta)\mu+2))^2}>0$, $\mu>\frac{3(1+\delta)A_3^R-(3+\delta)(A_3^R)'_\mu+\sqrt{(3(1+\delta)A_3^R-(3+\delta)(A_3^R)'_\mu)^2-8(1+\delta)(A_3^R)'_\mu(2(A_3^R)'_\mu-(3+\delta)A_3^R)}}{2(1+\delta)(A_3^R)'_\mu}$. □

Proof of Proposition 5.4. p_t^*: When $(\delta-3\mu-4)(B_1^R)'_\mu+3B_1^R<0$, then $\frac{\partial(\frac{B_1^R}{2(\delta+2)(\delta-3\mu-4)})}{\partial\mu}=\frac{2(\delta+2)(\delta-3\mu-4)\widetilde{B_1^R}_\mu+6(\delta+2)B_1^R}{(2(\delta+2)(\delta-3\mu-4))^2}<0$, $\{\mu\in R^+\mid B_1^R<\frac{(\delta-3\mu-4)(B_1^R)'_\mu}{-3}\}$.

Because $(\delta^2-(1+\mu)\delta-3\mu-4)+(\delta-\mu-2)(\delta+3)<0$, when the set $\{\mu\in R^+\mid B_2^R>\frac{-(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4){B_2^R}'_\mu}{(\delta^2-(1+\mu)\delta-3\mu-4)+(\delta-\mu-2)(\delta+3)}\}$ is satisfied, where R^+ denotes positive real number, then $\frac{\partial(\frac{B_2^R}{4(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)})}{\partial\mu}=\frac{4(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)\widetilde{B_2^R}_\mu+(4(\delta^2-(1+\mu)\delta-3\mu-4)+4(\delta-\mu-2)(\delta+3))B_2^R}{(4(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4))^2}<0$. Because $-((\delta-\mu-2)((1+\delta)\mu+2)+(1+\mu)(-((1+\delta)\mu+2)+(\delta-\mu-2)(1+\delta))>0$, then $-(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)(B_3^R)'_\mu<-((\delta-\mu-2)((1+\delta)\mu+2)+(1+\mu)(-((1+\delta)\mu+2)+(\delta-\mu-2)(1+\delta))B_3^R$, $\frac{\partial(\frac{B_3^R}{-8(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)})}{\partial\mu}=\frac{-8(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)(B_3^R)'_\mu-(-8(\delta-\mu-2)((1+\delta)\mu+2)-8(1+\mu)(-((1+\delta)\mu+2)+(\delta-\mu-2)(1+\delta))B_3^R}{(-8(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2))^2}<0$, then set $\{\mu\in R^+\mid B_3^R>\frac{(-(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)(B_3^R)'_\mu)}{(-((\delta-\mu-2)((1+\delta)\mu+2)+(1+\mu)(-((1+\delta)\mu+2)+(\delta-\mu-2)(1+\delta)))}\}$.

p_e^*: Because $(\delta+2)(\delta-3\mu-4)-3(\delta+2)(\mu+1)<0$, when $\frac{(\mu+1)(\delta+2)(\delta-3\mu-4)(C_1^R)'_\mu}{(\delta+2)(\delta-3\mu-4)-3(\delta+2)(\mu+1)}<C_1^R$, $\frac{\partial(\frac{C_1^R}{2(\mu+1)(\delta+2)(\delta-3\mu-4)})}{\partial\mu}=\frac{(2(\mu+1)(\delta+2)(\delta-3\mu-4)C_1^{R'}{}_\mu-(2(\delta+2)(\delta-3\mu-4)-6(\delta+2)(\mu+1))C_1^R)}{(2(\mu+1)(\delta+2)(\delta-3\mu-4))^2}>0$, then, the set $\{\mu\in R^+\mid \frac{((\mu+1)(\delta+2)(\delta-3\mu-4)(C_1^R)'_\mu)}{((\delta+2)(\delta-3\mu-4)-3(\delta+2)(\mu+1))}<C_1^R\}$.

When $(1+\mu)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)(C_2^R)'_\mu>((\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)+(1+\mu)(-(\delta^2-(1+\mu)\delta-3\mu-4)-(3+\delta)(\delta-\mu-2))C_2^R$, then $\frac{\partial(\frac{C_2^R}{8(1+\mu)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)})}{\partial\mu}=\frac{8(1+\mu)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)(C_2^R)'_\mu-(8(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)+8(1+\mu)(-(\delta^2-(1+\mu)\delta-3\mu-4)-(3+\delta)(\delta-\mu-2))C_2^R}{(8(1+\mu)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4))^2}>0$, $\{\mu\in R^+\mid C_2^R<\frac{(1+\mu)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)(C_2^R)'_\mu}{((\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)+(1+\mu)(-(\delta^2-(1+\mu)\delta-3\mu-4)-(3+\delta)(\delta-\mu-2))}\}$.

When $(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)(C_3^R)'_\mu<((\delta-\mu-2)((1+\delta)\mu+2)+(1+\mu)(-((1+\delta)\mu+2)+(\delta-\mu-2)(1+\delta))C_3^R$, $\frac{\partial(\frac{C_3^R}{-4(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)})}{\partial\mu}=\frac{(-4(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)(C_3^R)'_\mu-(-4(\delta-\mu-2)((1+\delta)\mu+2)-4(1+\mu)(-((1+\delta)\mu+2)+(\delta-\mu-2)(1+\delta))C_3^R)}{(-4(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2))^2}>0$, because $((\delta-\mu-2)((1+\delta)\mu+2)+(1+\mu)(-((1+\delta)\mu+2)+(\delta-\mu-2)(1+\delta))<0$, then $\{\mu\in R^+\mid C_3^R<\frac{(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)(C_3^R)'_\mu}{((\delta-\mu-2)((1+\delta)\mu+2)+(1+\mu)(-((1+\delta)\mu+2)+(\delta-\mu-2)(1+\delta))}\}$. □

Proof of Proposition 5.5. When $2\delta(\delta-3\mu-4)(H_1^R)'_\mu>-6\delta H_1^R$, we have $\frac{\partial(\frac{H_1^R}{2\delta(\delta-3\mu-4)})}{\partial\mu}=\frac{2\delta(\delta-3\mu-4)(H_1^R)'_\mu+6\delta H_1^R}{(2\delta(\delta-3\mu-4))^2}>0$, $\{\mu\in R^+\mid H_1^R>\frac{(\delta-3\mu-4)(H_1^R)'_\mu}{-3}\}$. When $-(\delta-\mu-2)(H_2^R)'_\mu>H_2^R$, we have $\frac{\partial(\frac{H_2^R}{-8\delta(\delta-\mu-2)})}{\partial\mu}=\frac{-8\delta(\delta-\mu-2)(H_2^R)'_\mu-8\delta H_2^R}{(-8\delta(\delta-\mu-2))^2}>0$, then $\{\mu\in R^+\mid H_2^R<-(\delta-\mu-2)(H_2^R)'_\mu\}$. When $-(1+\mu)(\delta-\mu-2)(H_3^R)'_\mu+((\delta-\mu-2)-(1+\mu))H_3^R>0$, $H_3^R<\frac{(1+\mu)(\delta-\mu-2)(H_3^R)'_\mu}{(\delta-\mu-2)(1+\mu)}$, we have $\frac{\partial(\frac{H_3^R}{-8\delta(1+\mu)(\delta-\mu-2)})}{\partial\mu}=\frac{-8\delta(1+\mu)(\delta-\mu-2)(H_3^R)'_\mu+(8\delta((\delta-\mu-2)-(1+\mu)))H_3^R}{(-8\delta(1+\mu)(\delta-\mu-2))^2}>0$, $\mu\in R^+\mid H_3^R<\frac{(1+\mu)(\delta-\mu-2)(H_3^R)'_\mu}{(\delta-\mu-2)(1+\mu)}$. □

Proof of Proposition 5.6. $\frac{\partial(\frac{(A_1^R-2c(\mu+1)(\delta+2))H_1^R}{4\delta(\mu+1)(\delta+2)(\delta-3\mu-4)})}{\partial\mu}=\frac{4\delta(\mu+1)(\delta+2)f_M^S}{(4\delta(\mu+1)(\delta+2)(\delta-3\mu-4))^2}$, if $f_M^S>0$, we have $\frac{\partial\pi_M^{S^*}}{\partial\mu}>0$.

$$\begin{aligned}f_M^S=&(\delta-3\mu-4)((A_1^R)'_\mu-2c(\delta+2))H_1^R+(A_1^R-2c(\mu+1)(\delta+2))(H_1^R)'_\mu)\\&-((\delta+2)(\delta-3\mu-4)-3(\mu+1)(\delta+2))((A_1^R-2c(\mu+1)(\delta+2))H_1^R).\end{aligned}\tag{A.9}$$

$\frac{\partial(\frac{(A_2^R-2c(\delta^2-(1+\mu)\delta-3\mu-4))H_2^R}{-16\delta(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)})}{\partial\mu}=\frac{16\delta f_M^E}{(-16\delta(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4))^2}$, if $f_M^E>0$, we have $\frac{\partial\pi_M^{E^*}}{\partial\mu}>0$.

$$\begin{aligned}f_M^E=&-(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)((A_2^{R'}{}_\mu+2c(\delta+3))H_2^R+(A_2^R-2c(\delta^2-(1+\mu)\delta-3\mu-4))H_2^{R'}{}_\mu)\\&+(-(\delta^2-(1+\mu)\delta-3\mu-4)-(\delta-\mu-2)(\delta+3))(A_2^R-2c(\delta^2-(1+\mu)\delta-3\mu-4))H_2^R.\end{aligned}\tag{A.10}$$

$\frac{\partial(\frac{(A_3^R-4c(\mu+1)((1+\delta)\mu+2))H_3^R}{-32\delta(\delta-\mu-2)((1+\delta)\mu+2)(1+\mu)^2})}{\partial\mu} = \frac{f_M^L}{(32\delta((\delta-\mu-2)((1+\delta)\mu+2)(1+\mu)^2)^2)}$, if $f_M^L > 0$, we have $\frac{\partial\pi_M^{L^*}}{\partial\mu} > 0$.

$$\begin{aligned} f_M^L = & -(\delta-\mu-2)((1+\delta)\mu+2)(1+\mu)^2((A_3^{R'}{}_\mu - 4c(((1+\delta)\mu+2)+(\mu+1)(1+\delta)))H_3^R \\ & + (A_3^R - 4c(\mu+1)((1+\delta)\mu+2))H_3^{R'}{}_\mu) + (-((1+\delta)\mu+2)(1+\mu)^2 + (\delta-\mu-2)((1+\delta)(1+\mu)^2 \\ & + 2((1+\delta)\mu+2)(\mu+1))(A_3^R - 4c(\mu+1)((1+\delta)\mu+2))H_3^R. \end{aligned} \tag{A.11}$$

$\frac{\partial\pi_{R_t}^{S^*}}{\partial\mu} = \frac{f_{R_t}^S}{4((\delta-1)(\mu+1)(\delta+2)^2(\delta-3\mu-4)^2)^2}$, if $f_{R_t}^S < 0$, we have $\frac{\partial\pi_{R_t}^{S^*}}{\partial\mu} < 0$.

$$\begin{aligned} f_{R_t}^S = & (\delta-1)(\mu+1)(\delta+2)^2(\delta-3\mu-4)^2((D_1^R)'_\mu((\mu+1)B_1^R - (\delta-3\mu-4)A_1^R \\ & - 2c_t(\delta+2)(\mu+1)(\delta-3\mu-4)) + D_1^R(B_1^R + (\mu+1)(B_1^R)'_\mu + 3A_1^R - (\delta-3\mu-4)(A_1^R)'_\mu \\ & - 2c_t(\delta+2)((\delta-3\mu-4)-3(\mu+1)))) - (\delta-1)(\delta+2)^2((\delta-3\mu-4)^2 \\ & - 24(\mu+1)(\delta-3\mu-4))D_1^R((\mu+1)B_1^R - (\delta-3\mu-4)A_1^R - 2c_t(\delta+2)(\mu+1)(\delta-3\mu-4)). \end{aligned} \tag{A.12}$$

$\frac{\partial\pi_{R_t}^{E^*}}{\partial\mu} = \frac{f_{R_t}^E}{32((\delta-1)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)^2)^2}$, if $f_{R_t}^E < 0$, we have $\frac{\partial\pi_{R_t}^{E^*}}{\partial\mu} < 0$.

$$\begin{aligned} f_{R_t}^E = & -(\delta-1)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)^2((D_2^R)'_\mu(B_2^R - 2(\delta-\mu-2)A_2^R \\ & - 4c_t(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)) + D_2^R((B_2^R)'_\mu + 2A_2^R - 2(\delta-\mu-2)(A_2^R)'_\mu \\ & - 4c_t(-(\delta^2-(1+\mu)\delta-3\mu-4)-(3+\delta)(\delta-\mu-2)))) + (\delta-1)(-(\delta^2-(1+\mu)\delta-3\mu-4)^2 \\ & - 2(3+\delta)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4))D_2^R(B_2^R - 2(\delta-\mu-2)A_2^R \\ & - 4c_t(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)). \end{aligned} \tag{A.13}$$

$\frac{\partial\pi_{R_t}^{L^*}}{\partial\mu} = \frac{f_{R_t}^L}{64((\delta-1)(1+\mu)(\delta-\mu-2)^2((1+\delta)\mu+2)^2)^2}$, if $f_{R_t}^L < 0$, we have $\frac{\partial\pi_{R_t}^{L^*}}{\partial\mu} < 0$.

$$\begin{aligned} f_{R_t}^L = & (\delta-1)(1+\mu)(\delta-\mu-2)^2((1+\delta)\mu+2)^2((D_3^R)'_\mu(B_3^R + 2(\delta-\mu-2)A_3^R \\ & + 8c_t(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)) + D_3^R((B_3^R)'_\mu - 2A_3^R + 2(\delta-\mu-2)A_3^{R'}{}_\mu \\ & + 8c_t(\delta-\mu-2)((1+\delta)\mu+2) + 8c_t(1+\mu)(-((1+\delta)\mu+2)+(\delta-\mu-2)(1+\delta)))) \\ & - (\delta-1)((\delta-\mu-2)^2((1+\delta)\mu+2)^2 + (1+\mu)(-(\delta-\mu-2)((1+\delta)\mu+2)^2 \\ & + (\delta-\mu-2)^2((1+\delta)\mu+2)(1+\delta)))D_3^R(B_3^R + 2(\delta-\mu-2)A_3^R \\ & + 8c_t(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)). \end{aligned} \tag{A.14}$$

$\frac{\partial\pi_{R_e}^{S^*}}{\partial\mu} = \frac{f_{R_e}^S}{(2\delta(\delta-1)((\mu+1)(\delta-3\mu-4)^2)^2)}$, if $f_{R_e}^S > 0$, we have $\frac{\partial\pi_{R_e}^{S^*}}{\partial\mu} > 0$.

$$\begin{aligned} f_{R_e}^S = & (\mu+1)(\delta-3\mu-4)^2((E_1^R)'_\mu(C_1^R - (\delta-3\mu-4)A_1^R - 2c_e(\delta+2)(\mu+1)(\delta-3\mu-4)) \\ & + E_1^R((C_1^R)'_\mu + 3A_1^R - (\delta-3\mu-4)(A_1^R)'_\mu - 2c_e(\delta+2)((\delta-3\mu-4)-3(\mu+1)))) \\ & - ((\delta-3\mu-4)^2 - 6(\mu+1)(\delta-3\mu-4))E_1^R(C_1^R - (\delta-3\mu-4)A_1^R \\ & - 2c_e(\delta+2)(\mu+1)(\delta-3\mu-4)). \end{aligned} \tag{A.15}$$

$\frac{\partial \pi_{R_e}^{E^*}}{\partial \mu} = \frac{f_{R_e}^E}{(64\delta(\delta-1)((1+\mu)(\delta-\mu-2)^2(\delta^2-(1+\mu)\delta-3\mu-4)^2)^2)}$, if $f_{R_e}^E > 0$, we have $\frac{\partial \pi_{R_e}^{E^*}}{\partial \mu} > 0$.

$$\begin{aligned} f_{R_e}^E = {} & (1+\mu)(\delta-\mu-2)^2(\delta^2-(1+\mu)\delta-3\mu-4)^2((E_2^R)'_\mu(C_2^R-4(1+\mu)(\delta-\mu-2)A_2^R \\ & -8c_e(1+\mu)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4))+E_2^R((C_1^R)'_\mu-4(\delta-\mu-2)A_2^R \\ & -4(1+\mu)(-A_2^R+(\delta-\mu-2)(A_2^R)'_\mu)-8c_e(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4) \\ & -8c_e(1+\mu)(-(\delta^2-(1+\mu)\delta-3\mu-4)+(3+\delta)(\delta-\mu-2)))) \\ & -((\delta-\mu-2)^2(\delta^2-(1+\mu)\delta-3\mu-4)^2+(1+\mu)(-2(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)^2 \\ & -2(3+\delta)(\delta-\mu-2)^2(\delta^2-(1+\mu)\delta-3\mu-4)))E_2^R(C_2^R-4(1+\mu)(\delta-\mu-2)A_2^R \\ & -8c_e(1+\mu)(\delta-\mu-2)(\delta^2-(1+\mu)\delta-3\mu-4)). \end{aligned} \tag{A.16}$$

$\frac{\partial \pi_{R_e}^{L^*}}{\partial \mu} = \frac{f_{R_e}^L}{32\delta(\delta-1)((1+\mu)^2(\delta-\mu-2)((1+\delta)\mu+2)^2)^2}$, if $f_{R_e}^L > 0$, then $\frac{\partial \pi_{R_e}^{L^*}}{\partial \mu} > 0$.

$$\begin{aligned} f_{R_e}^L = {} & -(1+\mu)^2(\delta-\mu-2)((1+\delta)\mu+2)^2(E_3^{R'}{}_\mu(C_3^R+(\delta-\mu-2)A_3^R+4c_e(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)) \\ & +E_3^R((C_3^R)'_\mu-A_3^R+(\delta-\mu-2)(A_3^R)'_\mu+4c_e(\delta-\mu-2)((1+\delta)\mu+2)+4c_e(1+\mu)(-((1+\delta)\mu+2) \\ & +(1+\delta)(\delta-\mu-2))))-(2(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)^2+(1+\mu)^2(-((1+\delta)\mu+2)^2 \\ & +2(1+\delta)(\delta-\mu-2)((1+\delta)\mu+2)))E_3^R(C_3^R+(\delta-\mu-2)A_3^R+4c_e(1+\mu)(\delta-\mu-2)((1+\delta)\mu+2)). \end{aligned} \tag{A.17}$$

□

Proof of Corollary 6.1. From Theorem 4.1 and Table 7, we can derive Corollary 6.1, the results could be seen in Figure 12. □

Proof of Corollary 6.2. By comparing Table A.1, we can derive Corollary 6.2.

Let $\mathcal{K}_1 = (4\delta^8+4((1-\emptyset)p_s^2-9)\delta^7+4(9\emptyset p_s^2-4B_1-9p_s^2+16)\delta^6+4(7B_1+56+p_s(B_1+C_1+16p_s(1-\emptyset)+B_1\emptyset-C_1\emptyset))\delta^5+(-40B_1-C_1^2+2B_1C_1-704-8p_s(\emptyset-1)(3B_1-3C_1+28p_s))\delta^4$,
$\mathcal{Q}_1 = (-80B_1-B_1^2+4C_1^2-8B_1C_1-64+16p_s(\emptyset-1)(B_1+C_1+44p_s))\delta^3+4(56B_1+B_1^2+3C_1^2-2B_1C_1+384+8p_s(\emptyset-1)(3B_1-7C_1+2p_s))\delta^2$,
$\mathcal{K}_2 = (64\delta^8+64((1-\emptyset)p_s^2-7)\delta^7+64(7(1-\emptyset)p_s^2+11)\delta^6+(-32B_2+1472-16p_s(\emptyset-1)(C_2+44p_s))\delta^5+(128B_2-C_2^2-4608+32p_s(\emptyset-1)(B_2+2C_2-46p_s))\delta^4$,
$\mathcal{Q}_2 = (-32B_2+2C_2^2+4B_2C_2+768-48p_s(\emptyset-1)(2B_2-C_2-96p_s))\delta^3+(-30B_2+7C_2^2-4B_2C_2+6144-32p_s(\emptyset-1)(2B_2+11C_2+24p_s))\delta^2$,
$\mathcal{K}_3 = (64\delta^4+16(4(1-\emptyset)p_s^2-B_3-20)\delta^3+16(3B_3+32+p_s(\emptyset-1)(B_3+20p_s))\delta^2$,
$\mathcal{K}_4 = (4(2(1-\emptyset)p_s+1)\delta^6+(-24\mu-20-4p_s(\emptyset-1)(p_s-12\mu-10))\delta^5+(24\mu-4B_1^R+36\mu^2-32+4p_s(\emptyset-1)(5p_s-12\mu+6\mu p_s-18\mu^2+16))\delta^4+(12B_1^R+288\mu+12\mu B_1^R+108\mu^2+176-4p_s(\emptyset-1)(144\mu-8p_s-C_1^R+\mu B_1^R+6\mu p_s+9\mu^2p_s+54\mu^2+88))\delta^3$,
$\mathcal{Q}_3 = (24B_1^R+96\mu+12\mu B_1^R+128+4p_s(\emptyset-1)(3\mu B_1^R-44p_s-48\mu-3C_1^R-3\mu C_1^R-72\mu p_s+3\mu^2B_1^R-27\mu^2p_s-64))\delta^2+(-384\mu-32B_1^R-24\mu B_1^R-2\mu(B_1^R)^2-(B_1^R)^2-144\mu^2+2B_1^RC_1^R-256+4p_s(\emptyset-1)(192\mu-32p_s-6C_1^R+6\mu B_1^R-3\mu C_1^R-24\mu p_s+3\mu^2B_1^R+72\mu^2+128))\delta$,
$\mathcal{K}_5 = (64(2(1-\emptyset)p_s+1)\delta^8+(-256\mu-448-64p_s(\emptyset-1)(p_s-8\mu-14))\delta^7+(1024\mu+384\mu^2+704+64p_s(\emptyset-1)(7p_s-32\mu+4\mu p_s-12\mu^2-22))\delta^6+(-32B_2^R+1024\mu-384\mu^2-256\mu^3+1472-64p_s(\emptyset-1)(11p_s+32\mu+16\mu p_s+6p_s\mu^2-12\mu^2-8\mu^3+46))\delta^5+(128B_2^R-7680\mu+64\mu B_2^R-3968\mu^2-512\mu^3+64\mu^4-4608-16p_s(\emptyset-1)(92p_s-C_2^R-960\mu+2\mu B_2^R+64\mu p_s-24\mu^2p_s-16\mu^3p_s-496\mu^2-64\mu^3+8\mu^4-576))\delta^4+(-32B_2^R+3328\mu-64\mu B_2^R-32\mu^2B_2^R+4424\mu^2+2048\mu^3+320\mu^4+768+32p_s(\emptyset-1)(144p_s-2C_2^R-208\mu+4\mu B_2^R-\mu C_2^R+240\mu p_s+2\mu^2B_2^R+124\mu^2p_s+16\mu^3p_s-2\mu^4p_s-264\mu^2-128\mu^3-20\mu^4-48))\delta^3$,
$\mathcal{Q}_4 = (-320B_2^R+12800\mu-320\mu B_2^R-64\mu^2B_2^R+9216\mu^2+2560\mu^3+192\mu^4+6144-16p_s(\emptyset-1)(48p_s-C_2^R+$

Table A.1. The equilibrium result of consumer surplus.

Consumer surplus
$CS_S^{N*} = \frac{\mathcal{K}_1+\mathcal{Q}_1+(-128B_1-4B_1^2-32C_1^2+32B_1C_1-1024-128p_s(\emptyset-1)(B_1+12p_s))\delta-64C_1^2+512p_s(\emptyset-1)(C_1+2p_s))}{8\delta(\delta-1)(\delta-2)^2(\delta+2)^2(\delta-4)^2}$
$CS_E^{N*} = \frac{\mathcal{K}_2+\mathcal{Q}_2+(256B_2-4B_2^2-8C_2^2-16B_2C_2-4096+256p_s(\emptyset-1)(B_2-24p_s))\delta-16C_2^2+512p_s(\emptyset-1)(C_2+8p_s))}{(128\delta(\delta-1)(\delta-2)^2(\delta^2-\delta-4)^2)}$
$CS_L^{N*} = \frac{\mathcal{K}_3+(-32B_3-B_3^2+4B_3C_3-256-32p_s(\emptyset-1)(B_3+C_3+16p_s))\delta-4C_3^2+64p_s(\emptyset-1)(C_3+4p_s))}{128\delta(\delta-1)(\delta-2)^2}$
$CS_S^{*} = \frac{\mathcal{K}_4+\mathcal{Q}_3-(C_1^R)^2-\mu^2(B_1^R)^2+2\mu B_1^RC_1^R-8p_s(\emptyset-1)(3\mu+4)(\mu B_1^R-8p_s-6\mu p_s-C_1^R)}{8\delta(\delta-1)(\delta+2)^2(\delta-3\mu-4)^2}$
$CS_E^{*} = \frac{\mathcal{K}_5+\mathcal{Q}_4-(C_2^R)^2-4\mu^2(B_2^R)^2+4\mu B_2^RC_2^R+16p_s(\emptyset-1)(\mu+2)(3\mu+4)(32p_s-C_2^R+2\mu B_2^R+40\mu p_s+12\mu^2p_s))}{128\delta(\delta-1)(\delta-\mu-2)^2(\delta^2-3\mu-\delta\mu-\delta-4)^2}$
$CS_L^{*} = \frac{\mathcal{K}_6+\mathcal{Q}_5+(16p_s(\emptyset-1)(\mu+1)(\mu+2)^2(16p_s-2C_3^R+\mu B_3^R-2\mu C_3^R+32\mu p_s+20\mu^2p_s+4\mu^3p_s))}{128\delta(\delta-1)(\mu+1)^2(\delta-\mu-2)^2(\mu+\delta\mu+2)^2}$

$+1600\mu+2\mu B_2^R-2\mu C_2^R+208\mu p_s+4\mu^2B_2^R+2\mu^3B_2^R-\mu^2C_2^R+264\mu^2p_s+128\mu^3p_s+20\mu^4p_s+1152\mu^2+320\mu^3+24\mu^4+768))\delta^2+(256B_2^R-10240\mu+320\mu B_2^R+96\mu^2B_2^R-8\mu(B_2^R)^2-4(B_2^R)^2-9472\mu^2-3840\mu^3-576\mu^4+4B_2^RC_2^R-4096-32p_s(\emptyset-1)(192p_s-5C_2^R-640\mu+10\mu B_2^R-5\mu C_2^R+400\mu p_s+10\mu^2B_2^R+2\mu^3B_2^R-\mu^2C_2^R+288\mu^2p_s+80\mu^3p_s+6\mu^4p_s-592\mu^2-240\mu^3-36\mu^4-256))\delta,$

$\mathcal{K}_6=((64\mu^2+128\mu^3+64\mu^4-128p_s(\emptyset-1)\mu^2(\mu+1)^2)\delta^6+(256\mu+320\mu^2-256\mu^3-448\mu^4-128\mu^5-64p_s(\emptyset-1)\mu(\mu+1)^2(\mu p_s-6\mu-4\mu^2+8))\delta^5+(-512\mu+16\mu B_3^R+16\mu^2B_3^R-2368\mu^2-2048\mu^3-256\mu^4+256\mu^5+64\mu^6+256+64p_s(\emptyset-1)(\mu+1)^2(32\mu-4\mu p_s+3\mu^2p_s+2\mu^3p_s+18\mu^2-4\mu^3-2\mu^4-8))\delta^4+(32B_3^R-2304\mu-48\mu^2B_3^R-16\mu^3B_3^R+704\mu^2+3840\mu^3+2816\mu^4+768\mu^5+64\mu^6-1280+16p_s(\emptyset-1)(\mu+1)(128\mu-16p_s-2\mu C_3^R+48\mu p_s+\mu^2B_3^R-2\mu^2C_3^R+100\mu^2p_s+28\mu^3p_s-12\mu^4p_s-4\mu^5p_s-216\mu^2-264\mu^3-88\mu^4-8\mu^5+160))\delta^3,$

$\mathcal{Q}_5=(-96B_3^R+6656\mu-144\mu B_3^R-48\mu^2B_3^R++7936\mu^2+3968\mu^3+448\mu^4-256\mu^5-64\mu^6+2048-16p_s(\emptyset-1)(\mu+1)(4C_3^R-80p_s+576\mu-2\mu B_3^R-64\mu p_s+2\mu^2B_3^R+\mu^3B_3^R-6\mu^2C_3^R-2\mu^3C_3^R+108\mu^2p_s+132\mu^3p_s+44\mu^4p_s+4\mu^5p_s+416\mu^2+80\mu^3-24\mu^4-8\mu^5+256))\delta^2+(64B_3^R-4096\mu+128\mu B_3^R+80\mu^2B_3^R-2\mu B_3^R+16\mu^3B_3^R-(B_3^R)^2-6656\mu^2-5632\mu^3-2624\mu^4-640\mu^5-64\mu^6+4B_3^RC_3^R+4\mu B_3^RC_3^R-1024-16p_s(\emptyset-1)(\mu+1)(\mu+2)(64p_s-6C_3^R-160\mu+3\mu B_3^R-6\mu C_3^R+112\mu p_s+48\mu^2p_s-4\mu^3p_s-4\mu^4p_s-144\mu^2-56\mu^3-8\mu^4-64))\delta-(8\mu(C_3^R)^2-4(C_3^R)^2-\mu^2(B_3^R)^2-4\mu^2(C_3^R)^2+4\mu B_3^RC_3^R+4\mu^2B_3^RC_3^R).$ □

Acknowledgements

This research was supported by the Hunan Key Laboratory of intelligent decision-making technology for emergency management (2020TP1013) and the National Natural Science Foundation of China under Grant Nos. 71771080, 71988101, and the Education Department of Shaanxi Provincial Government (19JK0355), the Shaanxi Science and Technology Department (2020KRM001).

References

[1] G. Ferrer and J.M. Swaminathan, Managing new and differentiated remanufactured products. *Eur. J. Oper. Res.* **203** (2010) 370–379.

[2] A. Atasu, M. Sarvary and L.N. Van Wassenhove, Remanufacturing as a marketing strategy. *Manag. Sci.* **54** (2008) 1731–1746.

[3] P. He, Y. He and H. Xu, Channel structure and pricing in a dual-channel closed-loop supply chain with government subsidy. *Int. J. Prod. Econ.* **213** (2019) 108–123.

[4] L. Xiao, X.J. Wang and K.S. Chin, Trade-in strategies in retail channel and dual-channel closed-loop supply chain with remanufacturing. *Transp. Res. Part E: Log. Transp. Rev.* **136** (2020) 101898.

[5] Y. Zhou, Y. Xiong and M. Jin, Less is more: consumer education in a closed-loop supply chain with remanufacturing. *Omega-Int. J. Manag. Sci.* **101** (2021) 102259.

[6] H. Vasudevan, V. Kalamkar and R. Terkar, Remanufacturing for sustainable development: keychallenges, elements, and benefits. *Int. J. Innov. Manag. Technol.* **3** (2021) 81.

[7] Y. Wang and B.T. Hazen, Consumer product knowledge and intention to purchase remanufactured products. *Int. J. Prod. Econ.* **181** (2016) 460–469.

[8] D. Ghosh, S. Gouda, R. Shankar, S. Swami and V.C. Thomas, Strategic decision making under subscription-based contracts for remanufacturing. *Int. J. Prod. Econ.* **200** (2018) 134–150.

[9] S. Ray, T. Boyaci and N. Aras, Optimal prices and trade-in rebates for durable, remanufacturable products. *M&SOM-Manuf. Serv. Oper. Manag.* **7** (2005) 208–228.

[10] A. Atasu, V.D.R. Guide and L.N. Van Wassenhove, So what if remanufacturing cannibalizes my new product sales? *Calif. Manag. Rev.* **52** (2010) 56–76.

[11] A. Ovchinnikov, V. Blass and G. Raz, Economic and environmental assessment of remanufacturing strategies for product + service firms. *Prod. Oper. Manag.* **23** (2014) 744–761.

[12] G.W. Hua, S.Y. Wang and T.C.E. Cheng, Price and lead time decisions in dual-channel supply chains. *Eur. J. Oper. Res.* **205** (2010) 113–126.

[13] X.J. Pu, L. Gong and X.H. Han, Consumer free riding: coordinating sales effort in a dual-channel supply chain. *Electron. Commer. Res. Appl.* **22** (2017) 1–12.

[14] J. Zhang, W.Y.K. Chiang and L. Liang, Strategic pricing with reference effects in a competitive supply chain. *Omega-Int. J. Manag. Sci.* **44** (2014) 126–135.

[15] N.N. Wang, T. Zhang, X.W. Zhu and P.M. Li, Online-offline competitive pricing with reference price effect. *J. Oper. Res. Soc.* **72** (2021) 642–653.

[16] J.M. Lattin and R.E. Bucklin, Reference effects of price and promotion on brand choice behavior. *J. Mark. Res.* **26** (1989) 299–310.

[17] W.M. Ma, Z. Zhao and H. Ke, Dual-channel closed-loop supply chain with government consumption-subsidy. *Eur. J. Oper. Res.* **226** (2013) 221–227.

[18] H. Jafari, S.R. Hejazi and M. Rasti-Barzoki, Pricing decisions in dual-channel supply chain with one manufacturer and multiple retailers: a game-theoretic approach. *RAIRO:RO* **51** (2017) 1269–1287.

[19] B. Pal, A. Sarkar and B. Sarkar, Optimal decisions in a dual-channel competitive green supply chain management under promotional effort. *Expert Syst. Appl.* **211** (2023) 118315.

[20] T.-M. Choi, Y. Li and L. Xu, Channel leadership, performance and coordination in closed loop supply chains. *Int. J. Prod. Econ.* **146** (2013) 371–380.

[21] G.C. Souza, Closed-loop supply chains: a critical review, and future research. *Decis. Sci.* **44** (2013) 7–38.

[22] K. Govindan, H. Soleimani and D. Kannan, Reverse logistics and closed-loop supply chain: a comprehensive review to explore the future. *Eur. J. Oper. Res.* **240** (2015) 603–626.

[23] R. Kumar and P. Ramachandran, Revenue management in remanufacturing: perspectives, review of current literature and research directions. *Int. J. Prod. Res.* **54** (2016) 2185–2201.

[24] L.G. Debo, L.B. Toktay and L.N. Van Wassenhove, Market segmentation and product technology selection for remanufacturable products. *Manag. Sci.* **51** (2005) 1193–1205.

[25] J.D. Abbey, M.G. Meloy, V.D.R. Guide and S. Atalay, Remanufactured products in closed-loop supply chains for consumer goods. *Prod. Oper. Manag.* **24** (2015) 488–503.

[26] P. Ma, Y. Gong and P. Mirchandani, Trade-in for remanufactured products: pricing with double reference effects. *Int. J. Prod. Econ.* **230** (2020) 107800.

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

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

[29] E. Almehdawe and B. Mantin, Vendor managed inventory with a capacitated manufacturer and multiple retailers: retailer versus manufacturer leadership. *Int. J. Prod. Econ.* **128** (2010) 292–302.

[30] X. Chen and X. Wang, Free or bundled: channel selection decisions under different power structures. *Omega-Int. J. Manag. Sci.* **53** (2015) 11–20.

[31] B. Zheng, C. Yang, J. Yang and M. Zhang, Dual-channel closed loop supply chains: forward channel competition, power structures and coordination. *Int. J. Prod. Res.* **55** (2017) 3510–3527.

[32] W. Yang, J. Zhang and H. Yan, Impacts of online consumer reviews on a dual-channel supply chain. *Omega-Int. J. Manag. Sci.* **101** (2021) 102266.

[33] X. Fan, X. Guo and S. Wang, Optimal collection delegation strategies in a retail-/dual-channel supply chain with trade-in programs. *Eur. J. Oper. Res.* **303** (2022) 633–649.

[34] R. Kumar and S.K. Kaushal, Examining factors affecting consumers' attitude and purchase intention with special reference to electronic durable goods. *NMIMS Manag. Rev.* **35** (2017) 25–45.

[35] P.K. Kopalle, A.G. Rao and J.L. Assuncão, Asymmetric reference price effects and dynamic pricing policies. *Mark. Sci.* **15** (1996) 60–85.

[36] T. Mazumdar, S.P. Raj and I. Sinha, Reference price research: review and propositions. *J. Mark.* **69** (2005) 84–102.

[37] I. Popescu and Y.Z. Wu, Dynamic pricing strategies with reference effects. *Oper. Res.* **55** (2007) 413–429.

[38] P.K. Kopalle, P.K. Kannan, L.B. Boldt and N. Arora, The impact of household level heterogeneity in reference price effects on optimal retailer pricing policies. *J. Retail.* **88** (2012) 102–114.

[39] J. Zhang, Q.L. Gou, L. Liang and Z.M. Huang, Supply chain coordination through cooperative advertising with reference price effect. *Omega-Int. J. Manag. Sci.* **41** (2013) 345–353.

[40] C.Y. Dye and C.T. Yang, Optimal dynamic pricing and preservation technology investment for deteriorating products with reference price effects. *Omega-Int. J. Manag. Sci.* **62** (2016) 52–67.

[41] Z.B. Lin, Price promotion with reference price effects in supply chain. *Transp. Res. Part E: Log. Transp. Rev.* **85** (2016) 52–68.

[42] Z. Wang, Technical note-intertemporal price discrimination via reference price effects. *Oper. Res.* **64** (2016) 290–296.

[43] R. Wang, When prospect theory meets consumer choice models: assortment and pricing management with reference prices. *M&SOM-Manuf. Serv. Oper. Manag.* **20** (2018) 583–600.

[44] P. Cao, N.G. Zhao and J. Wu, Dynamic pricing with Bayesian demand learning and reference price effect. *Eur. J. Oper. Res.* **279** (2019) 540–556.

[45] K. Matsui, When should a manufacturer set its direct price and wholesale price in dual-channel supply chains? *Eur. J. Oper. Res.* **258** (2017) 501–511.

[46] S.-L. Yang and Y.-W. Zhou, Two-echelon supply chain models: considering duopolistic retailers' different competitive behaviors. *Int. J. Prod. Econ.* **103** (2006) 104–116.

[47] C.A. Ingene and M.E. Parry, Mathematical Models of Distribution Channels. Springer (2004).

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

[49] R.C. Savaskan, S. Bhattacharya and L.N. Van Wassenhove, Closed-loop supply chain models with product remanufacturing. *Manag. Sci.* **50** (2004) 239–252.

[50] P.L. Swan, Optimum durability, second-hand markets, and planned obsolescence. *J. Polit. Econ.* **80** (1972) 575–585.

[51] L. Luo and J. Sun, New product design under channel acceptance: brick-and-mortar, online-exclusive, or brick-and-click. *Prod. Oper. Manag.* **25** (2016) 2014–2034.

[52] E. Brynjolfsson and M.D. Smith, Frictionless commerce? A comparison of internet and conventional retailers. *Manag. Sci.* **46** (2000) 563–585.

[53] K.S. Lee and S.J. Tan, E-retailing versus physical retailing: a theoretical model and empirical test of consumer choice. *J. Bus. Res.* **56** (2003) 877–885.

[54] J. Bulow, J. Geanakoplos and P. Klemperer, Multimarket oligopoly: strategic substitutes and complements. *J. Polit. Econ.* **93** (1985) 488–511.

[55] E. Gal-Or, First mover and second mover advantages. *Int. Econ. Rev.* **26** (1985) 649–653.

[56] J.H. Hamilton and S.M. Slutsky, Endogenous timing in duopoly games: Stackelberg or Cournot equilibria. *Games Econ. Behav.* **2** (1990) 29–46.

[57] E. Van Damme and S. Hurkens, Endogenous Stackelberg leadership. *Games Econ. Behav.* **28** (1999) 105–129.

[58] E. Van Damme and S. Hurkens, Endogenous price leadership. *Games Econ. Behav.* **47** (2004) 404–420.

[59] R. Amir and A. Stepanova, Second-mover advantage and price leadership in Bertrand duopoly. *Games Econ. Behav.* **55** (2006) 1–20.