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Research on Low-Carbon Strategies of Supply Chains, Considering Livestreaming Marketing Modes and Power Structures

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Abstract: A livestreaming supply chain composed of a single manufacturer and a single streamer in the low-carbon market is examined. Motivated by the actual production and operation, both the manufacturer and the streamer have a chance to dominate the supply chain. Low-carbon strategies and livestreaming marketing modes of the supply chain are studied. The impacts of the consumer's price sensitivity coefficient, low-carbon preference, and streamer's promotion sensitivity coefficient on the equilibrium results are further studied. The results show that: the streamer achieves the optimal level of promotion effort in the resale mode under both power structures. The manufacturer achieves the optimal low-carbon level in the commission mode when the promotion sensitivity coefficient is smaller under both of two power structures. The streamer's profit is optimal in the resale mode, while the manufacturer's profit is optimal in the commission mode when under the streamer-led structure. Two parties' profits are optimal in the commission mode when the promotion sensitivity coefficient is smaller under the manufacturer-led structure. The low-carbon level, streamer promotion effort and selling price in two livestreaming marketing modes will increase when the streamer promotion sensitivity coefficient and consumer low-carbon preference increase and will decrease when consumer price sensitivity increases under two power structures. Lastly, the selling price in resale mode is always higher than that in commission mode under two power structures.

Keywords: low-carbon strategy; livestreaming marketing mode; consumer low-carbon preference; level of low-carbon promotion effort; power structures

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1. Introduction

Global governments and environmental organizations have placed a high priority on the numerous climate and environmental issues caused by massive greenhouse gas emissions. In order to deal with this issue, the Chinese government has included carbon neutrality and peaking in its government work report for 2021, encouraging green and low-carbon development. Moreover, consumers' awareness of environmental protection has been continuously enhanced. Environmentally friendly, low-carbon products are more attractive to consumers [1–3]. With the development of online technology and the upgrading of shopping styles, consumers are increasingly turning to online shopping channels. According to Statista, global e-commerce sales will total about 5.2 billion U.S. dollars in 2021 and are expected to reach 8.1 billion U.S. dollars in 2026 [4]. To further cater to consumers, Facebook, TikTok, Jindong, Taobao, and others have started launching livestreaming marketing channels on their platforms. After the COVID-19 outbreak, livestreaming marketing has grown as a no-touch, interactive selling format. According to a report on livestreaming e-commerce in China, the number of livestreaming e-commerce users was 515 million as of December 2022 [5]. In that background, more manufacturers began to provide green products and adopt the popular livestreaming e-commerce channel to meet and promote consumers' low-carbon needs. The livestreaming e-commerce channel has been loved by a large number of consumers and manufacturers at present because it allows real-time interaction between consumers and steamers [6]. Then consumers can obtain professional explanations about the products or services, and manufacturers can obtain more sales. For the manufacturer, there are usually two main livestreaming marketing modes between manufacturers and streamers. One is the resale, and the other one is the commission. In the resale mode, the streamers have their own livestreaming room and operate the product sales channel; they purchase goods from manufacturers and resell them to consumers on the platform, such as Dongfangzhenxuan. Consumers buy the products in the livestreaming room, and the streamers gain sales revenue. In the commission mode, the manufacturers operate the product sales channel, and they hire the streamers to help them sell products in the streamers' live steaming room and pay a certain percentage of commission to the streamers, such as Li Jiaqi and Wei Ya. Consumers buy the products in manufacturers' online shops, and the manufacturers gain revenue. Streamers can stimulate consumers' willingness to buy low-carbon products.

However, the selection of the livestreaming marketing mode and low-carbon promotion effort is an important decision of the low-carbon livestreaming supply chain. Because although livestreaming marketing can attract more consumers to purchase low-carbon products through low-carbon promotion efforts made by streamers, many limitations remain. Under the commission mode, manufacturers are required to pay commissions to streamers, which typically account for 30–50% of sales [7], and the high commissions may squeeze manufacturers' profit margins. Under the resale mode, the manufacturer loses the power to price their products, and some streamers try to attract consumers by decreasing prices, which may create a psychology of fairness concern for consumers [8] and impact other sales channels of manufacturers. Moreover, different efforts will be made by the streamers in different livestreaming marketing modes. Then manufacturers need to choose the mode of cooperating with streamers, especially when the manufacturers or streamers play a leading role in the supply chain. What's more, manufacturers must also face the additional unit production cost of producing low-carbon goods. Obviously, high production costs often lead to higher product selling prices. The decision of low-carbon and selling price is also an important issue for manufacturers. Manufacturers' low-carbon strategy will also be affected by consumers' low-carbon preference and price sensitivity, streamer's promotion effort. Therefore, our study will also discuss how these factors affect the strategy of the livestreaming supply chain. We attempt to solve problems as follows:

(1) Optimal low-carbon strategies of the manufacturer and streamer under two livestreaming marketing modes when there are two different power structures, respectively, dominated by the manufacturer and the streamer.
(2) How do the marketing mode and power structure impact the optimal low-carbon strategies of the members? When to choose a "resale" or "commission" mode to obtain more profits?
(3) The impacts of the parameters, including the consumer price sensitivity coefficient, commission ratio, streamer's low-carbon promotion level coefficient and consumer's low-carbon preference on the optimal strategies of the manufacturer and streamer under the two livestreaming marketing modes.

To solve those issues, this paper establishes game models of a livestreaming supply chain and finds optimal strategies for livestreaming supply chain members on streaming marketing modes, prices and carbon emission reduction efforts. We discussed four supply chain structures: manufacturer-led in resale mode (model *wm*), streamer-led in resale mode (model *wl*), manufacturer-led in commission mode (model *am*), and streamer-led in commission mode (model *al*). Furthermore, the influences of model parameters on decision variables are analyzed. The results of our research will help the manufacturer and streamer manage and improve their strategies for livestreaming marketing mode selection and carbon emission reduction. The main contributions of this work include the following:

- This paper focuses on a livestreaming supply chain in which the manufacturer and the streamer need to decide both the low-carbon promotion level and optimal livestreaming marketing mode. Unlike previous research focused on the supply chain with manufacturers and e-commerce platforms [9,10], we considered the importance of streamers' low-carbon promotion which will influence consumers' willingness to purchase low-carbon products.
- We examine the influences of different power structures on manufacturers' and streamers' decisions to choose their livestreaming marketing mode. Studies on the choice of livestreaming marketing mode have only considered the case of power parity between manufacturers and streamer [6,7]. And interestingly, we found that the optimal selection of marketing mode of both the manufacturer and the streamer always depends on their position in the supply chain, and they will make the same selection in the manufacture-led structure and the opposite selection in the streamer-led structure.

This paper seeks the maximum low-carbon effort level. It is found that both the manufacturer's and streamer's optimal low-carbon effort levels do not depend on the power structure of the supply chain. The manufacturer's optimal low-carbon effort level only depends on the livestreaming marketing mode, while the streamer's low-carbon effort level depends on both the livestreaming marketing mode and the promotion sensitivity coefficient. The manufacturer always makes the maximal effort in the commission mode. The streamer makes the maximal promotion effort in the resale mode when the promotion sensitivity coefficient is smaller, and the streamer makes the maximal promotion effort in the commission mode when the promotion sensitivity coefficient is bigger. The rest part of the article is arranged as follows: In Section 2, related studies are offered. Section 3 is about model descriptions and assumptions. In Section 4, models of resale mode and commission mode are established, and the optimal decision is obtained. In Section 5, decision results are compared and analyzed. In Section 6, numerical experiments are conducted. In Section 7, a case is studied. Finally, the conclusions and limitations are in Section 8. All mathematical proofs are shown in Appendix A.

2. Related Works

2.1. Low-Carbon Strategies of Supply Chain

Consumer awareness of environmental protection is considered an important factor that can affect the emission reduction level of the supply chain. Zhang et al. [11] examined how consumers' low-carbon awareness and merchants' concerns about fairness in cost-sharing percentages and supply chain decisions. The research found that increasing consumers' environmental awareness and carbon emission reduction sharing ratio was beneficial to improving environmental quality. However, the more significant the retailers' fairness concern coefficient, the more unfavorable it was to environmental quality. Ji et al. [12] made a single-game model and a combined game model for reducing emissions. They found that the combined strategy for reducing emissions is good for both retailers and manufacturers. Wu et al. [13] created a differential game model with centralized versus decentralized decision-making. They discovered that consumer preferences for low-carbon products encouraged suppliers and manufacturers to reduce emission levels. The government's low-carbon policies also influence the emission reduction efforts of supply chain members [14,15]. Zhang et al. [16] studied the emission reduction of a dual-channel supply chain under the background of carbon quota. Chen et al. [17] compared manufacturers' channel choice and emission reduction under various government subsidies. Wang et al. [18] formulated a revenue-sharing contract with compensation. Wang et al. [19] considered retailers' altruistic preferences when making decisions and coordination. Gong et al. [20] studied the strategies of blockchain technology adoption and channel selection when consumers' willingness to pay for remanufactured products is low. Basiri et al. [21] proposed a supply chain coordination contract to improve product greenness while lowering retail prices. Zhang et al. [22] studied how an e-platform supply chain selects the optimal channel mode from platform mode and wholesale mode in the presence of a secondary marketplace. Dolai et al. [23] considered an EPQ model for screening imperfect products with GHG emission rates, and they concluded that higher screening rates lead to higher average profits when the screening rate is below a threshold, but higher screening rates may lead to lower profits when the screening rate is above a threshold. Manna et al. [24] proposes a two-plant production model that takes into account consumer demand. They believe that product warranty policies and rework policies are conducive to lowering greenhouse gas emissions and increasing average manufacturer profits and customer demand. Kumar et al. [25] developed a production inventory model with dynamic demand and found that reducing the cost of defective items facilitates manufacturers to increase their average profit. Manna et al. [26] studied the inventory problem of retailers with two warehouses based on the TDE algorithm.

Previous research on supply chain emission reduction mainly focused on manufacturers and retailers, but with the development of the platform economy, the mode of cooperation between manufacturers and streamers on the platform is becoming increasingly popular. Different from the previous research, we focus on the supply chain composed of manufacturers and streamers under the livestreaming marketing mode.

2.2. Livestreaming E-Commerce

There are few works of literature on livestreaming supply chains, and the existing research focuses primarily on manufacturers' livestreaming strategies and consumers' purchase behavior in live e-commerce. Zhang et al. [27] investigated the decision to implement live channels in multinational corporations while considering channel substitutability and tax differences. Gong et al. [28] discussed online retailers' live channel introduction strategy. Hao et al. [29] studied the effect of consumer returns and living sales on the selling mode chosen by e-commerce platforms and suppliers. Zhang et al. [30] found that live-streaming services always benefit e-commerce platforms, whereas manufacturers must consider production costs. Ma et al. [31] used an empirical approach to investigate the mechanism of streamer interaction's influence on consumer behavior and to analyze the factors influencing consumer purchase hesitation. Chen et al. [32] explored the mechanism of the role of weblebrities' traits and consumers' purchase intention and discovered that the more significant the weblebrities' traits, the stronger the consumers' purchase intention. Huang et al. [33] found that celebrity streamers selling hedonic goods and corporate streamers selling valuable goods are more likely to stimulate consumers' purchase desire. Xing et al. [34] examined the relationship between streamer commissions and streamer service quality efforts in both sign-up and non-sign-up scenarios. The research shows that the streamer's effort increases with the increase of streamer commission.

The preceding studies have empirically examined the impact of livestreaming marketing on consumers' purchase intention motivation and demonstrated the ability of streamers to stimulate consumers to purchase products. However, fewer studies have considered models to examine manufacturers' choices of livestreaming marketing mode and consider that manufacturers and streamers are in different power structures.

2.3. Power Structures of Supply Chain

Different power structures will lead to different decision results. Huang et al. [35] analyzed the supply chain members' optimal emission reduction decisions under different power structures, with manufacturers taking CSR and retailers taking social responsibility. It confirmed that the green degree and green publicity level of products are higher when the other party engages in CSR with both of the power structures. Li et al. [36] discovered that supply chain members always make more money when they have dominance. Lu et al. [37] studied the pricing problem with three structures: retailer-dominated, manufacturer-dominated, and power-parity situations. Chen et al. [38] explore the power structure's impact on the optimal O2O price and profit of retailers and suppliers. Generally, the manufacturer requires the dominant position between the streamer and the manufacturer, but not all streamers are subordinate, especially the celebrity streamers who can even take the initiative when cooperating with the manufacturer. Therefore, there are also different power structures between manufacturers and streamers under livestreaming marketing. Qiu et al. [39] considered a supply chain consisting of an online retail platform, a used sales platform, and a recycling platform and investigated the influence of different power structures on the integration strategies of used recycling platforms.

Most of the previous work considered the power imbalance between a manufacturer and an e-commerce platform and a manufacturer and a retailer in the supply chain. Our work differs from previous research in the following aspects. First, we consider the power imbalance between a manufacturer and a streamer in livestreaming marketing. Second, we study the impact of different power structures on the low-carbon strategies of the manufacturer and streamer.

To sum up, the existing literature has achieved specific results on low-carbon supply chain and livestreaming e-commerce, paying more attention to the low-carbon strategies between manufacturers and e-commerce platforms and the strategies about whether the manufacturer should choose a livestreaming channel, but the low-carbon problem of the livestreaming supply chain is rarely addressed. Not paying enough attention to the fact that the livestreaming platform is different from an e-commerce platform on the consumer's willingness to pay and the selection of the livestreaming marketing mode, especially when there are more than one livestreaming marketing mode and power structure. This paper will consider these facts. Our study can help manufacturers, and steamers determine the optimal livestreaming mode and emission reduction strategy.

3. Model Description and Assumption

3.1. Model Description

There is a manufacturer and a streamer. The decision objective of manufacturers and streamers is to maximize their own revenue. They have two livestreaming marketing modes to sell the products. One is resale mode, and the other one is commission mode. In the resale mode, the manufacturer sells the products to the streamer at a wholesale price, and the streamer reprices and sells them in the livestreaming room. Manufacturers gain income from wholesale products, and streamers gain income from product sales. In the commission mode, the streamer sells the products in the livestreaming room and draws a certain percentage of commission from each order, the selling price determined by the manufacturer. Manufacturers gain income from product sales.

There are two power structures between the manufacturer and the streamer: manufacturer-led and streamer-led. The research objective is to discuss the decision of low-carbon and livestreaming marketing mode of the manufacturer and streamer in four situations: manufacturer-led in resale mode (model *wm*), streamer-led in resale mode (model *wl*), manufacturer-led in commission mode (model *am*), and streamer-led in commission mode (model *al*). Then we build Stackelberg game models for four scenarios to analyze the optimal strategies of low-carbon efforts and livestreaming marketing modes.

3.2. Assumptions

Consumers are low-carbon conscious in the low-carbon supply chains; they are willing to pay higher prices for low-carbon products [40–43]. And consumers' purchasing needs in the livestreaming supply chain are also influenced by the promotion efforts of streamers [44]. Therefore, the consumer's demand in the low-carbon livestreaming supply chain is mainly influenced by the low-carbon level of the product e of manufacture, the low-carbon promotion effort level s of the streamer and the product price p. By increasing the low-carbon level of products, manufacturers attract low-carbon-preferring consumers to buy them [45], and streamers further strengthen consumers' low-carbon consciousness through product demonstration and narration, stimulating the growth of demand in the livestreaming room. According to [46–48], we have Assumption 1 about the demand function.

Assumption 1. *Consumers have a low-carbon preference, and more consumers are willing to pay higher prices for low-carbon products; manufacturers are willing to make low-carbon investments to meet consumers' low-carbon demand and gain more profits. The demand function of consumer's low-carbon products under the livestreaming marketing mode is*

$$d = a - \mu p + \eta e + \varphi s \tag{1}$$

where μ and η are the consumer's price sensitivity coefficient and low-carbon preference for the product, and the φ is the streamer low-carbon promotion sensitivity coefficient.

Assumption 2. *The manufacturer is responsible for improving the low-carbon level of the product, and the streamer is responsible for improving the low-carbon promotion effort level in the low-carbon supply chain. The manufacturer pays production and R&D costs for low-carbon products. The streamer pays promotion effort cost. Without losing generality, we assume the product's production cost is 0 without affecting the calculation result* [21,49]*. Refer to* [50,51]*. We assume the manufacturer's unit production cost is $c(e) = e^2/2$, and the streamer's unit sales cost is $c(s) = s^2/2$.*

Assumption 3. *Manufacturers pay the same percentage of commission to the same type of streamers in the industry in the commission mode. Because in actual operation, the manufacturer does not set a separate commission ratio for each streamer but often decides uniformly based on market conditions* [52]*, and usually less than 0.5* [29]*, then we assume that the streamer commission ratio θ is an exogenous variable, $0 < \theta < 0.5$.*

The definitions of parameters in the paper are shown in Table 1.

Table 1. Parameters definition.

Symbol	Description
d	Demand function of consumers
a	Potential maximum demand
p	Product selling price
w	Wholesale price in resale mode
k	product unit profit in the resale mode
μ	Price sensitivity coefficient
e	Product low-carbon level
η	Consumer low-carbon preference
s	Streamer low-carbon promotion effort level
φ	Streamer low-carbon promotion sensitivity coefficient
θ	Commission ratio
π_m^i, π_m^j	Manufacturer's profit under two livestreaming marketing modes
π_l^i, π_l^j	Streamers' profit under two livestreaming marketing modes
i, j	$i = wm, wl$, wm: manufacturer-led in the resale mode, wl: streamer-led in the resale mode $j = am, al$, am: manufacturer-led in the commission mode, al: streamer-led in the commission mode

In the resale mode, the manufacturer produces at level e^i, and resells it to the streamer at price w^i. The streamer decides its promotion effort level s^i and selling price p^i, where $p^i = k^i + w^i$, k^i stands for the product's profit per unit; as a result, the streamer decides the profit per unit product k^i.

In the commission mode, the manufacturer produces at level e^j, and sells it to the consumer with the help of the streamer at price p^j. The streamer promotion effort is s^j. The structure of the models in resale and commission mode are shown in Figure 1.

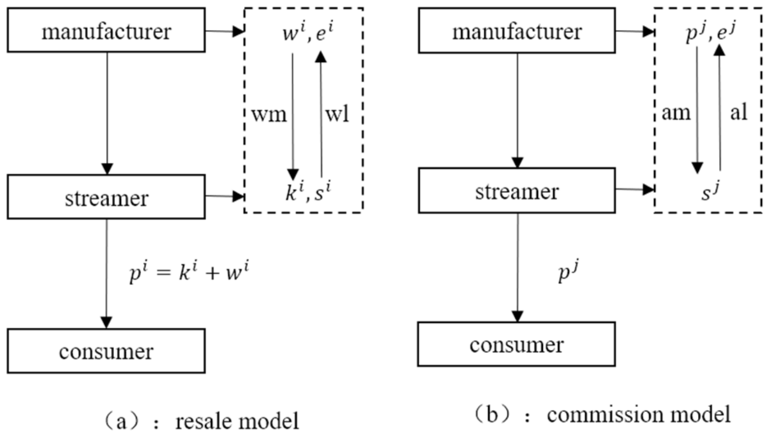


Figure 1. Model structure.

4. Modeling and Analysis

4.1. Resale Mode

The manufacturer's profit function in resale mode is:

$$\pi_m^i = w^i\left[a - \mu\left(k^i + w^i\right) + \eta e^i + \varphi s^i\right] - \frac{1}{2}\left(e^i\right)^2 \quad (2)$$

The streamer's profit function in resale mode is:

$$\pi_l^i = k^i\left[a - \mu\left(k^i + w^i\right) + \eta e^i + \varphi s^i\right] - \frac{1}{2}\left(s^i\right)^2 \quad (3)$$

4.1.1. Model *wm* (Manufacturer-Led)

In the model *wm*, the livestreaming marketing mode is the resale mode; the structure is manufacturer-led. The objective of the manufacturer and streamer is to maximize their own profit. The decision sequence is: (1) the manufacturer decides w and e, (2) the streamer decides k and s. Practice shows consumers' low-carbon preference and promotion sensitivity coefficient are not infinite, but there is a range. In order to make our study more realistic and have optimal solutions for functions (2) and (3), the following assumption about the model parameters are made regarding the studies of Wang et al. [19,48] scholars.

Assumption 4. *The parameters meet the following conditions*: the $\eta < \sqrt{-2\varphi^2 + 4\mu}$, $\varphi < \sqrt{-\frac{1}{2}\eta^2 + 2\mu}$ *in resale mode with a manufacturer-led structure.*

Lemma 1. *The optimal low-carbon strategies in resale mode with a manufacturer-led structure are as follows:*

$$e^{wm*} = -\frac{a\eta}{\eta^2 + 2\varphi^2 - 4\mu} \quad (4)$$

$$w^{wm*} = -\frac{a\left(-\varphi^2 + 2\mu\right)}{\mu\left(\eta^2 + 2\varphi^2 - 4\mu\right)} \quad (5)$$

$$k^{wm*} = \frac{a}{-\eta^2 - 2\varphi^2 + 4\mu} \quad (6)$$

$$p^{wm*} = \frac{a\left(-\varphi^2 + 3\mu\right)}{\mu\left(-\eta^2 - 2\varphi^2 + 4\mu\right)} \quad (7)$$

$$s^{wm*} = \frac{\varphi a}{-\eta^2 - 2\varphi^2 + 4\mu} \quad (8)$$

The following Propositions can be drawn from Lemma 1.

Proposition 1. $\frac{\partial e^{wm*}}{\partial \mu} < 0$, $\frac{\partial k^{wm*}}{\partial \mu} < 0$, $\frac{\partial s^{wm*}}{\partial \mu} < 0$.

From Proposition 1 we can find low-carbon level, unit profit and streamer's low-carbon promotion effort level are negatively related to the price sensitivity coefficient in resale mode with a manufacturer-led structure. That shows the higher the price sensitivity coefficient, consumers are easier influenced by the product's price, and the lower the selling price is. At the same time, the low-carbon product's selling price is always higher than the traditional product's price because of the higher R&D cost and streamer promotion cost. Consumers will be less interested in purchasing low-carbon products. The manufacturer will choose a lower low-carbon level; the streamer will choose a lower low-carbon promotion effort level.

Proposition 2. $\frac{\partial w^{wm*}}{\partial \eta} > 0$, $\frac{\partial e^{wm*}}{\partial \eta} > 0$, $\frac{\partial k^{wm*}}{\partial \eta} > 0$, $\frac{\partial p^{wm*}}{\partial \eta} > 0$, $\frac{\partial s^{wm*}}{\partial \eta} > 0$.

From Proposition 2, we can see wholesale price, low-carbon level, unit profit, selling price and streamer's low-carbon promotion effort are positively related to consumer's low-carbon preference in resale mode with manufacturer-led structure. The results are consistent with the reality. That shows both manufacturer and streamer will be motivated by consumers' low-carbon preference to pay more effort and costs for low-carbon promotion. The wholesale price, unit profit and selling price increase subsequently.

Proposition 3. $\frac{\partial w^{wm*}}{\partial \varphi} > 0$, $\frac{\partial e^{wm*}}{\partial \varphi} > 0$, $\frac{\partial k^{wm*}}{\partial \varphi} > 0$, $\frac{\partial p^{wm*}}{\partial \varphi} > 0$, $\frac{\partial s^{wm*}}{\partial \varphi} > 0$.

From Proposition 3 we can see wholesale price, low-carbon level, selling price, steamer's low-carbon promotion effort, and unit profit is positively related to the streamer's promotion sensitivity coefficient in resale mode with manufacturer-led structure. That means the streamer's low-carbon propaganda has positive feedback on the low-carbon level and product selling price, the product selling price has positive feedback on the streamer's low-carbon propaganda, then a feedback loop is formed.

4.1.2. Model *wl* (Streamer-Led)

In the model *wl*, the livestreaming marketing mode is the resale mode; the structure is streamer-led. The decision sequence is: (1) the streamer decides the value of k and s, and (2) the manufacturer decides the value of w and e.

Assumption 5. *The parameters meet the following conditions:* $\eta < \sqrt{\frac{-\varphi^2+4\mu}{2}}$, $\varphi < \sqrt{-2\eta^2 + 4\mu}$ *in resale mode with a streamer-led structure*.

The basis of Assumption 5 is similar to Assumption 4.

Lemma 2. *The optimal low-carbon strategies in resale mode with a streamer-led structure are as follows:*

$$e^{wl*} = \frac{a\eta}{-2\eta^2 - \varphi^2 + 4\mu} \tag{9}$$

$$w^{wl*} = \frac{a}{-2\eta^2 - \varphi^2 + 4\mu} \tag{10}$$

$$k^{wl*} = \frac{a\left(2\mu - \eta^2\right)}{(-2\eta^2 - \varphi^2 + 4\mu)\mu} \tag{11}$$

$$p^{wl*} = \frac{a\left(3\mu - \eta^2\right)}{(-2\eta^2 - \varphi^2 + 4\mu)\mu} \tag{12}$$

$$s^{wl*} = -\frac{a\varphi}{2\eta^2 + \varphi^2 - 4\mu} \tag{13}$$

The following Propositions can be drawn from Lemma 2.

Proposition 4. $\frac{\partial e^{wl*}}{\partial \mu} < 0$, $\frac{\partial w^{wl*}}{\partial \mu} < 0$, $\frac{\partial s^{wl*}}{\partial \mu} < 0$.

Proposition 4 shows low-carbon level, unit profit and streamer's low-carbon promotion effort level are negatively related to the price sensitivity coefficient in resale mode with a streamer-led structure. It is similar to Proposition 1.

Proposition 5. $\frac{\partial e^{wl*}}{\partial \eta} > 0$, $\frac{\partial w^{wl*}}{\partial \eta} > 0$, $\frac{\partial k^{wl*}}{\partial \eta} > 0$, $\frac{\partial p^{wl*}}{\partial \eta} > 0$, $\frac{\partial s^{wl*}}{\partial \eta} > 0$.

Proposition 5 means wholesale price, low-carbon level, unit profit, selling price and streamer's low-carbon promotion effort are positively related to consumer's low-carbon preference in resale mode with a streamer-led structure. It is similar to Proposition 2.

Proposition 6. $\frac{\partial e^{wl*}}{\partial \varphi} > 0$, $\frac{\partial w^{wl*}}{\partial \varphi} > 0$, $\frac{\partial k^{wl*}}{\partial \varphi} > 0$, $\frac{\partial p^{wl*}}{\partial \varphi} > 0$, $\frac{\partial s^{wl*}}{\partial \varphi} > 0$.

Proposition 6 shows that wholesale price, low-carbon level, selling price, steamer's low-carbon promotion effort, unit profit is positively related to a streamer's promotion sensitivity coefficient in resale mode to a streamer-led structure. Similar to Proposition 3.

4.2. Commission Mode

The manufacturer's profit function in commission mode is:

$$\pi_m^j = p^j(1-\theta)\left(a - \mu p^j + \eta e^j + \varphi s^j\right) - \frac{1}{2}\left(e^j\right)^2 \quad (14)$$

The streamer's profit function in commission mode is:

$$\pi_l^j = p^j\theta\left(a - \mu p^j + \eta e^j + \varphi s^j\right) - \frac{1}{2}\left(s^j\right)^2 \quad (15)$$

4.2.1. Model *am* (Manufacturer-Led)

In the model *am*, the livestreaming marketing mode is commission mode, and the structure is manufacturer-led. The objective of the manufacturer and streamer is to maximize their own profit. The decision sequence is: (1) the manufacturer decides p and e, (2) the streamer decides s. In order to make our study more realistic and have optimal solutions for functions (14) and (15), we propose Assumption 6. The basis of Assumption 6 is similar to Assumption 4.

Assumption 6. *The parameters meet the following conditions:* $\eta < \sqrt{\frac{2(\mu-\theta\varphi^2)}{1-\theta}}$, $\varphi < \sqrt{\frac{(\eta^2\theta-\eta^2+2\mu)}{2\theta}}$ *in commission mode with manufacturer-led structure.*

Lemma 3. *The optimal low-carbon strategies in commission mode with a manufacturer-led structure are as follows:*

$$e^{am*} = \frac{\eta(1-\theta)a}{\eta^2\theta - 2\theta\varphi^2 - \eta^2 + 2\mu} \quad (16)$$

$$p^{am*} = \frac{a}{\eta^2\theta - 2\theta\varphi^2 - \eta^2 + 2\mu} \quad (17)$$

$$s^{am*} = \frac{a\theta\varphi}{\eta^2\theta - 2\theta\varphi^2 - \eta^2 + 2\mu} \quad (18)$$

The following Propositions can be drawn from Lemma 3.

Proposition 7. $\frac{\partial e^{am*}}{\partial \mu} < 0$, $\frac{\partial p^{am*}}{\partial \mu} < 0$, $\frac{\partial s^{am*}}{\partial \mu} < 0$.

From Proposition 7, it can be seen that the low-carbon level, selling price and streamer's low-carbon promotion effort level are negatively related to the price sensitivity coefficient in commission mode with manufacturer-led structure. It's similar to Propositions 1 and 4.

Proposition 8. $\frac{\partial e^{am*}}{\partial \eta} > 0$, $\frac{\partial p^{am*}}{\partial \eta} > 0$, $\frac{\partial s^{am*}}{\partial \eta} > 0$.

Proposition 8 shows that low-carbon level, selling price and streamer's low-carbon effort are positively related to consumer's low-carbon preference in commission mode with a manufacturer-led structure. It's similar to Propositions 2 and 5.

Comparing Proposition 8 with Proposition 2, we can find that the mode of cooperation between streamer and manufacturer does not change the impact of low-carbon preferences on the members' optimal strategies.

Proposition 9. $\frac{\partial e^{am*}}{\partial \varphi} > 0$, $\frac{\partial p^{am*}}{\partial \varphi} > 0$, $\frac{\partial s^{am*}}{\partial \varphi} > 0$.

Proposition 9 shows that the low-carbon level, selling price and streamer's low-carbon promotion effort are positively related to the steamer's promotion sensitivity coefficient in commission mode with a manufacturer-led structure. It's similar to Propositions 3 and 6. This indicates that if we want to improve the low-carbon level and streamer's promotion effort, we'd better improve the steamer's promotion sensitivity coefficient.

Proposition 10. $\frac{\partial e^{am*}}{\partial \theta} < 0$, $\frac{\partial s^{am*}}{\partial \theta} > 0$.

Proposition 10 reveals that the low-carbon level is negatively related to the commission ratio, streamer's low-carbon promotion effort level is positively related to the commission ratio in the commission mode with a manufacturer-led structure.

4.2.2. Model *al* (Streamer-Led)

In model *al*, the livestreaming marketing mode is commission mode; the structure is streamer-led. The decision sequence is: (1) the streamer decides s, (2) the manufacturer decides p and e.

Assumption 7. *The parameters meet the following conditions:* $\eta < \sqrt{\frac{-2\mu+\varphi\sqrt{2\mu\theta}}{1-\theta}}$, $\varphi < \frac{\sqrt{2}(\eta^2\theta-\eta^2+2\mu)}{2\sqrt{\mu\theta}}$ *in commission mode with a streamer-led structure.*

The basis of Assumption 7 is similar to Assumption 4.

Lemma 4. *The optimal low-carbon strategies in commission mode with a streamer-led structure are as follows:*

$$e^{al*} = \frac{(1-\theta)\eta a\left((\theta-1)\eta^2+2\mu\right)}{(-1+\theta)^2\eta^4+4\mu(-1+\theta)\eta^2-2\varphi^2\theta\mu+4\mu^2} \tag{19}$$

$$p^{al*} = \frac{(-1+\theta)a\eta^2+2\mu a}{(-1+\theta)^2\eta^4+4\mu(-1+\theta)\eta^2-2\varphi^2\theta\mu+4\mu^2} \tag{20}$$

$$s^{al*} = \frac{2a\theta\mu\varphi}{(-1+\theta)^2\eta^4+4\mu(-1+\theta)\eta^2-2\varphi^2\theta\mu+4\mu^2} \tag{21}$$

The following Propositions can be drawn from Lemma 4. Due to the computational complexity, the effect of the consumers' low-carbon preference and commission ratio on optimal strategies will be discussed in the numerical study.

Proposition 11. $\frac{\partial e^{al*}}{\partial \mu} < 0$, $\frac{\partial p^{al*}}{\partial \mu} < 0$, $\frac{\partial s^{al*}}{\partial \mu} < 0$.

Proposition 11 shows that the low-carbon level, selling price and streamer's low-carbon promotion effort level is negatively related to the price sensitivity coefficient in commission mode with a streamer-led structure. It's similar to Propositions 1, 4 and 7. Comparing Propositions 1, 4, 7 and 11, it can be found that the impacts of the price sensitivity coefficient on the optimal strategies are not changed by both the power structure or livestreaming marketing mode.

Proposition 12. $\frac{\partial e^{al*}}{\partial \varphi} > 0$, $\frac{\partial p^{al*}}{\partial \varphi} > 0$, $\frac{\partial s^{al*}}{\partial \varphi} > 0$.

Proposition 12 shows that the low-carbon level, selling price and streamer's low-carbon promotion effort in commission mode with the streamer-led structure is positively related to the steamer's promotion sensitivity coefficient. It's similar to Propositions 3, 6 and 9. Comparing Propositions 3, 6, 9 and 12, it can be found that the impacts of the promotion sensitivity coefficient on the optimal strategies are not changed by both power structure or livestreaming marketing mode.

5. Results Comparison

Optimal results in resale mode and commission mode are compared on the basis of the above conclusions so that we can obtain the conclusions of the two parties' optimal choice about the livestreaming marketing mode under two different power structures.

Proposition 13. *When it's under the manufacturer-led structure: (1)* $e^{wm*} < e^{am*}$*, if* $0 < \varphi < \sqrt{\mu}$*;* $e^{wm*} > e^{am*}$*, if* $\varphi > \sqrt{\mu}$*. (2)* $s^{wm*} > s^{am*}$.

Proposition 13 suggests that the manufacturer's optimal low-carbon level in commission mode is higher than that in resale mode when the streamer's promotion sensitivity coefficient does not meet critical value. Otherwise, the low-carbon level in resale mode is higher. The streamer's optimal low-carbon promotion effort level in resale mode is always higher than that in commission mode. For the manufacturer, the commission mode is a better choice when the steamer's low-carbon promotion sensitivity coefficient is low. Otherwise, the resale mode is a better choice. The resale mode is always better for the steamer than the commission mode. Therefore, the choice of livestreaming marketing mode depends on the steamer's low-carbon promotion sensitivity coefficient under the manufacturer-led structure. Both parties will unanimously choose the resale mode when the steamer's low-carbon promotion sensitivity coefficient is big. When the steamer's low-carbon promotion sensitivity coefficient is small, the streamer can only choose the commission mode listening to the manufacturer in practice because the manufacturer has a stronger voice.

Proposition 14. *When it's under the streamer-led structure: (1)* $e^{wl*} > e^{al*}$*, if* $\theta > \theta'$*;* $e^{wl*} < e^{al*}$*, if* $\theta < \theta'$*, where* $\theta' = \frac{\sqrt{2\mu(2\mu-\varphi^2)(2\mu-\eta^2)(2\mu-\eta^2-\varphi^2)}+(2\mu-\eta^2)(2\mu-\eta^2-\varphi^2)}{\eta^2(4\mu-\eta^2-\varphi^2)}$*. (2)* $s^{wl*} > s^{al*}$.

Proposition 14 suggests that the manufacturer's optimal low-carbon level in commission mode is higher than that in resale mode when the streamer's commission ratio does not meet critical value. Otherwise, the low-carbon level in resale mode is higher. The streamer's optimal low-carbon promotion effort level in resale mode is always higher than that in commission mode. The resale mode is a better choice for the manufacturer than the resale mode when the commission ratio is low. Otherwise, the resale mode is the better choice. The resale mode is always better for the streamer than the commission mode. Therefore, the choice of livestreaming marketing mode depends on the commission ratio under the streamer-led structure. Both parties will unanimously choose the resale mode when the commission ratio is big. When the commission ratio is small, the manufacturer can only choose the resale mode listening to the streamer in practice because the streamer has a stronger voice.

Proposition 15. *(1) When it's under the manufacturer-led structure: $p^{wm*} > p^{am*}$.(2) When it's under the streamer-led structure: $p^{wl*} > p^{al*}$.*

Proposition 15 suggests the optimal product selling prices in resale mode are always higher than those in commission mode under both the manufacturer-led and streamer-led structures. Under the resale mode, the manufacturer and the streamer jointly determine the product's selling price, and both of them want to maximize their interests. Then the selling price is increased as much as possible.

Proposition 16. *(1) When it's under the manufacturer-led structure: $\pi_m^{wm*} < \pi_m^{am*}$, if $0 < \varphi < \sqrt{\mu}$; $\pi_m^{wm*} > \pi_m^{am*}$, $\varphi > \sqrt{\mu}$. (2) When it's under the streamer-led structure: $\pi_l^{wl*} > \pi_l^{al*}$.*

Proposition 16 suggests that the manufacturer can make more profit through the commission mode when the streamer promotion sensitivity factor is weak under the manufacturer-led structure. Otherwise, the manufacturer can make more profit through the resale mode. The streamer can always make more profit through the resale model. The comparison of the profits of the streamer under the manufacturer-led structure and the profits of the manufacturer under the streamer-led structure is too complex to calculate and is therefore analyzed in the numerical example.

6. Numerical Experiment Study

The effects of the parameters μ, η, φ and θ on the manufacturer's and streamer's optimal low-carbon strategy under two power structures have been simulated by numerical experiments. Referring to the numerical experiment studies of [12,19], it is assumed that $a = 40$, $\eta = 0.7$, $\mu = 0.5$, $\varphi = 0.4$, $\theta = 0.3$.

6.1. Impact of Coefficient μ

In this section, the values of parameter η, φ, θ are held constant, and the value of μ keeps increasing. Figure 2 shows that the low-carbon level, selling price, streamer's low-carbon promotion effort level, and profit of both parties all decrease with the increase of coefficient μ, which are consistent with Propositions 1, 4, 7, and 11. The selling price in resale mode is higher than that in commission mode, and Proposition 15 has the same conclusion. That shows when consumers' sensitivity coefficient to selling price increases, their willingness to buy decreases, then the selling price, low-carbon level, low-carbon promotion effort will be reduced. The profits of both parties will also decrease.

6.2. Impact of Preference η

In this section, the values of parameter μ, φ, θ are held constant, and the value of η keeps increasing. The results shown in Figure 3 are consistent with Propositions 2, 5, and 8. As can be seen in Figures 2b and 3a, in the resale mode, both the optimal low-carbon level of the product and the optimal low-carbon promotion effort level is higher when the streamer dominates the supply chain rather than under manufacturer domination. In the commission mode, even when streamers dominate the supply chain, the level of optimal low-carbon promotional effort is still higher than that under manufacturer domination. In addition, the more consumers that prefer low-carbon products in both the resale and commission models, the greater the influence of the power structure on the low-carbon strategies of manufacturers and streamers. It needs to be added that the power structure has less impact on the low-carbon level of the product in the commission model.

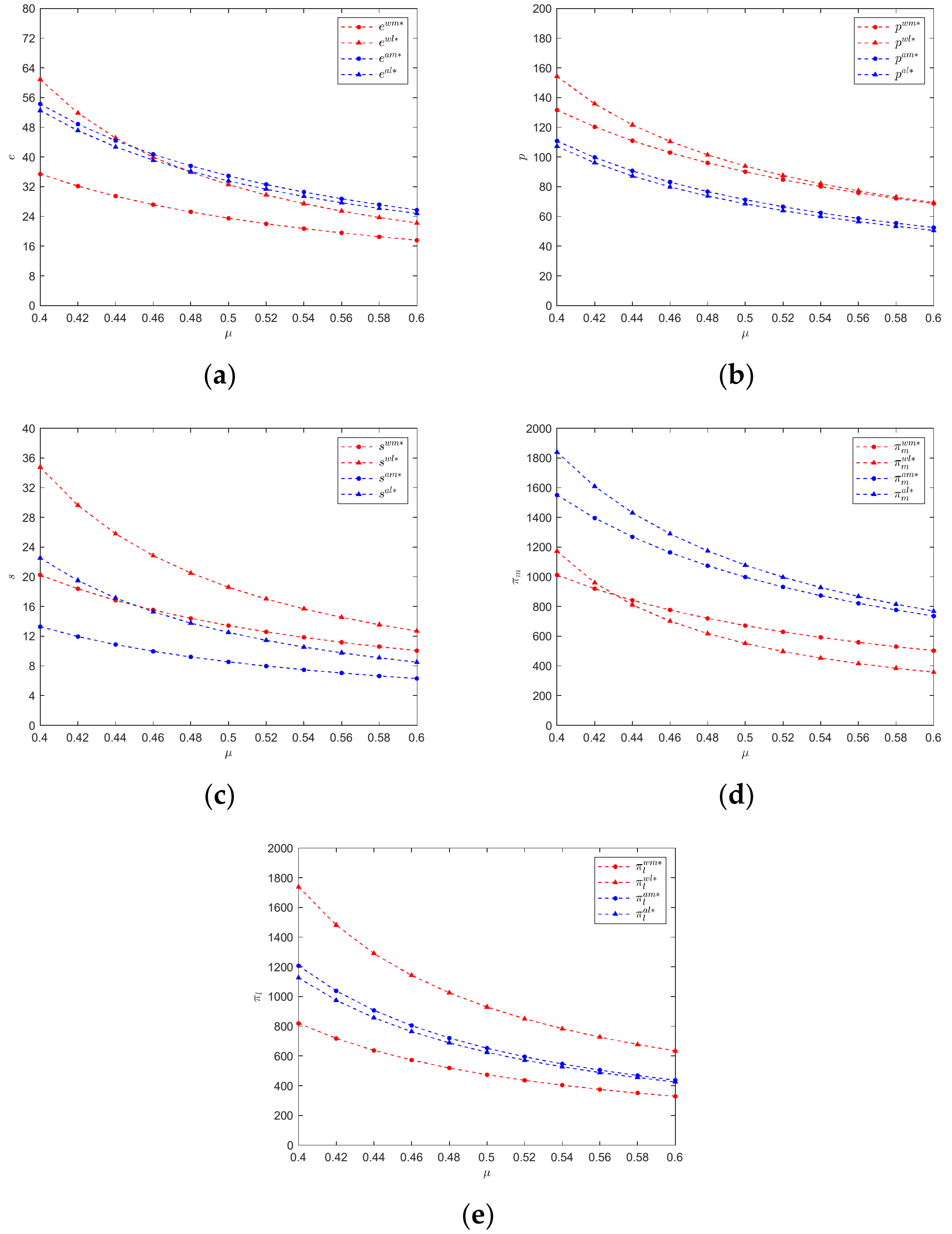


Figure 2. (**a**) changes of low-carbon level with μ; (**b**) changes of the product sale price with μ; (**c**) changes of low-carbon promotion efforts level with μ; (**d**) changes of manufacturer profits with μ; (**e**) changes of streamer profits with μ.

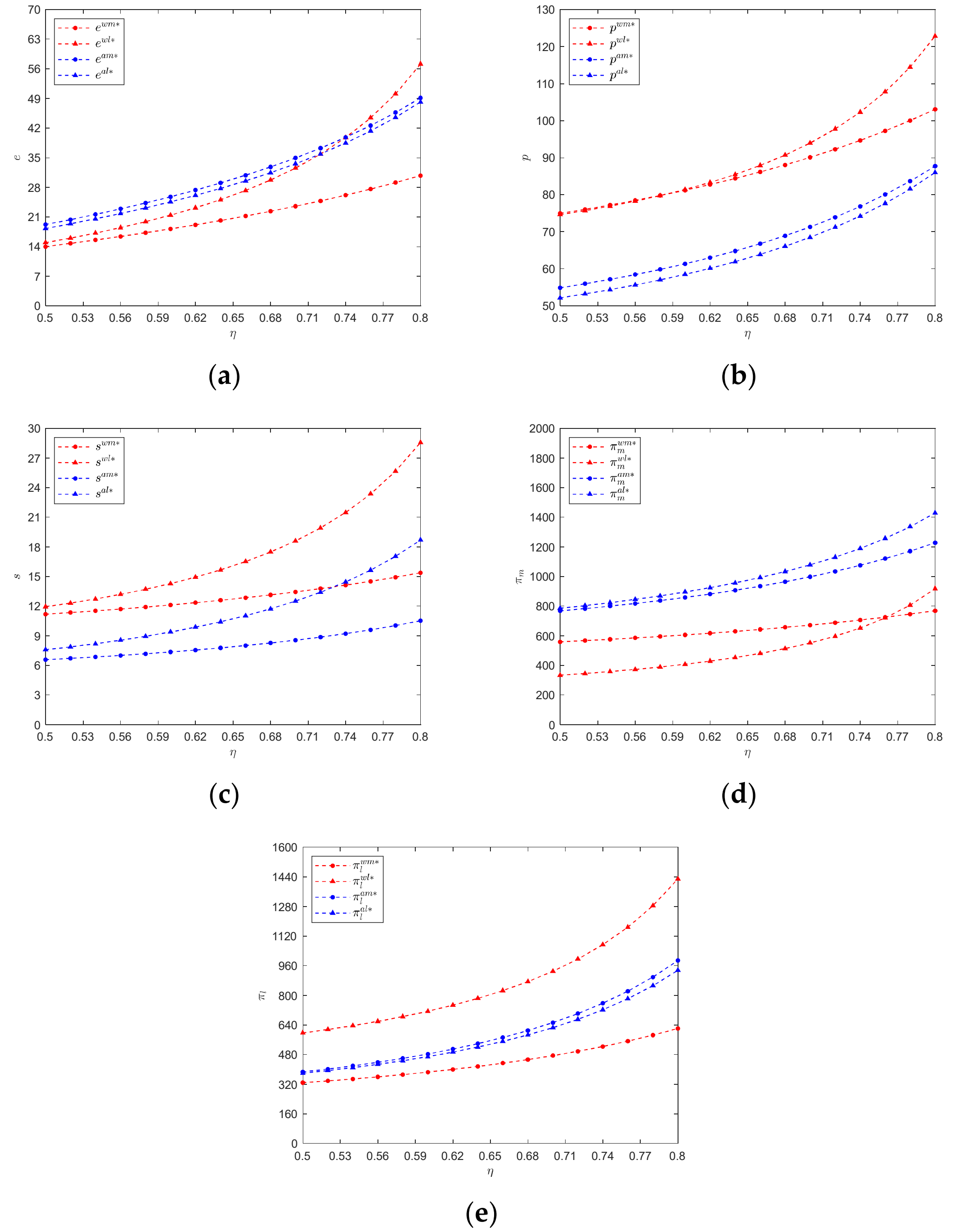


Figure 3. (**a**) changes of low-carbon level with η; (**b**) changes of the product sale price with η; (**c**) changes of low-carbon promotion efforts level with η; (**d**) changes of manufacturer profits with η; (**e**) changes of streamer profits with η.

6.3. Impact of Promotion Sensitivity Coefficient φ

In this section, the values of parameter η, μ, θ are held constant, and the value of φ keeps increasing. The results are shown in Figure 4a–c are consistent with Propositions 3, 6, 9, 12 and 15. (1) In the manufacturer-led structure. The manufacturer's optimal profit, shown in Figure 4d, and low-carbon level, shown in Figure 4a, in resale mode, are higher compared to the commission mode when φ is more than about 0.7. While it is better in commission mode when φ is less than about 0.7. The streamer's optimal profit in resale mode, shown in Figure 4e, is higher compared to the commission mode when φ is more than about 0.6. While it is higher in commission mode when φ is less than about 0.6. The streamer's optimal low-carbon promotion effort level in the resale mode shown in Figure 4c is always higher than that in commission mode regardless of the value of φ. (2) In the streamer-led structure. The manufacturer's optimal profit in commission mode, as shown in Figure 4d, is always higher than that in resale mode regardless of the value of φ. The low-carbon level shown in Figure 4a in resale mode is higher compared to the commission mode when φ is more than about 0.5. While it is better in commission mode when φ is less than about 0.5. The streamer's optimal profit and promotion effort level in the resale mode shown in Figure 4c,e is always higher compared to the commission mode, regardless of the value of φ. These results are consistent with Propositions 13 and 16.

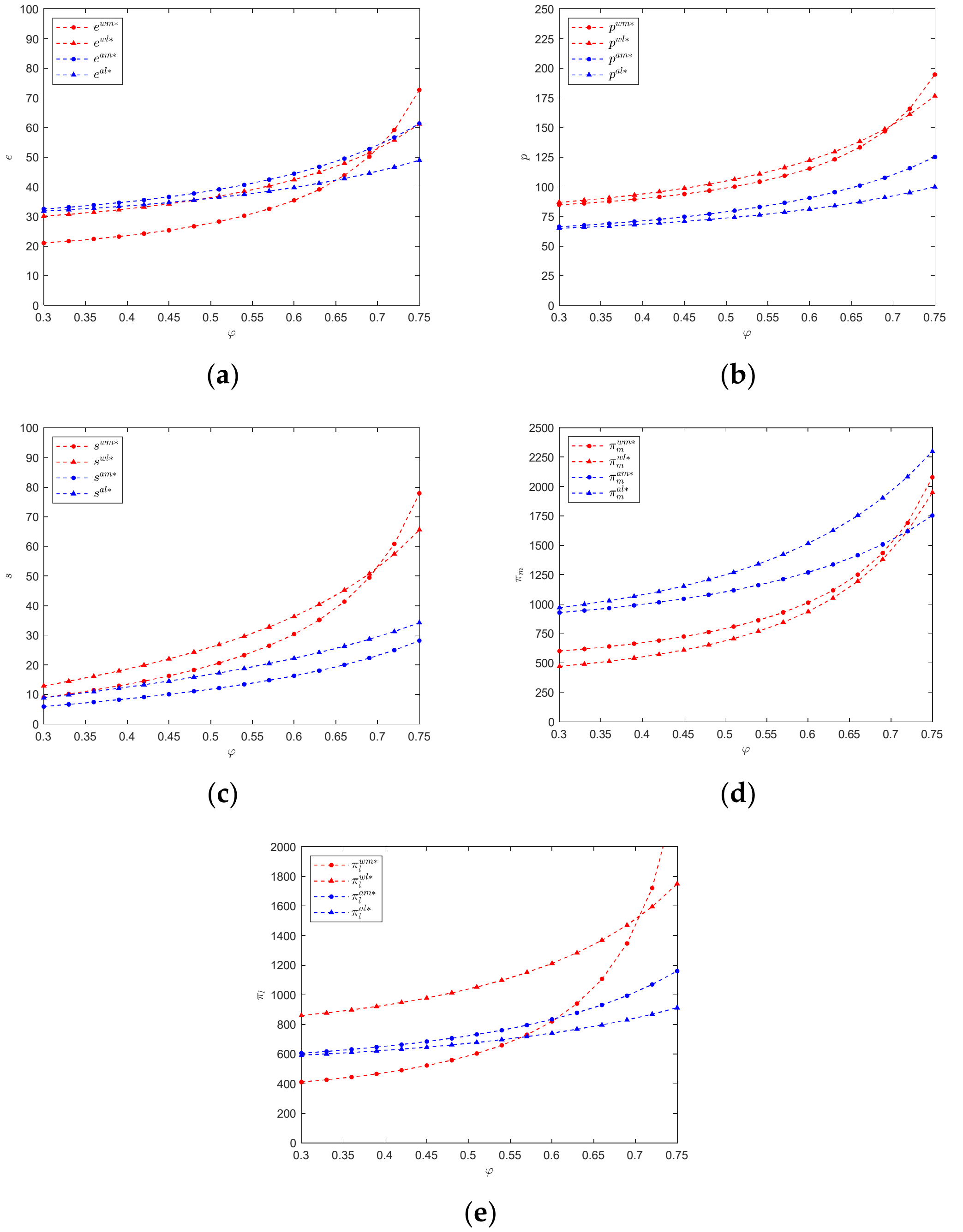
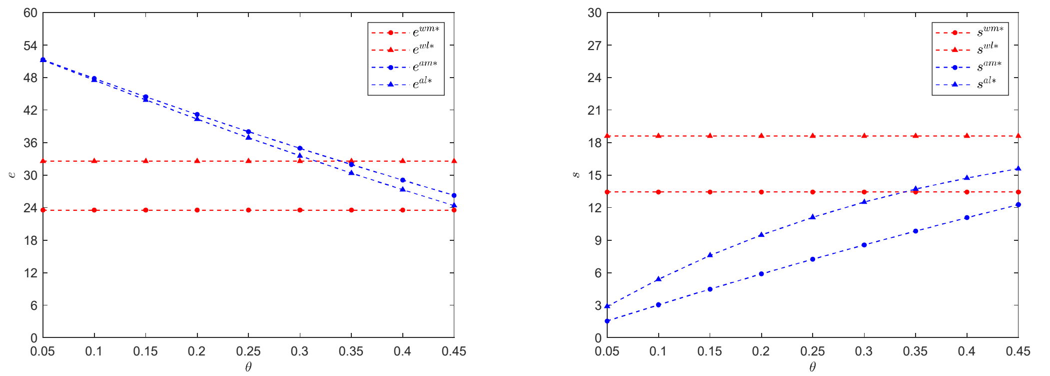


Figure 4. (**a**) changes of low-carbon level with φ; (**b**) changes of the product sale price with φ; (**c**) changes of low-carbon promotion efforts level with φ; (**d**) changes of manufacturer profits with φ; (**e**) changes of streamer profits with φ.

Thus, it can be observed that: (1) In the manufacturer-led structure. The manufacturer and streamer will choose the commission mode if the streamer's promotion sensitivity coefficient is smaller; otherwise, they will choose the resale mode if the streamer's promotion sensitivity coefficient is larger. In the above two cases, there is no disagreement between the manufacturer and streamer on the choice of livestreaming marketing mode. What's more, that choice will also make the manufacturer's low carbon level the highest, but the streamer's effort level is not optimal. (2) In the streamer-led structure. The streamer favors the resale mode, but the manufacturer prefers the commission mode, regardless of the value of the promotion sensitivity coefficient. This will need coordination between the manufacturer and the streamer. Generally, the weaker manufacturer will obey the streamer's decision to choose the resale mode in practice.

6.4. Impact of Commission Ratio θ

In this section, the values of parameters μ, φ, η are held constant, the value of θ keeps increasing. The results shown in Figure 5a,b are consistent with Propositions 10 and 14, respectively. We can find the manufacturer and streamer will make more efforts to low-carbon when they own the dominant position. The dominant player tends to be more active than that when they are a follower. It is also found from Figure 5a that when it is under the manufacturer-led structure, the optimal low-carbon level is always higher in commission mode, while the optimal promotion effort level is always higher in resale mode. From Figure 5b, when it is under the streamer-led structure, the optimal low-carbon level in commission mode is higher compared to the resale mode when θ is less than about 0.32. While it is higher in resale mode when θ is more than 0.32. The optimal promotion effort level is always higher in resale mode than that in the commission mode. It can be seen that regardless of the commission ratio and power structure, the resale mode has a higher incentive effect on the streamer's promotion effort.



(**a**) (**b**)

Figure 5. (**a**) changes of low-carbon level with θ; (**b**) changes of low-carbon promotion effort level with θ.

7. Case Study

In recent years, the Chinese government has vigorously implemented a "double carbon" policy to address climate change, which has been positively responded to by the Chinese home appliance brand, such as Midea and Gree, which have started to develop "low energy" products. At the beginning of 2020, the global COVID-19 pandemic greatly impacted the Chinese home appliance market, especially the large appliances mainly sold offline. According to the data from iimedia.cn, in the first quarter of 2020, the market share of Chinese home appliances was 117.2 billion CNY, down 36.1% year-on-year [53]. At the same time, the rapid development of "livestreaming + e-commerce", a new type of retail, has brought new development opportunities and sales chances for China's home appliance market. In order to adapt to market changes, some home appliance brands began to try livestreaming selling channels. For example, in May 2020, Dong Mingzhu of Gree Group livestreaming selling on the Kuaishou platform, and Midea Group combined with JD Five

Star Appliances to livestreaming selling; in June 2020, the AUX Group invited actor Lin Gengxin to livestream the selling of air conditioners. The common denominator in this series of livestreaming events is evident: livestreaming e-commerce has opened a new sales model for brands that mainly sell offline channels.

The most typical of these livestreaming events is the Gree Group, which had opened up new selling channels for Chinese manufacturing industries that stagnated during COVID-19. On 10 May 2020, Dong Mingzhu sold 44 million dollars in just three hours in a livestreaming event on the Kuaishou platform, attracting 16 million consumers to watch [54]. On 15 May, Dong conducted a livestreaming event on JD, generating 100 million dollars in sales in three hours, making it the highest sales in JD home appliance livestreaming marketing events [55]. The details of the two livestreaming events are shown in Table 2. In these two livestreaming events, the cooperation mode between Dong and Gree is different. In the Kuai livestreaming event, consumers buy products directly from Gree, so the cooperation mode can be regarded as commission mode, while in the JD livestreaming event, JD buys products from Gree and then resells them to consumers, so the cooperation mode can be regarded as resale mode. Comparing the two livestreaming events, we find that the sales in the JD are higher than those in the Kuaishou for the following reasons: First, in the JD livestreaming event, Dong introduced the technical features of the product from a professional perspective, with a higher level of low-carbon promotion effort, while in the Kuaishou livestreaming event, Dong was not yet skilled enough for livestreaming marketing, with a lower level of low-carbon promotion effort. Therefore, a higher level of low-carbon promotion can significantly increase consumer demand and improve manufacturer profits. Secondly, the Kuaishou livestreaming event mainly sells air purifiers, juicers and other small home appliances, and the low-carbon level of these products is relatively low; in JD livestreaming event, it mainly sells air conditioners and other large appliances, and the low-carbon level of these products is relatively high. The higher low-carbon level of products can increase the profits of manufacturers. Finally, we found that Dong, a socially well-known figure known as the "Queen of Home Appliances", dominated both the JD livestreaming event and Kuaishou livestreaming events. In addition, we know that the cooperation mode between Gree and Dong in Kuaishou livestreaming event is the commission model, and in JD livestreaming event is the resale model. It can be seen that Gree gained more profit in the resale mode when the streamer dominated. The above three points are reflected in our article, which fully illustrates the reasonableness and truthfulness of our proposed model.

Table 2. Comparison of Livestreaming Effect.

Gree Livestreaming	Commission Mode	Resale Mode
Time	11 May 2020	15 May 2020
Platform	Kuaishou	JD
Number of viewers	7.45 million	16 million
Power structure	streamer-led	streamer-led
Production low-carbon level	high	low
Low-carbon promotion effort level	high	low
Sales	$44 million	$100 million

Gree Group's success has caught the attention of other Chinese home appliance brand owners, driving livestreaming selling to become a virtual digital channel and development trend for Chinese home appliance sales. However, there are reasons behind Gree's success. There are two main reasons for Gree Group's success: First, as a company focused on home appliance manufacturing, Gree has been upholding the concept of low-carbon and environmental protection and constantly launching green and low-carbon home appliances. At the same time, Gree Group also actively promotes product innovation through the launch of the "photovoltaic air conditioning" project, successfully developed "zero carbon source" air conditioning technology; this advanced low-carbon technology has successfully attracted a large number of consumers. Secondly, Dong Mingzhu, the streamer of Gree, knows more about the products and has made more efforts to promote them, showing the features and advantages of Gree's low-carbon products to consumers and conveying the value of the products. At the same time, through the livestreaming Q&A, the recognition of Gree products was improved, further enhancing consumers' willingness to purchase low-carbon products and, thus, increasing product sales.

In general, with the awareness of green consumption has gradually gained popularity, and green consumption has become the mainstream trend. In order to adapt to the changing market trends, manufacturers must cater to consumer preferences and invest in the production of green, low-carbon products. In addition, consumers' consumption habits are also changing, and livestreaming e-commerce is highly sought after by consumers and has become one of the necessary channels for manufacturers to sell their products. By interacting with anchors in livestreaming, consumers will be more likely to recognize low-carbon products, leading to increased sales.

8. Conclusions

The optimal strategies of the low-carbon efforts and the livestreaming marketing mode of the manufacturer and streamer were studied. Two power structures are considered in the resale and commission cooperation modes. Members' profit functions are established under four scenarios: manufacturer-led in resale mode, streamer-led in resale mode, manufacturer-led in commission mode and streamer-led in commission mode. It also investigates the effects of supply chain power structure, and parameters concluding consumer's low-carbon preference and price sensitivity coefficient, streamer low-carbon promotion sensitivity coefficient, and commission ratio on the optimal product low-carbon level, low-carbon promotion effort level, profit, selling price and wholesale price. The significant findings can be summarized as follows.

(1) Consumers' price sensitivity coefficient is negatively related to the two parties' low-carbon efforts. Both the product's low-carbon level and promotion effort will decrease when the consumer's price sensitivity coefficient increases. That suggests that the more sensitive customers are to the price, the streamer and manufacturer are less motivated to promote low-carbon products. Therefore, it's necessary for the government to reduce taxes or provide financial subsidies to encourage the consumer and the manufacturer. For example, the Chinese government will subsidize consumers who buy new energy vehicles.

(2) Consumers' low-carbon preferences can deeply influence two parties' decisions. As long as it is improved, the low carbon efforts and profits of the two parties will increase, no matter in the resale mode or commission mode, or whether the manufacture-led structure or the streamer-led structure. So consumers' low-carbon preference should be improved through various ways, such as the manufacturer, the streamer and the government. For example, new energy vehicles can be exempted from restrictive measures, such as license plate auctions, lottery, and travel restrictions in China. This government policy has greatly improved the consumer's preference for new energy vehicles.

(3) The streamer's low-carbon effort coefficient is positively related to the manufacturer's profit and product low-carbon level, the streamer's promotion effort and profit, and the product sale price. This indicates that the more significant the impact of the streamer's low-carbon promotion on consumers, the more motivated the manufacturer and streamer are to make low-carbon efforts. So, the streamer can be encouraged to improve its influence of live broadcast skills through such means as cost-sharing with the manufacturer. So that the streamer's promotion effect can be improved, more consumers to buy. This is a win-win cooperation for the streamer and manufacturer.

(4) The commission ratio only affects the manufacturer's effort under the streamer-led structure. It is higher in commission mode when the commission ratio is smaller. The streamer's effort in resale mode is always higher than it is in the commission mode.

(5) The selection of the livestreaming marketing mode of the two parties is determined by the power structure and promotion sensitivity coefficient. When it is in the manufacturer-led structure, if the promotion sensitivity coefficient is smaller, the profits of two parties reach the maximization when choosing the commission mode, and the commission mode is the optimal choice for two parties; otherwise, the resale mode is the optimal choice. When in the streamer-led structure, the two parties' choices are opposite. The streamer prefers the resale mode, while the manufacturer prefers the commission mode.

(6) For the low-carbon effort level, the manufacturer makes the maximal effort in the commission mode, but the streamer makes the maximal effort in the resale mode. Accordingly, the streamer makes the maximal promotion effort in the resale mode, while the manufacturer makes the maximal effort in the commission mode if the promotion sensitivity coefficient is smaller.

Our study provides several managerial insights that may be useful to manufacturers, streamers, and governments.

Firstly, the manufacturer needs to continuously pay attention to consumers' low-carbon needs and market trends and adjust the low-carbon strategies in time. As for the government, it is necessary to take measures to make more consumers aware of low-carbon products, which also can motivate manufacturers to improve low-carbon technologies and achieve sustainable economic and social development. Secondly, manufacturers should focus on their position in the supply chain and the streamer's influence when choosing a cooperation mode. For example, when a manufacturer dominates the market, choosing the commission model is beneficial to increase profits if working with tail streamers; the resale model is the best choice if working with head streamers. Similarly, streamers should be concerned about their place in the supply chain. For example, the resale mode is best chosen when the streamer dominates the market.

Livestreaming marketing is now a new sales trend; our study provides theoretical support for strategies of low-carbon and the selection of livestreaming marketing modes. It is worth stating that there are some limitations to this study. Firstly, we assume that the commission ratio is given exogenously, but sometimes it is bargained by the two parties. Secondly, we find that in actual operation, besides livestreaming sales, manufacturers often have other sales channels, and the channels often have interactions with each other. Finally, corporate social responsibility(CSR) is also important for the low-carbon strategy. However, due to spatial constraints, we will further study the optimal low-carbon strategies of the manufacturer and the streamer when the manufacturer has two channels. And the cooperation mechanism between the manufacturer and the streamer when considering the CSR.

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Appendix A. Proofs

Proof of Lemma 1. With Equation (3), we can obtain $H_1 = \begin{bmatrix} -2\mu & \varphi \\ \varphi & -1 \end{bmatrix}$. From Assumption 4, H_1 is a negative definite matrix. Hence, π_l^{wm} is concave in k and s. Similarly, with

Equation (2), we can obtain $H_2 = \begin{bmatrix} -\frac{2\mu^2}{-\varphi^2+2\mu} & \frac{\mu\eta}{-\varphi^2+2\mu} \\ \frac{\mu\eta}{-\varphi^2+2\mu} & -1 \end{bmatrix}$. From Assumption 4, H_2 is also a negative definite matrix. Hence, π_m^{wm} is concave in w and e. Let $\frac{\partial \pi_l^{wm}}{\partial k} = 0$, $\frac{\partial \pi_l^{wm}}{\partial s} = 0$, then the best response of streamer is $k = \frac{\eta e - \mu w + \varphi s + a}{2\mu}$,$s = k\varphi$. Bring k and s to Equation (2), and let $\frac{\partial \pi_m^{wm}}{\partial w} = 0$, $\frac{\partial \pi_l^{wm}}{\partial e} = 0$, then we can obtain $w^{wm*},\ e^{wm*},\ k^{wm*},\ s^{wm*},\ p^{wm*}$. □

Proof of Lemma 2, 3, 4. The process of proving Lemma 2, 3, and 4 is identical to that of Lemma 1.

Proof of Proposition 1. $\frac{\partial e^{wm*}}{\partial \mu} = -\frac{4a\eta}{(\eta^2+2\varphi^2-4\mu)^2} < 0$, $\frac{\partial k^{wm*}}{\partial \mu} = -\frac{4a}{(-\eta^2-2\varphi^2+4\mu)^2} < 0$, $\frac{\partial s^{wm*}}{\partial \mu} = -\frac{4\varphi a}{(-\eta^2-2\varphi^2+4\mu)^2} < 0$. □

Proof of Proposition 2. $\frac{\partial e^{wm*}}{\partial \eta} = \frac{a(\eta^2-2\varphi^2+4\mu)}{(-\eta^2-2\varphi^2+4\mu)^2} > 0$, $\frac{\partial w^{wm*}}{\partial \eta} = \frac{2a(-\varphi^2+2\mu)\eta}{\mu(\eta^2+2\varphi^2-4\mu)^2} > 0$, $\frac{\partial k^{wm*}}{\partial \eta} = \frac{2a\eta}{(-\eta^2-2\varphi^2+4\mu)^2} > 0$, $\frac{\partial p^{wm*}}{\partial \eta} = \frac{2a(-\varphi^2+3\mu)\eta}{\mu(-\eta^2-2\varphi^2+4\mu)^2} > 0$, $\frac{\partial s^{wm*}}{\partial \eta} = \frac{2\varphi a\eta}{(-\eta^2-2\varphi^2+4\mu)^2} > 0$. □

Proof of Proposition 3. $\frac{\partial e^{wm*}}{\partial \varphi} = \frac{4\varphi a\eta}{(\eta^2+2\varphi^2-4\mu)^2} > 0$, $\frac{\partial w^{wm*}}{\partial \varphi} = \frac{2a\varphi\eta^2}{\mu(\eta^2+2\varphi^2-4\mu)^2} > 0$, $\frac{\partial k^{wm*}}{\partial \varphi} = \frac{4\varphi a}{(-\eta^2-2\varphi^2+4\mu)^2} > 0$, $\frac{\partial p^{wm*}}{\partial \varphi} = \frac{2a\varphi(\eta^2+2\mu)}{\mu(\eta^2+2\varphi^2-4\mu)^2} > 0$, $\frac{\partial p^{wm*}}{\partial \varphi} = \frac{a(-\eta^2+2\varphi^2+4\mu)}{(-\eta^2-2\varphi^2+4\mu)^2} > 0$. □

Proof of Proposition 4. $\frac{\partial e^{wl*}}{\partial \mu} = -\frac{4a\eta}{(-2\eta^2-\varphi^2+4\mu)^2} < 0$, $\frac{\partial w^{wl*}}{\partial \mu} = -\frac{4a}{(-2\eta^2-\varphi^2+4\mu)^2} < 0$, $\frac{\partial s^{wl*}}{\partial \mu} = -\frac{4a\varphi}{(2\eta^2+\varphi^2-4\mu)^2} < 0$. □

Proof of Proposition 5. $\frac{\partial e^{wl*}}{\partial \eta} = \frac{a(2\eta^2-\varphi^2+4\mu)}{(2\eta^2+\varphi^2-4\mu)^2} > 0$, $\frac{\partial w^{wl*}}{\partial \eta} = \frac{4a\eta}{(-2\eta^2-\varphi^2+4\mu)^2} > 0$, $\frac{\partial k^{wl*}}{\partial \eta} = \frac{2a\eta\varphi^2}{(2\eta^2+\varphi^2-4\mu)^2\mu} > 0$, $\frac{\partial p^{wl*}}{\partial \eta} = \frac{2a\eta(\varphi^2+2\mu)}{(2\eta^2+\varphi^2-4\mu)^2\mu} > 0$, $\frac{\partial s^{wl*}}{\partial \eta} = \frac{4a\varphi\eta}{(2\eta^2+\varphi^2-4\mu)^2} > 0$. □

Proof of Proposition 6. $\frac{\partial e^{wl*}}{\partial \varphi} = \frac{2a\eta\varphi}{(-2\eta^2-\varphi^2+4\mu)^2} > 0$, $\frac{\partial w^{wl*}}{\partial \varphi} = \frac{2a\varphi}{(-2\eta^2-\varphi^2+4\mu)^2} > 0$, $\frac{\partial k^{wl*}}{\partial \varphi} = -\frac{2a(\eta^2-2\mu)\varphi}{(2\eta^2+\varphi^2-4\mu)^2\mu} > 0$, $\frac{\partial s^{wl*}}{\partial \varphi} = \frac{a(-2\eta^2+\varphi^2+4\mu)}{(-2\eta^2-\varphi^2+4\mu)^2} > 0$, $\frac{\partial p^{wl*}}{\partial \varphi} = -\frac{2a(\eta^2-3\mu)\varphi}{(2\eta^2+\varphi^2-4\mu)^2\mu} > 0$. □

Proof of Proposition 7. $\frac{\partial e^{am*}}{\partial \mu} = \frac{2\eta(\theta-1)a}{(\eta^2\theta-2\theta\varphi^2-\eta^2+2\mu)^2} < 0$, $\frac{\partial p^{am*}}{\partial \mu} = -\frac{2a}{(\eta^2\theta-2\theta\varphi^2-\eta^2+2\mu)^2} < 0$, $\frac{\partial s^{am*}}{\partial \mu} = -\frac{2a\theta\varphi}{(\eta^2\theta-2\theta\varphi^2-\eta^2+2\mu)^2} < 0$. □

Proof of Proposition 8. $\frac{\partial e^{am*}}{\partial \eta} = -\frac{a(\theta-1)(-\eta^2\theta-2\theta\varphi^2+\eta^2+2\mu)}{(\eta^2\theta-2\theta\varphi^2-\eta^2+2\mu)^2} > 0$, $\frac{\partial p^{am*}}{\partial \eta} = \frac{2a\eta(1-\theta)}{(\eta^2\theta-2\theta\varphi^2-\eta^2+2\mu)^2} > 0$, $\frac{\partial s^{am*}}{\partial \eta} = \frac{2\eta a\theta\varphi(1-\theta)}{(\eta^2\theta-2\theta\varphi^2-\eta^2+2\mu)^2} > 0$. □

Proof of Proposition 9. $\frac{\partial e^{am*}}{\partial \varphi} = \frac{4a\theta\varphi(1-\theta)\eta}{(\eta^2\theta-2\theta\varphi^2-\eta^2+2\mu)^2} > 0$, $\frac{\partial p^{am*}}{\partial \varphi} = \frac{4a\theta\varphi}{(\eta^2\theta-2\theta\varphi^2-\eta^2+2\mu)^2} > 0$, $\frac{\partial s^{am*}}{\partial \varphi} = \frac{a\theta(\eta^2\theta+2\theta\varphi^2-\eta^2+2\mu)}{(\eta^2\theta-2\theta\varphi^2-\eta^2+2\mu)^2} > 0$. □

Proof of Proposition 10. According to Lemma 3, we can obtain $\eta^2\theta - \eta^2 - 2\theta\varphi^2 + 2\mu > 0$. Because $\eta^2\theta - \eta^2 < 0$, so $-\theta\varphi^2 + \mu > 0$. Hence, $\frac{\partial e^{am*}}{\partial \theta} = -\frac{2\eta a(-\varphi^2+\mu)}{(\eta^2\theta-2\theta\varphi^2-\eta^2+2\mu)^2} < 0$, $\frac{\partial s^{am*}}{\partial \theta} = \frac{a\varphi(-\eta^2+2\mu)}{(\eta^2\theta-2\theta\varphi^2-\eta^2+2\mu)^2} > 0$. □

Proof of Proposition 11. $\frac{\partial e^{al*}}{\partial \mu} = \frac{[(-1+\theta)^2\eta^4+4\mu\eta^2(-1+\theta)+\varphi^2\theta\eta^2(1-\theta)+4\mu^2](-1+\theta)a\eta}{2[(-1+\theta)^2\eta^4+4\mu(-1+\theta)\eta^2+2\mu(-\varphi^2\theta+2\mu)]^2} < 0$, $\frac{\partial p^{al*}}{\partial \mu} = -\frac{a[(-1+\theta)^2\eta^4+4\mu\eta^2(-1+\theta)+\varphi^2\theta\eta^2(1-\theta)+4\mu^2]}{2[(-1+\theta)^2\eta^4+4\mu(-1+\theta)\eta^2+2\mu(-\varphi^2\theta+2\mu)]^2} < 0$, $\frac{\partial s^{al*}}{\partial \mu} = \frac{2a\theta\varphi[(-1+\theta)^2\eta^4-4\mu^2]}{[(-1+\theta)^2\eta^4+4\mu(-1+\theta)\eta^2+2\mu(-\varphi^2\theta+2\mu)]^2} < 0$. □

Proof of Proposition 12. $\frac{\partial e^{al*}}{\partial \varphi} = \frac{4\varphi\theta\mu\eta a(1-\theta)[(\theta-1)\eta^2+2\mu]}{[(-1+\theta)^2\eta^4+4\mu(-1+\theta)\eta^2-2\varphi^2\theta\mu+4\mu^2]^2} > 0$, $\frac{\partial p^{al*}}{\partial \varphi} = \frac{4a\varphi\theta\mu[(-1+\theta)\eta^2+2\mu)]}{[(-1+\theta)^2\eta^4+4\mu(-1+\theta)\eta^2-2\varphi^2\theta\mu+4\mu^2]^2} > 0$, $\frac{\partial s^{al*}}{\partial \varphi} = \frac{2a\theta\mu[(-1+\theta)^2\eta^4+4\mu(-1+\theta)\eta^2+2\varphi^2\theta\mu+4\mu^2]}{[(-1+\theta)^2\eta^4+4\mu(-1+\theta)\eta^2-2\varphi^2\theta\mu+4\mu^2]^2} > 0$. □

Proof of Proposition 13. $s^{wm*} - s^{am*} = \frac{\varphi a(1-2\theta)(-\eta^2+2\mu)}{(-\eta^2-2\varphi^2+4\mu)(\eta^2\theta-2\theta\varphi^2-\eta^2+2\mu)} > 0$, thus, $s^{wm*} > s^{am*}$.

$e^{wm*} - e^{am*} = \frac{2a\eta(2\theta-1)(-\varphi^2+\mu)}{(-\eta^2-2\varphi^2+4\mu)(\eta^2\theta-2\theta\varphi^2-\eta^2+2\mu)}$, since $0 < \theta < 0.5$, thus, when $\varphi < \sqrt{\mu}$, $e^{wm*} < e^{am*}$; otherwise, $e^{wm*} > e^{am*}$. □

Proof of Proposition 14. $e^{wl*} - e^{al*} = \frac{\eta a}{-2\eta^2-\varphi^2+4\mu} + \frac{a\eta(\theta-1)[(\theta-1)\eta^2+\mu]}{(\theta-1)^2\eta^4+4\mu(\theta-1)\eta^2-2\mu\theta\varphi^2+4\mu^2}$, let $e^{wl*} > e^{al*}$, then we can obtain $\frac{\eta a}{-2\eta^2-\varphi^2+4\mu} > -\frac{a\eta(\theta-1)[(\theta-1)\eta^2+\mu]}{(\theta-1)^2\eta^4+4\mu(\theta-1)\eta^2-2\mu\theta\varphi^2+4\mu^2}$. Thus, when $\theta > \theta'$, then $e^{wl*} > e^{al*}$, otherwise $e^{wl*} < e^{al*}$.

$s^{wl*} - s^{al*} = -\frac{a\varphi[(\theta-1)^2\eta^4+\mu(4\theta-1)\eta^2-\mu^2(4\theta-1)]}{2[(\theta-1)^2\eta^4+4\mu(\theta-1)\eta^2+\mu(-2\theta\varphi^2+4\mu)](-4\eta^2-2\varphi^2+8\mu)} > 0$, thus, $s^{wl*} > s^{al*}$. □

Proof of Proposition 15. $p^{wm*} - p^{am*} = \frac{a(-\varphi^2+3\mu)}{\mu(-\eta^2-2\varphi^2+4\mu)} - \frac{a}{\eta^2\theta-2\theta\varphi^2-\eta^2+2\mu} > 0$,

$p^{wl*} - p^{al*} = \frac{(\eta^2-3\mu)a}{(2\eta^2+\varphi^2-4\mu)\mu} - \frac{(\theta-1)a\eta^2+2a\mu}{(\theta-1)^2\eta^4+4\mu(\theta-1)\eta^2-2\mu\theta\varphi^2+4\mu^2} > 0$.

Thus, $p^{wm*} > p^{am*}$, $p^{wl*} > p^{al*}$. □

Proof of Proposition 16. $\pi_m^{wm*} - \pi_m^{am*} = \frac{a^2(2\theta-1)(-\varphi^2+\mu)}{(-\eta^2-2\varphi^2+4\mu)(\eta^2\theta-2\theta\varphi^2-\eta^2+2\mu)}$, thus, when $\varphi < \sqrt{\mu}$, then $\pi_m^{wm*} < \pi_m^{am*}$, otherwise, $\pi_m^{wm*} > \pi_m^{am*}$.

$\pi_l^{wl*} - \pi_l^{al*} = \frac{[(\theta-1)^2\eta^4+\mu(4\theta-1)\eta^2-\mu^2(4\theta-1)]a^2}{[(\theta-1)^2\eta^4+4\mu(\theta-1)\eta^2+\mu(-2\theta\varphi^2+4\mu)](-4\eta^2-2\varphi^2+8\mu)} > 0$, thus, $\pi_l^{wl*} > \pi_l^{al*}$. □

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