


Research Article

Joint Optimization Decision of Online Retailers' Pricing and Live-Streaming Effort in the Postepidemic Era

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The isolation requirements of the coronavirus epidemic and the intuitive display advantages of live-streaming have led to an increasing number of retailers shifting to social live-streaming platforms and e-commerce live-streaming platforms to promote and sell their products in real time. However, the provision of live-streaming services will also incur high live-streaming effort costs. In this paper, we develop two decision models for retailers to sell goods through a single online shop and both online shop and live-streaming room; we also present the optimal decisions of pricing and live-streaming efforts. Furthermore, we identify the profitability conditions for retailers to determine when to provide live-streaming services. In addition, we examine the impact of the provision of live-streaming services on the optimal price and live-streaming effort. We obtain three findings. First, there is a unique optimal decision on the price and live-streaming effort under certain conditions. Second, when the effect coefficient of the live-streaming room reaches a certain threshold, there are enough customers who enter the live-streaming room to watch and buy and it is profitable for retailers to provide live-streaming service. Finally, the optimal price and live-streaming effort increase with the increase in average return loss, the effect coefficient of live-streaming effort, and the extra return rate and decrease with the increase in the proportion of customers who choose to buy in the online shop and the price discount coefficient in the live-streaming room.

1. Introduction

Since the beginning of 2020, the COVID-19 pandemic has had a severe impact on the global economy. China's emerging live-streaming (LS) e-commerce industry has witnessed explosive growth amid the COVID-19 pandemic, thus creating new growth opportunities for a wide range of businesses and injecting new impetuses into the economy.

China has resumed work and production, and its economic recovery is faster than that of the world. Under strict prevention and control policy, the domestic epidemic situation has stabilized, and it is the first to enter the "post-epidemic era." The so-called postepidemic era is not that the epidemic we originally imagined completely disappeared, and everything returned to the previous state. It is that the epidemic fluctuates from time to time and with small-scale outbreaks at any time, returning from foreign countries and

seasonal outbreaks, and the delay is long. Time has a profound impact on all aspects [1].

China's LS industry has become an important platform for economic recovery. LS surged in 2020. LS users in China reached 617 million as of December 2020, according to the 2020 China Statistical Report on Internet development released by the China Internet Network Information Centre. Statistics show that 66.2 percent of e-commerce LS users shopped at least once via e-commerce LS, 17.8 percent of whom spent more than one-third of their total expenses of online shopping via e-commerce LS. The e-commerce LS activates users' perceptual consumption through "content-grass," professional selection, intuitive display, and real-time interaction, which can reduce circulation costs, save the cost of information communication, greatly improve the purchase conversion rate and user experience, and benefit all parties in the industry chain. Meanwhile, many subsidiary

forms and participants have been derived and developed. In addition to traditional brands and LS platforms (including content platforms and trading platforms), some emerging brands, live commerce streamers, e-commerce MCN (MultiChannel Network) institutions, and third-party streaming service providers, etc., are also seizing the opportunity for rapid development [2].

The typical LS e-commerce session involves celebrities promoting and selling goods while answering questions from an online audience, with everything taking place in real time via devices such as smartphones. LS is increasingly gaining popularity as a new online shopping platform among Chinese netizens, creating a significant market worth of more than 970 billion yuan (\$149.9 billion) in 2020. According to a survey conducted by the China Consumers Association, e-commerce giant Alibaba's Taobao Live has taken the lion's share of live-streaming, as 68.5 percent of consumers use the service. Short video platforms, Douyin and Kuaishou, have taken second and third spots, respectively. Other large Chinese Internet and e-commerce players, such as JD.com, have also thrown their hats into the ring. Viya, one of China's top e-commerce live streamers, sold over 1.1-billion-yuan worth of merchandise on November 10 last year, which earned her 450,000 new fans [3]. The Gree Electric Appliances Chairwoman Dong Mingzhu, known as the mainland's "home appliances queen," sold 310 million yuan of goods in a three-hour LS event in Kuaishou in May 2020, showing the power of the sales channel in China.

Through the LS shopping function, sellers can use real video to present products and interact with potential buyers. Consumers can also express their opinions and post their comments on a real-time basis [4]. Moreover, in the LS room, consumers always want a more intuitive understanding of the actual situation of the product and obtain a certain price discount or coupon deduction. In contrast, online retailers always want to obtain higher LS sales and profits with lower LS effort costs and higher prices. However, when many online retailers request Internet celebrities or MCNs to live stream their products, they often must pay high agency fees. The sales prices are also kept low. If the sales amount does not meet the expectation, it may cause significant losses.

Therefore, in this study, we consider the online retailer live stream and pricing by themselves. They purchase LS equipment to build LS rooms, participate in LS training, take various promotion measures, and live streams online for several hours every day to improve their influence and skills in LS sales continuously. Online retailers will face the following three problems in e-commerce LS retailing:

- (1) How can an online retailer determine a joint optimal decision of pricing and LS effort?
- (2) What is the profitable condition for an online retailer to provide LS service?
- (3) How does the provision of LS service affect the retailer's optimal decisions on pricing and LS effort?

To answer these questions, we develop analytical models to present the optimal price and LS effort decisions before

and after providing LS service. Then, we identify the profitability conditions for an online retailer to provide LS service by comparing the maximum profits. In addition, we examine the impact of the provision of LS service on the retailer's optimal decisions.

Our first main finding is that if the effect coefficient of LS effort is less than a certain threshold or the unit cost and effect coefficient of LS effort, the price sensitivity and the return rate satisfy a specific relationship, there is a unique joint optimal decision of pricing and LS effort.

Our second result is that it is not always profitable for retailers to provide LS service. When the effect coefficient of the LS room reaches a certain threshold, there are enough customers who enter the LS room to watch and buy, the total demand and profit increase, and it is profitable for retailers to provide LS service.

Finally, the optimal price and LS effort increase with the increase in the average return loss, the effect coefficient of LS effort, and the extra return rate and decrease with the increase in the proportion of customers who choose to buy in the online shop and the price discount coefficient in the LS room.

The main contributions of this paper are described as follows:

- (1) To the best of our knowledge, this paper is the first to explore the optimal price and LS effort in e-commerce retailing. Prior studies mainly focus on the impact of LS on consumers' purchase intention or influencing factors of customers watching LS.
- (2) We consider the proportion of consumers who transfer from online shop to LS room to purchase goods, which is more in line with the fact that some consumers are not sensitive to LS price and LS effort and will not transfer.
- (3) When constructing the decision-making model, we pay attention to the difference in online return rate between the online shop and the LS room, the benefit and cost of providing LS service, and the customer's purchase choice in the LS room or directly in the online shop, making the research results closer to corporate practice.

The remainder of this paper is organized as follows. Related studies are reviewed in Section 2, while the decision models are built and solved before and after providing LS service in Section 3. The numerical test is presented in Section 4. Finally, conclusions and future research directions are discussed in Section 5.

2. Literature Review

This section sheds light on two streams of literature. The first stream addresses pricing and service or sales effort decisions, and the second stream addresses live-streaming.

Many works have considered the pricing and service or sales effort decisions in a supply chain from all aspects except live-streaming, such as manufacturer-giant retailers [5], complementary products [6], fair preference behavior [7],

BOPS mode [8, 9], capital constraint relief [10], free-riding [11], and freshness preservation [12]. Furthermore, Li et al. [13] found that the optimal retail price and sales effort level only depend on the effort cost under the integrated supply chain model. In a decentralized supply chain, the effort level is related to the wholesale price, effort cost, and free-riding coefficient. Chen et al. [14] pointed out that the uncertainty of sales effort elasticity significantly impacts pricing and effort decisions. In contrast, the uncertainty of price elasticity has a moderate impact on these decisions. Wang and Li [15] indicated that the platform's service level is lower, and profit is higher in the mode dominated by the dominant platform. Furthermore, the sales price and the platform's service and profit will increase with the growth of the commission and decrease with the service cost elasticity coefficient. Kong et al. [16] found that the optimal price and service level correlate positively in centralization, and the relation relies on consumers' price sensitivity in decentralization. Obviously, the above literature on pricing and service or sales effort decisions are all researches on supply chain optimization involving two or more companies, rather than research on decision optimization within a single company, and the research fields of the above literature do not involve e-commerce live-streaming. And this study is a joint optimization decision of a single online retailer's pricing and live-streaming effort.

The research on live-streaming mainly focuses on the live-streaming influencing factors of customers' watching and consumers' purchase intention. For example, the influencing factors of customers watching live-streaming are streamer motives [17, 18], viewer engagement [19–23], social viewing strategy [24, 25], IT affordance [26], viewers' social interaction in paid gifting [27, 28], popularity of video content [29], and reward income sharing [30]. In addition, many scholars have begun to study consumers' purchase intention in live-streaming commerce; for example, Gong et al. [31] examined the impact of live-streaming scene atmosphere clues on consumers' impulsive purchase intention. Hou et al. [32] found that sex and humor appeals, social status display, and interactivity play considerable roles in viewers' behavioral intentions in live-streaming and that their effects vary across different live-streaming types. Dong et al. [33] pointed out that the ultimate success of the mobile live video platform depends on users' repeated consumption intention. Liu et al. [34] verified the influence of the identity of the influencer image and product image on the influence of the influencer's information source characteristics and consumers' perception of practical shopping value. Xu et al. [35] pointed out that streamer attractiveness, parasocial relationships, and information quality directly affect cognitive assimilation and arousal. Park and Lin [36] proposed that Internet celebrities positively affect attracting viewers and increasing the possibility of purchases. Wang et al. [37] found that consumers are willing to purchase products in live-streaming commerce because of the appropriate information about the products and the enjoyable shopping atmosphere. Lu and Chen [38] proposed that live-streaming can help reduce product uncertainty and cultivate trust for consumers with similar physical traits and values. Huang

and Suo [39] confirmed that price promotion, time pressure, interpersonal interaction, and visual appeal significantly affect consumer impulse buying decisions. The above literature is mostly empirical research on the impact of live-streaming on customer behavior and does not involve optimization decisions on pricing and live-streaming effort.

In the postepidemic era, live-streaming e-commerce is favored by an increasing number of retailers and consumers because of the intuitive product display and explanatory effect of one-to-many voice and image. However, the joint optimal decision of pricing and live-streaming effort has not yet been studied. Therefore, this research aims to fill the gap. In this paper, we develop two decision models for retailers to sell goods through a single online shop and both online shop and live-streaming room and identify the profitability conditions for an online retailer to provide LS service. This study contributes to the literature on e-commerce live-streaming by the joint optimization decision of pricing and live-streaming effort. This study also provides decision support for retailers to implement e-commerce live-streaming.

3. Model Building

We assume that an online retailer sells products through an online shop. If he provides LS, he can sell products through an online shop and LS room, and the retailer or his salesperson acts as the streamer; otherwise, he sells products through the online shop.

Some customers will consider all available channels when making a purchase, while some customers will only make a purchase on fixed channels that they are familiar with [40]. Moreover, customers can place orders in the online shop 24 hours a day, but the streamer cannot live stream and sell products in the LS room for 24 hours. Therefore, after the retailer provides the LS service, not all consumers switch to buying in the LS room, there are still some consumers who cannot wait for the LS period or are insensitive to price or more confident in product quality, or do not have enough mobile data to watch live-streaming or just old-fashioned and choose to buy in the online shop.

In the LS room, consumers can have a more intuitive and detailed understanding of the products, such as the colors, styles, materials, application scenarios, and overall effects of clothes or shoes through the streamer's trial, try-on, and voice explanation of the products. Thus, the return rate is relatively lower than that of only looking at the pictures and texts when buying in the online shop. Similar to Cao et al.'s definition of extra unit sourcing cost for products sold through the Store channel [40], without loss of generality, we define the return rate of buying in the LS room as 0 such that it simply represents the extra return rate of buying in the online shop.

Generally, the e-commerce industry regards the return loss as part of the variable costs, so the return loss caused by the extra return rate of buying in the online shop should be made up by the profit of the products sold in the online shop, that is, average return loss shared by products sold in the online shop.

The notations used in this study and their definitions are detailed in Table 1.

To avoid trivial situations, we make several assumptions in our model: (1) $b < b_L$, customers always think that they can obtain a certain discount when buying in the LS room, so they are willing to wait and buy during the LS period, that is, customers who buy in the LS room are more sensitive to the price; (2) after providing LS service, the proportion of customers who choose to buy in the online shop is α , and the proportion of customers who choose to buy in the LS room is $1 - \alpha$ [11, 40]; and (3) the streamer's trial and explanation of products and the purchasing atmosphere in the LS room help increase demand λe , and the LS effort incur LS effort cost $he^2/2$ [41].

Next, we build and solve the joint decision model of pricing and LS effort before and after providing LS service.

3.1. Before Providing LS Service. Before providing LS service, the retailer only sells products through an online shop, and the LS effort is 0, i.e., $e = 0$. We propose a linear demand function based on previous research and assume that market demand is price sensitive [42]. According to the above statement about the extra return rate of buying in the online shop and the average return loss shared by products sold in the online shop, the return loss caused by the extra return rate θ is shared by the products sold in the online shop, and average return loss shared by products sold in the online shop r as part of the variable costs. Each returned unit generates a net loss to the retailer. Thus, we obtain the following demand function and profit function under channel O (online shop):

$$D_1(p, e) = a - bp, \quad (1)$$

$$\begin{aligned} \Pi_1(p, e) &= (1 - \theta)(p - c - r)D_1(p, e) \\ &= (1 - \theta)(p - c - r)(a - bp). \end{aligned} \quad (2)$$

Theorem 1. Before providing LS service, we obtain the following results:

(i) The optimal price can be obtained as follows:

$$p_1^* = \frac{a + b(c + r)}{2b}. \quad (3)$$

(ii) The optimal demand D_1^* and the maximum profit Π_1^* are described as follows:

$$\begin{aligned} D_1^* &= \frac{1}{2}(a - bc - br), \\ \Pi_1^* &= \frac{(a - bc - br)^2(1 - \theta)}{4b}. \end{aligned} \quad (4)$$

Please refer to the Appendix for all the proofs of the paper. Theorem 1 shows that there always exists a unique optimal price to maximize the retailer's profit before providing LS service.

3.2. After Providing LS Service. After providing LS service, potential market demand for an online shop with a proportion of α still choose to buy in the online shop and potential market demand for an online shop with a proportion of $1 - \alpha$ transfer to buy in the LS room [11, 40]. Then, the potential market demand for online shops decreases to αa , and the potential market demand for LS room increases to $a_L + a(1 - \alpha)$. Thus, similar to Section 3.1, we obtain the demand and profit functions as follows:

$$\begin{aligned} D_O(p, e) &= \alpha a - bp, \\ D_L(p, e) &= a(1 - \alpha) + a_L + e\lambda - p\delta b_L, \\ D_2(p, e) &= D_O(p, e) + D_L(p, e) \\ &= a + a_L - bp + e\lambda - p\delta b_L, \\ \Pi_2(p, e) &= (1 - \theta)(p - c - r)D_O(p, e) + (p - c)D_L(p, e) - \frac{he^2}{2} \\ &= (1 - \theta)(p - c - r)(\alpha a - bp) + (p - c)[a(1 - \alpha) + a_L + e\lambda - p\delta b_L] - \frac{he^2}{2}. \end{aligned} \quad (5)$$

Theorem 2. *The retailer's profit function is jointly concave in p and e given that $\lambda < \sqrt{2bh(1-\theta) + 2hb_L\delta}$, i.e., $|H_2| = 2bh(1-\theta) + 2hb_L\delta - \lambda^2 > 0$ after providing LS service. Moreover, we obtain the following results:*

(i) *The optimal price and LS effort can be obtained as follows:*

$$\begin{aligned} p_2^* &= \frac{a_L h + bh(c+r)(1-\theta) + ah(1-\alpha\theta) - c\lambda^2 + ch\delta b_L}{|H_2|}, \\ e_2^* &= \frac{\lambda[a_L + a(1-\alpha\theta) - b(c-r)(1-\theta) - c\delta b_L]}{|H_2|}. \end{aligned} \quad (6)$$

$$\begin{aligned} D_2^* &= \frac{[bh[a_L + a_L(1-2\theta) - b(c+r)(1-\theta) - a\theta(2-\alpha)] - [aa\theta - b(r-r\theta + c\theta)]\lambda^2 + h\delta b_L[a_L + a(1+\alpha\theta) - b(2c+r-c\theta-r\theta) - c\delta b_L]}{|H_2|}, \\ \Pi_2^* &= \frac{[a^2 h(1-\alpha\theta)^2 + 2a(1-\theta)[ra\lambda^2 - bh(c-r+2ra) - bha\theta(c+r)]a_L h[2b(c-r)(1-\theta) - 3a_L - 2a(1-\alpha\theta)] + c^2 h\delta^2 b_L^2 + 2h\delta b_L[bc(c+r)(1-\theta) - a(c+2ra) + a(c+2r)a\theta + a_L c] + b(1-\theta)[bh(c+r)^2(1-\theta) - 2cr\lambda^2]}{|H_2|}. \end{aligned} \quad (7)$$

Theorem 2 shows that if the effect coefficient of LS effort is less than a certain threshold or the unit cost and effect coefficient of LS effort, the price sensitivity and the extra return rate of buying in the online shop relative to in the LS room satisfy a specific relationship, there is a unique joint optimal decision of pricing and LS effort.

3.3. Comparison and Analysis. In this subsection, we explore the factors that the online retailer must consider when deciding whether to provide LS service and the influence of the LS service on the optimal pricing and LS effort decisions.

Proposition 1. *There exists a unique threshold $\sqrt{(E+F-G)/H}$ if $\lambda > \bar{\lambda}$, $\Pi_2^* > \Pi_1^*$; otherwise, $\Pi_2^* \leq \Pi_1^*$, where $E = 2a_L bh[2a_L + 2b(c-r)(1-\theta) - 2a(1-\alpha\theta)]$, $F = 2bh(1-\alpha)[2b(1-\theta)(c\theta - 2r + \theta r) - a\theta(2-\theta - \alpha\theta)]$, $G = 2h\delta b_L\{(1-\theta)[b^2(c^2 - r^2) - a^2 + 2abr(1-2\alpha)] + bc[c\delta b_L - 2a_L - 2a\theta(1-\alpha)]\}$, $H = (1-\theta)[a^2 + b^2(c-r)^2 - 2ab(c+r-2r\alpha)]$, and $\bar{\lambda} = \sqrt{(E+F-G)/H}$.*

Proposition 1 implies that the maximum profit after providing LS service is not always larger than that before providing LS service. Intuitively, when the effect coefficient of LS effort λ reaches a certain threshold $\bar{\lambda}$, the demand in the LS room and the total profit increase. That is, it is beneficial for the retailer to provide LS service; otherwise, the benefits of LS effort are lower than the cost of LS effort; thus, the total profit decreases, and there is no need to provide LS service.

(ii) *The optimal demand D_2^* and the maximum profit Π_2^* are described as follows:*

Normally, the better the effect coefficient of LS effort, the more consumers who enter the LS room to watch and buy, the higher the weight of the LS room, the more traffic the e-commerce platform distributes, and the more profits increase. This circle is a virtuous circle.

In addition, by the first-order conditions and the envelope theorem, we obtain the following result.

Corollary 1. *Given that $|H_2| > 0$, $\lambda_\delta = 2h[a_L + br(1-\theta) + (1-\alpha\theta)a]$, and $\lambda_\theta = 2hb[a_L + (1-\alpha)a] - 2(\alpha a + br)h\delta b_L$,*

- (i) p_2^*, e_2^* increase in λ
- (ii) p_2^*, e_2^* decrease in α
- (iii) if $\lambda > \sqrt{\lambda_\delta/c}$, p_2^*, e_2^* decrease in δ
- (iv) p_2^*, e_2^* increase in r
- (v) if $\lambda > \sqrt{\lambda_\theta/(\alpha a - bc + br)}$, p_2^*, e_2^* increase in θ

Corollary 1(i) reveals that the optimal price p_2^* and LS effort e_2^* always increase with the effect coefficient of LS effort λ . The greater the effect coefficient of LS effort, the better the effect of LS effort, and the more customers who watch and place orders in the LS room. Thus, the retailer can appropriately increase the sales price and LS effort to gain more profit.

Corollary 1(ii) shows that the optimal price p_2^* and LS effort e_2^* always decrease with the proportion of customers who choose to buy in the online shop after providing LS

TABLE 1: Notations and definitions.

Notation	Definition
p	Price of the product (decision variable)
e	LS effort (decision variable)
c	Cost of the product
a, a_L	Potential market demand for online shop and LS room (the subscript L in a_L means LS room)
b, b_L	Price sensitivity of customers buying in the online shop and in the LS room ($0 < b < b_L$)
δ	Price discount coefficient in the LS room ($0 < \delta < 1$)
λ	Effect coefficient of LS effort
α	Proportion of customers who choose to buy in the online shop after providing LS service ($0 < \alpha < 1$)
θ	The extra return rate of buying in the online shop ($0 < \theta < 1$)
r	Average return loss shared by products sold in the online shop
h	Unit cost of LS effort
D_O, D_L	Potential market demand for online shop and LS room after providing LS service (the subscript O in D_O means online shop)
D_j	Total demand before and after providing LS service ($j = 1, 2$)
Π_j	Total profit before and after providing LS service ($j = 1, 2$)

service α . The greater the proportion of customers who choose to buy in the online shop after providing LS service, the worse the effect of LS effort, and the fewer customers who watch and place orders in the LS room. Therefore, the retailer can reduce the sales price while reducing LS effort to maximize profit.

Corollary 1(iii) shows that if the effect coefficient of LS effort λ reaches a certain threshold $\sqrt{\lambda_\delta/c}$, the optimal price p_2^* and LS effort e_2^* decrease with the price discount coefficient in the LS room δ . When the effect coefficient of LS effort λ is high, the advantages of product display and explanation in the LS room are obvious; the larger the price discount coefficient in the LS room δ , the smaller the discount that consumers obtain. Therefore, the retailer can reduce the sales price to attract customers to buy while reducing the LS effort to reduce the total cost of LS effort.

Corollary 1(iv) indicates that the optimal price p_2^* and LS effort e_2^* always increase with the average return loss shared by each customer who bought in the online shop r . The optimal price can increase the profit of a single item, and the optimal LS effort can increase the purchase conversion rate and reduce returns. Therefore, online retailers can increase the product price and LS effort to compensate for the loss caused by the return.

Corollary 1(v) testifies that if the effect coefficient of LS effort λ reaches a certain threshold $\sqrt{\lambda_\theta/(\alpha a - bc + br)}$, the optimal price p_2^* and LS effort e_2^* increase with the extra return rate of buying in the online shop relative to in the LS room θ . The higher the extra return rate θ , the more obvious the advantages of product display and explanation in the LS room, and the more consumers transfer from the online shop to the LS room to purchase. Therefore, the retailer can increase the sales price and LS effort to obtain more profit.

The extra return rate of buying in the online shop relative to the LS room

4. Numerical Test

In this section, we first verify the profitable condition for the retailer to provide LS service and then examine the impact of the provision of LS service on the retailer's optimal decisions.

According to the model's description in Section 3 and the e-commerce LS industry practices, the data setting for the parameters in the numerical test is as follows: $c = 50$, $\alpha = 0.5$, $\delta = 0.8$, $\theta = 0.3$, $a = 600$, $a_L = 600$, $b = 2$, $b_L = 8$, $r = 30$, $h = 15$, and the value range of λ is set as $[1, 10]$.

Figure 1 shows that when the effect coefficient of LS effort λ reaches the threshold $\bar{\lambda}$, we have $\Pi_2^* > \Pi_1^*$. Therefore, the profitable condition for the retailer to provide LS service is $\lambda > \bar{\lambda}$. The trend of the optimal decisions in Figure 1 is consistent with Proposition 1. Obviously, by enhancing the anchor's personal charm and professional explanation ability, setting up LS room promotions and actively communicating and interacting with fans, the effect coefficient of LS effort can be greatly improved, thereby increasing the purchase conversion rate and product sales.

Figure 2(a) shows that the optimal price p_2^* and LS effort e_2^* increase with the effect coefficient of LS effort λ . A good effect coefficient of LS effort in the LS room can bring good sales. It requires sufficient LS effort but also helps the product to sell at a high price. This is a virtuous circle and highlights the importance of the effect coefficient of LS effort.

Figure 2(b) shows that the optimal price p_2^* and LS effort e_2^* decrease with the proportion of customers who choose to buy in the online shop after providing LS service α . Figure 2(c) shows that the optimal price p_2^* and LS effort e_2^* decrease with the price discount coefficient in the LS room δ . The higher the proportion of online shop customers transferred to the LS room, the lower the optimal price and LS effort, which shows that more customers want to get price concessions in the LS room. Therefore, retailers should not blindly adopt discounted price promotion methods in the LS room. They can consider the promotion strategy of giving

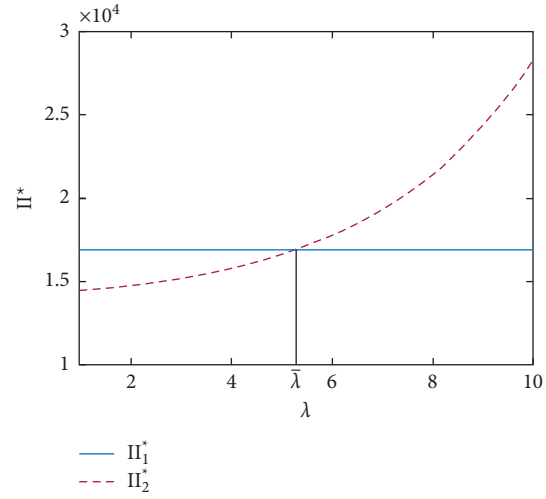


FIGURE 1: Profitable condition for the retailer to provide LS service.

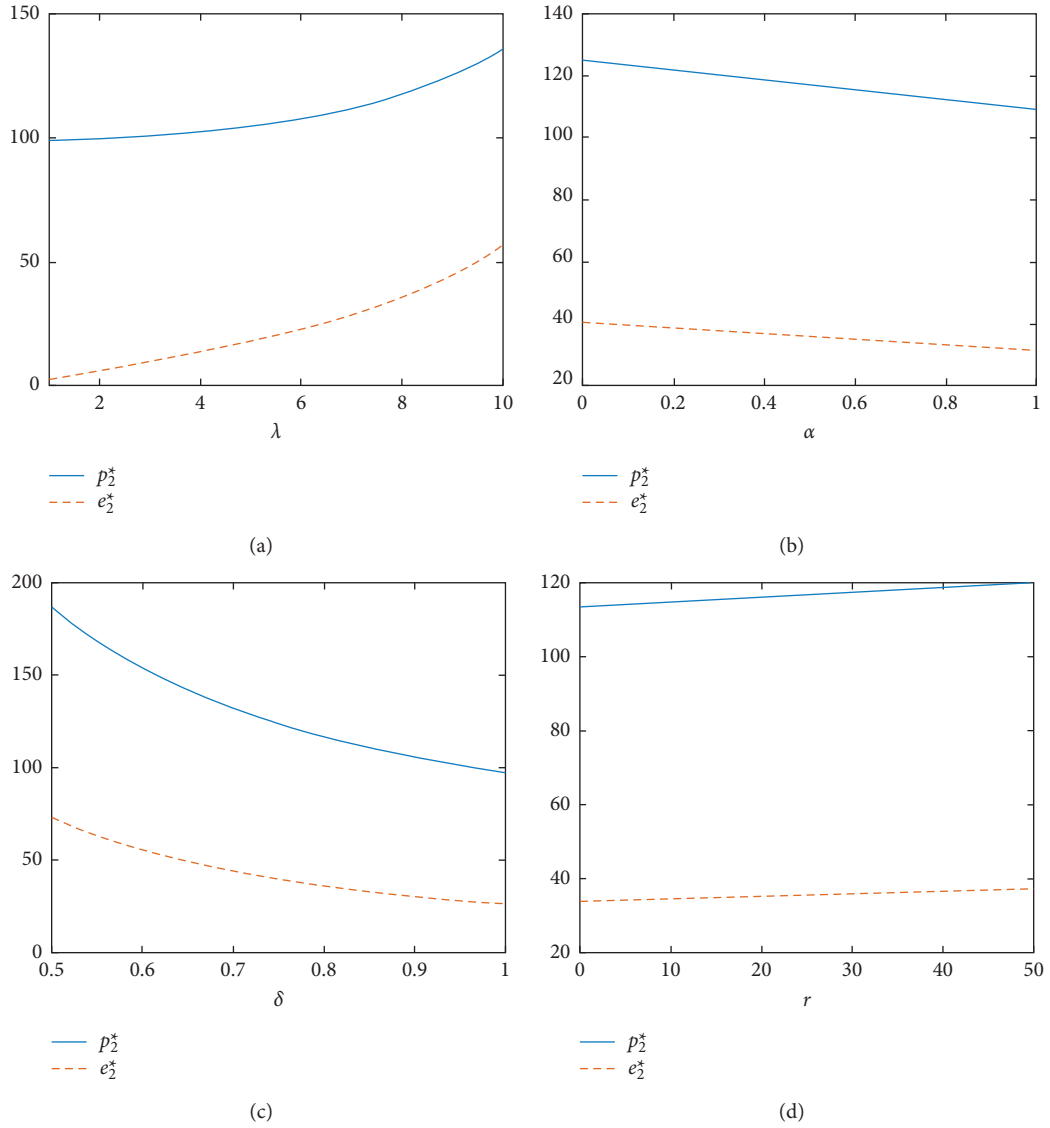


FIGURE 2: Continued.

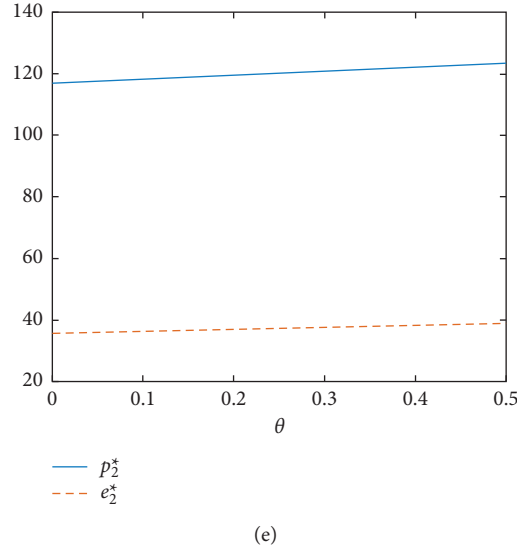


FIGURE 2: The impact of the provision of LS service on optimal decisions.

gifts or selling more and giving more so as not to damage the product price system and dare not invest more in LS. This is a vicious circle, and retailers need to pay attention to this phenomenon.

Figure 2(d) shows that the optimal price p_2^* and LS effort e_2^* increase with the average return loss shared by each customer who bought in the online shop r . Figure 2(e) shows that the optimal price p_2^* and LS effort e_2^* increase with the extra return rate of buying in the online shop relative to the LS room θ . Retailers can reduce the extra return rate of buying in the online shop by purchasing freight insurance, choosing appropriate product packaging methods, and doing strict product quality inspections, thereby reducing the average return loss shared by each customer who bought in the online shop, so as to avoid the loss of profits caused by increased price and LS effort.

Obviously, the trends of all the optimal decisions in Figure 2 are consistent with Corollary 1.

5. Conclusions

The coronavirus pandemic, in fact, propelled people to shop online and watch live-streaming to seek interactive and immersive experiences. Live-streaming e-commerce is a key channel for small brands and farmers to reach consumers, helping a wide range of businesses survive the pandemic. In the postepidemic era, it is very important to study the profitable conditions for retailers to provide live-streaming services and the corresponding optimization decisions. In this study, we develop two decision models for retailers to sell goods through a single online shop and through both online shop and live-streaming room to determine when an online retailer should provide live-streaming services. We identify the joint optimal decision of pricing and live-streaming effort and the profitability condition for the online retailer to provide live-streaming service. Furthermore, we examine the impact of the provision of live-streaming services on the optimal price and live-streaming effort.

We find a unique optimal decision on the price and live-streaming effort under certain conditions. When the effect coefficient of the live-streaming room reaches a certain threshold, it is profitable for the retailer to provide a live-streaming service. In addition, the optimal price and live-streaming effort increase with the increase in the average return loss shared by each customer who bought in the online shop, the effect coefficient of live-streaming effort, and the extra return rate of buying in the online shop relative to in the live-streaming room and decrease with the increase in the proportion of customers who choose to buy in the online shop after providing live-streaming service and the price discount coefficient in the live-streaming room.

This study has the following management implications for live-streaming e-commerce. Successful live-streaming is inseparable from a good live-streaming operation team, the configuration of the live-streaming equipment and the layout of the live-streaming room, and the cultivation of the streamer's live-streaming ability. Therefore, investment in live-streaming efforts makes it not always profitable for retailers to provide live-streaming services. Moreover, retailers should do well in advancing the live-streaming process planning, script design, and field control strategy and design the promotion plan of the live-streaming room to enhance the live-streaming effect and obtain the maximum profit. Furthermore, if the return rate or return loss of the product in the online shop is high, consumers need clearer and more intuitive product displays and explanations. At this time, retailers can provide live-streaming services and increase the price and live-streaming effort. Strict product quality assurance and reasonable packaging and transportation methods and the purchase of freight insurance can help reduce retailers' return losses. Do not blindly adopt the strategy of discounts or direct price reductions in the live-streaming room, and the strategy of giving gifts or buying more and getting more will help protect retailers' product price system. In addition, retailers cannot just provide short videos or live broadcasts and ignore the production of

pictures and texts on product detail pages, thus losing traditional online shopping consumers.

The limitation of this study is that we only consider the situation where retailers provide live-streaming services and do not consider the situation where MCN celebrities or Internet influencers provide live-streaming services. This research direction is important in the future.

In addition, it is a common phenomenon for retailers to entrust celebrities or Internet influencers to clear inventory at low prices through the live-streaming sales mode. However, retailers may lose money due to excessively high live-streaming costs, too few sales, or too low prices. Therefore, the joint optimization decision of pricing, live-streaming effort, and inventory control is also a future research direction.

Appendix

A. All Proofs

Proof of Theorem 1. (i) The second-order derivatives of profit function (2) regarding price p is as follows:

$$\frac{\partial^2 \Pi_1(p, e)}{\partial p^2} = -2b(1 - \theta) < 0. \quad (\text{A.1})$$

Obviously, the profit function has a maximum value. Intuitively, the optimal price $p_1^* = a + bc + br/2b$ can be found by solving the first-order condition $\partial \Pi_1(p, e)/\partial p = 0$.

(ii) Substituting p_1^* into equations (1) and (2), we can obtain the optimal demand $D_1^* = 1/2(a - bc - br)$ and the maximum profit $\Pi_1^* = (a - bc - br)^2(1 - \theta)/4b$.

Proof of Theorem 2. (i) The second-order partial derivatives and Hessian matrix for-profit function (9) regarding price p and LS effort e are as follows:

$$\begin{aligned} \frac{\partial^2 \Pi_2(p, e)}{\partial p^2} &= -2b(1 - \theta) - 2\delta b_L < 0, \\ \frac{\partial^2 \Pi_2(p, e)}{\partial p \partial e} &= \frac{\partial^2 \Pi_2(p, e)}{\partial e \partial p} = \lambda, \\ |H_2| &= \begin{vmatrix} \frac{\partial^2 \Pi_2(p, e)}{\partial p^2} & \frac{\partial^2 \Pi_2(p, e)}{\partial p \partial e} \\ \frac{\partial^2 \Pi_2(p, e)}{\partial p \partial e} & \frac{\partial^2 \Pi_2(p, e)}{\partial e^2} \end{vmatrix} \\ &= \begin{vmatrix} -2b(1 - \theta) - 2\delta b_L & \lambda \\ \lambda & -h \end{vmatrix} \\ &= 2bh(1 - \theta) - \lambda^2 + 2h\delta b_L. \end{aligned} \quad (\text{A.2})$$

Thus, the profit function for selling products through the online shop and LS room is strictly and jointly concave in p and e given that $2bh(1 - \theta) + 2h\delta b_L > \lambda^2$ or $|H_2| > 0$. Intuitively, the optimal price $p_2^* = a_L h + bh(c + r)(1 - \theta) + ah(1 - \alpha\theta) - c\lambda^2 + ch\delta b_L/|H_2|$ and LS effort $e_2^* = \lambda[a_L + a(1 - \alpha\theta) - b(c - r)(1 - \theta) - c\delta b_L]/|H_2|$ can be

obtained by simultaneously solving first-order conditions $\partial \Pi_1(p, e)/\partial p = 0$ and $\partial \Pi_2(p, e)/\partial p = 0$.

(ii) Substituting p_2^* and e_2^* into equations (6) and (7), we can obtain the optimal demand D_2^* and the maximum profit Π_2^* as follows:

$$D_2^* = \frac{\{bh[a + a_L(1-\theta) - b(c+r)(1-\theta) - a\theta(2-\alpha)] - [aa\theta - b(r-r\theta+c\theta)]\lambda^2 + h\delta b_L[a_L + a(1+\alpha\theta) - b(2c+r-c\theta-r\theta) - c\delta b_L]\}}{|H_2|},$$

$$\Pi_2^* = \frac{\{a^2h(1-\alpha\theta)^2 + 2a(1-\theta)[ra\lambda^2 - bh(c-r+2\alpha) - bha\theta(c+r)]a_Lh[2b(c-r)(1-\theta) - 3a_L - 2a(1-\alpha\theta)] + c^2h\delta^2b_L^2 + 2h\delta b_L[bc(c+r)(1-\theta) - a(c+2\alpha) + a(c+2r)\alpha\theta + a_Lc] + b(1-\theta)[bh(c+r)^2(1-\theta) - 2cr\lambda^2]\}/2}{|H_2|} \quad (\text{A.3})$$

Proof of Proposition 1. According to equations (5) and (13), we have the following:

$$\Pi_2^* - \Pi_1^* = \frac{\{2h\delta b_L(1-\theta)[b^2(c^2-r^2) - a^2 + 2abr(1-2\alpha)] + 2h\delta b_L[c\delta b_L - 2a_L - 2a\theta(1-\alpha)] - 2abh(1-\alpha)[2b(1-\theta)(c\theta-2r+\theta r) - a\theta(2-\theta-\alpha\theta)] - 2a_Lbh[2a_L + 2b(c-r)(1-\theta) - 2a(1-\alpha\theta)] + (1-\theta)[a^2 + b^2(c-r)^2 - 2ab(c+r-2\alpha)]\lambda^2/4b}{|H_2|} \quad (\text{A.4})$$

Obviously, if $\lambda > \sqrt{(E+F-G)/H}$, $\Pi_2^* > \Pi_1^*$; otherwise $\Pi_2^* \leq \Pi_1^*$, where $E = 2a_Lbh[2a_L + 2b(c-r)(1-\theta) - 2a(1-\alpha\theta)]$, $F = 2bh(1-\alpha)[2b(1-\theta)(c\theta-2r+\theta r) - a\theta(2-\theta-\alpha\theta)]$, $G = 2h\delta b_L\{(1-\theta)[b^2(c^2-r^2) - a^2 + 2abr(1-2\alpha)] + bc[c\delta b_L - 2a_L - 2a\theta(1-\alpha)]\}$, $H = (1-\theta)[a^2 + b^2(c-r)^2 - 2ab(c+r-2\alpha)]$.

Proof of Corollary 1. When $|H_2| = 2bh(1-\theta) + 2hb_L\delta - \lambda^2 > 0$,

- (i) Due to $\partial p_2^*/\partial\lambda = 2he_2^*/|H_2| > 0$, $\partial e_2^*/\partial\lambda = e_2^*(|H_2| + 2\lambda^2)/\lambda|H_2| > 0$. Thus, p_2^* , e_2^* increase in λ .
- (ii) Due to $\partial p_2^*/\partial\alpha = -ah\theta/|H_2| < 0$, $\partial e_2^*/\partial\alpha = -ah\theta/|H_2| < 0$. Thus, p_2^* , e_2^* decrease in α .
- (iii) Due to $\partial p_2^*/\partial\delta = -hb_L(\lambda_\delta - c\lambda^2)/|H_2|^2$, and $\partial e_2^*/\partial\delta = -hb_L(\lambda_\delta - c\lambda^2)/|H_2|^2$, where $\lambda_\delta = 2h[a_L + br(1-\theta) + (1-\alpha\theta)a]$. Obviously, if $\lambda > \sqrt{\lambda_\delta/c}$, $\partial p_2^*/\partial\delta < 0$ and $\partial e_2^*/\partial\delta < 0$; otherwise, $\partial p_2^*/\partial\delta > 0$ and $\partial e_2^*/\partial\delta > 0$.
- (iv) Due to $\partial p_2^*/\partial r = (1-\theta)bh/|H_2| > 0$, $\partial e_2^*/\partial r = (1-\theta)bh/|H_2| > 0$. Thus, p_2^* , e_2^* increase in r .
- (v) Due to $\partial p_2^*/\partial\theta = h[(\alpha a - bc + br)\lambda^2 - \lambda_\theta]/|H_2|^2$, and $\partial e_2^*/\partial\theta = h[(\alpha a - bc + br)\lambda^2 - \lambda_\theta]/|H_2|^2$, where $\lambda_\theta = 2hb[a_L + (1-\alpha)a] - 2(\alpha a + br)h\delta b_L$. Obviously, if $\lambda > \sqrt{\lambda_\theta/(\alpha a - bc + br)}$, $\partial p_2^*/\partial\theta > 0$ and $\partial e_2^*/\partial\theta > 0$; otherwise, $\partial p_2^*/\partial\theta < 0$ and $\partial e_2^*/\partial\theta < 0$.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Additional Points

Highlights. There is a unique joint optimal decision on the price and live-streaming effort. There is a proportion of consumers considering switching from online shop to live-streaming room. The profitability conditions for the provision of live-streaming service are identified. The impact of live-streaming service on the optimal decisions is analyzed.

Conflicts of Interest

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

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