Research Article

Pricing and Distribution Strategies of Fresh Agricultural Product Supply Chain considering Substitutes

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Received 20 January 2022; Accepted 2 April 2022; Published 4 May 2022

Academic Editor: A. M. Bastos Pereira

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In this article, we study the distribution, ordering, and pricing strategies when the supplier has a limited output and the retailer has substitute suppliers in a fresh agricultural product supply chain. The Stackelberg game method is adopted to study the optimal strategy of suppliers and retailers with suppliers as the leader and retailers as the follower. The results show that the wholesale price and selling price of suppliers are related to the price of substitutes and the substitution rate, the wholesale price and online selling price increase when the retailer introduces high-quality substitutes. When substitutes exist, the supplier is willing to distribute more fresh agricultural products to retailers. As the substitution rate increases, suppliers are willing to distribute more quantities. Therefore, retailers should choose more suppliers and fresh agricultural products with a higher substitution rate.

1. Introduction

Fresh agricultural products are perishable and have a short life cycle, and consumers are more sensitive to the decline in the freshness of fresh agricultural products [1]. Therefore, in order to obtain higher profits, retailers and suppliers usually implement dynamic pricing for fresh agricultural products [2] and consider the freshness of fresh agricultural products and other factors during the sales process [3].

Meanwhile, with the development of e-commerce, more and more suppliers have opened their own direct stores online [4–7]. The model that online and offline sales channels for fresh agricultural products coexist enables supply chain members to have independent pricing and sales channels, so they can get closer to end consumers and understand their preferences and needs. Furthermore, they can better control distribution, inventory, and set reasonable wholesale and sales prices. For consumers, some intermediate links in the supply chain are eliminated, so they can buy the same quality fresh agricultural products at a lower price [8]. However, there is competition between channels [9], and suppliers usually give priority to supplying online channels in order to ensure the sales volume and their own profit of online channels. Furthermore, suppliers have certain uncertainties during the supply process [10]. In reality, the production quantity of fresh agricultural products is affected by multiple factors such as the planting environment, climate of the planting area, the implementation of chemical fertilizers, and manual management as well as by some emergencies like the COVID-19 [11]. The quantity of fresh agricultural products supplied by suppliers will be limited to a certain extent. Under this circumstance, suppliers will reasonably allocate limited fresh agricultural products to obtain higher profits, and retailers will also need to decide how to purchase substitutes to meet the needs of offline consumers.

Currently, there has been a lot of research on the subject of dual-channel supply chains. However, few scholars put suppliers in the perspective of proactively arranging the production and distribution of fresh agricultural products in a planned way. The research that considers the dynamic
pricing and distribution strategies of fresh agricultural product dual-channel supply chain with limited output is not ample, too. Fewer studies consider the presence of alternative suppliers in this situation.

In order to study the pricing problems of suppliers and retailers in the context of allocating limited output and purchasing substitutes, the impact of product substitution rates on the relevant decisions of supply chain members is found out, this paper considers that the quantity of fresh agricultural products supplied by suppliers is limited, and there are competitive suppliers who provide substitutes. The demand of suppliers and retailers is affected by price, substitute price [13], freshness, and random market disturbances. We study suppliers’ distribution of limited fresh agricultural products and retailers’ orders and the dynamic pricing strategy of the dual-channel supply chain.

By considering suppliers’ actively plan and arranging the production and distribution of fresh agricultural products, combined with dynamic pricing and substitutes in dual-channel supply chains, this article studies the pricing strategy and supply competition between suppliers’ opening online direct sales channels and traditional retail channels, and retailer’s ordering strategy. It can eliminate the negative impact of suppliers having to make reactive contingency strategies when production is reduced due to severe weather and unexpected circumstances (e.g., COVID-19.). Furthermore, our results can help supply chain members make decisions to earn more profits.

The key contributions of this article are as follows: First, we provide theoretical support for supplier distribution and retailer ordering as well as the dynamic pricing strategy of supply chain members to a certain extent. Second, when studying the supply chain of fresh agricultural products, this article considers the freshness characteristics of fresh agricultural products and incorporates the limited output into the model constraints, which makes the article have certain practical significance.

The rest of this study is organized as follows: In Section 2, we briefly review the relevant literature. The main research issues, notation, and assumptions are presented in Section 3. Section 4 establishes and solves the models. Section 5 provides numerical examples. Section 6 presents the conclusions and further discussion.

2. Literature Review

The literature related to this article mainly involves studies on supply chain pricing of fresh agricultural products, dual-channel supply chain, limited production, and dual-source procurement.

2.1. Pricing of Fresh Agricultural Products. The pricing of fresh agricultural products has always been one of the focuses of research in the field of fresh agricultural product supply chain [14–16]. The research theories and practices such as single pricing [17], two-stage pricing [18], and dynamic pricing [19] are relatively mature. Due to the quality and quantity loss of fresh agricultural products over time, dynamic pricing is one of the key research directions in practical business management and academic research. Herbon and Khmelnitsky [20] aimed at maximizing the retailer’s profit, considered the retailer’s optimal replenishment time and dynamic pricing decisions, and compared them with single pricing. They found that dynamic pricing is more profitable than single pricing. Tunuguntla et al. [21] studied the dynamic pricing decision problem when perishable products are sold online. They considered that under multiperiod stochastic dynamic programming, retailers use search advertising to attract customers and make up for the cost of search bidding by adopting dynamic pricing. Yu et al. [22] studied the responsive pricing problem with considering the uncertain demand, and they also took utility into account when constructing the demand function. However, there are few studies on the dynamic pricing of dual-channel fresh agricultural product supply chains, and few articles consider both suppliers’ limited output and the existence of alternative pricing strategies.

In addition, due to the characteristics of the perishable and short sales cycle of fresh products, many scholars also consider the characteristics of fresh products. Among them, some scholars directly introduce the characteristics of fresh products into the demand functions and study the pricing of fresh products by constructing relevant demand functions. Piramuthu and Zhou [23] used an exponential function to describe the relationship between product quantity depletion, value depletion, and time. They also studied inventory management decisions for perishable products. Wang and Jiang [24] considered that consumer demand is affected by price and time, assuming that fresh food retailers can adjust prices before the end of sales, and studied the problem of optimal price and order quantity. He et al. [25] formulated the demand function of the products’ real-time quality. For a more detailed discussion about fresh products, the reader is referred to He et al. [26] and the references therein.

2.2. Dual-Channel Supply Chain. With the development of e-commerce, suppliers are faced with three different channel choices: retailer channel sales, online direct sales channels, and dual-channel sales of fresh agricultural products. Some scholars have compared and analyzed different channel selection strategies. Zhang et al. [27] studied demand distribution, profit behavior, optimal pricing strategy, and channel selection strategy through three case studies for a three-channel supply chain in which manufacturers have traditional channels, direct sales network channels, and online shopping platforms. Yang et al. [28] considered these sales models and investigated the optimal pricing strategies. They compared the dual-channel model with the O2O model and found that the dual-channel mode will be better for the supplier in decentralized systems. Some scholars have studied the impact of manufacturers’ online channel invasion on the original supply chain. For example, Li et al. studied the pricing and greenness of dual-channel supply chain members and pointed out that when the greening cost is greater than a given threshold, manufacturers will not open direct sales channels. Wang et al. [29] researched the
“buy online and pick up in store” (BOPS) mode. They used the Stackelberg game model to analyze two competing retailers, which one is the follower. The results showed that the follower will price higher when the following retailer earns per unit additional profit from cross-selling is low. Zheng et al. [30] and Xu et al. [31] also studied the pricing of different channels and supply chain coordination from the perspective of channel competition in the supply chain.

Few articles have studied supplier distribution, retailer ordering, and pricing strategies for dual-channel supply chains in situations where supplier production is constrained and alternative fresh produce exists in the market.

2.3. Limited Production. Most of the research on the limited production capacity of suppliers is aimed at industrial products. Kangi et al. [32] considered the problem of multiproduct production to meet external market demand with limited inventory. Zhang et al. [33] studied the problem of mass production and delivery under limited production capacity and transportation conditions. Qing et al. [34] studied the capacity allocation of suppliers under different channel structures (retail, direct sales, and dual-channel).

As for the fresh agricultural product supply chain, to some extent, the output of fresh agricultural product suppliers can be controlled by adjusting factors such as the climate of the planting environment and the implementation of chemical fertilizers and feeds. In order to maximize their own profits, suppliers can determine the input of their controllable parts according to their own sales needs and the retailer’s purchase volume. In the research related to limited production or production capacity, some scholars theoretically analyzed the distribution of benefits among members of the supply chain with limited production capacity and its influencing factors. Xin et al. [35] studied the allocation strategy of suppliers producing general products under limited output. Robert [36] further studied the allocation of scarce resources and determined the optimal allocation strategy of scarce resources according to the principles of profit maximization and fair distribution. Durango-Cohen and Li [37] used stochastic dynamic programming to characterize optimal multicycle capacity allocation contracts.

Some scholars have also studied using presales and other methods to alleviate the problem of insufficient supply due to limited production capacity. Yu [38] showed that the supplier’s presale allocation quantity and differential pricing strategy change with the existing output. However, this type of literature assumes that suppliers only focus on their own production capacity distribution decisions and do not enter the retail market to compete with downstream retailers.

2.4. Dual-Source Procurement. Due to the uncertainty of production and supply, companies often purchase from multiple suppliers to avoid being restricted by a single supplier in the actual operation process. Some scholars have studied and analyzed different procurement models. Jain and Hazra [39] analyzed the capacity investment of upstream suppliers under three different modes of symmetric dual-source procurement, asymmetric dual-source procurement, and single procurement. Some scholars studied the optimal dual-source procurement strategy. For example, Ju [40] considered purchasing issues with the existence of local reliable supply sources, global unreliable supply sources, lead times, and stochastic returns. Some scholars considered dual-source procurement in a certain context. For example, Zhao et al. [41] studied the two-cycle dual-source procurement strategy in a mixed market environment. However, the above literature mainly studied channel selection, procurement, and pricing strategies in single-channel and dual-channel distribution scenarios and ignored the limited output problems, which has impacts on the effectiveness of dual-source procurement strategies. Huang et al. [42] researched that one firm sourced from two capacity constraint suppliers, but they focused on the optimal procurement mechanism and information asymmetry. They did not consider the pricing of fresh agricultural products and the dual-channel supply chain.

On the basis of summarizing the existing literature, we found that in the field of fresh agricultural products, few scholars put suppliers in the perspective of actively and planned production and distribution of fresh agricultural products. The studies rarely analyzed suppliers’ distribution and dynamic pricing in the presence of limited supplier output and the existence of substitutes, and retailers’ ordering and dynamic pricing strategies are also rarely studied. Most literature studied the suppliers’ passive distribution and stage pricing strategies for limited products when natural disasters or other conditions lead to a decline in the production of fresh agricultural products produced by suppliers. Research on dynamic pricing is relatively scarce. Therefore, based on the perspective of planned production positively by suppliers, this article analyzes the distribution of suppliers, the ordering of retailers, and the dynamic pricing strategy of the supply chain with limited output based on the dual-channel supply chain. At the same time, the existing literature on limited output focuses on the products of industrial manufacturing, while the research on the field of fresh agricultural products is relatively rare. To this end, taking the supply chain of fresh agricultural products as the research object, this article considers the characteristics of the freshness of fresh agricultural products and incorporates the limited output into the model constraints to study, which makes the article has certain practical significance.

3. Problem Description and Assumptions

This article considers a two-level supply chain consisting of two unidirectional fresh produce suppliers and a retailer. We study the supplier’s distribution and pricing strategy as well as the retailer’s ordering and pricing strategy. The information between the two parties is symmetrical. We assume that supplier 1 and supplier 2 produce fresh agricultural products 1 and 2, respectively (represented by Products 1 and 2 in the following analysis), the retailer preferentially purchases from supplier 1, and only initiates purchase demand from supplier 2 when fresh agricultural product 1
cannot meet the consumer demand. In the decision-making process, the supplier is the leader of the Stackelberg game, and the retailer is the follower. Supplier 1 first determines the production quantity, wholesale price, and online channel pricing of fresh agricultural product 1. Second, supplier 2 determines the wholesale price of fresh agricultural product 2. Third, the retailer determines the retail prices and orders the quantities of fresh agricultural products 1 and 2.

The supply chain structure of fresh agricultural products considering one-way substitution under limited output is shown in Figure 1. The notation used in this study is summarized in Table 1.

We make the following assumptions to avoid uninteresting cases.

**Assumption 1.** Both the supplier and the retailer sell the same type of fresh produce, and the supplier is the retailer’s only purchase channel.

**Assumption 2.** Supplier 1 is dominant. Its maximum quantity of fresh agricultural product 1 is limited, and the maximum quantity is $K$. Both suppliers and retailers are rational decision-makers and risk-neutral. They make decisions based on maximizing their own profit target.

**Assumption 3.** Because of the randomness of market demand, members of the supply chain cannot make the most accurate decisions according to the actual market demand, which reflects by the volatility of demand in the demand function, and the fresh agricultural product 1 and 2’s demand is affected by price, product freshness, and product substitutability.

**Assumption 4.** When the quantity of product 1 supplied by supplier 1 to the retailer is not enough to meet its demand, the retailer will purchase product 2 from supplier 2 to replace product 1 for sale.

**Assumption 5.** After the end of the sales cycle, the unit processing cost of unsold fresh produce is $\varepsilon$.

**Assumption 6.** Suppliers and retailers have better protection measures in the sales process, so there are no inventory costs and quantity loss of fresh agricultural products.

**4. Model**

We consider the dual-channel Stackelberg game structure of fresh produce, in which supplier 1 is the leader and the retailer is the follower. The specific game sequence is shown as follows. In the first stage, that is, before the arrival of the sales season, the supplier first determines the quantity of product 1 that can be wholesaled to the retailer, wholesale price $w_1$ and online sales price $p_1$. And then the retailer determines the amount of fresh agricultural product 1 that can be wholesaled to the retailer and sales price $p_1^s$ based on past sales data and experience. In the second stage, after the arrival of the sales season, supplier 2 determines the wholesale price of the fresh agricultural product 2, and then the retailer determines the order quantity $q_2^*\text{ and the sales price of the fresh agricultural product 2 according to the actual sales situation in the market. Among them, the quantity of fresh agricultural products produced by supplier 1 is limited with the maximum output K.}

Following Karakul et al. [43] and Yang et al. [28], we assume that the customer demand can be denoted as $D_i = a_i - b p_i^s + \phi_i(1 - \alpha) + \lambda \theta(t) + \xi_i, i = r \text{ or } s$, and $j = 1 \text{ or } 2$. Where $a_i$ indicates the market demand for products 1 and 2, $\theta(t)$ represents the change function of the freshness of fresh agricultural products over time. $\phi_j$ is the replacement rate between products 1 and 2. When $\phi_j > 0$, there is a two-way substitution between products 1 and 2; when $\phi_j < 0$, products 1 and 2 are complementary; and when $\phi_j = 0$, products 1 and 2 are independent of each other. When $\phi_1 = 0$ and $\phi_2 > 0$ or $\phi_2 = 0$ and $\phi_1 > 0$, there can only be one-way substitution between the two products. This article only studies the situation that product 2 can substitute for product 1 in one direction, but product 1 cannot substitute for product 2, at this time $\phi_1 = 0$ and $\phi_2 > 0$ (the following directly replaces $\phi$ for $\phi_j$). The product’s own demand is less affected by other products than the price, that is, $0 < \phi < b < 1$. The larger the $\phi$, the higher the degree that the fresh agricultural product 2 can replace product 1, and the lower the vice versa. $\xi_i$ reflects the volatility and uncertainty of demand as a random disturbance term, and $F(\xi_i)$ is the distribution function of $\xi_i$, and $f(\xi_i)$ is the probability density function.

Based on the above assumptions, the retailer’s offline channel demand is $D_i = (1 - \alpha)U - b p_i^s + \lambda \theta(t) + \phi \xi_i$. However, due to the volatility of the retailer’s offline channel demand, the retailer orders from suppliers 1 and 2 according to the determined part of the demand function, that is, the retailer’s order quantity from supplier 1 is $q_1^* = (1 - \alpha)U - b p_i^s + \lambda \theta(t) + \phi \xi_i$, where the actual order quantity also needs to be determined according to the quantity Q wholesaled by the supplier to the retailer. And when the quantity of fresh agricultural product 1 ordered in the actual sales process is not enough to meet the needs of online consumers, the retailer will order fresh agricultural product 2 from supplier 2 to replace the fresh agricultural product 1 and continue to sell them. The order quantity is the actual demand of traditional channel minus the order quantity of fresh agricultural product 1, that is, the order quantity of fresh agricultural product 2 is $q_2^* = D_i - q_1^*$. At the end of the selling season, if supplier 1 or the retailer still has fresh produce that has not been sold, it is assumed that the unit handling cost of the fresh produce is $\varepsilon$.

The demand for supplier 1’s online channel is $D_i = aU - b p_s + \lambda \theta(t) + \xi_i$ (owing to this article only considers that supplier 1 owns online channels, we use $D_i$ to represent $D_i$ in the following analysis). Because the profit of the supplier is related to the sales volume of the supplier’s online channel, it is divided into the following two situations:

1. When $q_1^* > D_i$: under this circumstance, the actual demand of the supplier’s online channel is greater than the supplier’s stockpile. When the sales season ends, the remaining fresh agricultural products that have not
been sold need to be processed. Therefore, the supplier’s profit function is
\[ \pi_s = (\omega_1 - c_1)\min(q_s^1, Q) + (p_s - c_1)D_s - (q_s - D_s)\varepsilon. \]

(1)

(2) \( q_s \leq D_s \): under this circumstance, the quantity of fresh agricultural products reserved by the supplier for himself is completely sold, so the profit function of the supplier is
\[ \pi_s = (\omega_1 - c_1)\min(q_s^1, Q) + (p_s - c_1)q_s. \]

(2)

Since the quantity of fresh agricultural product 1 produced by supplier 1 is limited, the following conditions must meet:
\[ \text{S.t.} \min(q_s^1, Q) + q_s \leq K. \]

(3)

The profit of the retailer is affected by the quantity \( Q \) that the fresh agricultural product 1 wholesaled to the retailer by the supplier, the order quantity \( q_s^1 \) initiated by itself, and the actual demand \( D_s^1 \) of the offline channel. When product 1’s quantities are insufficient, retailers will also purchase fresh agricultural product 2 from supplier 2 to meet the needs of offline traditional channel consumers. Therefore, the following four situations need to be discussed, which are represented by \( \pi_{r1}, \pi_{r2}, \pi_{r3}, \) and \( \pi_{r4} \), respectively.

(1) When \( q_s^1 < Q \) and \( q_s^1 < D_s^1 \): the quantity of fresh produce 1 ordered by the retailer is \( q_s^1 \), which is lesser than the actual demand \( D_s^1 \), so the retailer will continue to order fresh produce 2 from supplier 2, and the order quantity is \( D_s^1 - q_s^1 \), at which point all the fresh produce ordered by the retailer is sold. Therefore, the retailer’s profit function is

\[ \pi_r = p_1 r^1 + p_2 r^2. \]
fluctuation between the retailer’s order quantity and the supplier’s expected profit function is

\[\pi_r = (p_r - \omega_1)q_r + (p_r^2 - \omega_2)(D_r - q_r^1). \tag{4}\]

(2) When \(q_r^1 < Q\) and \(Q > D_r^1\): the quantity of fresh produce 1 ordered by the retailer is \(q_r^1\), which is greater than the actual demand of the offline channel, so the order quantity of fresh produce 2 is 0. After the end of the period, fresh produce 1 is on sale and there is still remaining. The remaining amount is \(q_r^1 - D_r^1\). Therefore, the retailer’s profit function is

\[\pi_{r2} = (p_r - \omega_1)D_r^1 - \epsilon(q_r^1 - D_r^1). \tag{5}\]

(3) When \(q_r^1 > Q\) and \(Q < D_r^1\): the quantity of fresh agricultural product 1 ordered by the retailer is \(Q\), which is lesser than the actual demand for fresh agricultural product 1 in the offline channel of the retailer. Therefore, the retailer will continue to order fresh agricultural product 2 from supplier 2, and the order quantity is \(D_r^1 - Q\). The retailer sells all fresh produce at the end of the sales period. Therefore, the retailer’s profit function is

\[\pi_{r3} = (p_r - \omega_1)Q + (p_r^2 - \omega_2)(D_r^1 - Q). \tag{6}\]

(4) When \(q_r^1 > Q\) and \(Q > D_r^1\): the quantity of fresh agricultural product 1 ordered by the retailer is \(Q\), which is greater than the retailer’s offline channels’ actual demand \(D_r^1\), so the quantity of fresh agricultural product 2 is 0, and the fresh agricultural product 1 ordered by the retailer at the end of the sales period still have remaining, and the remaining quantity is \(Q - D_r^1\). Therefore, the retailer’s profit function is

\[\pi_{r4} = (p_r - \omega_1)Q - \epsilon(Q - D_r^1). \tag{7}\]

Therefore, the retailer’s expected profit function is

\[E(\pi_r) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \left[ (p_r - \omega_1)q_r + (p_r^2 - \omega_2)(D_r - q_r^1) \right] f(\xi) f(\xi) \, d\xi \, d\xi, \tag{8}\]

The supplier’s expected profit function is

\[E(\pi_s) = \int_{0}^{\infty} \int_{0}^{\infty} \left[ (\omega_1 - c_1)\min(q_r^1, Q) + (p_s - c_1)D_s - (q_s - D_s)\epsilon \right] f(\xi) f(\xi) \, d\xi \, d\xi, \tag{9}\]

Because \(\xi\) satisfies \(U(A, B)\) and \(A < 0, B > 0\), there is a fluctuation between the retailer’s order quantity and the actual demand. Thus, equations (8) and (9) can be simplified to

\[E(\pi_r) = (p_r - \omega_1)\left(q_r + 2Q - \frac{A^2}{2(B - A)}\right) + (p_r^2 - \omega_2)\left(q_r^1 - Q + \frac{2B^2 - A^2}{2(B - A)}\right) - \epsilon(Q - q_r^1). \tag{10}\]

\[E(\pi_s) = (\omega_1 - c_1)\min(q_r^1, Q) + (p_s - c_1)q_s - \frac{A^2(p_s - c_1 + \epsilon)}{2(B - A)}. \tag{11}\]
We use the backward induction method to solve the models and get some interesting results.

Proposition 1. When the output of supplier 1 is limited, and supplier 2 can provide alternative fresh agricultural products for the retailer to sell, the optimal decision of supplier 1 and retailer is as follows:

\[
Q = \frac{A^2(\varphi + b)}{2b(B - A)} \frac{(1 - b)\varphi \epsilon}{b},
\]

\[
q_r^1 = \frac{(\varphi - 4)A^2}{2(\varphi + b)(B - A)} + \frac{(B - 2A)(\varphi + b)A^2}{2b(B - A)^2} \frac{- \varphi \epsilon (B - 2A)(1 - b)}{b(B - A)},
\]

\[
\omega_1 = \frac{2\epsilon(\varphi + 1)(b - 1)}{\varphi + b} + \frac{A^2}{2B(B - A)} + \frac{(2b - 1)[aU + \lambda \theta(t)]}{2b} - 2K,
\]

\[
p_s = \frac{aU + \lambda \theta(t)}{2b} + c_1 + \frac{\varphi}{2} - \frac{A^2}{4b(B - A)} \frac{- aU + \lambda \theta(t) - K}{b} + \frac{\epsilon(\varphi + 1)(b - 1)}{b(\varphi + b)},
\]

\[
p_r^1 = \frac{A^2(2b + B)}{bB(\varphi + b)(B - A)} - \frac{2\epsilon \varphi(\varphi + 1)(1 - b)}{(\varphi + b)^2} + \frac{(2b\varphi - \varphi - 2b)aU}{2b(\varphi + b)} + \frac{U - 2\varphi K}{\varphi + b} + \frac{(2b\varphi - \varphi + 2b)\lambda \theta(t)}{2b(\varphi + b)},
\]

\[
p_r^2 = \frac{A^2(B + b)}{2B(\varphi + b)(B - A)} - \frac{2\varphi(\varphi + 1)(1 - b)}{(\varphi + b)^2} + \frac{(2b + 1)aU + (2b - 3)\lambda \theta(t) - 2U}{2(\varphi + b)} - \frac{\epsilon + 2bK - b\omega_s}{\varphi + b}.
\]

All related proofs are presented in Appendix. From this, the quantity of fresh agricultural product 1 sold by the supplier’s online channel can be obtained as \( q_s = aU - bp_s + \lambda \theta(t) = K - \epsilon(\varphi + 1)(b - 1)/\varphi + b \).

Substituting the optimal solution and \( q_r \) from above into equations (10) and (11), the expected profits of supplier and retailer can be obtained as follows:

\[
E(\pi_r) = (p_r^1 - \omega_1) \left( q_r^1 + 2Q - \frac{A^2}{2(B - A)} \right) + (p_r^2 - \omega_2) \left( q_r^2 - Q + \frac{2B^2 - A^2}{2(B - A)} \right) - \epsilon(Q - q_r^1),
\]

\[
E(\pi_r) = (\omega_1 - c_1)\min(q_r^1, Q) + (p_s - c_1)q_s - \frac{A^2(p_s - c_1 + \epsilon)}{2(B - A)}.
\]

From Proposition 1, it is easy to draw the following corollaries.

Corollary 1. The expected quantity of fresh produce ordered by the retailer 2 is \( \varphi \epsilon(1 - b) - 2A^2/b(B - A) + A + B/2 \), and its expected quantity increases with the increase of the fresh agricultural products’ replacement rate \( \varphi \).

Corollary 2. The order quantity of fresh agricultural product 2 is related to price-sensitive factors, when \( 0 < b < \sqrt{2A^2/\varphi \epsilon(B - A)} \), and the expected order quantity of fresh produce 2 decreases with the increase of the market’s price sensitivity factor \( b \). When \( \sqrt{2A^2/\varphi \epsilon(B - A)} < b < 1 \), the expected order quantity increases as \( b \) increases. The expected order quantity of the substitute fresh agricultural product 2 has nothing to do with the market share of the fresh agricultural product 1 from the retailer’s traditional channel.

Corollaries 1 and 2 show that when there are alternative fresh agricultural products, and there is only one purchase channel for fresh agricultural product 1 in retail, the higher the substitution rate between fresh agricultural products, the greater the order quantity of such alternatives by retailers. The expected quantity of substitutes ordered by retailers is related to the price-sensitive factor, that is, when consumers are less sensitive to the price of fresh agricultural products, the expected quantity of substitutes increases with the increase of the sensitive factor; otherwise, they will decrease.

Therefore, in practice, it is necessary to distinguish the substitution rate and price sensitivity of different fresh agricultural products to arrange order. Specifically, when the substitution rate of fresh agricultural products is high and the price sensitivity is low, more orders are required. Substitutes are used to supply sales demand; and when substitution is low and price sensitivity is high, less ordering is required to avoid excessing inventory and increasing processing costs.
In addition, the expected order quantity of substitutes is not related to the size of the retail market share, because offline consumers are likely to purchase substitutes when they have no other choice. The original production and wholesale of fresh produce are completely controlled by suppliers, and the retailer is in a passive position. If retailers order too many substitutes, it may cause suppliers to increase the wholesale price of products 1 and reduce the wholesale volume. This will make some offline consumers turn to online channels to supply their own needs, too. Therefore, in the actual process, retailers should not be limited by one supplier, but need to develop multiple suppliers, so as not to be suppressed in the supply channel. If retailers make some compromises and concessions, it will affect their own interests.

Corollary 3. The supplier’s online channel selling price is related to the replacement rate $\phi$ and increases with the increase of $\phi$.

Corollary 4. Wholesale prices of suppliers are related to the replacement rate $\phi$ and increase with the increase of $\phi$.

Corollaries 3 and 4 show that the sales price $p_2$ of the online channel opened by the supplier and the wholesale price to the retailer are related to the substitution rate and increase with the increase of the substitution rate. In practice, suppliers control the production and distribution rights of fresh agricultural product 1. They can increase the wholesale price of fresh agricultural products and limit the quantity of fresh agricultural products wholesaled to retailers to force them to order alternative fresh agricultural products with higher prices and quality. In this way, they can indirectly raise the selling price and wholesale price of their own fresh products and then obtain higher profits.

Corollary 5. When $\phi \geq 2eb/(1-b)/-A^2(2b+B)/bB(B-A)-1/2[(2b+1)\alpha U+(2b-3)\lambda \theta(t)]+4e(1-b)+2bK+U$, the products’ price $p_1^2$ in offline channels increases with the increase of the substitution rate $\phi$. When $\phi < 2eb/(1-b)/-A^2(2b+B)/bB(B-A)-1/2[(2b+1)\alpha U+(2b-3)\lambda \theta(t)]+4e(1-b)+2bK+U$, $p_1^2$ decreases with the increase of product substitution rate $\phi$. When $\phi \leq 4eb/(1-b)^2/A^2(2b+B)/bB(B-A)+1/2[(2b+1)\alpha U+(2b-3)\lambda \theta(t)]-2eb(1-b)-e-2bK+bw_2-U-b$, $p_1^2$ increases with the increase of the substitution rate $\phi$. When $\phi > 4eb/(1-b)^2/A^2(2b+B)/bB(B-A)+1/2[(2b+1)\alpha U+(2b-3)\lambda \theta(t)]-2eb(1-b)-e-2bK+bw_2-U-b$, $p_1^2$ decreases with the increase of the substitution rate $\phi$.

From Corollary 5, it can be obtained that the pricing of fresh agricultural products and their substitutes is related to the substitution rate. When the substitution rate of fresh agricultural products is high, it has a positive effect on the pricing of fresh agricultural products sold initially. However, it may have a negative effect on the pricing of substitutes. That is, when the substitution rate is within a certain range, the pricing of fresh agricultural products increases with the increase of the substitution rate, while in another range, the pricing of its substitutes increases with the increase of the substitution rate. Otherwise, it decreases with the increase of the substitution rate in their respective complementary intervals. Therefore, in the actual sales process, retailers need to choose substitutes with appropriate substitution rates, so that they can combine the two sales stages to determine the most appropriate price to maximize their own profits.

5. Numerical Analysis

We assume $U = 30, b = 0.6, \lambda = 0.4, T = 30, n = 0.6, K = 25, c = 5, \omega_1 = 8, \omega_2 = 12$, and $\varepsilon = 2$. The range of changes in market demand is $[U - 5, U + 5]$. We study when the above parameters remain unchanged and the maximum output of fresh agricultural products produced by the supplier is 25 (less than the market demand), how the one-way substitution rate $\phi$ between fresh agricultural products and the price sensitivity factor $b$ will affect suppliers’ channels distribution, pricing and profits as well as the retailer’s ordering, pricing, and profits.

5.1. The Impact of Substitution Rates on Supplier Pricing

Taking the retailer’s market share $a = 0.3$ and 0.8, respectively, and keeping other parameters unchanged, Figure 2 shows the influence of the fresh agricultural product substitution rate $\phi$ on the supplier’s selling price and wholesale price.

As can be seen from Figure 2, when the supplier’s output is limited and the retailer can purchase fresh substitutes from other suppliers in the market for sale, the online channel sales price and wholesale price of the suppliers increase with the increase of the replacement rate $\phi$ of fresh agricultural products. The reason is that suppliers have complete control rights over the production and distribution of fresh agricultural products and can obtain higher profits by raising the wholesale price of fresh agricultural products and limiting the wholesale quantity. In addition, it can be found that the growth trend in the supplier’s selling price in the online channel is greater than its wholesale price. The reason is that the supplier’s online channel sales are not affected by the offline channel, and suppliers limit the retailer’s offline channel sales by raising prices and limiting wholesale quantities, so that users can only buy through online channels, and then increase online channel prices to obtain higher profits.

Furthermore, it can be seen from the figure that the growth trend in the sales price and wholesale price of the supplier’s online channel with the increase of the replacement rate of fresh agricultural products gradually slows down. The reason is that when there are other high alternative fresh agricultural products on the market, if suppliers raise wholesale prices, retailers will choose to mainly purchase fresh agricultural products from other suppliers for sale, thereby forcing suppliers cannot raise prices indefinitely.

5.2. The Impact of Substitution Rates on Retailer Pricing

Taking the retailer’s market share $a = 0.3$ and 0.8, respectively, and keeping other parameters unchanged, Figure 3 shows the influence of the substitution rate $\phi$
of fresh agricultural products on the optimal pricing of fresh agricultural products and its substitutes for retailers.

As can be seen from Figure 3, when the supplier’s output is limited and the retailer can purchase fresh substitutes from other suppliers in the market for sale, if the supply is insufficient, the sales price of fresh agricultural product 1 decreases with the increase of the product substitution rate, until it reaches 0, that is, no fresh agricultural product 1 is sold. The substitutes for fresh agricultural products increase with the increase of the product substitution rate. The reason is that when the substitution rate of substitutes reaches a certain level, the retailer will choose to purchase substitutes from other suppliers in the market for sale because of the high wholesale prices and quantity restrictions of suppliers, so the pricing of fresh produce 1 on offline channels is gradually decreasing, while the pricing of its substitutes is gradually increasing. Furthermore, it can be seen from Figure 3 that when the market share of retailers is large enough, the price increase of fresh agricultural product substitutes will be larger, and the price decline of fresh agricultural product 1 will also be larger. The reason is that when retailers occupy a larger market share, the retailer has more right to speak in the market. When the supplier proposes to limit the wholesale volume and raise the wholesale price, the retailer has more gaming chips and can fight for greater rights and interests for themselves, that is,
they can reduce purchases and prices of fresh agricultural products, while sourcing alternatives from other suppliers in the market for sale.

5.3. The Impact of Replacement Rate on Sales. Taking the retailer’s market share $\alpha = 0.3$ and 0.8, respectively, and keeping other parameters unchanged, Figures 4 and 5 show the influence of the fresh agricultural product substitution rate $\varphi$ on the supplier and retailer’s order and wholesale quantities, respectively.

From Figure 4, when the supplier’s output is limited and the retailer can purchase substitutes from other suppliers in the market for sale, if the supply is insufficient, the retailer’s order quantity of fresh agricultural product 1 decreases with the increase of the product substitution rate $\varphi$, while the order quantity of its substitutes increases with the increase of the substitution rate $\varphi$ of fresh agricultural products. The reason is that when the substitution rate gradually increases, retailers have more choices, and they are no longer limited to the fresh agricultural products provided by suppliers. Therefore, with the squeeze of suppliers, retailers will choose to purchase fresh agricultural product substitutes from other suppliers for sale to increase their profits. In addition, we find that the quantity that suppliers are willing to wholesale to retailers is also gradually increasing, but the increase is smaller than the decrease in the order quantity of fresh agricultural products. The reason is that suppliers also know that retailers have more choices, so it is proposed that more quantities can be wholesaled to meet the needs of retailers.

Comparing Figures 4 and 5, it can be seen that the retailer’s fresh agricultural products and its substitutes’ order quantity have nothing to do with the retailer’s market share. The supplier’s wholesale quantity has nothing to do with the retailer’s market share, too. The reason is that suppliers have complete control rights over the production and distribution of fresh agricultural products, and this right will not be changed by the size of the market share, and retailers are always constrained by the supplier’s supply.

6. Conclusion

This article takes the dual-channel supply chain composed of two fresh agricultural products’ suppliers with one-way substitution and a single retailer as the research object. We considered that when the fresh agricultural products’ suppliers have limited output, the retailers’ supply is insufficient, and they can purchase substitutes from other suppliers. We construct the demand function of suppliers and retailers is affected by price, freshness, and random fluctuations in the market. Based on the Stackelberg game with suppliers as the dominant players and retailers as followers, we studied the distribution and pricing decisions for periodic suppliers as well as ordering and pricing decisions for retailers.

Through the analysis, it is concluded that the wholesale prices and sale prices of suppliers are related to the price of substitutes and substitution rate. When retailers introduce high-quality substitutes, wholesale prices and online selling prices increase, while decreasing when low-quality substitutes are introduced. Because suppliers have full control over the production and distribution of fresh produce, additional profits can also be made by limiting wholesale quantities and rising wholesale prices. However, the difference is that when the price is too high, retailers will choose to buy more substitutes, which in turn will impose certain constraints on the behavior of suppliers. Therefore, when the substitution rate is high, suppliers are willing to wholesale more fresh agricultural products to retailers, and the increase in wholesale prices and online sales prices will not be large.

In addition, through numerical analysis, it is found that retailers’ pricing of fresh agricultural products and their substitutes shows the opposite trend with the change of substitution rate. It indicates that when there are substitutes in the market, retailers also have more choices and get rid of the supplier’s monopoly on the supply of goods. Therefore, in the actual operation process, retailers try to choose as many suppliers as possible, so that there is a certain competitive relationship between each supplier, which can prevent itself from being monopolized by one supplier in the supply of goods. At the same time, the competition of different suppliers is also beneficial to them to lower wholesale prices and increase their own profits. Furthermore, when there is no supply of the same products, retailers should choose products with the highest substitution rate as much as possible. Therefore, in the process of the game between the two parties, retailers will have more rights to speak, and conditions that are more beneficial to themselves will be obtained. The above conclusions provide a theoretical basis and realistic guiding significance for suppliers’ decisions on distribution, ordering, and pricing under the condition of limited production and the existence of substitutes [44].

The research in this article is based on the supplier as the active agent. In reality, some large retailers control the production and distribution of upstream fresh agricultural products, and some even use the direct supply model, or a supplier supplies multiple retailers. For these scenarios, the supplier distribution and pricing as well as the retailer’s ordering and pricing strategy can be further studied in the future. In addition, the research in this article mainly considers the impact of substitutes on the demand for fresh agricultural products when introducing substitutes but does not consider consumers’ preferences for different fresh agricultural products and channels. In the future, consumers’ channel preferences and product preferences can be further considered.

Appendix

Proof of Proposition 1. Using backward induction approach, first, the optimal solution of the retailer under the determined wholesale price is solved, that is, the retailer’s sales price $p^*_r$ and $p^*_s$ is first solved.

Taking formula (10) for the first derivative of $p^*_r$ and $p^*_s$, respectively, we get
\[ \frac{\partial E(\pi_r)}{\partial p_r^1} = (1 - \alpha)U - b p_r^1 + \lambda \theta(t) + \varphi p_r^2 - b (p_r^1 - \omega_1 + p_r^2 - \omega_2) - \frac{A^2}{2(B - A)} - \varepsilon b, \]

\[ \frac{\partial E(\pi_r)}{\partial p_r^2} = (1 - \alpha)U - b p_r^1 + \lambda \theta(t) + \varphi (p_r^1 - \omega_1 + 2p_r^2 - \omega_2) - Q + \frac{2B^2 - A^2}{2(B - A)} + \varepsilon \varphi. \]

(A.1)

Second, taking the second derivative and partial derivative of the retailer’s profit with respect to the sales price \( p_r^1 \) and \( p_r^2 \), we obtained \( \partial^2 E(\pi_r)/\partial p_r^{12} = 2\varphi \) and \( \partial^2 E(\pi_r)/\partial p_r^1 \partial p_r^2 = \varphi - b \). The Hessian matrix of retailer’s expected profit function with respect to \((p_r^1, p_r^2)\) is

\[
\left( \begin{array}{c}
\frac{\partial^2 E(\pi_r)}{\partial p_r^{12}} \\
\frac{\partial^2 E(\pi_r)}{\partial p_r^1 \partial p_r^2} \\
\frac{\partial^2 E(\pi_r)}{\partial p_r^2 \partial p_r^1} \\
\frac{\partial^2 E(\pi_r)}{\partial p_r^{22}}
\end{array} \right) = \left( \begin{array}{cc}
-2b & \varphi - b \\
\varphi - b & 2\varphi
\end{array} \right) = -(\varphi + b)^2. 
\]

(A.2)

We can find that the sequential principal minor is \(-(\varphi + b)^2 < 0\), therefore, the retailer’s expected profit function is a negative definite matrix about the price \((p_r^1, p_r^2)\), that is the retailer’s expected profit is a concave function about the sales price \( p_r^1 \) and \( p_r^2 \), so \( E(\pi_r) \) has the largest optimal solution. Let the first derivatives \( \partial E(\pi_r)/\partial p_r^1 \) and \( \partial E(\pi_r)/\partial p_r^2 \) equal to zero:

\[ \frac{\partial E(\pi_r)}{\partial p_r^1} = (1 - \alpha)U - b p_r^1 + \lambda \theta(t) + \varphi p_r^2 - b (p_r^1 - \omega_1 + p_r^2 - \omega_2) - \frac{A^2}{2(B - A)} - \varepsilon = 0, \]

\[ \frac{\partial E(\pi_r)}{\partial p_r^2} = (1 - \alpha)U - b p_r^1 + \lambda \theta(t) + \varphi (p_r^1 - \omega_1 + 2p_r^2 - \omega_2) - Q + \frac{2B^2 - A^2}{2(B - A)} + \varepsilon \varphi = 0. \]

(A.3)

The optimal price of the retailer can be solved as follows:

\[
p_r^1 = \frac{(\varphi - b)(Q - \varepsilon \varphi - \varepsilon)}{(\varphi + b)^2} + \frac{(1 - \alpha)U + \lambda \theta(t) + \varphi (\omega_1 + \omega_2) - \varepsilon}{\varphi + b} - \frac{A^2}{2(\varphi + b)(B - A)}, \]

\[ p_r^2 = \frac{2b(Q - \varepsilon \varphi - \varepsilon)}{(\varphi + b)^2} - \frac{(1 - \alpha)U + \lambda \theta(t) - b (\omega_1 + \omega_2) - \varepsilon}{\varphi + b} + \frac{A^2}{2(\varphi + b)(B - A)}, \]

(A.4)

(A.5)

Therefore, the expected quantity of fresh produce 1 ordered by the retailer is

\[ q_r^1 = \int_0^\infty q_r^1 f(\xi) d\xi + \int_0^\infty q_r^1 f(\xi) d\xi + \int q_r^1 F(\xi) d\xi. \]

Substituting the above equations (A.4) and (A.5) into \( q_r^1 \), the quantity of fresh agricultural product 1 purchased by the retailer can be obtained as follows:

\[ E(\pi_s) = (\omega_1 - c_1) \min \left( \frac{bQ + \varepsilon \varphi (1 - b)}{\varphi + b} - \frac{A^2}{2(B - A)}Q, (p_r - c_1)q_r - \frac{A^2 (p_r - c_1 + \varepsilon)}{2(B - A)} \right). \]

(A.6)
Since the constraint condition (3) is satisfied, the constraint condition is relaxed into the objective function to establish the Lagrangian function as

\[
L(\omega_1, p_s, Q, \rho) = (\omega_1 - c_1) \min \left( \frac{bQ + \epsilon \varphi (1 - b)}{\varphi + b} - \frac{A^2}{2(B - A)} Q \right) \\
+ (p_s - c_1) \left[ aU - b p_s + \lambda \theta(t) \right] - \frac{A^2 (p_s - c_1 + \epsilon)}{2(B - A)} \\
+ \lambda \left( K - \min \left( \frac{bQ + \epsilon \varphi (1 - b)}{\varphi + b} - \frac{A^2}{2(B - A)} Q \right) - aU + b p_s - \lambda \theta(t) \right),
\]

where \( \lambda \) is the Lagrange multiplier. The following two cases are discussed separately:

1. When \( bQ + \epsilon \varphi (1 - b)/\varphi + b - A^2/2(B - A) > Q \): the first-order partial derivative of the Lagrangian function with respect to \( \omega_1 \) is \( \frac{\partial L}{\partial \omega_1} = 0 \). Then by the Karush–Kuhn–Tucker first-order condition, we have: \( Q = 0 \). It is obviously inconsistent with the actual situation (\( Q > 0 \)), so this situation is discarded.

2. When \( bQ + \epsilon \varphi (1 - b)/\varphi + b - A^2/2(B - A) \leq Q \): the above Lagrangian function can be simplified to

\[
L(\omega_1, p_s, Q, \rho) = (\omega_1 - c_1) \left[ \frac{bQ + \epsilon \varphi (1 - b)}{\varphi + b} - \frac{A^2}{2(B - A)} \right] + (p_s - c_1) \left[ aU - b p_s + \lambda \theta(t) \right] \\
- \frac{A^2 (p_s - c_1 + \epsilon)}{2(B - A)} + \lambda \left( K - \min \left( \frac{bQ + \epsilon \varphi (1 - b)}{\varphi + b} - \frac{A^2}{2(B - A)} Q \right) - aU + b p_s - \lambda \theta(t) \right).
\]

Therefore, by the Karush–Kuhn–Tucker first-order condition, we have:

\[
\frac{\partial L}{\partial \omega_1} = \frac{bQ + \epsilon \varphi (1 - b)}{\varphi + b} - \frac{A^2}{2(B - A)} = 0,
\]

\[
\frac{\partial L}{\partial p_s} = aU - b p_s + \lambda \theta(t) - b(p_s - c_1) - \frac{A^2}{2(B - A)} + b \rho = 0,
\]

\[
\frac{\partial L}{\partial Q} = \frac{b(\omega_1 - c_1)}{\varphi + b} - \frac{b \rho}{\varphi + b} = 0,
\]

\[
\frac{\partial L}{\partial \rho} = K - aU + b p_s - \lambda \theta(t) - \frac{bQ + \epsilon \varphi (1 - b)}{\varphi + b} + \frac{A^2}{2(B - A)} = 0.
\]

Combining (A.10)–(A.13), we get the optimal decision of the supplier as follows:
Substituting $Q = A^2(q + b)/2b(B - A) - (1 - b)\varphi e/b$ into equation (A.6), we obtained fresh agricultural product ordered by retailers to get desired quantity: $(q - 4) A^2/(q + b) (B - A) + (B - 2A) (q + b) A^2/2b(B - A) - \varphi e(B - 2A)(1 - b)/b(B - A)$. Proofs of Corollary 1 and Corollary 2. The quantity of fresh agricultural product 2 ordered by retailers is divided into four situations, which are as follows:

1. When $q_1 < Q$ and $q_1 < D^*_1$, it indicates that the quantity of fresh agricultural product 1 ordered by the retailer cannot meet the needs of its offline channel consumers, so it will continue to order a certain amount of fresh agricultural product 2 from supplier 2, and the order quantity of fresh agricultural product 2 is $D^*_1 - q_1$.

2. When $q_1 < Q$ and $q_1 > D^*_1$, it means that the quantity of fresh product 1 ordered by the retailer is still left at the end of the sales season, so the order quantity of fresh agricultural product 2 is 0.

3. When $q_1^* > Q$ and $Q < D^*_1$, it means that the quantity supplied by the supplier to the retailer is not enough to supply its demand, so the retailer also needs to order an additional quantity of fresh agricultural product 2 of $D^*_1 - Q$ for offline sales.

4. When $q_1^* > Q$ and $Q > D^*_1$, it means that the quantity of fresh agricultural products supplied by the supplier to the retailer is sufficient to supply the consumer demand of the retailer’s offline channels, so the order quantity of fresh agricultural product 2 is 0.

To sum up, the expected quantity of fresh agricultural product 2 ordered by the retailer is

$$q_2^* = \int_{-\infty}^{0} D^*_1 - q_1 d\xi_r + \int_{-\infty}^{0} D^*_1 - Q d\xi_r = \varphi e(1 - b) - \frac{A^2}{2b(B - A)} + \frac{A + B}{2}.$$ (A.15)

Taking the first derivative of $q_2^*$ with respect to the substitution rate $\varphi$, we obtain: $\partial q_2^*/\partial \varphi = \varepsilon(1 - b)$. Because $0 < b < 1$, $\partial q_2^*/\partial \varphi = \varepsilon(1 - b) > 0$, the retailer’s expected order quantity of fresh agricultural product 2 increases with the increase of the substitution rate between the products.

In the same way, taking the first derivative of $q_2^*$ to the price-sensitive factor $b$ of market demand, we obtain: $\partial q_2^*/\partial b = q + 2A^2/b^2(B - A)$. Making $-\varphi e + 2A^2/b^2(B - A) = 0$, we get $b = \sqrt{2A^2/\varphi e}(B - A)$. Because $0 < b < 1$, when $0 < b < \sqrt{2A^2/\varphi e}(B - A)$, $\partial q_2^*/\partial b < 0$, at this time $q_2^*$ decreases with the increase of the price-sensitive factor $b$. When $\sqrt{2A^2/\varphi e}(B - A) < b < 1$, $\partial q_2^*/\partial b > 0$, $q_2^*$ increases with the increase of the price-sensitive factor $b$.

From $\varphi e(1 - b) (b + \varphi) / (q + b) - 2A^2/b(B - A) + A + B/2$, it can be seen that the expected quantity $q_2^*$ ordered by the retailer has nothing to do with the market share of the retailer.

Proof of Corollary 3. It can be seen from the above calculation that $p_1 = aU + \lambda\theta(t) - K/b + \varepsilon(\varphi + 1)(b - 1)/b(\varphi + b)$, differentiating $p_1$ with respect to $\varphi$: $\partial p_1/\partial \varphi = \varepsilon(2 + \varphi - b)/(\varphi + b)(1 - b)$, at this time $p_1$ increases with the increase of $\varphi$. Otherwise, when $\varphi < 2eb(1 - b)/(-A^2(2b + B)BB(B - A)) - (1/2) ((2b + 1)\alpha U + (2b - 3)\lambda\theta(t)) + 4\varepsilon(1 - b) + 2bK + U$, $\partial p_1/\partial \varphi < 0$, $p_1$ decreases with the increase of $\varphi$. Therefore, the fresh agricultural product 1’s selling price $p_1$ in the supplier’s online channel increases with the increase of the replacement rate of fresh agricultural product $\varphi$.
Differentiating $p_r^2$ with respect to $\varphi$, we get $\frac{\partial p_r^2}{\partial \varphi} = -A^2(b + B)/2B(B - A)(\varphi + b)^2 + 2eb(2 + \varphi - b)/(\varphi + b)z + 2kb - b\omega_2/(\varphi + b)^2 - (2b + 1)\alpha U + (2b - 3)\lambda \delta(t) - 2U/2(\varphi + b)^2$. Making $\frac{\partial p_r^2}{\partial \varphi} \geq 0$, we get $\varphi \leq 4eb(1 - b)^2/(A^2 + b - B)/2B(B - A) + (1/2)((2b + 1)\alpha U + (2b - 3)\lambda \delta(t)) - 2eb(1 - b) - \varepsilon - 2bK + b\omega_2 - U - b$, at this time $p_r^2$ increases with the increase of $\varphi$. Otherwise, when $\varphi \geq 4eb(1 - b)^2/(A^2 + b - B)/2B(B - A) + (1/2)((2b + 1)\alpha U + (2b - 3)\lambda \delta(t)) - 2eb(1 - b) - \varepsilon - 2bK + b\omega_2 - U - b$, the price $p_r^2$ of fresh agricultural product 2 decreases with the increase of the substitution rate $\varphi$.

**Data Availability**

No data were used to support this study.

**Conflicts of Interest**

The authors declare that they have no conflicts of interest.

**Acknowledgments**

The research was supported by the Natural Science Foundation of Jiangsu Province (Grant no. BK20201144) and the National Natural Science Foundation of China (Grant nos. 72171047 and 71771053).

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