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Fresh Produce Supply Chain Coordination Based on Freshness Preservation Strategy

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Abstract: Today, consumers are increasingly demanding higher quality in fresh agricultural products. The issues that need to be addressed now are how to keep fresh products fresh and how to coordinate the operations of supply chain participants. Three decision models are developed in this paper using the Stackelberg model: supplier-led decision making, retailer-led decision making, and centralized decision making. The comparative model analysis shows the following: (1) Regardless of the decision model, the supply chain system under centralized decision-making is always more profitable than the supplier-led or retailer-led one. (2) The optimal profit and freshness preservation strategy of the supply chain system depends on the sensitivity coefficient of consumers to price and freshness. (3) Suppliers and retailers can coordinate the costs of freshness inputs according to how the cost-sharing coordination contract is structured. (4) Finally, the numerical analysis is applied to demonstrate the correction of the model.

Keywords: fresh agricultural products; supply chain coordination; freshness input levels; freshness cost-sharing coordination contract

1. Introduction

Fresh agricultural products play a major role in people’s daily lives. Consumers now have higher expectations for the quality of fresh produce as living standards rise [1]. According to a 2018 survey by the China Internet Consumer Association, customers are increasingly choosing fresh agricultural products based on the quality of the product [2]. In addition, countries have adopted a series of measures on quality and safety standards for fresh produce [3–5]. Fresh produce, however, is perishable, difficult to preserve, and subject to steep circulation losses [6,7]. Therefore, all players involved in the fresh produce supply chain need to increase their freshness input levels, which in China is forecast to reach 419.83 billion yuan in 2023 [8]. However, while the market is growing in scope, the loss rate for fresh produce is also expanding. According to estimates, faulty storage maintenance accounts for between 15 and 20 percent of China’s perishable fresh products [9]. The main problems are inadequate cold chain technology [10], asymmetric information in the supply chain system [11], and uneven distribution of benefits among supply chain participants [10]. In particular, in transportation and distribution links, traditional supply chains have many circulation links, leading to reduced freshness. As a result, supply chains need to reduce circulation and increase fresh produce.

To address these issues in the fresh produce supply chain, the “Farm-to-Supermarket” mode connects retailers and farmers directly, streamlines the distribution chain, and reduces physical contact losses of fresh produce during transportation [12] compared to the traditional supply chain. Supply chain participants enter into price-corresponding cooperation agreements to ensure information symmetry and avoid cascading price increases for fresh products, so they can make better profits and assume reallocation obligations. The Indian government, for example, helps farmers work directly with companies to eliminate...
intermediaries in the supply chain for perishable products [13]. Supermarkets in numerous countries, including Wal-Mart and Carrefour, also use this format [14]. Meanwhile, low-income countries focus more on the front end of the supply chain, where fresh produce is lost due to poor infrastructure, while high-income countries focus more on the back end of the supply chain, where fresh produce is lost due to lack of freshness [15]. Thus, optimizing supply chain processes for fresh produce is beneficial in both types of countries. The “farm-to-supermarket” mode has research implications for streamlining the supply chain process. However, each supply chain member prioritizes profit maximization, resulting in increased double marginalization [15,16], which does not guarantee the cost level of fresh product preservation inputs. In short, while streamlining the supply chain process, the emphasis should also be on harmonizing the interests of all supply chain participants to increase the level of fresh produce preservation inputs and promote the sustainable development of the fresh produce supply chain.

Fresh produce markets are prone to supply and demand mismatches. When this phenomenon occurs, it is necessary to adopt a suitable decision-making approach to solve the supply chain coordination problem. In this paper, the Stackelberg game model is used to show that the decision order also affects the profit of the supply chain, which provides a decision basis for fresh produce enterprises, increases the enthusiasm of enterprises to cooperate, and promotes the sustainable development of the supply chain. Based on the related literature, we find that the Stackelberg model has been widely used. Therefore, from the perspective of fresh produce, in this paper, we use the Stackelberg game model to construct a three-layer supply chain system model and implement supply chain coordination and profit maximization through contract design.

In summary, many scholars have studied from the perspective of retailers or suppliers [17–19], rarely considering the impact of supplier, retailer, and consumer behavior on the supply chain. At the same time, when considering the coordination mechanism of the supply chain, most previous studies have considered the contract combining revenues and costs [20,21], while the freshness cost-sharing contract proposed in this paper is more convenient to realize coordination and implementation. Therefore, our study is different in two aspects: First, considering the input level of fresh agricultural products, the Stackelberg game model is constructed to analyze the equilibrium decision under supplier-led, retailer-led, and centralized decisions, respectively, and the influences of different decision models on supply chain profit and decisions are compared; the model compensates for the lack of influence of the consumer price and freshness sensitivity coefficients on the game outcome. Second, this paper combines a fresh produce supply chain with a freshness cost-sharing coordination contract to better allocate fresh produce costs, promote cooperation among supply chain members, control fresh produce losses, and contribute to the long-term development of the fresh produce market. Furthermore, based on the above research background, it is important to study the supply chain for fresh produce. In this paper, we focus on the impact of fresh produce preservation input levels, internal cooperation of supply chain members, and sustainable development of supply chain systems, and discuss strategies to improve the overall profitability of the supply chain and supply chain coordination. For the supply chain, the members of the supply chain coordinate and cooperate to properly allocate preservation costs and facilitate the smooth operation of the supply chain system. For consumers, they receive top-quality, affordable fresh produce with guaranteed quality and quantity. As a result, the supply chain for fresh produce plays a critical role for both members of the supply chain and consumers and forms a system that is recyclable and sustainable.

Considering the problem of the profit coordination mechanism of fresh produce supply chain system, this paper attempts to investigate the following aspects:

1. What are the effects of different decision models on supplier profit, retailer profit, and total supply chain profit?
2. How does consumer sensitivity to price and freshness affect decision-making?
(3) How to design a coordination mechanism to improve the willingness of supply chain participants to bear fresh-keeping costs and achieve the profit of a centralized decision-making model?

Based on the above analysis, this paper constructs a three-tier supply chain structure of suppliers, retailers, and consumers. We then discuss profit in both decentralized and centralized decision-making scenarios, led by suppliers and retailers, and analyze the impact of consumer price and freshness sensitivity on the decision. The analysis results show that the supply chain profit under the centralized decision-making scenario is consistently higher than the other two scenarios. Finally, this paper designs freshness cost-sharing contracts and finds that freshness cost-sharing ratios can harmonize the supply chain within a certain percentage range.

The contributions of this paper to the literature are as follows:

(1) This paper proposes a “farm-to-super docking” model that reduces the distribution chain compared with the traditional supply chain. We then investigate the impact of different decision sequences on the fresh produce supply chain through a Stackelberg game model. Meanwhile, a “cost-sharing coordination contract” is designed to ensure the profit maximization and stability of the fresh produce supply chain system.

(2) Previous studies mainly focused on the behaviors of suppliers and retailers, while this paper also focuses on the sensitivity of consumer demand to the price and freshness of fresh agricultural products in order to improve the sense of participation of supply chain subjects and maintain supply chain stability.

The rest of the paper is presented as follows. Section 2 contains the literature related to this study. Section 3 constructs the model and its derivation in terms of the game order. Section 4 presents the numerical analysis of the optimal strategy generated by the supply chain system and the effect of the associated sensitivity coefficient on the optimal decision, in addition to the effect of the cost-sharing coordination contract on the decision and profit. Section 5 discusses the academic and practical implications of this paper, and Section 6 concludes the study by pointing out shortcomings and directions for future additional research.

2. Literature Review

While the scope of the supply chain has been enriched and developed, it is only limited to applications in the manufacturing industry. With the improvement of people’s living standards, the supply chain has been extended to agricultural products [22]. Compared with other supply chains, the fresh produce supply chain is more complex to manage. Therefore, this paper mainly considers the impact of different dominant scenarios in the supply chain system on fresh produce preservation strategies, consumer sensitivity coefficients to diverse parameters, and the impact of cost-sharing contracts on supply chain coordination. The research in this paper is related to three areas: fresh agricultural products supply chain management; input level decision for preservation products; and supply chain coordination issues.

2.1. Fresh Agricultural Products Supply Chain Management

The efficient management of the fresh produce supply chain affects the entire supply chain system [23]. Today’s complex and diverse environment emphasizes the importance of supply chain management. The behavior of supply chain participants affects supply chain management. Tannis Thorlakson argued that the relationships of supply chain members affect agricultural supply chain sustainability, using empirical research to improve agricultural supply chains in South Africa [17]. Carlos Mena, B. Adenso-Díaz, and Oznur Yurt examined supply chain suppliers and retailers using empirical analysis in the UK and Spain to discuss the causes of food waste in supply chain management [18]. Stella Despoudi presented the challenges of reducing food losses and the use of semi-structured interviews from the perspective of agricultural producers, inspiring future research [19].
Pérez-Mesa J C et al. focused on perishable supply chains, emphasizing supplier response and retailer requirements [24]. However, the previous study validates the supply chain member coordination relationship from an empirical point of view and fails to consider how decision sequence differences affect supply chain coordination. Numerous scholars have improved the management of supply chains by constructing two-channel supply chains. Zhinan Li et al. considered coordinating the operational management of a dual-channel fresh food supply chain in the case of supply chain disruptions, using decentralized and centralized decision models to enhance the resilience and sustainability of fresh food firms for the supply chain [25]. Wan N et al. designed two supply chain structures to investigate the impact on option coordination separately. Their study showed that the supply chain structure makes sustainable decisions for fresh produce supply chain members [26]. Y Yu, T Xiao, et al. presented the problem of cold chain decision making and price consolidation with competing suppliers, divided into horizontal and vertical consolidation, and concluded that vertical consolidation is more beneficial to increase retailers’ profits [27]. Hobbs J E proposed that unexpected events cause supply chain disruptions and argues that supply chain players need to trust each other and increase supply chain resilience [28]. In addition, B Yan et al. investigated corporate financing to aid the operational management of fresh produce and proposed a joint operation model. Their findings demonstrated that the freshness of fresh produce becomes strongly correlated with the optimal level of corporate financing [29]. However, in this paper, the fresh produce supply chain is combined with freshness cost-sharing contracts to coordinate supply chain management.

Some studies have used technology to implement supply chain management. Iftekhar A, Cui X. proposed technologies such as blockchain, which can trace products and improve supply chain performance [30]. Cui X presented the complete supply chain with the example of the fresh tomato supply chain in the United States, improving supply chain management performance [31]. Dellino G et al. suggested a decision support system (DSS) to predict the sales and orders of fresh produce, established a corresponding model selection system, and put the product in a reliable operation management system [32]. Different from the existing literature, we consider the impact of the game behavior of supply chain players on profits and propose a freshness cost-sharing contract so that suppliers and retailers are more willing to bear freshness costs and consumers receive superior-quality fresh produce.

2.2. Input-Level Decision for Preservation of Products

The level of freshness preservation input affects the freshness of fresh agricultural products. Chao Liu et al. constructed a dynamic control model in which the producer ensures freshness preservation efforts and the retailer decides on advertising investment efforts; a linear bonus plan and decision matrix were designed to secure the effectiveness of freshness preservation efforts [33]. Clark M, Tilman found that increasing the agricultural preservation inputs can reduce costs and protect the environment [34]. In addition, several studies applied relevant techniques to ensure their freshness input levels [35,36]. Various studies have applied methods such as relevant technologies and inventory management to improve the freshness of fresh produce [35–39]. Wladimir E. Soto-Silva et al. developed a program for the procurement, transportation, and storage of Chilean apples to improve their freshness [37]. Rana R S and Kumar D et al. made decisions on perishable items involving two warehouse scheduling policies to maximize the quality of fresh produce [38]. Murmu V and Kumar D considered the effects on the storage of perishable products under unexpected events. A dual warehouse inventory model was used to reduce the loss of perishable products and enhance the cost control of suppliers [39]. Francesco Lolli et al. developed decision support systems (DSS) with carefully designed maintenance and spare parts inventory management to ensure coordinated operation of production systems [40]. However, the above literature has not considered consumer factors in supply chain systems and differences in decision sequences that can affect the cost of preserving inputs.
2.3. Supply Chain Coordination Issues

Supply chain coordination provides an interdependent relationship among the participants. It facilitates information sharing and joint decision-making among participants to achieve overall performance [41]. Numerous scholars have studied methods to ensure supply chain coordination, among which the contractual form is an excellent means to achieve supply chain coordination [20]. The main forms of contracts for supply chain coordination include wholesale price contracts, quantity discount contracts, two-part tariffs [21], revenue sharing, rebates, and quantity flexibility contracts [42]. As research has progressed, contracting mechanisms have been combined with different perspectives to improve the resiliency of supply chain coordination. Govindan et al. applied volume-elastic contracts to the O2O context and compared three coordination mechanisms leading to higher profits in the supply chain [21]. Yan B et al., Peng H et al., and Wang YL developed relevant contractual mechanisms from the perspective of consumer, retailer, and farmer behavior [2,43,44]. Zhou L et al. [45], Peng H et al. [44], and Xie L [46] designed option contracts and repurchase and risk sharing (BBRS) and supply chain repurchase contracts to facilitate supply chain coordination with each other. In the face of supply chain disruptions due to force major factors, Guohua S et al. introduced a game model to identify a two-part tariff contract that can effectively coordinate supply disruptions in the fresh produce supply chain [47]. In this paper, we design a “cost-sharing coordination contract” that allows farmers and retailers to bear the cost of freshness and supply chain coordination within a certain percentage of freshness.

2.4. Insights and Findings

From the above literature, this paper finds that, firstly, scholars use technology and inventory management to maintain the freshness of fresh produce, but they ignore the fact that the different decision sequences of supply chain participants also affect the freshness of fresh produce [36–40]. Therefore, this paper designs a “freshness cost-sharing contract” to facilitate the coordinated operation of the supply chain. Secondly, related scholars only focus on profit maximization of suppliers and retailers, or only focus on the impact of consumer behavior on the supply chain [2,43,44]. There is no integrated consideration of the gaming behavior of farmers and retailers and the impact of consumer behavior on the market.

2.5. Summary

In summary, this paper builds a supply chain system for suppliers, retailers, and consumers. The Stackelberg model has been used to study equilibrium profits under supplier-led, retailer-led, and centralized decision-making, respectively, and to compare and analyze the selection of supply chain decisions under different decision models. The impact of the consumer sensitivity coefficient on the outcome of the game is analyzed, and the “freshness cost-sharing coordination contract” to coordinate supply chain is designed. Finally, numerical analysis is performed to verify the authenticity of the game results and the validity of the contracts.

3. Model Analysis

3.1. Problem Description and Assumptions

The farm-to-supermarket clarifies that farmers can directly supply fresh produce to supermarkets or markets [48]. This mode reduces circulation, controls the cost of fresh produce loss, and achieves a win-win situation for farmers, retailers, and markets. Therefore, this paper introduces the “farm-to-supermarket” mode and a Stackelberg game in which suppliers, retailers, and consumers jointly build a three-level supply chain. Among them, suppliers provide fresh produce to farmers and are responsible for the level of freshness; farmers are responsible for the level of freshness; and retailers play an intermediary role between suppliers and consumers. The retail price is \( p \). The supply chain flow chart of fresh agricultural products is shown in Figure 1.
Figure 1. Fresh agricultural products supply chain flow chart.

To better investigate the model, assumptions and associated notation are introduced:

**Assumption 1.** This study applies to the case of information symmetry.

**Assumption 2.** Fresh produce is perishable and is subject to quantitative and qualitative losses during transportation and marketing. Quantitative loss is the complete loss of fresh produce. Qualitative loss is the loss of freshness but does not affect the supplier’s sales. Therefore, it is assumed that there is no surplus stock within the trading area.

**Assumption 3.** Fresh produce freshness $\pi(t)$ decreases over time $t$, and freshness decays faster over time, namely $\pi'(t) < 0, \pi''(t) \leq 0$.

**Assumption 4.** Draw on relevant literature [49]. Let the freshness function of fresh produce by

$$\pi(t) = \pi_0 + mh - \beta(t)^2$$

where $\pi_0$ is represented by the initial freshness, $\beta$ is the rate of decline in freshness, and $m$ is the sensitivity coefficient of freshness input level.

**Assumption 5.** Increasing the input level of fresh-keeping is conducive to improving product quality and increasing the number of products. According to Chambers’ analysis [49], the cost of fresh produce preservation input levels is

$$c_h = \frac{1}{2} \alpha h^2$$

$\alpha > 0$ denotes the freshness input factor.

**Assumption 6.** The market demand [49] is

$$D(p, \pi) = \chi[1 - \eta y - y\pi(t)]$$

where $\chi$ is expressed as market demand, $p$ is the sales price, and $\eta > 0$ is the price sensitivity factor. $y > 0$ is the freshness sensitivity factor.

**Assumption 7.** This paper assumes $V - \beta(c_1 + c_2) > 0$ and $2\alpha\eta - \chi y^2 m^2 T > 0$. Two small assumptions guarantee a positive profit.

The parameters used in the model are as follows, where $i = 1, 2$ represent suppliers, and retailers, respectively. $j = a, b$ represents the supplier-led model and the retailer-led model, respectively.

- $\theta_i$: Profits for all parties in the supply chain node;
- $Q_s$: Sales volumes;
- $\theta$: Overall supply chain profits;
- $\theta_c$: Centralized decision-making on total profit;
3.2. Model Construction and Analysis

Assume the following decision sequence: the supplier provides produce to the retailer based on freshness $h$ and wholesale price $w$, and the retailer determines the retail price $p$ to sell to the consumer based on freshness. Meanwhile, the sales market feeds the retailer, and the retailer feedbacks to the supplier, resulting in a good supply chain structure.

Based on (1) and (3), at a time $t$, the demand function for fresh agricultural products is

$$D(p, \pi) = \chi [1 - \eta p - y\pi(t)]$$

Substituting (1) into (4) and the entire period gives the total sales volume of the retailer over the entire sales cycle $T$:

$$Q = \int_0^T \chi \left(1 - \eta p + y\pi_0 + mh - \beta(t)^2\right) dt = \chi [1 + y(\pi_0 - \frac{1}{3}\beta) - \eta p + y\pi(t)]T$$

To simplify calculations $V = 1 + y(\pi_0 - \frac{1}{3}\beta)$.

3.2.1. Supplier-Led Decision Model

Under the supplier-led model, the supplier first determines the wholesale price and preserves the input level according to the market demand. The retailer then sets the retail price based on the supplier’s choice. The equation below is solved using a backward recursive approach. Then the total profit from their sales is

$$Q_1 = (V - \eta p + ymh_1)\chi T$$

The profit maximization function of the retailer is

$$\theta_{2a} = (p_1 - \omega_1 - c_1)Q_1 = (p_1 - \omega_1 - c_1)(V - \eta p_1 + ymh_1)\chi T$$

Next, let $\frac{\partial \theta_{2a}}{\partial p_1} = (V - \eta p + ymh_1)\chi T + (p_1 - \omega_1 - c_1)\chi T = 0$. The following can be obtained:

$$p_1^* = \frac{V + \eta\omega_1 + ymh_1 + \eta c_1}{2\eta}$$

The second order derivative $p_1$ can be found in Equation (7): $\frac{\partial^2 \theta_{2a}}{\partial p_1^2} = -\chi\eta T + (-\chi\eta T) = -2\chi\eta T < 0$, which gives $\theta_{2a}$ a concave function of $p_1$, so there exists a unique $p_1$ that maximizes the profit.

At this point, the supplier’s profit function is

$$\theta_{1a} = (\omega_1 - c_2)Q_1 - c_h = (\omega_1 - c_2)(V - \eta p + ymh_1)\chi T - \frac{1}{2}\alpha h^2$$

Substituting Equation (8) into Equation (9), we get

$$\theta_{1a} = (\omega_1 - c_2) \frac{V + ymh_1 - \beta(\omega_1 + c_1)}{2} \chi T - \frac{1}{2}\alpha h^2$$
From Equation (10) the Hesse matrix is derived: \( G_1 = \begin{bmatrix} \frac{\partial^2 \theta_{1a}}{\partial w^2} & \frac{\partial^2 \theta_{1a}}{\partial h\partial w} \\ \frac{\partial^2 \theta_{1a}}{\partial h\partial w} & \frac{\partial^2 \theta_{1a}}{\partial h^2} \end{bmatrix} = \begin{bmatrix} -\frac{2cV(\eta+\eta_1+\rho_2)}{4\zeta_2^2} & \frac{cV(\eta+\eta_1+\rho_2)}{4\zeta_2^2} \\ \frac{cV(\eta+\eta_1+\rho_2)}{4\zeta_2^2} & \frac{\chi^2}{2} - \alpha \end{bmatrix} \), where \( |G_1| = \frac{(4\chi^2 - \chi^2m^2T)}{4} > 0 \). Therefore, the Hessian matrix \( G_1 \) is negative definite, so there exists a unique \((w_1^*, h_1^*)\) that maximizes \( \theta_{1a} \).

**Proposition 1.** In the supplier-led decision model, the optimal wholesale price set by the supplier is \( w_1^* \), the optimal effort level is recorded as \( h_1^* \), and the best-selling price for fresh agricultural products is \( p_1^* \). Therefore, the optimal profit of the supplier is \( \theta_1^* \) and the optimal profit of the retailer is \( \theta_2^* \), so the total profit of the supply chain system is \( \theta^* \).

\[
\begin{align*}
\begin{cases}
  w_1^* = \frac{2cV[\eta(\eta_1+\rho_2)] - \chi^2m^2T_c}{4\chi^2 - \chi^2m^2T} \\
h_1^* = \frac{V-\eta(\eta_1+\rho_2)}{4\chi^2 - \chi^2m^2T} \chi m T \\
p_1^* = \frac{\alpha V[2\eta(\eta_1+\rho_2)] - \chi^2m^2T_c}{4\chi^2 - \chi^2m^2T}
\end{cases}
\end{align*}
\tag{11}
\]

\[
\begin{align*}
\begin{cases}
  \theta_1^* = \frac{\alpha V[2\eta(\eta_1+\rho_2)]^2}{4(4\chi^2 - \chi^2m^2T)} \\
  \theta_2^* = \frac{\alpha V[2\eta(\eta_1+\rho_2)]^2}{4(4\chi^2 - \chi^2m^2T)} \\
  \theta^* = \theta_1^* + \theta_2^* = \frac{\alpha V[6\eta(\eta_1+\rho_2)]^2}{2(4\chi^2 - \chi^2m^2T)}
\end{cases}
\end{align*}
\tag{12}
\]

**Proof.** See Appendix A. \( \square \)

3.2.2. Retailer-Led Decision Model

In the retailer-led situation, the retailer, as the dominant player in the supply chain system, first decides the level of markup \( \rho \). Following the retailer’s decision, the supplier calculates its wholesale price \( w \) and degree of freshness input \( p \) based on the retailer’s decision. At this point, the supplier’s total sales volume is

\[
Q_2 = V - y(w_2 + \rho_2) + \eta mh_1
\tag{13}
\]

According to the inverse recursion method, the supplier’s profit function is

\[
\theta_{1b} = (w_2 - c_1)Q_2 - c_h = (w_2 - c_1)[V - y(w_2 + \rho_2) + \eta mh_1]\chi T - \frac{1}{2}\chi h_2^2
\tag{14}
\]

The Hesse matrix is obtained by Equation (14): \( G_2 = \begin{bmatrix} \frac{\partial^2 \theta_{1b}}{\partial w^2} & \frac{\partial^2 \theta_{1b}}{\partial h\partial w} \\ \frac{\partial^2 \theta_{1b}}{\partial h\partial w} & \frac{\partial^2 \theta_{1b}}{\partial h^2} \end{bmatrix} = \begin{bmatrix} -2\chi y T \chi m T & \chi m T \\ \chi m T & -\alpha \end{bmatrix} \),

\[|G_2| = \chi T(2\chi y - \chi m^2T) > 0\], such that the Hesse matrix is negative definite, at which point there exists a unique \((w_2^*, h_2^*)\) that maximizes \( \theta_{1b} \).

Let \( \frac{\partial \theta_{1b}}{\partial w} = \frac{\partial \theta_{1b}}{\partial h} = 0 \), solve for optimal wholesale prices and preservation input levels:

\[
\begin{align*}
\begin{cases}
  w_2^*(\rho_2) = \frac{\alpha V + \alpha \eta(\eta_1+\rho_2) - \chi^2m^2T_c}{2\chi^2 - \chi^2m^2T} \\
h_2^*(\rho_2) = \frac{V-\eta(\eta_1+\rho_2)}{2\chi^2 - \chi^2m^2T} \chi m T
\end{cases}
\end{align*}
\tag{15}
\]

It follows that when \( V - \eta(\eta_1+\rho_2) > 0 \) makes the level of preservation input meaningful. The retailer’s profit function is

\[
\theta_{2b} = (\rho_2 - c_2)Q_2 = (\rho_2 - c_2)[V - y(w_2 + \rho_2) + \eta mh_1]\chi T
\tag{16}\]
Substituting Equation (15) into Equation (16) leads to the final profit function for the retailer. From the above equation, it follows that \( \frac{\partial^{2} \theta_{2b}}{\partial p_{2b}^{2}} = -\frac{2 \alpha \chi y^{2} T}{\alpha \eta y} < 0 \). Therefore, \( \theta_{2b} \) is a concave function of \( p_{2} \). Let \( \frac{\partial \theta_{2b}}{\partial p_{2}} = 0 \) the optimal degree of mark-up for the retailer is obtained as
\[
\rho_{2}^{*} = \frac{(V - \eta (c_{1} - c_{2}))}{2 \eta}
\]  

Proposition 2. In the retailer-led decision-making model, the supplier’s optimal wholesale price is \( w_{2}^{*} \), the supplier’s optimal level of effort is \( h_{2}^{*} \), the optimal retail price of fresh produce is \( p_{2}^{*} \), and the retailer’s optimal profit is \( \theta_{2}^{*} \). The optimal profit for the supplier is \( \theta_{1}^{*} \) and the total supply chain profit is \( \theta^{*} \). Then,
\[
\begin{align*}
\begin{cases}
w_{2}^{*} &= \frac{\alpha [V - \eta (c_{1} + c_{2})]}{2(2 \alpha \eta - \chi y^{2} m^{2} T)} + c_{1} \\
h_{2}^{*} &= \frac{V - \eta (c_{1} + c_{2})}{2(2 \alpha \eta - \chi y^{2} m^{2} T)} y m x T
\end{cases}
\end{align*}
\]  

Proof. See Appendix B. □

Retailers’ best retail prices:
\[
p_{2}^{*} = w_{2}^{*} + \rho_{2}^{*} = \frac{(3 \alpha \eta - \chi y^{2} m^{2} T) V + (\alpha \eta - \chi y^{2} h^{2} T) \eta (c_{1} + c_{2})}{2 \eta (2 \alpha \eta - \chi y^{2} m^{2} T)}
\]  

It is clear from the above that the equilibrium solution for profit maximization can only be found when \( 2 \alpha \eta - \chi y^{2} m^{2} T > 0 \).

3.2.3. Centralized Decision Model

Suppliers and retailers adopt centralized decision-making to maximize their mutual benefits. In this approach, both parties do not consider their wholesale prices \( w_{c} \) but only the level of fresh inputs \( h_{c} \) and retail prices \( p_{c} \). In this decision model, their total sales volume is
\[
Q_{3} = (V - \eta p_{c} + y m h_{c}) x T
\]  

The total supply chain system profit is
\[
\theta_{c} = (p_{c} - c_{1} - c_{2}) Q_{3} - c_{h} = (p_{c} - c_{1} - c_{2}) (V - \eta p_{c} + y m h_{c}) x T - \frac{1}{2} \chi h_{c}^{2}
\]  

This gives the Hesse matrix \( G_{3} = \begin{bmatrix}
\frac{\partial^{2} Q_{3}}{\partial p_{c}^{2}} & \frac{\partial^{2} Q_{3}}{\partial h_{c} \partial p_{c}} \\
\frac{\partial^{2} Q_{3}}{\partial h_{c} \partial p_{c}} & \frac{\partial^{2} Q_{3}}{\partial h_{c}^{2}}
\end{bmatrix} = \begin{bmatrix}
-2 \chi y^{2} T & \chi m T \\
\chi m T & - \alpha
\end{bmatrix} \), which gives \( |G_{3}| = 2 \chi \alpha \eta T - \chi^{2} y^{2} m^{2} T^{2} > 0 \); the Hesse matrix is negative definite, so that there is a unique optimal pricing and preservation input level that maximizes the supply chain system.

Proposition 3. In the centralized decision model, the optimal selling price of fresh produce is \( p_{c}^{*} \). The optimal level of effort of the supplier is \( h_{c}^{*} \), and the optimal profit of the supplier is \( \theta_{c}^{*} \); then,
\[
\begin{aligned}
    p^*_c &= \frac{\alpha[V + \eta(c_1 + c_2) - (c_1 + c_2) \chi y^2 m^2 T]}{2 \alpha \eta - \chi y^2 m^2 T} \\
    h^*_c &= \frac{V - \eta(c_1 + c_2)}{2 \alpha \eta - \chi y^2 m^2 T} \\
    \theta^* &= \frac{\alpha \chi T[V - \eta(c_1 + c_2)]^2}{2(2 \alpha \eta - \chi y^2 m^2 T)}
\end{aligned}
\] (23)

**Proof.** See Appendix C. □

3.3. Model Comparison and Analysis

3.3.1. Compare \( h^*_1, h^*_2 \) and \( h^*_c \)

**Inference 1.** \( h^*_2 < h^*_1 < h^*_c \): Compared to the other two decisions, fresh produce under centralized decision-making has the highest freshness.

When \( \alpha \eta - \chi y^2 m^2 T > 0 \), the freshness input levels in Equations (11) and (18) above are subtracted, respectively, to obtain

\[
h^*_1 - h^*_2 = \frac{\chi y^2 m^2 T[V - \eta(c_1 + c_2)]}{2(2 \alpha \eta - \chi y^2 m^2 T)(4 \alpha \eta - \chi y^2 m^2 T)} y m x T > 0
\]

When \( \alpha \eta - \chi y^2 m^2 T > 0 \), the above Equation (23) and the freshness input level in Equation (11) are subtracted to give

\[
h^*_c - h^*_1 = \frac{V - \eta(c_1 + c_1)}{2(2 \alpha \eta - \chi y^2 m^2 T)} y m x T > 0
\]

This leads to \( h^*_2 < h^*_1 < h^*_c \).

3.3.2. Compare \( p^*_1, p^*_2 \) and \( p^*_c \)

**Inference 2.** \( p^*_c < p^*_1 < p^*_2 \): Compared to the other two decisions, the price of fresh produce is lowest under the centralized decision.

When \( \alpha \eta - \chi y^2 m^2 T > 0 \), \( V - \eta(c_1 + c_2) > 0 \), the retail prices in Equations (11) and (20) above are subtracted to give

\[
p^*_2 - p^*_1 = \frac{[V - \eta(c_1 + c_2)](\alpha \eta - \chi y^2 m^2 T)}{2(2 \alpha \eta - \chi y^2 m^2 T)(4 \alpha \eta - \chi y^2 m^2 T)} > 0
\]

When \( \alpha \eta - \chi y^2 m^2 T > 0 \), \( V - \eta(c_1 + c_2) > 0 \), the retail prices in Equations (11) and (23) above are subtracted to give

\[
p^*_1 - p^*_c = \frac{[V - \eta(c_1 + c_2)](\alpha \eta - \chi y^2 m^2 T)}{2 \eta(2 \alpha \eta - \chi y^2 m^2 T)} > 0
\]

The conclusion is \( p^*_c < p^*_1 < p^*_2 \).

From the analysis in this section, it can be concluded that the centralized decision model has the lowest retail price, the highest fresh input, and the highest supply chain profit compared to the supplier-led or retailer-led decision models. Therefore, this paper designs a “cost-sharing coordination contract” to find different freshness cost-sharing ratios within the supply chain to achieve perfect coordination.

3.4. Cost-Sharing Coordination Contract

To maximize the efficiency of the supply chain system, in this paper, we will transform decentralized decision-making into an optimal decision-making model in the presence of
centralized decision-making. By designing a coordination contract, the cost-sharing strategy of the participants in the supply chain is analyzed to achieve coordination. Specifically, the retailer shall first publicly state the proportion of storage costs incurred and the degree of markup. The supplier then determines the wholesale price and the level of preservation input based on the retailer’s information and market demand.

**Proposition 4.** Under the freshness cost-sharing contract, when the fresh-keeping cost sharing ratio is \( \varphi \in \left[ \frac{1}{4}, \frac{3}{4} \right] \), the supply chain can be coordinated.

**Proof.** See Appendix D. \( \Box \)

### 4. Numerical Analysis

This paper is based on the “farm-to-supermarket” mode in order to analyze more intuitively the impact of different decision-making models, freshness sensitivities, and the use of cost-sharing coordination contracts on the profitability of supply chain participants and systems. From the previous section, we can obtain \( \varphi \in \left[ \frac{1}{4}, \frac{3}{4} \right] \). Based on the above assumptions and prerequisites that should be satisfied by each parameter within the model and assuming the following parameters are used for illustration (\( \chi = 180, \eta = 0.5, y = 0.4, \pi_0 = 0.65, \beta = 0.6, m = 0.25, \alpha = 160, T = 10, c_1 = 1.2, c_2 = 0.2 \)), we will make a better understanding of the theoretical results, which are analyzed numerically in this section. This paper takes a fresh agricultural product of the type banana as an example.

#### 4.1. Optimal Decision and Profit Values under the Three Models

The changes in the total profit of the supply chain system under different models are discussed and compared below and shown in Table 1.

<table>
<thead>
<tr>
<th>Supplier-Led Model</th>
<th>Retailer-Led Model</th>
<th>Centralized Decision-Making Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p^* )</td>
<td>2.18</td>
<td>2.17</td>
</tr>
<tr>
<td>( h^* )</td>
<td>0.29</td>
<td>0.31</td>
</tr>
<tr>
<td>( w^* )</td>
<td>1.93</td>
<td>1.48</td>
</tr>
<tr>
<td>( \theta_1 )</td>
<td>115.39</td>
<td>61.35</td>
</tr>
<tr>
<td>( \theta_2 )</td>
<td>46.48</td>
<td>122.70</td>
</tr>
<tr>
<td>( \theta^* )</td>
<td>161.87</td>
<td>183.35</td>
</tr>
</tbody>
</table>

Table 1 depicts the total profit of the supply chain system in the three models. The calculation results can be observed as follows: The supplier-led model has the highest retail price but the lowest level of input preservation because suppliers are only interested in raising wholesale prices, and retailers make up for the profits extracted by suppliers by raising retail prices. Steep prices and low quality can occur in the market. After a retailer-led price increase is set, the supplier then raises the wholesale price. However, the market feedback was that the selling price was too high, which affected overall profits. Consumers have better access to quality fresh produce in this scenario than in other models. In addition, the fresh produce preservation inputs are the highest under centralized decision-making, but the total profit of the supply chain system is also the highest, indicating that the supply chain system is coordinated under centralized decision-making.

#### 4.2. Sensitivity Analysis

##### 4.2.1. Impact of \( y \)

We plotted the variation curves of optimal supplier profit, retailer profit, and system profit with fresh produce preservation sensitive coefficient \( y \) under the three decision models. This is illustrated by Figure 2 below.
According to the figure above, regardless of the model, supplier profit, retailer profit, and total profit are positively correlated with the freshness sensitivity coefficient $y$ of fresh products. From a practical point of view, as consumers in the market become more sensitive to freshness, this spurs retailers to demand freshness, which then feeds back to suppliers, who are more willing to invest in freshness. However, as the suppliers consider their interests, they increase the cost of freshness in the form of compensating for the higher wholesale price, and the retailer at this time increases the retail price based on its interests.
As a result, strong consumer demand for fresh produce will affect the availability of quality fresh produce on the market at low prices. In addition, higher retail prices for fresh produce also affect consumer demand, but the demand generated by ensuring the freshness of fresh produce more than offsets the impact of higher retail prices. Eventually, the overall size of the market grows.

4.2.2. Impact of $\eta$

The variation of the optimal supplier profit, retailer profit, and system profit versus fresh product price $\eta$ is plotted under the three decision models. This is presented in the following Figure 3.

Figure 3. The influence of price sensitivity coefficient on each subject under three decision-making models.
As can be seen in Figure 3, supplier profit, retailer profit, and supply chain system profit for all three decision models decrease as the price sensitivity coefficient increases. The reason is that as the price of fresh produce becomes more sensitive to consumers, retailers will lower their retail prices and suppliers will lower their wholesale prices. At this point, suppliers will reduce their input levels for fresh products to maximize their profits, which will lead to quality issues with fresh products. In addition, while lower prices stimulate consumers’ willingness to buy, the freshness of fresh produce weakens consumers’ desire to spend. Finally, the entire market is in an unhealthy state.

4.3. Optimal Decision and Profit Values under the Contract

Table 2 shows that when the sum of the profits of suppliers and retailers in this range is always equal to the total profit of the supply chain system, it is the same as in the centralized decision. Thus, the level and selling price of fresh inputs in a cost-sharing coordination contract is the same as in the centralized model, showing that the contract is effective for supply chain coordination and indicating that consumers are more likely to buy fresh products at excellent prices in the market. At this point, the total supply chain system is constantly regulated by retailers and suppliers, and ultimately the total profit remains the same.

<table>
<thead>
<tr>
<th>The Fresh-Keeping Cost Sharing Ratio</th>
<th>Wholesale Prices</th>
<th>Total Retailer Profits</th>
<th>Total Supplier Profits</th>
<th>Centralized Decision Optimal Total Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>1.48</td>
<td>122.71</td>
<td>122.71</td>
<td>245.41</td>
</tr>
<tr>
<td>0.55</td>
<td>1.45</td>
<td>110.43</td>
<td>134.98</td>
<td>245.41</td>
</tr>
<tr>
<td>0.60</td>
<td>1.38</td>
<td>98.16</td>
<td>147.25</td>
<td>245.41</td>
</tr>
<tr>
<td>0.65</td>
<td>1.36</td>
<td>85.89</td>
<td>159.52</td>
<td>245.41</td>
</tr>
<tr>
<td>0.70</td>
<td>1.34</td>
<td>73.62</td>
<td>171.79</td>
<td>245.41</td>
</tr>
<tr>
<td>0.75</td>
<td>1.31</td>
<td>61.35</td>
<td>184.06</td>
<td>245.41</td>
</tr>
</tbody>
</table>

5. Discussion

5.1. Theoretical Implications

Based on the context of “farm-to-supermarket”, this paper considers fresh produce preservation and supply chain coordination using the Stackelberg model. We analyze different game sequences and consider the impact of price and freshness on decision-making. We find that the location of the supply chain affects one’s profit, while consumer characteristics influence market outcomes. Finally, a freshness cost-sharing contract is designed to verify the coordination effect of the contract. In this paper, we consider the impact of supplier, retailer, and consumer behavior on supply chain profits, which addresses the shortcomings of existing studies on the impact of consumer price and freshness sensitivity coefficients on game outcomes. Moreover, this study expands the perspective of contract coordination for fresh produce, which has theoretical implications for follow-up studies. At the same time, the fresh produce supply chain should be coordinated so that suppliers can promote centralized production and grow fresh produce to meet consumer demand as reflected in the market. Retailers, as an intermediate link in the supply chain, can effectively supply demand not only of suppliers but also of consumers, thereby matching supply and demand. Consumers can obtain quality fresh produce at low prices throughout the supply chain system. The whole supply chain system is in a virtuous cycle.

5.2. Practical Implications

Consumer demand for fresh produce is huge. Without proper decision-making methods to adapt to changes in the market, this can lead to losses in fresh produce. The Stackelberg model has been widely used in this field and has proven to be a theoretical and practical approach. The methodology and results are instructive: through the analysis, supply chain members realized that cooperation can maximize overall profits. However, in
real life, supply chain members only consider the maximization of their own interests and ultimately fail to obtain the maximum profit from the supply chain system. As such, the model sheds some light on supply chain players. At the same time, consumer perceptions of the price and freshness of fresh produce can influence decisions. As a result, suppliers and retailers continue to focus on consumer demand and stay abreast of developments in the fresh produce market. Finally, the coordinated cost-sharing strategy of freshness preservation is combined with the supply chain of fresh products to promote the rational allocation of fresh product costs and improve the overall efficiency of the supply chain.

6. Conclusions and Recommendations

In order to coordinate the supply chain of fresh agricultural products and allocate the preservation cost reasonably, this paper constructed a supply chain system composed of suppliers, retailers, and consumers, respectively studied and compared the profit of the supply chain of fresh agricultural products under three decision-making situations, coordinated the relationship between suppliers and retailers, and improved the preservation input level. At the same time, consumer preferences in terms of freshness and price are analyzed, with a focus on consumer demand. Additional designs for preservation cost-sharing contracts are implemented for supply chain coordination.

The results show the following: (1) In the centralized decision-making model, the supply chain has the highest preservation level, the lowest selling price, and the highest total profit, making the entire supply chain system sustainable. (2) With the increase of the price sensitivity coefficient of consumers, the respective profits of the three decision models all decline; however, as consumer sensitivity to freshness increases, the profit of each of the three decision models increases. (3) This paper designs the contract of preservation cost sharing and finds that supply chain coordination can be realized within a certain range and supply chain profit is consistent with centralized decision-making.

The limitations of this paper are the following: First, the model is built on the basis of information symmetry, whereas in real life, information asymmetry may occur as the size of each player in the supply chain expands. Second, to simplify the calculations, no functions related to operating inventories and building fresh products are assumed, as required for model analysis. Throughout the follow-up study, we were able to build a multi-channel supply chain with multiple players to ensure freshness of produce. Additionally, considering the surplus value and the scarcity of fresh produce, increasing the practicality of the model is a direction for future research.

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Appendix A

Let \( \frac{\partial \theta_1}{\partial w} = \frac{\partial \theta_1}{\partial h} = 0 \), which yields \( w_1, h_1 \):

\[
\begin{align*}
\frac{\partial \theta_1}{\partial w} &= \frac{V + ym(h - n(w_1 + c_2))}{x} + (w_1 - c_1)(-\frac{y}{2})xT = 0 \\
\frac{\partial \theta_1}{\partial h} &= \frac{(w_1 - c_1)}{2\alpha} ymxT = 0
\end{align*}
\]

(A1)
Substituting \( h_1 \) into \( w_1 \) yields the optimal strategy \( w_1^* \); similarly, substituting \( w_1 \) into \( h_1 \) yields the optimal strategy \( h_1^* \):

\[
\begin{align*}
  w_1^* &= \frac{\eta (c_2 - c_1) + V + ym (w_1 - c_1)}{2n} + \eta ymT \\
  h_1^* &= \frac{ymT}{2\alpha} \left( \frac{\eta (c_2 - c_1) + V + ym h_1}{2n} \right) - c_1.
\end{align*}
\]  

(A2)

Collation gives

\[
\begin{align*}
  w_1^* &= \frac{2\alpha [V + \eta (c_1 + c_2)] - \chi y^2 m^2 T c_1}{4\alpha \eta - \chi y^2 m^2 T} \\
  h_1^* &= \frac{V - \eta (c_1 + c_2)}{4\alpha \eta - \chi y^2 m^2 T} \chi y m T.
\end{align*}
\]  

(A3)

Substituting \( w_1^* , h_1^* \) into Equation (8) gives the optimum value \( p_1^* \):

\[
\begin{align*}
  p_1^* &= \frac{V + ym V - \eta (c_1 + c_2)}{4\alpha \eta - \chi y^2 m^2 T} \chi y m T + \eta c_1 + \eta \left( \frac{2\alpha V + \eta (c_1 + c_2) - \chi y^2 m^2 T c_1}{4\alpha \eta - \chi y^2 m^2 T} \right) \\
  &= \frac{\alpha [3V + \eta (c_1 + c_2)] - \chi y^2 m^2 T (c_1 + c_2)}{4\alpha \eta - \chi y^2 m^2 T}.
\end{align*}
\]  

(A4)

By taking Equations (A3) and (A4) into Equation (7), we can obtain the retailer’s optimum profit:

\[
\begin{align*}
  \theta_2^* &= \left( \frac{\alpha [3V + \eta (c_1 + c_2)] - \chi y^2 m^2 T (c_1 + c_2)}{4\alpha \eta - \chi y^2 m^2 T} - \frac{2\alpha [V + \eta (c_1 + c_2)] - \chi y^2 m^2 T c_1}{4\alpha \eta - \chi y^2 m^2 T} \right) (V - \eta p_1 + ym V - \eta (c_1 + c_2) - \chi y m T) x T \\
  &= \frac{\alpha^2 y T (V - \eta (c_1 + c_2))^2}{(4\alpha \eta - \chi y^2 m^2 T)^2}.
\end{align*}
\]  

(A5)

By taking Equations (A2)–(A4) into Equation (10), we can obtain the supplier’s optimum profit:

\[
\begin{align*}
  \theta_1^* &= (w_1 - c_1) (V - \eta p_1 + ym V - \eta (c_1 + c_2) - \chi y m T) x T - \frac{1}{2} \alpha h_1^2 \\
  &= \frac{\alpha^2 x T (V - \eta (c_1 + c_2))^2}{2(4\alpha \eta - \chi y^2 m^2 T)}.
\end{align*}
\]  

(A6)

Therefore, the final total supply chain profit is derived as

\[
\begin{align*}
  \theta^* &= \theta_1^* + \theta_2^* \\
  &= \frac{\alpha^2 x T (V - \eta (c_1 + c_2))^2}{2(4\alpha \eta - \chi y^2 m^2 T)} + \frac{\alpha^2 y T (V - \eta (c_1 + c_2))^2}{(4\alpha \eta - \chi y^2 m^2 T)^2} \\
  &= \frac{\alpha^2 x T (6\alpha y - \chi y^2 m^2 T (V - \eta (c_1 + c_2))^2)}{2(4\alpha \eta - \chi y^2 m^2 T)^2}.
\end{align*}
\]  

(A7)

### Appendix B

Letting \( \frac{\partial \theta_1^*}{\partial w_2} = \frac{\partial \theta_1^*}{\partial h_2} = 0 \), the optimal wholesale price and preservation input level can be obtained as follows:

\[
\begin{align*}
  \frac{\partial \theta_1^*}{\partial w_2} &= [V - y(w_2 + \rho_2) + \eta m h_1] x T + (w_2 - c_1) (-\eta) x T = 0 \\
  \frac{\partial \theta_1^*}{\partial h_2} &= (w_2 - c_1) y m x T - \alpha h_1 = 0
\end{align*}
\]  

(A8)

Next sorting to obtain

\[
\begin{align*}
  h_2 &= \frac{(w_2 - c_1) y m x T}{\alpha} \\
  w_2 &= \frac{\eta (c_1 - \rho_2) + y m h_2 + V}{2n}
\end{align*}
\]  

(A9)
Sustainability, retailer and supply chain, which is similar to the supplier dominated model. Let

\[ w_2 = \frac{\eta(c_1 - \rho_2) + \eta y m \chi \alpha}{2n} + V \]

\[ h_2 = \frac{\eta(c_1 - \rho_2) + \eta y m \chi T}{\alpha n} \]

Finding out

\[ w_2^*(\theta) = \frac{\alpha V + \alpha \eta(c_1 - \rho_2) - \chi y^2 m^2 T c_1}{2 \alpha n - \chi y^2 m^2 T} \]

\[ h_2^*(\theta) = \frac{V - \eta(c_1 + \rho_2)}{2 \alpha n - \chi y^2 m^2 T} y m \chi T \]

Substitute (B4) into the retailer’s profit function and get

\[ \theta_{2h} = (\rho_2 - c_2) Q_2 = (\rho_2 - c_2) [V - y(w_2 + \rho_2) + \eta m h_1] \chi T \]

\[ = (\rho_2 - c_2) [V - y\left(\frac{\alpha V + \alpha \eta(c_1 - \rho_2) - \chi y^2 m^2 T c_1}{2 \alpha n - \chi y^2 m^2 T} + \rho_2\right) + \eta m \frac{V - \eta(c_1 + \rho_2)}{2 \alpha n - \chi y^2 m^2 T} y m \chi T]\] \chi T \]

By substituting (B4) and (B5) into Formula (17), we can get

\[ w_2^* = \frac{\alpha V + \alpha \eta(c_1 - \rho_2) - \chi y^2 m^2 T c_1}{2 \alpha n - \chi y^2 m^2 T} + c_1 \]

\[ h_2^* = \frac{V - \eta(c_1 + \rho_2)}{2 \alpha n - \chi y^2 m^2 T} y m \chi T \]

Substitute \( w_2^* \), \( h_2^* \) and \( \rho_2 \) into Formulas (17) and (B8) to find the total profit of supplier, retailer and supply chain, which is similar to the supplier dominated model.

\[ \theta_1^* = \frac{\alpha V - \eta(c_1 + c_2)}{2(2 \alpha n - \chi y^2 m^2 T)} + c_1 - c_1 [V - y\left(\frac{\alpha V - \eta(c_1 + c_2)}{2(2 \alpha n - \chi y^2 m^2 T)} + \frac{V - \eta(c_1 - c_2)}{2n}\right) + \eta m \frac{V - \eta(c_1 + c_2)}{2(2 \alpha n - \chi y^2 m^2 T)} y m \chi T] - \frac{\chi}{2} \]

\[ = \frac{\alpha \chi T [V - \eta(c_1 + c_2)]}{2(2 \alpha n - \chi y^2 m^2 T)} \]

\[ \theta_2^* = \left\{ \frac{[V - \eta(c_1 - c_2)]}{2n} - c_2 \right\} \frac{V - \eta\left(c_1 + \frac{[V - \eta(c_1 - c_2)]}{2\eta}\right)}{2 \alpha n - \chi y^2 m^2 T} \alpha n \chi T \]

\[ = \frac{\alpha \chi T [V - \eta(c_1 + c_2)]}{2(2 \alpha n - \chi y^2 m^2 T)} \]

\[ \theta^* = \theta_1^* + \theta_2^* = \frac{\alpha \chi T [V - \eta(c_1 + c_2)]}{8(2 \alpha n - \chi y^2 m^2 T)} + \frac{\alpha \chi T [V - \eta(c_1 + c_2)]}{4(2 \alpha n - \chi y^2 m^2 T)} \]

\[ = \frac{3 \alpha \chi T [V - \eta(c_1 + c_2)]}{8(2 \alpha n - \chi y^2 m^2 T)} \]

Appendix C

Let \( \frac{\partial \theta_1}{\partial h_c} = \frac{\partial \theta_2}{\partial h_c} = 0 \); we can get the optimal retail price and preservation input level under the centralized decision:

\[ \left\{ \begin{array}{l} \frac{\partial \theta_1}{\partial p_c} = (V - \eta p_c + y m h_c) \chi T + (p_c - c_1 - c_2)(-\eta) \chi T = 0 \\ \frac{\partial \theta_2}{\partial h_c} = (p_c - c_1 - c_2) y m \chi T - \alpha h_c = 0 \end{array} \right. \]
Sorting out:

\[ p_e = \frac{\eta(c_1 + c_2) + V + \gamma m_h c}{2y} \]

\[ h_e = \frac{\gamma m x (p - c_1 - c_2)}{\alpha} \]  

Substituting \( h_e \) for \( p_e \), we solve for \( p_e^* \); substituting \( p_e \) for \( h_e \) find \( h_e^* \), that is

\[ p_e = \frac{\eta(c_1 + c_2) + V + \gamma m_h c}{2y} \]

\[ h_e = \frac{\gamma m x (\eta(c_1 + c_2) + V + \gamma m_h c)}{\alpha} \]

After solving:

\[ p_e^* = \frac{\alpha[V + \eta(c_1 + c_2)] - (c_1 + c_2)x y^2 m^2 T}{2 \alpha \eta - x y^2 m^2 T} \]  

\[ h_e^* = \frac{V - \eta(c_1 + c_2)}{2 \alpha \eta - x y^2 m^2 T} \]  

It follows that only when \( 2 \alpha \eta - x y^2 m^2 T > 0 \) can the equilibrium solution of maximizing profit be obtained.

Substituting (C3), (C4) into Equation (22):

\[ \theta_e^* = \left( \frac{\alpha[V + \eta(c_1 + c_2)] - (c_1 + c_2)x y^2 m^2 T}{2 \alpha \eta - x y^2 m^2 T} - c_1 - c_2 \right) + \frac{\gamma m x (\eta(c_1 + c_2) + V + \gamma m_h c) - (c_1 + c_2)x y^2 m^2 T}{2 \alpha \eta - x y^2 m^2 T} \]

\[ + \frac{ym (V - \eta(c_1 + c_2) x y^2 m^2 T)}{2 \alpha \eta - x y^2 m^2 T} \]  

\[ \frac{\alpha x T (\eta(c_1 + c_2) + V + \gamma m_h c)}{2 \alpha \eta - x y^2 m^2 T} \]  

\[ = \frac{\alpha x T (V - \eta(c_1 + c_2))}{2 \alpha \eta - x y^2 m^2 T} \]  

\[ \frac{\alpha x T (\eta(c_1 + c_2))}{2 \alpha \eta - x y^2 m^2 T} \]

\[ = \frac{\alpha x T (V - \eta(c_1 + c_2))}{2 \alpha \eta - x y^2 m^2 T} \]

Appendix D

When the contract \( (\varphi, w_3) \), \( p_3 = p_e^* = \frac{\alpha[V + \eta(c_1 + c_2)] - (c_1 + c_2)x y^2 m^2 T}{2 \alpha \eta - x y^2 m^2 T} \), its supply chain profit function is

\[ \theta_{1c} = (w_3 - c_1)(V - \eta p_e + y m h_3)x T - \frac{1}{2}(1 - \varphi)\alpha h_3^2 \]

Let us find the optimal fresh-keeping input level:

\[ \frac{\partial \theta_{1c}}{\partial h_3} = (w_3 - c_1)y m x T - (1 - \varphi)\alpha h_3 = 0, \frac{\partial^2 \theta_{1c}}{\partial h_3^2} = -(1 - \varphi) < 0 \]

Because \( h_3 \) is a concave function of \( \theta_{1c} \), there is a maximum; after sorting, we obtain

\[ h_3^*(\varphi) = \frac{(w_3 - c_1)y m x T}{(1 - \varphi)\alpha} \]

When \( w_3(\varphi) = (1 - \varphi)(p_e^* - c_1 - c_2) + c_1 \), the contract \( (\varphi, w_3) \) is implemented, and the retail price and fresh-keeping input level are consistent with the centralized decision, so the optimal profit of the supplier is

\[ \theta_{1c}^* = (w_3^* - c_1)Q_{s}^* - (1 - \varphi)c_{h3}^* = (1 - \varphi)[(p_e^* - c_1 - c_2)]Q_e^* - c_{h3}^* = (1 - \varphi)\theta_e \]

As a result,

\[ \theta_{1c}^* - \theta_{1b}^* = (1 - \varphi)\theta_e^* - \theta_{1b}^* = \frac{(1 - \varphi)\alpha x T (V - \eta(c_1 + c_2))}{2 \alpha \eta - x y^2 m^2 T} - \frac{(1 - \varphi)\alpha x T (V - \eta(c_1 + c_2))}{8 \alpha \eta - x y^2 m^2 T} \]

\[ = \frac{(1 - \varphi)\alpha x T (V - \eta(c_1 + c_2))}{2 \alpha \eta - x y^2 m^2 T} - \frac{(1 - \varphi)\alpha x T (V - \eta(c_1 + c_2))}{8 \alpha \eta - x y^2 m^2 T} \]
Solving from the above equation, it follows that at $\varphi \leq \frac{1}{5}$, $\theta_{\text{sc}}^* \geq \theta_{\text{lb}}^*$.

Under contractual harmonization, the optimal profit for the retailer is

$$\theta_{\text{sc}}^* - \theta_{\text{lb}}^* = \varphi \theta_{\text{sc}}^* - \theta_{\text{lb}}^* = \frac{\varphi c T (V-n(c_1+c_2))}{2(2s-n+c_2 \cdot T)} - \frac{c T (V-n(c_1+c_2))}{2(2s-n+c_2 \cdot T)}$$

$$= (\varphi - \frac{1}{2}) \frac{[\theta^* c_2 - (c_1 - c_2)]}{2(2s-n+c_2 \cdot T)}$$

From the above equation, it follows that at $\varphi \geq \frac{1}{4}$, $\theta_{\text{sc}}^* \geq \theta_{\text{lb}}^*$.

Therefore, the distribution ratio of $\varphi \in [\frac{1}{4}, \frac{3}{4}]$, $w_2(\varphi) = (1-\varphi)(p_{\text{sc}}^*-c_1+c_2) + c_1$ suppliers and retailers in this range is optimal. The specific distribution ratio depends on the bargaining power of both parties. The better the coordination between the two parties, the higher the profit distribution.

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