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Fresh Supply Chain Coordination Considering Preservation Efforts and Freshness

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Abstract:

A two-level fresh supply chain is composed of a single fresh product supplier and a single retailer, in which the supplier is responsible for transporting the product to the retailer. The fresh-keeping efforts of the supplier and the transportation time influence the freshness of the product. Simultaneously, the market demand of the product is related to its freshness and the market price. Given the perishable and vulnerable characteristics of fresh products, this paper introduces freshness, preservation effort level, preservation effort cost, and other factors to construct centralized and decentralized decision-making models and propose two pricing contracts to study the coordination of the fresh supply chain. The results indicate that adopting a two-part pricing contract can effectively improve the total profit of the supply chain, realize the Pareto improvement of the profit of the supply chain members, and stimulate the growth of fresh product market demand. There are five main conclusions: (1) The rational use of a two-part pricing contract can improve the total profit of the supply chain, which is closer to the centralized decision, and can realize Pareto improvement of supplier and retailer profit. (2) Using an appropriate two-part pricing contract by supply chain members can effectively improve the adverse impact of large fresh-keeping effort cost coefficient on the total profit of the supply chain under the lack of significant fresh-keeping technology advantage in the fresh supply chain. (3) Reasonable adoption of a two-part pricing contract by supply chain members can improve product market demand, increase the order quantity by suppliers, face retailers a larger market, and achieve a win-win situation. (4) The effect of cold chain service adopted by suppliers is not apparent when fresh products are sensitive to transportation time, while transportation time should be shortened to improve product freshness. (5) When the product is sensitive to the preservation effort level, the supplier can increase the investment in the preservation effort to improve the product's freshness to stimulate the profit growth of the supply chain. However, this paper only considers the factors associated with suppliers and retailers in the supply chain without considering customer satisfaction. Future research can improve preservation efforts, product freshness, and customer satisfaction.

Keywords: *Preservation efforts, Freshness, Supply chain coordination, Two-part pricing contract*

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I. INTRODUCTION

With the gradual improvement of living standards, people's consumption concept is continuously changing, and they pay more attention to the quality and safety of fresh products. According to the relevant knowledge of consumer psychology [1], People take the price and freshness of products as an essential reference index while buying fresh products. However, the cold chain transportation technology and equipment are imperfect, while the product in transit loss is significant. This affects the consumer demand and the supply chain members and declines the corporate profits. Thus, suppliers of funds to maintain product freshness are limited in the transportation process, and the retailer should cooperate with suppliers to provide a fresh supply chain.

In recent years, domestic and foreign researchers on fresh supply chain research have mainly focused on supply chain coordination and fresh product ordering or pricing. The research on the coordination of fresh supply chain primarily focuses on using quantity discount contracts, revenue sharing contracts, cost-sharing contracts, buyback contracts, option or joint contracts, and other relevant contracts for supply chain coordination. For example, Zheng et al. [2] assumed that members in the fresh agricultural supply chain, composed of one supplier and multiple retailers, have signed quantity discount contracts in independent and joint procurements and provided the optimal pricing decisions of suppliers and optimal procurement decisions of retailers while signing quantity discount contracts. Yan et al. [3] proposed an improved revenue-sharing contract for the three-level fresh supply chain composed of manufacturers, distributors, and retailers, to find the optimal solution of supply chain profit maximization under three decision-making scenarios. They established a profit distribution model to realize supply chain coordination. Wang et al. [4] studied the supply chain in which farmers invest in the production of green fresh products and retailers transport and sell green fresh products to final consumers to construct a decentralized model without cost-sharing, a decentralized Stackelberg cost-sharing model, and a Nash bargaining model with cost-sharing. Respectively. Zhou et al. [5] proposed an option contract model to compare and analyze the new agricultural supply chain's output, profit, risk, and information sharing under different conditions. Wang et al. [6] studied a newsvendor problem for fresh produce with bidirectional option contracts with price-dependent stochastic demand. The condition of the fresh production may deteriorate during circulation. The optimal ordering and pricing decisions can be deduced under the condition of two-way options and circulation loss. Wang et al. [7] employed the newspaper supplier framework to study the combination contract of the wholesale price and call option and introduced the optimal ordering strategy of retailers and the optimal pricing strategy of suppliers in the fresh agricultural supply chain composed of suppliers and retailers. Feng et al. [8] established a two-level decision-making model for the supply chain of fresh agricultural products with risk-neutral suppliers and risk-averse retailers and evaluated the impact of fresh agricultural product demand on product freshness and price. They demonstrated that the traditional cost-sharing and cost-benefit-sharing contracts could not coordinate the supply chain. Nevertheless, supply chain coordination can be accomplished by adjusting the compensation amount combined with cost-sharing and compensation strategies. Bojun Gu et al. [9] considered a fresh-product supply chain in which the supplier and the e-tailer invest in quality-improvement effort and fresh-keeping effort, respectively. Bai Shizhen et al. [10] designed the

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demand function to propose the "revenue-cost-sharing" contract and analyzed the supply chain coordination problems of fresh and secondary e-commerce.

Besides, among the factors influencing the ordering and pricing strategies of fresh supply chain, fresh products' characteristics have also attracted scholars' attention. Maihami [11] proposed a joint pricing and inventory control method for deteriorating goods in the slow process, established the demand function on price and time and determined the optimal price, optimal replenishment plan, and order quantity. Yiyan Qin et al. [12] studied the pricing and batch of products when product quality and physical quantity deteriorate simultaneously. Jia JX et al. [13] studied the pricing and order mix problem of the perishable supply chain of one supplier and one retailer in a limited view. The results demonstrated that the optimal pricing strategy of non-fresh products only depends on its inventory. In contrast, the optimal pricing strategy of fresh products and the optimal order quantity only depend on its wholesale price, and there is a constant relationship between them. Cao Yu et al. [14] performed a comparative study on the cooperation between suppliers and retailers and the influence of changes in their dominant positions on the preservation effort level and pricing of the supply chain, considering the dual situation of severe loss of fresh products and excessive fresh preservation. Yan, B et al. took the secondary supply chain of fresh agricultural products as the research object to study the optimal supply chain ordering and coordination based on two-stage price, wholesale price, and options contract [15], and then investigates decisions considering fairness concerns [16]. He, Y et al. [17] designed the profit model of fresh food retail enterprises selling two quality levels to solve the problem of fresh food quality classification. By analyzing the distribution of fresh food quality levels, retailers' optimal classification, pricing, and ordering of fresh food are determined based on quality selection model.

As mentioned above, many analyses have been performed on variables like product deterioration rates and preservation efforts in the fresh supply chain. At present, researchers believe that freshness is only related to freshness effort level. However, they ignore the coordination problem of the freshness supply chain when product transportation time and supplier freshness effort level jointly affect freshness. This paper indicates that product freshness is influenced by the level of freshness effort and the required time to ship the product by the supplier. The supply chain decision-making is studied in decentralized and centralized conditions, considering that the market demand for fresh products is related to the products' selling price and freshness, respectively. Finally, a two-part pricing contract is proposed to study the supply chain coordination problem.

The rest of this paper is organized as follows. Parameter description and model assumptions are presented in Sect. 2. The models are established in Sect. 3. Sect. 4 analyzes the case and experimental simulation results. Finally, Sect. 5 concludes the paper.

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II. PARAMETER DESCRIPTION AND MODEL ASSUMPTIONS

2.1 Parameter Description

The description of parameters is presented in Table I.

Table I: The description of parameters.

Symbol	The variable name
c	Unit variable cost of product
C_b	Supplier's cost of preservation
w	Unit wholesale price of products
p	Product sales price
t	The time it takes to transport a product from a supplier to a retailer
λ	Preservation effort cost coefficient, $\lambda \in (0,1)$
b	Preservation effort level, $b > 0$
a	Product market size
π_s	Supplier profit
π_r	Retailer profit
α	Freshness preservation effort sensitivity coefficient, $\alpha > 0$
β	Freshness time sensitivity coefficient, $\beta > 0$
k	Elasticity of price demand
g	Elasticity of freshness
ρ	Product freshness
D	The market demand

2.2 Model Assumptions

This paper considers that the supplier is responsible for producing fresh products to meet the retailer's order quantity and simultaneously should transport the products to the retailer and provide preservation efforts. Retailers order products from suppliers according to the market demand, influenced by the selling price and freshness of products. Both the required time to ship the product to the retailer by the supplier and the supplier's preservation efforts influence product freshness. Based on the current research results, the following hypotheses are proposed.

Assumption 1:

The unit variable cost is c, the unit wholesale price is w, and the retailer sells the product at a price.

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Assumption 2:

According to previous studies, the preservation effort cost is convex. Thus, the supplier preservation cost can be expressed as $C_b = \frac{\lambda}{2}b^2$, where λ ($\lambda \in (0,1)$) is the preservation effort cost coefficient, and b ($b > 0$) is the preservation effort level.

Assumption 3:

Given the product freshness subject to the time it takes to transport a product from a supplier to a retailer and the supplier's freshness preservation effort level, according to reference [18] the product freshness can be described as $\rho = \frac{\alpha b}{1+\beta t^2}$, where α ($\alpha > 0$) is the freshness preservation effort sensitivity coefficient, and β ($\beta > 0$) is the freshness time-sensitivity coefficient. The greater the freshness preservation effort sensitivity coefficient, the more sensitive the freshness of the product to the preservation effort. Different fresh products have different sensitivities to time. The greater the freshness time-sensitivity coefficient is, the more sensitive the product is to time.

Assumption 4:

Considering that the market demand status is related to the product sales price and freshness, the market demand may be expressed as $D = a - kp + g\rho$, where a ($a > 0$) is the product market size, k ($k > 0$) is the elasticity of price demand, and g ($g > 0$) is the elasticity of freshness.

Assumption 5:

In order to ensure non-negative conditions for product demand, $a - kc > 0$, and ensure the preservation efforts level, $b > 0$, and $2\lambda k - G^2 > 0$.

III. MODEL ESTABLISHMENT

3.1 The Game Model under the Centralized Condition

Under the centralized condition, suppliers and retailers can maximize the total supply chain profit when the total supply chain profit is expressed as:

$$\pi_c = (p-c)(a-kp+g\rho) \tag{1}$$

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Proposition 1:

Under the centralized condition, the retailer gives the product sales price as

$p_c^* = \frac{\lambda(a+kc) - G^2 c}{2k\lambda - G^2}$, the supplier of the best preservation effort is $b_c^* = \frac{G(a-kc)}{2k\lambda - G^2}$, the market demand is $D_c^* = \frac{k\lambda(a-kc)}{2\lambda k - G^2}$, and the total supply chain profit is $\pi_c^* = \frac{\lambda(a-kc)^2}{2\left(2\lambda k - G^2\right)}$.

Proof:

To simplify the computational process, set $\frac{ga}{1+\beta t^2}$ to G. The following calculations are similar.

The first partial derivatives of π_c with respect to p_c and b_c are given by:

$$\begin{cases} \frac{\partial \pi_c}{\partial p_c} = a - 2kp_c + Gb_c + kc \\ \frac{\partial \pi_c}{\partial b_c} = -\lambda b_c + G(p_c - c) \end{cases} \tag{2}$$

Now, the second-order partial derivatives of π_c with respect to p_c and b_c are calculated as:

$$\begin{cases} \frac{\partial^2 \pi_c}{\partial {p_c}^2} = -2k < 0 \\ \frac{\partial^2 \pi_c}{\partial {b_c}^2} = -\lambda < 0 \end{cases} \tag{3}$$

Then, the product sales price and the best preservation efforts are obtained as:

$$p_c^* = \frac{\lambda(a+kc) - G^2 c}{2k\lambda - G^2} \tag{4}$$

$$b_c^* = \frac{G(a-kc)}{2k\lambda - G^2} \tag{5}$$

The market demand and the total profit of the supply chain are:

$$D_c^* = \frac{k\lambda(a-kc)}{2\lambda k - G^2} \tag{6}$$

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$$\pi_c^* = \frac{\lambda(a-kc)^2}{2(2k\lambda - G^2)} \tag{7}$$

This completes the proof.

3.2 The Game Model under the Decentralized Condition

Before analyzing the supply chain based on a two-part pricing contract, the supply chain under general decentralized decision is analyzed. Under decentralized decision-making (represented by subscript D), there is a Stackelberg game between suppliers and retailers. In this case, the profit function of enterprises can be expressed as:

$$\pi_d^s = (w-c)(a-kp+g\rho) - c_b \tag{8}$$

$$\pi_d^r = (p-w)(a-kp+g\rho) \tag{9}$$

Proposition 2:

Under the decentralized condition, the retailer gives the product sales price as $p_d^* = \frac{\lambda(3a+kc)-G^2c}{4\lambda k - G^2}$, the optimal wholesale price given by the supplier is $w_d^* = \frac{2\lambda(a+kc)\text{-}G^2c}{4\lambda k - G^2}$, the supplier of the best preservation effort is $b_d^* = \frac{G(a-kc)}{4\lambda k - G^2}$, the market demand is $D_d^* = \frac{k\lambda(a-kc)}{4\lambda k - G^2}$, the best profit for retailers is $\pi_d^{r*} = \frac{k\lambda^2(a-kc)^2}{(4\lambda k - G^2)^2}$, the best profit of the supplier is $\pi_d^{s*} = \frac{\lambda(a-kc)^2}{2(4\lambda k - G^2)}$, the total supply chain profit is $\pi_d^* = \frac{\lambda(a-kc)^2(6\lambda k - G^2)}{2(4\lambda k - G^2)^2}$.

Proof:

The first partial derivative of (9) with respect to p_d is obtained as:

$$\frac{\partial \pi_d^r}{\partial p_d} = a - 2kp_d + Gb + kc \tag{10}$$

By equating relation (10) to zero, we have:

$$p_d' = \frac{a+Gb+kc}{2k} \tag{11}$$

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Inserting equation (11) into equation (8), the first partial derivatives of (8) with respect to b_d and w_d are calculated as:

$$\begin{cases} \dfrac{\partial \pi_d^s}{\partial b_d} = G(w-c) - 2\lambda b_d \\ \dfrac{\partial \pi_d^s}{\partial w_d} = a + Gb + kc - 2kw_d \end{cases} \tag{12}$$

Now, the second-order partial derivatives of (8) with respect to p_d and w_d can be obtained as:

$$\begin{cases} \dfrac{\partial^2 \pi_d^s}{\partial {p_d}^2} = -2\lambda < 0 \\ \dfrac{\partial^2 \pi_d^s}{\partial {w_d}^2} = -2k < 0 \end{cases} \tag{13}$$

According to (13), π_d^s is a concave function of b_d and w_d, Thus, there are the optimal solutions b_d^* and w_d^*.

Equating (12) to zero gives:

$$b_d^* = \frac{G(a-kc)}{4\lambda k - G^2} \tag{14}$$

$$w_d^* = \frac{2\lambda(a+kc)\text{-}G^2c}{4\lambda k - G^2} \tag{15}$$

$$p_d^* = \frac{\lambda(3a+kc) - G^2c}{4\lambda k - G^2} \tag{16}$$

Market demand, supply chain member profits, and total supply chain profits are obtained as:

$$D_d^* = \frac{k\lambda(a-kc)}{4\lambda k - G^2} \tag{17}$$

$$\pi_d^{r*} = \frac{k\lambda^2(a-kc)^2}{(4\lambda k - G^2)^2} \tag{18}$$

$$\pi_d^{s*} = \frac{\lambda(a-kc)^2}{2(4\lambda k - G^2)} \tag{19}$$

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$$\pi_d^{\ *} = \frac{\lambda(a-kc)^2(6\lambda k - G^2)}{2(4\lambda k - G^2)^2} \tag{20}$$

The proof is completed.

3.3 The Game Model under a Two-part Pricing Contract

Under the two-part pricing contract, the retailer proposes a wholesale price ‘w ’and gives an optimal transfer price ‘F’, while the supplier can choose whether to accept this contract; that is, the retailer puts forward two pricing contracts (F, W) to the supplier. The profit formula of suppliers and retailers are given as follows:

$$\pi_t^s = (w-c)(a-kp+g\rho) - c_b + F \tag{21}$$

$$\pi_t^r = (p-w)(a-kp+\rho g) \tag{22}$$

Proposition 3:

Under a two-part pricing contract, the retailer gives the product sales price as $p_t^* = \frac{G^2(2\lambda a - cG^2) + 2\lambda^2 k(a+kc)}{G^2(2\lambda k - G^2) + 4\lambda^2 k^2}$, the optimal wholesale price is $w_t^* = \frac{2\lambda a G^2 + c(4\lambda^2 k^2 - G^4)}{G^2(2\lambda k - G^2) + 4\lambda^2 k^2}$, the supplier of the best preservation effort is $b_t^* = \frac{G^3(a-kc)}{G^2(2\lambda k - G^2) + 4\lambda^2 k^2}$, the market demand is $D_t^* = \frac{2\lambda^2 k^2(a-kc)}{G^2(2\lambda k - G^2) + 4\lambda^2 k^2}$, the best profit for retailers is $\pi_t^{r*} = \frac{\lambda(a-kc)^2(2\lambda k + G^2)}{2[G^2(2\lambda k - G^2) + 4\lambda^2 k^2]} - \frac{\lambda(a-kc)^2}{2(4\lambda k - G^2)}$, the best profit of the supplier is $\pi_t^{s*} = \frac{\lambda(a-kc)^2}{2(4\lambda k - G^2)}$, the total supply chain profit is $\pi_t^{\ *} = \frac{\lambda(a-kc)^2(2\lambda k + G^2)}{2[G^2(2\lambda k - G^2) + 4\lambda^2 k^2]}$, and the optimal transfer price is $F^* = \frac{\lambda(a-kc)^2}{2(4\lambda k - G^2)} - \frac{\lambda G^2(a-kc)^2(8\lambda^2 k^2 - G^4)}{2[G^2(2\lambda k - G^2) + 4\lambda^2 k^2]^2}$.

Proof:

The first partial derivative of (22) with respect to p_t is given by:

$$\frac{\partial \pi_t^r}{\partial p_t} = a - 2kp_t + Gb + kw \tag{23}$$

Setting (23) to zero gives:

$$p_t^{'} = \frac{a + Gb + kw}{2k} \tag{24}$$

Combining equations (24) and (21) gives the first partial derivative of (22) with respect to b_t as:

$$\frac{\partial \pi_t}{\partial b_t} = -2\lambda b_t + G(w-c) \tag{25}$$

Equating (25) to zero yields

$$b_t^{'} = \frac{G(w-c)}{2\lambda} \tag{26}$$

By replacing equations (24) and (26) into (22), the retailer optimization problem can be expressed as:

$$\pi_t^r(w,F) = \frac{[2\lambda(a-kw) + G^2(w-c)]^2}{16\lambda^2 k} - F \tag{27}$$

Bringing equations (24) and (26) into (21) gives the following constraint:

$$s.t.\pi_t^s = \frac{4\lambda(w-c)(a-kw) + (w-c)^2 G^2}{8\lambda} + F \geq \pi_d^{s*} \tag{28}$$

Here,

$$F = \frac{\begin{Bmatrix} 4\lambda^2(a-kc)^2 \\ -(4\lambda k - G^2)[4\lambda(w-c)(a-kw) + (w-c)^2 G^2] \end{Bmatrix}}{8\lambda(4\lambda k - G^2)} \tag{29}$$

By combining equations (29) and (27), it can be concluded that the second derivative of π_t^r with respect to w is negative; that is, π_t^r is a 'w' concave function, and the optimal wholesale price of π_t^r can be obtained by setting its first derivative with respect to w to zero:

$$w_t^* = \frac{2\lambda a G^2 + c(4\lambda^2 k^2 - G^4)}{G^2(2\lambda k - G^2) + 4\lambda^2 k^2} \tag{30}$$

Replacing (30) into (29) gives:

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$$F^{*} = \frac{\lambda(a-kc)^2}{2(4\lambda k-G^2)} - \frac{\lambda G^2(a-kc)^2(8\lambda^2k^2-G^4)}{2[G^2(2\lambda k-G^2)+4\lambda^2k^2]^2} \tag{31}$$

Therefore, the total profit of the supply chain is obtained as:

$$D_t^{*} = \frac{2\lambda^2k^2(a-kc)}{G^2(2\lambda k-G^2)+4\lambda^2k^2} \tag{32}$$

$$\pi_t^{s*} = \frac{\lambda(a-kc)^2}{2(4\lambda k-G^2)} \tag{33}$$

$$\pi_t^{r*} = \frac{\lambda(a-kc)^2(2\lambda k+G^2)}{2[G^2(2\lambda k-G^2)+4\lambda^2k^2]} - \frac{\lambda(a-kc)^2}{2(4\lambda k-G^2)} \tag{34}$$

$$\pi_t^{*} = \frac{\lambda(a-kc)^2(2\lambda k+G^2)}{2[G^2(2\lambda k-G^2)+4\lambda^2k^2]} \tag{35}$$

The proof is completed.

Corollary 1:

According to propositions 1-3, although the total profit of the supply chain under a centralized condition is higher than the decentralized one, the centralized condition is in an idealized state and difficult to achieve. Although the total profit of the supply chain does not reach the level of supply chain profit under the centralized condition while adopting the two-part pricing contract, it is improved compared with the supply chain profit under the decentralized condition. Simultaneously, the retailer's profit is improved without degrading the supplier's profit, and Pareto improvement of supplier and retailer's profit is realized.

Proof:

$$\pi_c^{*}\text{-}\pi_d^{*} = \frac{4\lambda^3k^2}{2(2\lambda k-G^2)(4\lambda k-G^2)^2} > 0 \tag{36}$$

$$\pi_c^{*}\text{-}\pi_t^{*} = \frac{2\lambda^2G^2k(a-kc)^2}{2(2\lambda k-G^2)[G^2(2\lambda k-G^2)+4\lambda^2k^2]} > 0 \tag{37}$$

$$\pi_t^{*}\text{-}\pi_d^{*} = \frac{2\lambda^2k(a-kc)^2(2\lambda k-G^2)^2}{2[G^2(2\lambda k-G^2)+4\lambda^2k^2](4\lambda k-G^2)^2} > 0 \tag{38}$$

Thus:

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$$\pi_c^{\ *} > \pi_t^{\ *} > \pi_d^{\ *} \tag{39}$$

$$\pi_t^{s*} = \pi_d^{s*} \tag{40}$$

$$\pi_t^{r*} > \pi_d^{r*} \tag{41}$$

The proof is completed.

Corollary 2:

According to propositions 1-3, the market demand under the centralized condition is optimal, and the two-part pricing contract can improve the market demand level and make it closer to the market demand under the centralized condition.

Proof:

$$D_c^* - D_t^* = \frac{G^2 k\lambda(a-kc)(4\lambda k - G^2)}{(2\lambda k - G^2)[G^2(2\lambda k - G^2) + 4\lambda^2 k^2]} > 0 \tag{42}$$

$$D_t^* - D_d^* = \frac{k\lambda(a-kc)(G^2 - 2k\lambda)^2}{(4\lambda k - G^2)[G^2(2\lambda k - G^2) + 4\lambda^2 k^2]} > 0 \tag{43}$$

Therefore:

$$D_c^* > D_t^* \ D_t^* > D_d^* \tag{44}$$

This completes the proof.

IV. EXAMPLE ANALYSIS

In order to verify the correctness and effectiveness of the above conclusions, this section performs a numerical analysis to verify the influence of preservation effort cost coefficient and product freshness sensitivity coefficient on decision variables.

4.1 Influence of Preservation Effort Cost Coefficient

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This section studies the changes of λ, the preservation effort cost coefficient, product sales price, market demand, and overall supply chain. Based on the hypothesis of $a=1000$, $k=50$, $c=6$, $g=40$, $t=5$, $\alpha=0.15$, $\beta=0.08$, $\lambda=0.08{:}0.02{:}1$, the results are obtained, as shown in Figure 1-Figure 3.

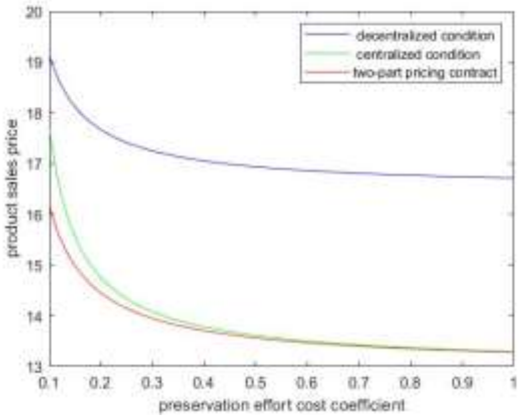

Figure 1: Influence of preservation effort cost coefficient on product sales price

As shown in Figure 1, the selling price of fresh products decreases with the increase of the preservation effort cost coefficient, while the cost of preservation gradually increases with the increase of the cost coefficient of the preservation effort. Suppliers do their best to reduce the input of preservation of products to reduce losses and costs. Simultaneously, to stimulate consumer consumption, retailers sell products at lower prices. As a result, the sales price of the product is falling. Under the two-part pricing contract, the retailer first provides a specific fixed fee to the supplier, while the unit wholesale price of the product significantly reduces using this contract so that the retailer can choose to sell the product at a lower price.

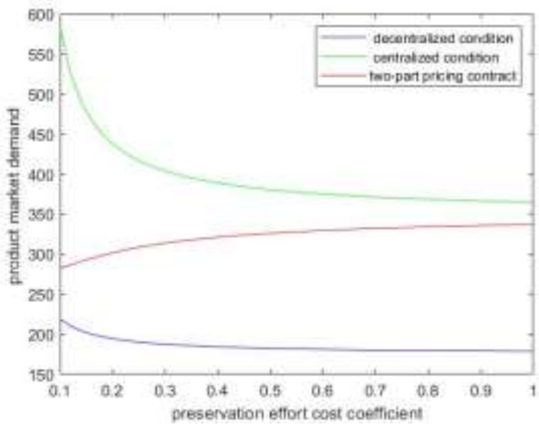

Figure 2: Influence of preservation effort cost coefficient on market demand

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Figure 2 directly reflects the influence of the preservation effort cost coefficient on the fresh product market demand under the three modes. It can be seen that although the product demand is lower than under the centralized condition under the two-part pricing contract, it is still higher than that obtained under the decentralized condition.

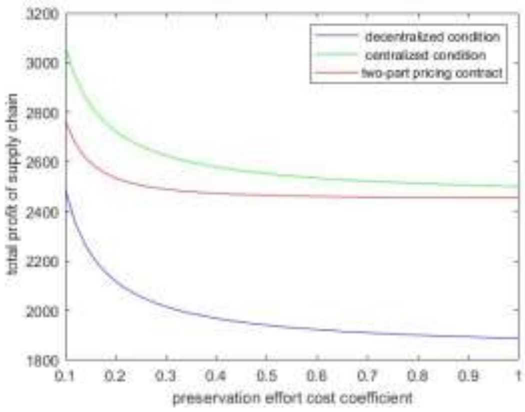

Figure 3: Influence of preservation effort cost coefficient on total profit of supply chain

As presented in Figure 3, the total profit of the supply chain under the three modes decreases with the increase of the preservation effort cost coefficient. The decrease of market demand and sales price of products under centralized and decentralized conditions decreases the supply chain profits. If the negative effect of the price decline is more significant than the positive effect of demand growth under a two-part pricing contract, supply chain profit tends to decline. The total profit of the supply chain under the centralized decision is higher than that under the decentralized condition and the two-part pricing contract. The two-part pricing contract optimizes the situation that the profit under the decentralized decision is closer to that under the centralized one, demonstrating the effectiveness of two-part pricing contract in improving the total profit of the supply chain. Compared with the other two models, the profit change of the supply chain under the two-part pricing contract is gentler. Therefore, using the appropriate two-part pricing contract can effectively improve the adverse impact of the more significant fresh-keeping effort cost coefficient on the supply chain under the lack of apparent fresh-keeping technology advantage in the fresh supply chain.

4.2 Influence of Freshness Preservation Effort Sensitivity Coefficient

This section studies the changes in the supply chain preservation effort level and the overall profit of the supply chain for different values of α. Hypothesis $a=1000$, $k=50$, $c=6$, $g=40$, $t=5$, $\lambda=0.5$, $\beta=0.08$, $\alpha=0{:}0.02{:}1$, the results are shown in Figure 4 and Figure 5.

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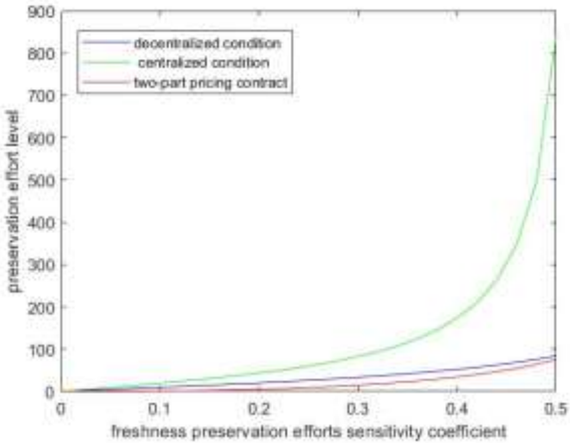

Figure 4: Influence of freshness preservation efforts sensitivity coefficient on the preservation efforts level

As shown in Figure 4, the preservation effort level of suppliers in the three modes presents an upward trend with the increase of freshness preservation efforts sensitivity coefficient. In the beginning, with the increase of the sensitivity coefficient of freshness preservation effort level, the growth rate of preservation effort level is slow, but when it exceeds a specific range, the growth rate of preservation effort level accelerates. Product freshness becomes more sensitive to the supplier's preservation effort level for larger values of the sensitivity coefficient of freshness preservation effort level. Suppliers can improve product freshness by increasing their investment in product preservation.

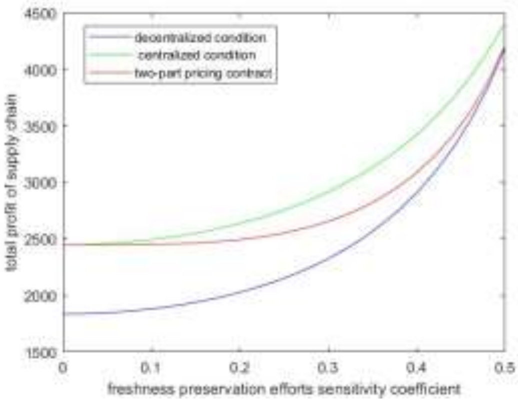

Figure 5: Influence of freshness preservation efforts sensitivity coefficient on the total profit of the supply chain

It can be concluded from Figure 5 that the profit of the supply chain increases in the three cases with the increase of coefficient α. Within a specific range, the profit growth rate of the supply chain is slow, but beyond a specific range, the improvement rate of preservation effort level is accelerated, stimulating the profit growth rate of the supply chain. Although the profit of the supply chain cannot reach the profit of

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a centralized state using a two-part pricing contract, its value is higher than that of the decentralized condition.

4.3 Influence of Freshness Time Sensitivity Coefficient

This section studies the changes in the supply chain preservation effort level and the overall profit of the supply chain for different values of β. Hypothesis $a=1000$, $k=50$, $c=6$, $g=40$, $t=5$, $\lambda=0.5$, $\alpha=0.15$, $\beta=0:0.02:1$, the results are obtained, as presented in Figure 6 and Figure 7.

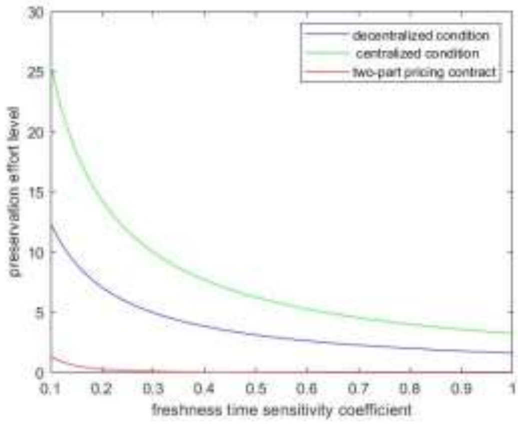

Figure 6: Effect of freshness time-sensitivity coefficient on preservation effort level

It can be seen from Figure 6 that when the freshness time-sensitivity coefficient increases within a specific range, the preservation effort level of suppliers decreases rapidly. In contrast, when the freshness time-sensitivity coefficient exceeds a specific range, the decline of suppliers' freshness preservation effort level slows down. The greater the time-sensitivity coefficient, the higher the sensitivity of the product to the transportation time. At this point, the supplier's efforts to increase the freshness is not ideal, and the transportation time of the product significantly affects the freshness of the product. Therefore, some approaches should be employed to shorten the transportation time of the product.

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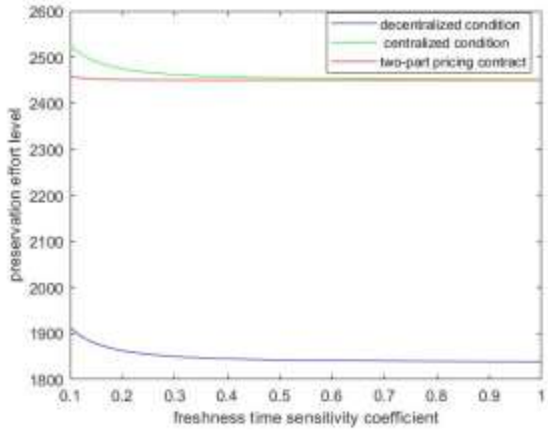

Figure 7: Influence of freshness time-sensitivity coefficient on total profit of supply chain

As shown in Figure 7, supply chain profit is negatively correlated with the time-sensitivity coefficient in the three cases, similar to the changing trend of preservation effort level. Supply chain profit decreases rapidly within a specific range, while it decreases slowly and eventually becomes stable beyond a specific range.

V. CONCLUSIONS

This paper studies the coordination problem of the fresh supply chain under the influence of product freshness by supplier's transportation time and supplier's preservation effort level and proposes a two-part pricing contract to coordinate. The research results and management implications are as follows: (1) The rational use of a two-part pricing contract can improve the total profit of the supply chain, which is closer to the centralized decision, and can realize Pareto improvement of supplier and retailer profit. (2) Using an appropriate two-part pricing contract by supply chain members can effectively improve the adverse impact of large fresh-keeping effort cost coefficient on the total profit of the supply chain under the lack of significant fresh-keeping technology advantage in the fresh supply chain. (3) Reasonable adoption of a two-part pricing contract by supply chain members can improve product market demand, increase the order quantity by suppliers, face retailers a larger market, and achieve a win-win situation. (4) The effect of cold chain service adopted by suppliers is not apparent when fresh products are sensitive to transportation time, while transportation time should be shortened to improve product freshness. (5) When the product is sensitive to the preservation effort level, the supplier can increase the investment in the preservation effort to improve the product's freshness to stimulate the profit growth of the supply chain.

The optimal supply chain coordination cannot be realized in the market under various complex factors. In order to stimulate the market demand in the supply chain and make profits of supplier and retailer optimization, the two should make joint efforts to attach importance to take the role of two-part pricing contract. However, this paper only considers the factors associated with suppliers and retailers in the supply chain without considering customer satisfaction. Future research can improve preservation efforts, product freshness, and customer satisfaction.

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