

Research on Dual-channel Supply Chain Pricing of Agricultural Products

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ABSTRACT

As China's primary industry, agriculture is crucial to China's development, and the vast land and differentiated climate make China's agricultural products form a comprehensive complementarity. The country's agricultural products are diverse, and the supply chain has become a bridge for agricultural products to flow to consumers. In the supply chain of agricultural products, due to its vulnerability characteristics, coupled with climate, pests and other factors, the output of agricultural products is always not fixed, and also forms a distinct size of the year, making it difficult to well meet market demand. With the development of online shopping in recent years, suppliers are no longer bound to traditional offline sales channels and have opened self-operated online sales channels, forming a dual-channel sales situation. This expands their market share and profits, but also leads to a decrease in retailers' market share, resulting in channel conflicts. Therefore, by analyzing the optimal pricing and maximum profit of suppliers and retailers under centralized and decentralized decision-making, this paper introduces the revenue sharing contract model to enable suppliers and retailers to achieve coordination in the dual-channel supply chain, so as to improve the profits of suppliers, retailers and the overall supply chain.

KEYWORDS

Agricultural products; Dual-channel supply chain; Contract coordination

1. INTRODUCTION

China has a vast territory and has always regarded agriculture as the primary industry. The vast land is rich in various agricultural products. With the development of the times, people's living conditions have been continuously improving, and the quality of life has also been constantly rising. As a result, people's requirements for agricultural products have gradually increased. Some agricultural products cannot be supplied throughout the year like greenhouse vegetables, which leads to their seasonal nature. This results in the supply of agricultural products being concentrated in just three or four months or even less, making the rapid sale of goods within a short period of time a key point.

In recent years, with the continuous development of the e-commerce economy, people can easily purchase products from all over the country without leaving their homes, which has become a daily occurrence. However, for farmers, facing new things, how to adapt quickly has become a problem. In the traditional economy, farmers generally sold their products nearby or had them purchased by others, which was a relatively simple process, merely involving the exchange of money and goods. But now, they have to deal with orders from others, send out the goods, and only receive payment after the recipients confirm the receipt of the goods. There is also the risk of damage to the goods during logistics.

Against this backdrop, the sales channels for agricultural products in rural areas have been expanded, forming a dual-channel situation. In this context, the conflict between the two channels gradually emerges. In the dual-channel supply chain of agricultural products, farmers supply agricultural products to retailers and consumers. In the traditional channel, farmers and retailers have a cooperative relationship, while in the online channel, they form a competitive relationship. How the members of the supply chain set prices and continuously coordinate to achieve maximum profits becomes crucial. Long-term cooperation can bring long-term benefits to all members. Therefore, this article will explore the sales and pricing issues of the agricultural product supply chain to resolve the conflicts in the dual channels.

2. ANALYSIS OF PRICING DECISIONS FOR DUAL-CHANNEL SUPPLY CHAINS OF AGRICULTURAL PRODUCTS

This article mainly studies the agricultural product supply chain composed of a single supplier and a single retailer. Due to seasonal, weather, pest and disease disasters and other reasons, the output of agricultural products is limited. In addition, they are prone to spoilage and the quality of the products is easily affected. Therefore, suppliers also need to carry out preservation treatment on the products. Meanwhile, in a dual-channel supply chain, consumers' channel preferences will also have an impact on the overall supply chain. Therefore, this chapter focuses on production constraints, the preservation costs of agricultural products, and the impact of consumers' preferences for both channels on the supply chain.

2.1. Problem Description and Model Assumptions

2.1.1. Problem Description

This paper mainly considers a single agricultural product supplier as the supply entity, responsible for supplying agricultural products and covering the cost of preservation. In the past, traditional sales were carried out by retailers in large quantities on-site, and then the retailers conducted offline sales. With the development of the e-commerce economy, suppliers, on the one hand, develop online sales channels and sell to consumers at P_1 prices; on the other hand, they wholesale to retailers at w prices, and retailers then sell to consumers at P_2 prices. As shown in Figure 3-1:

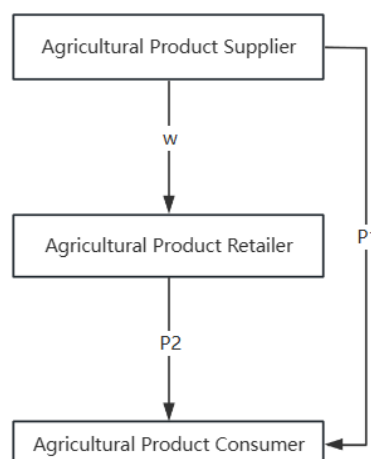


Figure 1. Agricultural Product Supply Chain Structure

2.1.2. Model Assumptions

This paper only assumes that the supplier provides one agricultural product to the market, and there is only one dual-channel supplier and one retailer that only conducts offline sales in the supply chain. Assumptions are introduced:

Hypothesis 1: The fresh agricultural products produced by suppliers are affected by various factors such as climate and growth environment. The output time is approximately in October and November each year, and the output is limited. According to the principle of rational equilibrium, all agricultural products can be sold in the market. At this time, the utility of consumers and the profit of sellers reach the maximum.

Hypothesis 2: It is assumed that the freshness θ_v of agricultural products provided by suppliers during transportation is linearly correlated with the level of preservation effort v . Referring to the relevant research results of Wang Lei et al [1], the function is set as $\theta_v = v\theta_0$, where $0 \leq \theta_0 \leq 1$, and θ_0 is the initial freshness of agricultural products when they are provided by suppliers. The level of preservation effort will have an impact on the freshness of agricultural products. Suppliers need to bear the preservation cost of agricultural products. Referring to the research results of Zhou Tao et al [2], the function between the level of preservation effort provided by suppliers and the preservation cost they pay is $e(v) = \frac{\lambda v^2}{2}$, $\lambda > 0$, and $e'(v) > 0$, $e''(v) > 0$, λ is the preservation input coefficient.

Hypothesis 3: Let consumers have channel preferences for dual channels. The degree of consumers' preference for offline sales channels is $0 \leq m \leq 1$. $(1-m)$ represents the degree of consumers' preference for online channels. The sensitivity coefficient of consumers to price is α , with $\alpha > 0$. The sensitivity coefficient to the freshness of agricultural products is β , with $\beta > 0$. The cross-price elasticity coefficient between the two channels of agricultural products is γ . $\gamma > 0$. Therefore, we can construct the market demand functions for the online channels of agricultural product suppliers and the offline channels of agricultural product retailers as:

$$D_1 = (1 - m)a - \alpha P_1 + \gamma P_2 + \beta v \theta_0 \quad (2.1)$$

$$D_2 = ma - \alpha P_2 + \gamma P_1 + \beta v \theta_0 \quad (2.2)$$

Thus, the total market demand for agricultural products can be obtained as:

$$D = D_1 + D_2 = a - (\alpha - \gamma)(P_1 + P_2) + 2\beta v \theta_0 \quad (2.3)$$

2.1.3. Symbol Meaning Table

Table 1. Symbol Meaning Table

Symbol	Meaning
S	Yield of agricultural products provided by the supplier
a	Potential market demand for agricultural products
D ₁	Market demand for the supplier's online sales
D ₂	Market demand for the retailer's offline sales
D	Total market demand for agricultural products
P ₁	Online selling price of the supplier in the agricultural product supply chain
P ₂	Offline selling price of the retailer in the agricultural product supply chain
c	Unit cost of agricultural products, 0 < c < P ₂
w	Wholesale price of the retailer in the agricultural product supply chain, w > c
m	Consumers' preference level for offline sales channels
e	Freshness preservation cost borne by the supplier
λ	Freshness investment coefficient of the supplier
θ _v	Freshness level of agricultural products
v	Freshness effort level of the supplier
θ ₀	Initial freshness of agricultural products before transportation, 0 ≤ θ ₀ ≤ 1
α	Consumers' price sensitivity coefficient, α > 0
β	Consumers' sensitivity coefficient to agricultural product freshness, β > 0
γ	Cross-price elasticity coefficient between the two channels, γ > 0 and γ < α
Π ₁	Profit obtained by the supplier
Π ₂	Profit obtained by the retailer
Π	Total profit of the supply chain system

2.2. Optimal Decision-making of Agricultural Product Supply Chain under Two Models

2.2.1. Centralized Decision-making Model

Dual-channel supply chain centralized decision-making means that in the supply chain, suppliers and retailers make decisions as a collective, taking into account factors such as production constraints and preservation costs, to maximize the profits of the entire supply chain system. Since all the preservation costs are borne by the supplier, the profit obtained by the supplier is:

$$\Pi_1^C = (P_1 - c)D_1 - \frac{\lambda v^2}{2} \quad (2.4)$$

Profits earned by retailers:

$$\Pi_2^C = (P_2 - c)D_2 \quad (2.5)$$

Therefore, the total profit of the supply chain system is:

$$\Pi^C = (P_1 - c)D_1 + (P_2 - c)D_2 - \frac{\lambda v^2}{2} \quad (2.6)$$

From (2.3), it can be known that the total market demand D is only affected by P₁, P₂ and the preservation effort level v. Therefore, we find the first-order partial derivatives of P₁, P₂ and v for Π:

$$\frac{\partial \Pi}{\partial P_1} = (1 - m)a - 2\alpha P_1 + 2\gamma P_2 + \beta v \theta_0 + (\alpha - \gamma)c \quad (2.7)$$

$$\frac{\partial \Pi}{\partial P_2} = ma - 2\alpha P_2 + 2\gamma P_1 + \beta v \theta_0 + (\alpha - \gamma)c \quad (2.8)$$

$$\frac{\partial \Pi}{\partial v} = (P_1 + P_2 - 2c)\beta \theta_0 - \lambda v \quad (2.9)$$

Continuing to find the second-order partial derivatives of P_1 , P_2 and v for the above three expressions, we can obtain: $\frac{\partial \Pi}{\partial P_1^2} = -2\alpha$, $\frac{\partial \Pi}{\partial P_1 P_2} = 2\gamma$, $\frac{\partial \Pi}{\partial P_1 v} = \beta \theta_0$, $\frac{\partial \Pi}{\partial P_2 P_1} = 2\gamma$, $\frac{\partial \Pi}{\partial P_2^2} = -2\alpha$, $\frac{\partial \Pi}{\partial P_2 v} = \beta \theta_0$, $\frac{\partial \Pi}{\partial v P_1} =$

$\beta \theta_0$, $\frac{\partial \Pi}{\partial v P_2} = \beta \theta_0$, $\frac{\partial \Pi}{\partial v^2} = -\lambda$, therefore, the Hessian matrix $H_{s1} = \begin{bmatrix} -2\alpha & 2\gamma & \beta \theta_0 \\ 2\gamma & -2\alpha & \beta \theta_0 \\ \beta \theta_0 & \beta \theta_0 & -\lambda \end{bmatrix}$ can be

obtained. The first-order, second-order, and third-order principal sub-expressions of the matrix are respectively $H_1 = -2\alpha$, $H_2 = 4\alpha^2 - 4\gamma^2$, $H_3 = 4(\alpha + \gamma)[\beta^2 \theta_0^2 + \lambda(\gamma - \alpha)]$. To maximize the total profit of the supply chain, the Hessian matrix H is negative constant. If $H_1 < 0$ and $H_2 > 0$, then setting $H_3 < 0$, gives $\lambda > \frac{\beta^2 \theta_0^2}{\alpha - \gamma}$. Therefore, when $\lambda > \frac{\beta^2 \theta_0^2}{\alpha - \gamma}$, there is an optimal solution undefined, undefined, undefined such that the total profit of the supply chain reaches the optimum.

Further, the first derivative of (2.6) can be set to zero. Using Mathematica, the optimal online sales price P_1^{C*} for suppliers under centralized decision-making, the optimal offline sales price P_2^{C*} for retailers, and the optimal preservation effort level v^{C*} can be calculated as follows:

$$P_1^{C*} = -\frac{-a\beta\theta + am\beta\theta + ma\beta\theta - 4c\alpha\beta\theta - 4c\beta\theta\gamma - 2\alpha\lambda - 2\gamma\lambda}{4\beta\theta(\alpha + \gamma)} \quad (2.10)$$

$$P_2^{C*} = -\frac{a\beta\theta - am\beta\theta - ma\beta\theta - 4c\alpha\beta\theta - 4c\beta\theta\gamma - 2\alpha\lambda - 2\gamma\lambda}{4\beta\theta(\alpha + \gamma)} \quad (2.11)$$

$$v^{C*} = \frac{2c\alpha\theta - \frac{2c\alpha\alpha\theta}{\alpha + \gamma} - \frac{2c\alpha\theta\gamma}{\alpha + \gamma}}{-\lambda + \frac{\alpha\alpha\theta\lambda}{\beta\theta(\alpha + \gamma)} + \frac{\alpha\theta\gamma\lambda}{\beta\theta(\alpha + \gamma)}} \quad (2.12)$$

Then, substitute (2.10), (2.11), and (2.12) into (2.1), (2.2), and (2.6). When the profit is at its peak and all products are sold out, let $D=S$. Thus, the online demand of suppliers D_1^{C*} , the offline demand of retailers D_2^{C*} , and the optimal total profit of the supply chain Π^{C*} can be obtained as follows:

$$D_1^{C*} = \frac{2S - (2m - 1)a}{4} \quad (2.13)$$

$$D_2^{C*} = \frac{2S + (2m - 1)a}{4} \quad (2.14)$$

$$\Pi^{C*} = \frac{4\lambda(\alpha^2 - \gamma^2)S[a - 2c(\alpha - \gamma)] + \lambda(\alpha - \gamma)^2(1 - 2m)^2 a^2 - 4(\alpha + \gamma)S^2[\lambda(\alpha - \gamma) - \beta^2 \theta_0^2]}{8\lambda(\alpha - \gamma)^2(\alpha + \gamma)} \quad (2.15)$$

2.2.2. Decentralized Decision-making Model

Decentralized decision-making in dual-channel supply chains means that in the supply chain, suppliers and retailers make decisions based on their own maximum profits, still taking into account factors such as production constraints and preservation costs. Preservation costs are still borne by suppliers. This analysis is based on centralized decision-making. We can conclude that the online sales profit model of suppliers, the offline sales profit model of retailers, and the total profit model of the supply chain system are respectively:

$$\Pi_1^I = (P_1 - c)D_1 + (w - c)D_2 - \frac{\lambda v^2}{2} \quad (2.16)$$

$$\Pi_2^I = (P_2 - w)D_2 \quad (2.17)$$

$$\Pi^I = (P_1 - c)D_1 + (P_2 - w)D_2 + (w - c)D_2 - \frac{\lambda v^2}{2} \quad (2.18)$$

According to the Stackelberg game model, it is assumed that the supplier takes the lead in determining the w of agricultural products and the online sales price P_1 in combination with various situations, and then the w determined by the retailer supplier determines the offline sales price P_2 . First, determine the value of P_2 by using the reverse solution method. From (2.17), the first derivative of Π_2 with respect to P_2 can be obtained:

$$\frac{\partial \Pi_2}{\partial P_2} = ma - 2\alpha P_2 + \gamma P_1 + \beta v \theta_0 - w\alpha \quad (2.19)$$

Then, by finding the second derivative of Π_2 with respect to P_2 , we can obtain: $\frac{\partial \Pi_2}{\partial P_2^2} = -2\alpha < 0$. From this, it can be known that there exists a unique offline sales price P_2 that maximizes the offline sales profit Π_2 value. Let the first derivative (2.19) be 0, and the response function of the offline sales price can be obtained as:

$$P_2 = \frac{ma + \gamma P_1 + \beta v \theta_0 + w\alpha}{2\alpha} \quad (2.20)$$

Substitute (2.20) into (2.16), and find the first derivative of Π_1 with respect to P_1 , w , and v :

$$\frac{\partial \Pi_1}{\partial P_1} = \frac{m(\gamma - 2\alpha) + 2\alpha}{2\alpha} a + \frac{\gamma^2 - 2\alpha^2}{\alpha} P_1 + \gamma w - \frac{\gamma^2 - 2\alpha^2 + \gamma\alpha}{2\alpha} c + \frac{\gamma + 2\alpha}{2\alpha} \beta v \theta_0 \quad (2.21)$$

$$\frac{\partial \Pi_1}{\partial w} = \frac{ma}{2} + \gamma P_1 - \alpha w + \frac{\alpha - \gamma}{2} c + \frac{\beta v \theta_0}{2} \quad (2.22)$$

$$\frac{\partial \Pi_1}{\partial v} = \frac{\gamma + 2\alpha}{2\alpha} \beta \theta_0 P_1 + \frac{\beta \theta_0}{2} w - \frac{\gamma + 3\alpha}{2\alpha} \beta \theta_0 - \lambda v \quad (2.23)$$

Then, take the second derivatives of (2.21), (2.22), and (2.23) with respect to P_1 , w , and v , and we can obtain $\frac{\partial \Pi_1}{\partial P_1^2} = \frac{\gamma^2 - 2\alpha^2}{\alpha}$, $\frac{\partial \Pi_1}{\partial P_1 w} = \gamma$, $\frac{\partial \Pi_1}{\partial P_1 v} = \frac{\gamma + 2\alpha}{2\alpha} \beta \theta_0$, $\frac{\partial \Pi_1}{\partial w P_1} = \gamma$, $\frac{\partial \Pi_1}{\partial w^2} = -\alpha$, $\frac{\partial \Pi_1}{\partial w v} = \frac{\beta \theta_0}{2}$, $\frac{\partial \Pi_1}{\partial v P_1} =$

$$\frac{\gamma + 2\alpha}{2\alpha} \beta \theta_0, \frac{\partial \Pi_1}{\partial v w} = \frac{\beta \theta_0}{2}, \frac{\partial \Pi_1}{\partial v^2} = -\lambda, \text{ From this, the Hesse matrix } H_{s2} = \begin{bmatrix} \frac{\gamma^2 - 2\alpha^2}{\alpha} & \gamma & \frac{\gamma + 2\alpha}{2\alpha} \beta \theta_0 \\ \gamma & -\alpha & \frac{\beta \theta_0}{2} \\ \frac{\gamma + 2\alpha}{2\alpha} \beta \theta_0 & \frac{\beta \theta_0}{2} & -\lambda \end{bmatrix} \text{ can}$$

be obtained.

Then we can obtain $H_4 = \frac{\gamma^2 - 2\alpha^2}{\alpha} < 0$, $H_5 = 2(\alpha^2 - \gamma^2) > 0$, $H_6 = -\frac{(\alpha + \gamma)(-3\alpha\beta\theta_0^2 - \beta\theta_0^2\gamma + 4\alpha^2\lambda - 4\alpha\gamma\lambda)}{2\alpha}$.

To make Π_1^I have a maximum value, let $H_6 < 0$, and we can obtain $\lambda > \frac{3\alpha\beta\theta_0^2 + \beta\theta_0^2\gamma}{4\alpha^2 - 4\alpha\gamma}$. At this time, there exists P_1^I , w^I , v^I such that Π_1^I is the maximum.

Let the first derivatives (2.21), (2.22), and (2.23) of (2.16) be 0, and $S = D$. By solving the equations simultaneously, we can obtain that under decentralized decision-making, the optimal online sales

price P_1^{I*} of the supplier, the optimal wholesale price w^{I*} of the retailer, and the optimal preservation effort level v^{I*} are respectively:

$$P_1^{I*} = \frac{a\lambda(\alpha-\gamma)[\alpha^2(5-4m)+\gamma\alpha(3+2m)+2\gamma^2m]-2(\alpha+\gamma)S[2\lambda\alpha(\alpha-\gamma)-(\gamma+3\alpha)\beta^2\theta^2]}{2\lambda(\alpha-\gamma)^2(\alpha+\gamma)(\gamma+3\alpha)} \quad (2.24)$$

$$w^{I*} = \frac{a\lambda(\alpha-\gamma)[2\beta^2(1+m)+\gamma\alpha(5-2m)+\gamma^2]-2(\alpha+\gamma)S[2\lambda\alpha(\alpha-\gamma)-(\gamma+3\alpha)\beta^2\theta^2]}{2\lambda(\alpha-\gamma)^2(\alpha+\gamma)(\gamma+3\alpha)} \quad (2.25)$$

$$v^{I*} = \frac{\beta\theta S}{\lambda(\alpha-\gamma)} \quad (2.26)$$

Substituting (2.24), (2.25), and (2.26) into (2.20), (2.1), and (2.2), it can be obtained that in the case of decentralized decision-making, the optimal offline sales price P_2^{I*} of the retailer, the optimal online demand D_1^{I*} of the supplier, and the optimal offline demand D_2^{I*} of the retailer are respectively:

$$P_2^{I*} = \frac{a\lambda(\alpha-\gamma)[\alpha^2(1+4m)+\gamma\alpha(5-2m)+2\gamma^2(1-m)]-2(\alpha+\gamma)S[\lambda(\alpha^2-\gamma^2)-(\gamma+3\alpha)\beta^2\theta^2]}{2\lambda(\alpha-\gamma)^2(\alpha+\gamma)(\gamma+3\alpha)} \quad (2.27)$$

$$D_1^{I*} = \frac{2S(\gamma+2\alpha)-2\alpha ma+\alpha a}{2(\gamma+3\alpha)} \quad (2.28)$$

$$D_2^{I*} = \frac{2S\alpha+2\alpha ma-\alpha a}{2(\gamma+3\alpha)} \quad (2.29)$$

From this, the maximum profits of suppliers, retailers and the overall supply chain can be obtained as follows:

$$\Pi_1^{I*} = \frac{4\lambda(\alpha^2-\gamma^2)S[c(\gamma+3\alpha)(\gamma-\alpha)+ma(\gamma-\alpha)+2\alpha a]+\lambda\alpha(\alpha-\gamma)^2(1-2m)^2a^2-2(\alpha+\gamma)S^2[4\lambda\alpha(\alpha-\gamma)-(\gamma+3\alpha)\beta^2\theta^2]}{4\lambda(\alpha-\gamma)^2(\alpha+\gamma)(\gamma+3\alpha)} \quad (2.30)$$

$$\Pi_2^{I*} = \frac{\alpha(2S+2ma-a)^2}{4(\gamma+3\beta)^2} \quad (2.31)$$

$$\Pi^{I*} = \frac{a^2\lambda\alpha(\alpha-\gamma)^2(\gamma+2\alpha)(1-2m)^2+(\alpha+\gamma)S^2[(\gamma+3\alpha)^2\beta^2\theta^2-2\lambda\alpha(5\alpha+3\lambda)(\alpha-\lambda)]+2\lambda(\alpha^2-\gamma^2)S[c(\gamma+3\alpha)^2(\gamma-\alpha)+ma(\gamma^2-\alpha^2)+5\alpha^2+3\gamma\alpha+2\alpha]}{2\lambda(\alpha-\gamma)^2(\alpha+\gamma)(\gamma+3\alpha)^2} \quad (2.32)$$

2.3. Decision-making Analysis of Agricultural Product Supply Chain under Two Models

Proposition 1: Under the decentralized decision-making model, the price of agricultural products sold by retailers offline will change along with the wholesale price of agricultural products, and there is a positive correlation.

Proof: From (2.20), we know that the price response function of agricultural products sold offline by retailers is $P_2 = \frac{ma+\gamma P_1+\beta v\theta_0+w\alpha}{2\alpha}$. By finding the partial derivative of P_2 with respect to w , we can obtain:

$$\frac{\partial P_2}{\partial w} = \frac{1}{2} > 0 \quad (2.33)$$

From this, it can be known that P_2 will increase as w increases and decrease as w decreases, showing a positive correlation. When the wholesale price w given by the supplier to the retailer rises, the

retailer needs to increase the offline sales price P_2 accordingly to compensate for the cost from consumers.

Proposition 2: The overall profit of the agricultural product supply chain under decentralized decision-making is smaller than that under centralized decision-making.

Proof: It can be known from (3.15) and (3.32) that:

$$\Delta\Pi = \frac{(\alpha+\gamma)[2S-a(1-2m)]^2}{8(\gamma+3\alpha)^2} > 0 \quad (2.34)$$

From this, it can be known that when making decentralized decisions, since both suppliers and retailers strive for their maximum profits, the overall profit during decentralized decision-making is less than that during centralized decision-making. Therefore, a coordination mechanism needs to be designed to enhance the overall profit under decentralized decision-making.

3. COORDINATION ANALYSIS OF THE REVENUE-SHARING CONTRACT MODEL FOR DUAL-CHANNEL SUPPLY CHAINS OF AGRICULTURAL PRODUCTS

According to Proposition 2, it is difficult for suppliers and retailers to reach the profit level under centralized decision-making when making decentralized decisions. Therefore, this chapter introduces the revenue-sharing contract model to achieve coordination between suppliers and retailers and increase the total profit of the supply chain.

The revenue-sharing contract model refers to the situation where suppliers lower wholesale prices, and retailers share a portion of their profits with suppliers. By establishing this model, both individual profits and overall profits can be increased.

Under the contract, the profits we can obtain from suppliers and retailers are respectively:

$$\Pi_1^J = (P_1 - c)D_1 + \varphi(P_2 - w^J)D_2 \quad (3.1)$$

$$\Pi_2^J = (1 - \varphi)(P_2 - w^J)D_2 \quad (3.2)$$

Here, φ represents the proportion of revenue shared by the supplier with the retailer, $(1 - \varphi)$ represents the proportion received by the retailer, $0 \leq \varphi \leq 1$, w^J represents the wholesale price of the retailer under the coordination mechanism, $c \leq w^J \leq w$.

After introducing the contract model, in order to maximize profits, the online sales price of suppliers, the level of preservation effort, and the offline sales price of retailers are all set to be consistent with the optimal values during centralized decision-making, that is, $P_1^{C*} = P_1^{J*}$, $v^{C*} = v^{J*}$, $P_2^{C*} = P_2^{J*}$. Substituting these into the (2.20) response function, the optimal wholesale price after coordination between both parties can be obtained as:

$$w^{J*} = \frac{(a\lambda(\alpha-\gamma)(2\alpha^2+\gamma\alpha(3-2m)+\gamma^2(1-2m))-2(\alpha+\gamma)S(\lambda(\alpha-\gamma)(2\alpha-\gamma)-2\alpha\beta^2\theta^2))}{4\lambda\alpha(\alpha-\gamma)^2(\alpha+\gamma)} \quad (3.3)$$

Proposition 3: After the inclusion of the revenue-sharing contract, in order to maximize profits by achieving the same optimal selling prices for both channels as during centralized decision-making, the wholesale price of the retailer needs to be reduced.

Proof: As can be seen from (2.25) and (3.3), $\Delta w = w^{J*} - w^{I*} = -\frac{(2+\gamma)[2S-a(1-2m)]}{4(\gamma+3\alpha)} < 0$. Therefore, it can be proved that the wholesale price of the retailer is lower than the wholesale price without joining the contract.

After substituting the optimal decision after contract coordination into equations (3.1) and (3.2), the coordinated online sales market demand of suppliers, the offline sales market demand of retailers, the maximum profit of suppliers, the maximum profit of retailers, and the total maximum profit of the supply chain can be obtained as follows:

$$D_1^{J*} = \frac{(2S-2ma+a)}{4} \quad (3.4)$$

$$D_2^{J*} = \frac{(2S+2ma-a)}{4} \quad (3.5)$$

$$\Pi_1^{J*} = \frac{a^2(\alpha-\gamma)(1-2m)^2}{16\alpha(\alpha+\gamma)} - \frac{S(4c\alpha(\alpha-\gamma)+a(\gamma-2m\gamma-3\alpha+2m\alpha))}{4\alpha(\alpha-\gamma)} - \frac{(3\alpha-\gamma)(\alpha+\gamma)S^2}{4\alpha(\alpha-\gamma)^2} + \frac{\varphi(2S-2ma+a)^2}{16\alpha} + \frac{\beta^2\theta^2S^2}{2\lambda(\alpha-\gamma)^2} \quad (3.6)$$

$$\Pi_2^{J*} = (1-\varphi)\left[\frac{a^2(\alpha-\gamma)(1-2m)^2}{16\alpha(\alpha+\gamma)} - \frac{Sa(\gamma-2m\gamma-3\alpha+2m\alpha)}{4\alpha(\alpha-\gamma)} - (Sc) - \frac{(3\alpha-\gamma)(\alpha+\gamma)S^2}{4\alpha(\alpha-\gamma)^2}\right] \quad (3.7)$$

$$\Pi^{J*} = \Pi_1^{J*} + \Pi_2^{J*} \quad (3.8)$$

From (2.30) and (3.6), it can be obtained that:

$$\Delta\Pi_1^* = \Pi_1^{J*} - \Pi_1^{I*} = \frac{-4a(-1+2m)S(\alpha-\gamma)^2(\alpha+\gamma+\alpha^2(3\alpha+\gamma)\varphi) + 4S^2(-\alpha^3-17\alpha^2\gamma+\alpha\gamma^2+\gamma^3+\alpha^2(\alpha-\gamma)^2(3\alpha+\gamma)\varphi) + a^2(1-2m)^2(\alpha-\gamma)^2(-\gamma+\alpha(-1+\alpha(3\alpha+\gamma)\varphi))}{16\alpha(\alpha-\gamma)^2(3\alpha+\gamma)} \quad (3.9)$$

From (2.31) and (3.7), it can be obtained that:

$$\Delta\Pi_2^* = \Pi_2^{J*} - \Pi_2^{I*} = \frac{(a-2am-2S)^2\alpha}{4(3\alpha+\gamma)^2} - \frac{1}{16}\left(-16cS + \frac{4S^2(1-\frac{4\alpha^2}{(\alpha-\gamma)^2})}{\alpha} + 4aS\left(\frac{1-2m}{\alpha} + \frac{2}{\alpha-\gamma}\right) + \frac{a^2(1-2m)^2(\alpha-\gamma)}{\alpha(\alpha+\gamma)}\right)(1-\varphi) \quad (3.10)$$

To ensure the overall coordination of the supply chain, the profits of both suppliers and retailers after joining the coordination must be greater than those before joining, that is, $\Delta\Pi_1^* \geq 0$, $\Delta\Pi_2^* \geq 0$. Solving the system of simultaneous equations gives:

$$\frac{2a^2\alpha^5-48a^2m\alpha^5+12a^2m^2\alpha^5+124aS\alpha^5-58amS\alpha^5-94S^2\alpha^5-144cS\alpha^6}{9a^2\alpha^5-36a^2m\alpha^5+36a^2m^2\alpha^5+108aS\alpha^5-72amS\alpha^5-108S^2\alpha^5-144cS\alpha^6} \leq \varphi \leq \frac{5a^2\alpha^5-20a^2m\alpha^5+20a^2m^2\alpha^5+124aS\alpha^5-104amS\alpha^5-124S^2\alpha^5-144cS\alpha^6}{9a^2\alpha^5-36a^2m\alpha^5+36a^2m^2\alpha^5+108aS\alpha^5-72amS\alpha^5-108S^2\alpha^5-144cS\alpha^6} \quad (3.11)$$

From this, it can be appropriately stated as

$\varphi \in \left[\frac{2a^2\alpha^5-48a^2m\alpha^5+12a^2m^2\alpha^5+124aS\alpha^5-58amS\alpha^5-94S^2\alpha^5-144cS\alpha^6}{9a^2\alpha^5-36a^2m\alpha^5+36a^2m^2\alpha^5+108aS\alpha^5-72amS\alpha^5-108S^2\alpha^5-144cS\alpha^6}, \frac{5a^2\alpha^5-20a^2m\alpha^5+20a^2m^2\alpha^5+124aS\alpha^5-104amS\alpha^5-124S^2\alpha^5-144cS\alpha^6}{9a^2\alpha^5-36a^2m\alpha^5+36a^2m^2\alpha^5+108aS\alpha^5-72amS\alpha^5-108S^2\alpha^5-144cS\alpha^6}\right]$, the profits of both suppliers and retailers increase, achieving Pareto improvement and dual-channel supply chain coordination.

4. CONCLUSION

Through research, this article has reached the following conclusions:

- (1) In terms of price, the online direct sales price is higher when centralized decision-making is made than when decentralized decision-making is made, while the offline sales price is lower when centralized decision-making is made. The levels of preservation efforts in the two decision-making scenarios are equal. On the demand side, the demand for online sales is lower when decisions are made centrally than when decisions are made decentrally, while the demand for offline sales is higher when decisions are made centrally than when decisions are made decentrally. To maximize profits, the demand for both channels equals the supply volume. In terms of profit, the total profit of the supply chain is higher when centralized decision-making is made than when decentralized decision-making is adopted. This indicates that under decentralized decision-making, both suppliers and retailers make decisions with the goal of maximizing their own profits, making it difficult to achieve the maximization of supply chain profits. Therefore, coordination and improvement are still needed.
- (2) Under decentralized decision-making, supply chain members pursue the maximization of their own profits, making it difficult for the supply chain system to reach the optimal state. After joining the revenue-sharing contract, when the revenue-sharing is within a certain range, the profits of suppliers and retailers can exceed those before coordination, and the overall profit of the supply chain also increases. Due to the high preference coefficient of consumers for online channels, the profits of suppliers are significantly greater than those of retailers after joining new channels.

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