The Pricing Strategy of the Agricultural Product Supply Chain with Farmer Cooperatives as the Core Enterprise

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Abstract: The pricing strategy of agricultural products not only affects the product demand and purchasing behavior of consumers, but also the income distribution of node enterprises and the overall profit of the agricultural supply chain. This paper studies the pricing strategy of the agricultural product supply chain with farmer cooperatives as the core enterprise. Considering the heterogeneous demand of consumers, this paper introduces the degree of agricultural product characteristics and establishes a dynamic pricing model for agricultural products under decentralized decision-making and centralized decision-making and designs a revenue sharing coordination contract. The results indicate that the overall profit of the supply chain obtained by pricing agricultural products through a decentralized decision-making model is lower than that created under centralized decision-making. Improving the degree of agricultural product's characteristics and adopting the revenue sharing contract is conducive to the Pareto improvement of supply members. The relevant recommendations provide a reference for the product pricing strategy of this type of agricultural product supply chain.

Keywords: agricultural product supply chain; pricing strategy; Stackelberg game; revenue sharing contract

1. Introduction

With the gradual improvement of the agricultural product supply chain system, global agricultural product trade has developed rapidly. According to the "2020 Agricultural Products Market Status", the global agricultural product's trade volume has more than doubled from 1995 to 2018 and has increased from 680 billion dollars to 1.5 trillion dollars. Agricultural product trade plays an important role in promoting the economic development of countries. In the increasingly diverse and open agricultural product market, smallholders are in a weak position in agricultural product pricing due to their lack of bargaining power [1–3]. In order to occupy a more dominant position in market competition, farmer cooperatives have been gradually established and actively integrated into the agricultural product supply chain, becoming an important part of the global trading system [4,5].

The agricultural product supply chain is market-oriented [6], led by core enterprises, and connects suppliers, manufacturers, retailers, and consumers into a whole network chain structure [7]. The core enterprises of the supply chain master the core resource endowment in the supply chain [8] and play a role in coordinating and controlling the operation of the supply chain. At present, there are many manufacturers and retailers as the core enterprises in the agricultural product supply chain [9]. For some agricultural products requiring intensive processing, the manufacturers and retailers control the core processing technology, consumer demand information, and other core resources, so they are more likely to become the core enterprises in the supply chain [10,11]. However, the

"reverse technology" development of agricultural products is becoming more and more obvious, and consumers are increasingly favoring agricultural products with characteristic, healthy, and even primitive agricultural products. Therefore, non-processed or primary processed characteristic agricultural products are gradually occupying the market. The core competitiveness of this agricultural product supply chain mainly comes from the resource endowment and climate conditions of the planting area which are determined by the production end of the agricultural product supply chain. As producers in the supply chain, farmer cooperatives gradually integrate into the supply chain with the expansion of their business scale and the standardized development of internal management. Some cooperatives occupy the core position of the supply chain by virtue of resource advantages such as characteristic agricultural products [12].

Becoming a core enterprise in the supply chain of agricultural products is not only conducive to obtaining high-quality resources in the supply chain [13] but also can further improve the voice and pricing power of agricultural product trade [14]. Most of the agricultural product supply chains in the United States take farmer cooperatives as the core enterprises. Farmer cooperatives play a core role in the quality and safety management of agricultural products through standardized production, sorting, unified storage, transportation, and other management measures [15], and have a certain voice in the process of agricultural product pricing [16]. China's farmer cooperatives are also growing. The number of farmers joining farmer cooperatives accounts for 49.1% of the national farmers. Some large-scale cooperatives make use of local characteristic resource endowments to build regional brands and become core enterprises in the supply chain [17]. Farmer cooperatives effectively connect with manufacturers and retailers and successfully solve the sales problems of agricultural products for members [18]. From its development experience, farmer's cooperatives have become the core enterprises in the supply chain, which can not only manage the quality and safety of agricultural products in the supply chain but also win more benefits for farmers and contribute to the overall supply chain through reasonable pricing of characteristic agricultural products [19,20].

However, the current premium space for characteristic agricultural products mostly stays in the downstream enterprises of the supply chain. There exists an asymmetric relationship between the producer price and the retailer price [21]. The core competitiveness of characteristic agricultural products is mainly created by the planting end of agricultural products. If farmer cooperatives bring added value in terms of product quality and characteristic degree but do not obtain reasonable benefits, their production enthusiasm will be reduced, which will affect the characteristic degree and quality of characteristic products [22,23]. Existing research shows that the core enterprises in the supply chain have pricing power. Reasonable product pricing can promote the fair distribution of income [24] and adjust consumer demand for products and the market share of enterprises [25,26]. For some agricultural product supply chains with farmer cooperatives as their core enterprises, which are mainly engaged in characteristic agricultural products, it is of practical significance to rationally formulate their pricing strategies. On the one hand, reasonable pricing can balance the interests of various entities in the supply chain [27,28] and ensure the stability of the cooperative relationship between the main entities in the agricultural supply chain [29]. On the other hand, reasonable pricing can avoid overstocking and value waste in the supply chain [30,31] and maintain the coordinated and sustainable development of the supply chain [32]. Therefore, how to formulate an optimal pricing strategy in the agricultural product supply chain is the core issue to be studied in this paper.

The article is arranged as follows: Section 2 is a literature review. Section 3 presents the model description and basic assumptions. Next, the pricing model construction and solution under the two models of decentralized decision-making and centralized decision-making will be introduced in Section 4. Section 5 examines the impact of key parameters and different pricing strategies on the overall profit of the supply chain through a numerical example analysis. Finally, Section 6 highlights the main conclusions and summarizes the research information.

2. Literature Review

2.1. Research on the Agricultural Product Supply Chain

With the increasing international trade volume of agricultural products and the continuous improvement of consumers' requirements for the quality of agricultural products, the supply chain of agricultural products has become a hot issue for exploration by scholars. At present, scholars mainly focus on the dominant mode, stability, and coordinated operation of the agricultural supply chain. In recent years, there have been relatively many retailers and manufacturers as leading enterprises in the agricultural product supply chain [9]. Leading enterprises can control or influence the decisions of other node enterprises in the supply chain. When the supply chain is dominated by retailers or manufacturers, farmer cooperatives can only passively accept price fluctuations as agricultural product suppliers [31]. Since farmers are risk-averse, when facing the dual risks of output uncertainty and price fluctuation [33], their production enthusiasm will be reduced [34], which may lead to the obstruction of the supply of agricultural products [35]. Therefore, node enterprises will not blindly pursue the dominant position and will more rationally consider their economic interests and development trends. According to changes in the external environment, product nature, and other factors, the evolutionary drift of core enterprises in the supply chain will occur. Leading enterprises hold a variety of core resources and market information in the supply chain [8], and there are significant differences in supply chain management decisions (such as pricing strategies, ordering decisions, etc.) under different rights structures. The particularity of agricultural products determines the weak anti-risk ability of the agricultural product supply chain [36]. Through the coordinated operation of the agricultural product supply chain, it is possible to achieve a win-win situation for all parties and make the supply chain member relationship more stable. Fair operations are significant to enhance trust between parties [37]. Li et al. [38] designed a heuristic algorithm to maximize the price and minimize the difference between farmers' incomes. Research on the coordination mechanism of the agricultural product supply chain mainly focuses on benefit-sharing [23], risk-sharing [33], quantity discount [32], repurchase contracts [39], portfolio contracts [40], etc.

2.2. Research on the Pricing of the Agricultural Product Supply Chain

Research on the pricing of the agricultural product supply chain mainly focuses on the effects of different right structures on pricing strategies [41] and how changes in various parameters affect the decision making and profits of participants [42,43]. Existing pricing research methods mainly include the Bertrand game [44], Nash game [45], Stackelberg game [46], etc. Both Bertrand's game and Nash's game are static games, and the players make decisions at the same time. Liu et al. [47] used the Bertrand game to study the price competition of agricultural products with regional brands. Yan et al. [45] considered the fairness concerns of producers and compared the impact of fairness concerns on the supply chain profits under the Nash game and traditional pricing methods. The Stackelberg game is a dynamic game. Compared with static pricing, the dynamic pricing strategy is more conducive to the long-term coordination and stability of the supply chain, and the model has typical significance in analyzing master-slave problems [48,49]. Supply chain pricing is mostly a dynamic game dominated and controlled by retailers and manufacturers [50]. Therefore, the Stackelberg game is more widely used in the research of supply chain pricing. Jena and Ghadge [51] used the Stackelberg game to study the impact of bundling decisions and advertising on the total profit of the supply chain under different right balance structures. Yin et al. [52] constructed a three-level supply chain model based on the Stackelberg game to explore the impact of price on the supply mechanism of fresh agricultural products. Through the Stackelberg game, the main revenue game is carried out to coordinate the channel conflict, and the equilibrium strategy of enterprise production can be obtained [53]. Game analysis helps enterprises adjust inventory and production in time according to the changes in consumer demand [54] and make strategic decisions to maximize production benefits [48].

Most of the current research on agricultural supply chain pricing is based on manufacturers or retailers [55], and most of them focus on two-level supply chain pricing research. However, few studies have been done on the pricing of the three-level agricultural product supply chain with cooperatives as the core enterprise. The previous pricing decision of agricultural products did not take into account the heterogeneous demand of consumers and ignored the impact of the degree of agricultural product characteristics on its pricing strategy and the profit distribution of enterprises at each node of the supply chain. Therefore, based on the characteristic agricultural products that the producers and operators have certain pricing power, this paper incorporates the parameter of the degree of agricultural product characteristics into the pricing decision and considers the two types of ordinary agricultural products and characteristic agricultural products operating simultaneously in the supply chain. According to the decision-making process of each main body in the supply chain, the pricing decision is divided into centralized decision-making and decentralized decision-making. This paper studies what factors affect the product pricing in the agricultural product supply chain with farmer cooperatives as the core enterprise, and how each subject in the supply chain formulates a reasonable pricing strategy to achieve Pareto improvement of each member in the supply chain. The research provides a reference for the product pricing strategy of this type of agricultural product supply chain and enriches the related research on the pricing strategy of the agricultural product supply chain.

3. Materials and Methods

3.1. Model Description

This paper studies the three-level agricultural product supply chain with farmer cooperatives as the core enterprise which is composed of farmer cooperatives, manufacturers, and retailers. Due to the heterogeneous demand of consumers, the supply chain operates ordinary agricultural products and characteristic agricultural products at the same time. It is beneficial to improve the market competitiveness of the entire supply chain through market segmentation and separate pricing of the two types of agricultural products. It is the precondition for farmer cooperatives to dominate the supply chain of agricultural products to master the superior resources and produce characteristic agricultural products. Therefore, the degree of characteristic agricultural products is introduced into the model. Based on this premise, this paper studies the optimal pricing of each node enterprise and the overall profit of the supply chain under decentralized decision-making and centralized decision-making, analyzes the impact of main parameter changes and different pricing strategies on the overall profit of the supply chain, and designs the revenue sharing coordination contract. In the decentralized decision-making model, farmer cooperatives, as the leader of the Stackelberg game, determine the market demand for agricultural products and the degree of characteristic agricultural products according to market information and consumer demand information fed back by retailers in the supply chain, providing ordinary agricultural products and characteristic agricultural products to manufacturers as followers (characteristic agricultural products account for the main trading share). At this time, the node enterprises in the supply chain all choose the optimal action strategy to maximize their profits. In the centralized decision-making model, farmer cooperatives outsource non-core businesses to downstream manufacturers and retailers to achieve effective integration of internal and external resources, aiming at maximizing the overall profit of the supply chain. Under the two decision models, we obtain the optimal price of ordinary agricultural products and characteristic agricultural products and the overall profit of the supply chain. Then, we observe the impact of the changes in main parameters on the overall profit and design the revenue sharing contract to make the farmer cooperatives, manufacturers, retailers, and the whole supply chain achieve Pareto improvement. The basic research framework is shown in Figure 1.
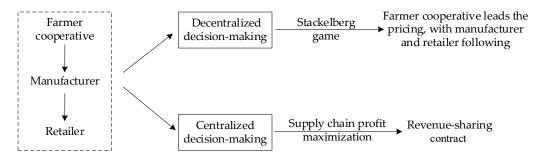
Figure 1. Basic research framework.

3.2. Model Assumptions

Assumption 1: Farmer cooperatives produce agricultural products according to market demand information, and the quality of ordinary agricultural products and characteristic agricultural products is certain. Characteristic agricultural products are products with cultural connotations or historical backgrounds, which depend on the unique resource endowments such as local primitive geography, soil, water resources, and human environment, and have significant geographical and regional characteristics. Therefore, the degree of characteristic agricultural products is mainly realized by the production links of farmer cooperatives.

Assumption 2: Regardless of the impact of emergencies, the market demand for agricultural products is certain. In the case of meeting basic survival needs, when the pricing of agricultural products is within a reasonable range, according to the utility maximization theory, consumers will give priority to buying characteristic agricultural products. If the price-performance ratio of characteristic agricultural products does not meet consumers' expectations, consumers will choose to buy ordinary agricultural products to meet their basic living needs. Based on the demand function theory of price competition of substitutes, the demand functions of characteristic agricultural products and ordinary agricultural products are as follows:

$$Q_i = a - bP_i + rP_j + \mu e \tag{1}$$

$$Q_j = \theta - dP_i + rP_j \tag{2}$$

where Q_i represents the demand for characteristic agricultural products and Q_j represents the demand for ordinary agricultural products. a represents the potential market capacity of characteristic agricultural products and θ represents the potential market capacity of ordinary agricultural products. b represents the price sensitivity of characteristic agricultural products, and d represents the price sensitivity of ordinary agricultural products. The price sensitivity of ordinary agricultural products is slightly lower than that of special agricultural products due to the characteristics of survival necessities. r is the competitive substitution coefficient between the two agricultural products, and $b > d > r > 0$, that is, the demand is more sensitive to the price of the commodity itself than to the price of the substitute commodity. P_i and P_j represent the retail prices of characteristic agricultural products and ordinary agricultural products, respectively ($P_i > P_j > 0$). μ is the characteristic preference coefficient, and e is the degree of agricultural product characteristics.

Assumption 3: Since agricultural products are perishable, we assume that the quantity loss rate of agricultural products is $\beta(0 < \beta < 1)$. Considering that the quantity loss in the production and circulation of agricultural products will affect the order quantity, when the order quantity of the retailer is Q, the actual production quantity of the farmer cooperative is $Q/(1 - \beta)$. Since grain agricultural products can promote respiration due to processing, the nutrients in the products are lost to some extent. Therefore, cereal agricultural products should follow the order-pull production method. Inventories are mainly concentrated in farmer cooperatives, and manufacturers and retailers should minimize the inventory.

This paper only considers the cost of agricultural product quantity loss borne by farmer cooperatives at the production end.

Assumption 4: The unit production costs of characteristic agricultural products and ordinary agricultural products are C_i and C_j, respectively ($C_i > C_j > 0$). The purchase prices of manufacturers are W_i and W_j, respectively, and the purchase prices of retailers are S_i and S_j, respectively. The processing costs of manufacturers are C_{im} and C_{jm}, respectively, and the profits of manufacturers are π_{im} and π_{jm}, respectively. Due to $S_i = W_i + C_{im} + \pi_{im}$, the relationship between the purchase prices of manufacturers and the purchase prices of retailers can be expressed as $S_i \geq W_i$ and $S_j \geq W_j$. For the convenience of calculation, it is assumed that the transportation cost and inventory cost of agricultural products are included in the purchase price and will not be calculated separately.

The variables involved in the model are shown in Table 1.

Table 1. Variables and descriptions.

Variables	Meaning	Variables	Meaning
Q_i	The demand for characteristic agricultural products (kg)	a	The potential market capacity of characteristic agricultural products (kg)
Q_j	The demand for ordinary agricultural products (kg)	θ	The potential market capacity of ordinary agricultural products (kg)
P_i	The retail prices of characteristic agricultural products (yuan)	b	The price sensitivity of characteristic agricultural products (kg)
P_j	The retail prices of ordinary agricultural products (yuan)	d	The price sensitivity of ordinary agricultural products (kg)
S_i	The purchase prices of retailers for characteristic agricultural products (yuan)	r	The competitive substitution coefficient
S_j	The purchase prices of retailers for ordinary agricultural products (yuan)	β_i	The quantity loss rate of characteristic agricultural products
W_i	The purchase prices of manufacturers for characteristic agricultural products (yuan)	β_j	The quantity loss rate of ordinary agricultural products
W_j	The purchase prices of manufacturers for ordinary agricultural products (yuan)	μ	The characteristic preference coefficient
C_i	The production costs of characteristic agricultural products (yuan)	e	The degree of agricultural products characteristics
C_j	The production costs of ordinary agricultural products (yuan)		

The profit function consists of two parts: the profit of characteristic agricultural products and the profit of ordinary agricultural products. The product profit is the product of the difference between the selling price and cost of the product and the sales volume. Based on the above assumptions, the profit function of farmer cooperatives is:

$$\pi_f = \left(W_i - \frac{C_i}{1 - \beta_i}\right)(a - bP_i + rP_j + \mu e) + \left(W_j - \frac{C_j}{1 - \beta_j}\right)(\theta - dP_i + rP_j) \quad (3)$$

The profit function of the manufacturer is:

$$\pi_m = (S_i - W_i)(a - bP_i + rP_j + \mu e) + (S_j - W_j)(\theta - dP_i + rP_j) \quad (4)$$

The profit function of the retailer is:

$$\pi_n = (P_i - S_i)(a - bP_i + rP_j + \mu e) + (P_j - S_j)(\theta - dP_i + rP_j) \quad (5)$$

The overall profit function of the three-level supply chain is:

$$\pi_s = \left(P_i - \frac{C_i}{1 - \beta_i}\right)(a - bP_i + rP_j + \mu e) + \left(P_j - \frac{C_j}{1 - \beta_j}\right)(\theta - dP_i + rP_j) \quad (6)$$

4. Results

4.1. Decision-Making Model

Farmer cooperatives are the core enterprises in the agricultural product supply chain and occupy a dominant position. Therefore, the agricultural product supply chain constitutes a dynamic Stackelberg game dominated by farmer cooperatives under complete information. The reverse induction method is used to analyze and solve as follows:

As the follower of supply chain decision making, the retailer takes the market retail prices P_i and P_j as its decision variables, and thus, the objective function of decision-making is:

$$\max \pi_n = (P_i - S_i)(a - bP_i + rP_j + \mu e) + (P_j - S_j)(\theta - dP_i + rP_j) \tag{7}$$

Therefore, the Hessian matrix of the retailer's profit function is:

$$H^n = \begin{pmatrix} \frac{\partial^2 \pi_n}{\partial P_i^2} & \frac{\partial^2 \pi_n}{\partial P_i \partial P_j} \\ \frac{\partial^2 \pi_n}{\partial P_j \partial P_i} & \frac{\partial^2 \pi_n}{\partial P_j^2} \end{pmatrix} = \begin{pmatrix} -2b & 2r \\ 2r & -2d \end{pmatrix} \tag{8}$$

H^n is a negative definite matrix, so the profit function of the retailer π_n is a joint concave function about P_i and P_j. Then the first-order optimal condition is $\frac{\partial \pi_n}{\partial P_i} = 0$ and $\frac{\partial \pi_n}{\partial P_j} = 0$ and the optimal reflection function of the retailer is:

$$P_i = \frac{S_i}{2} + \frac{\mu ed + r\theta + ad}{2(bd - r^2)} \tag{9}$$

$$P_j = \frac{S_j}{2} + \frac{\mu er + b\theta + ar}{2(bd - r^2)} \tag{10}$$

As the follower of supply chain decision-making, the manufacturer takes the purchase prices of the retailer S_i and S_j as its decision variables, and the objective function of decision-making is:

$$\max \pi_m = (S_i - W_i)(a - bP_i + rP_j + \mu e) + (S_j - W_j)(\theta - dP_i + rP_j) \tag{11}$$

Therefore, the Hessian matrix of the manufacturer's profit function is:

$$H^m = \begin{pmatrix} \frac{\partial^2 \pi_m}{\partial S_i^2} & \frac{\partial^2 \pi_m}{\partial S_i \partial S_j} \\ \frac{\partial^2 \pi_m}{\partial S_j \partial S_i} & \frac{\partial^2 \pi_m}{\partial S_j^2} \end{pmatrix} = \begin{pmatrix} -b & r \\ r & -d \end{pmatrix} \tag{12}$$

H^m is a negative definite matrix, so the profit function of the manufacturer π_m is a joint concave function about S_i and S_j. Then, the first-order optimal condition is $\frac{\partial \pi_m}{\partial S_i} = 0$ and $\frac{\partial \pi_m}{\partial S_j} = 0$ and the optimal reflection function of the manufacturer is:

$$S_i = \frac{W_i}{2} + \frac{\mu ed + r\theta + ad}{2(bd - r^2)} \tag{13}$$

$$S_j = \frac{W_j}{2} + \frac{\mu er + b\theta + ar}{2(bd - r^2)} \tag{14}$$

As the decision maker of the agricultural product supply chain, the farmer cooperative takes the purchase prices of manufacturers as its decision-making variables, and the objective function of decision-making is:

$$\max \pi_f = \left(W_i - \frac{C_i}{1 - \beta_i}\right)(a - bP_i + rP_j + \mu e) + \left(W_j - \frac{C_j}{1 - \beta_j}\right)(\theta - dP_i + rP_j) \tag{15}$$

H^f is a negative definite matrix, so the profit function of the farmer cooperatives π_f is a joint concave function about W_i and W_j. Then, the first-order optimal condition is $\frac{\partial \pi_f}{\partial W_i} = 0$ and $\frac{\partial \pi_f}{\partial W_j} = 0$ and the optimal reflection function of the farmer cooperatives are:

$$w_i = \frac{C_i}{2(1 - \beta_i)} + \frac{\mu ed + r\theta + ad}{2(bd - r^2)} \tag{16}$$

$$w_j = \frac{C_j}{2\left(1 - \beta_j\right)} + \frac{\mu er + b\theta + ar}{2(bd - r^2)} \tag{17}$$

Bringing the above results into S_i, S_j, P_i^*, P_j^*, Q_i^*, Q_j^* we obtain the following results:

(1) The optimal retail prices of characteristic agricultural products and ordinary agricultural products are, respectively,

$$P_i^* = \frac{C_i}{8(1 - \beta_i)} + \frac{7(\mu ed + r\theta + ad)}{8(bd - r^2)}; P_j^* = \frac{C_j}{8\left(1 - \beta_j\right)} + \frac{7(\mu er + b\theta + ar)}{8(bd - r^2)} \tag{18}$$

(2) The optimal purchase prices of the retailers of characteristic agricultural products and ordinary agricultural products are, respectively,

$$S_i = \frac{C_i}{4(1 - \beta_i)} + \frac{3(\mu ed + r\theta + ad)}{4(bd - r^2)}; S_j = \frac{C_j}{4\left(1 - \beta_j\right)} + + \frac{3(\mu er + b\theta + ar)}{4(bd - r^2)} \tag{19}$$

(3) The optimal purchase prices of the manufacturers of characteristic agricultural products and ordinary agricultural products are, respectively,

$$w_i = \frac{C_i}{2(1 - \beta_i)} + \frac{\mu ed + r\theta + ad}{2(bd - r^2)}; w_j = \frac{C_j}{2\left(1 - \beta_j\right)} + \frac{\mu er + b\theta + ar}{2(bd - r^2)} \tag{20}$$

(4) The optimal order quantities of characteristic agricultural products and ordinary agricultural products are, respectively,

$$Q_i^* = \frac{a}{8} + \frac{\mu e}{8} + \frac{rC_j}{8\left(1 - \beta_j\right)} - \frac{bC_i}{8(1 - \beta_i)}; Q_j^* = \frac{\theta}{8} + \frac{rC_i}{8(1 - \beta_i)} - \frac{dC_j}{8\left(1 - \beta_j\right)} \tag{21}$$

(5) The profit of the node enterprises are as follows, and the profit of the farmer cooperatives is twice the profit of the manufacturers:

$$\pi_f = \left[\frac{\mu ed + r\theta + ad}{2(bd - r^2)} - \frac{C_i}{2(1 - \beta_i)}\right] Q_i^* + \left[\frac{\mu er + b\theta + ar}{2(bd - r^2)} - \frac{C_j}{2\left(1 - \beta_j\right)}\right] Q_j^* \tag{22}$$

$$\pi_m = \left[\frac{\mu ed + r\theta + ad}{4(bd - r^2)} - \frac{C_i}{4(1 - \beta_i)}\right] Q_i^* + \left[\frac{\mu er + b\theta + ar}{4(bd - r^2)} - \frac{C_j}{4\left(1 - \beta_j\right)}\right] Q_j^* \tag{23}$$

$$\pi_n = \left[\frac{\mu ed + r\theta + ad}{8(bd - r^2)} - \frac{C_i}{8(1 - \beta_i)}\right] Q_i^* + \left[\frac{\mu er + b\theta + ar}{8(bd - r^2)} - \frac{C_j}{8\left(1 - \beta_j\right)}\right] Q_j^* \tag{24}$$

$$\pi_f = 2\pi_m = 4\pi_n \tag{25}$$

(6)　The total profit of the agricultural product supply chain is:

$$\pi_{s1} = \left[\frac{7(\mu ed + r\theta + ad)}{8(bd - r^2)} - \frac{7C_i}{8(1 - \beta_i)} \right] \left[\frac{a}{8} + \frac{\mu e}{8} + \frac{rC_j}{8(1 - \beta_j)} - \frac{bC_i}{8(1 - \beta_i)} \right]$$
$$+ \left[\frac{7(\mu er + b\theta + ar)}{8(bd - r^2)} - \frac{7C_j}{8(1 - \beta_j)} \right] \left[\frac{\theta}{8} + \frac{rC_i}{8(1 - \beta_i)} - \frac{dC_j}{8(1 - \beta_j)} \right] \tag{26}$$

4.2. Centralized Decision-Making Model

On the premise of stable cooperation among the main bodies of the supply chain, the goal is to maximize the overall profit of the agricultural product supply chain. Under centralized decision-making, farmer cooperatives, manufacturers and retailers cooperate to determine the optimal order quantity and optimal retail price of agricultural products so as to maximize the overall profit of the agricultural product supply chain.

Under centralized decision-making, the retail price of agricultural products P_i and P_j is its decision variable, and the objective function of decision-making is:

$$\max \pi_s = \left(P_i - \frac{C_i}{1 - \beta_i} \right)(a - bP_i + rP_j + \mu e) + \left(P_j - \frac{C_j}{1 - \beta_j} \right)(\theta - dP_i + rP_j) \tag{27}$$

Therefore, the Hessian matrix of the overall profit function of the supply chain is:

$$H^s = \begin{pmatrix} \frac{\partial^2 \pi_s}{\partial P_i^2} & \frac{\partial^2 \pi_s}{\partial P_i \partial P_j} \\ \frac{\partial^2 \pi_s}{\partial P_j \partial P_i} & \frac{\partial^2 \pi_s}{\partial P_j^2} \end{pmatrix} = \begin{pmatrix} -2b & 2r \\ 2r & -2d \end{pmatrix} \tag{28}$$

H^s is a negative definite matrix, so the overall profit function of the supply chain π_s is a joint concave function about P_i and P_j. Then the first-order optimal condition is $\frac{\partial \pi_s}{\partial P_i} = 0$, $\frac{\partial \pi_s}{\partial P_j} = 0$ and the optimal reflection function of the overall supply chain is:

$$P_i^* = \frac{C_i}{2(1 - \beta_i)} + \frac{\mu ed + r\theta + ad}{2(bd - r^2)} \tag{29}$$

$$P_j^* = \frac{C_j}{2(1 - \beta_j)} + \frac{\mu er + b\theta + ar}{2(bd - r^2)} \tag{30}$$

$$Q_i^* = \frac{a}{2} + \frac{\mu e}{2} + \frac{rC_j}{2(1 - \beta_j)} - \frac{bC_i}{2(1 - \beta_i)} \tag{31}$$

$$Q_j^* = \frac{\theta}{2} + \frac{rC_i}{2(1 - \beta_i)} - \frac{dC_j}{2(1 - \beta_j)} \tag{32}$$

The following conclusions can be drawn:

(1)　The optimal retail prices of characteristic agricultural products and ordinary agricultural products are, respectively,

$$P_i^* = \frac{C_i}{2(1 - \beta_i)} + \frac{\mu ed + r\theta + ad}{2(bd - r^2)}; P_j^* = \frac{C_j}{2(1 - \beta_j)} + \frac{\mu er + b\theta + ar}{2(bd - r^2)} \tag{33}$$

(2)　The optimal order quantities of characteristic agricultural products and ordinary agricultural products are, respectively,

$$Q_i^* = \frac{a}{2} + \frac{\mu e}{2} + \frac{rC_j}{2(1 - \beta_j)} - \frac{bC_i}{2(1 - \beta_i)}; Q_j^* = \frac{\theta}{2} + \frac{rC_i}{2(1 - \beta_i)} - \frac{dC_j}{2(1 - \beta_j)} \tag{34}$$

(3) The total profit of the agricultural product supply chain is:

$$
\begin{aligned}
\pi_{s2} = {} & \left[\frac{C_i}{2(1-\beta_i)} + \frac{\mu ed + r\theta + ad}{2(bd-r^2)} \right] \left[\frac{a}{2} + \frac{\mu e}{2} + \frac{rC_j}{2(1-\beta_j)} - \frac{bC_i}{2(1-\beta_i)} \right] \\
& + \left[\frac{C_j}{2(1-\beta_j)} + \frac{\mu er + b\theta + ar}{2(bd-r^2)} \right] \left[\frac{\theta}{2} + \frac{rC_i}{2(1-\beta_i)} - \frac{dC_j}{2(1-\beta_j)} \right]
\end{aligned}
\tag{35}
$$

4.3. Revenue Sharing Contract

Under the centralized decision-making model, this paper designs the coordination mechanism of "revenue sharing" to coordinate the income distribution of farmer cooperatives, manufacturers, and retailers in the agricultural product supply chain. To make up for the brand value created by farmer cooperatives and their management efficiency occupying the core position in the supply chain, and overcome the double marginal effect, this paper considers that the node enterprises in the agricultural product supply chain dominated by farmer cooperatives produce and sell agricultural products according to orders and reach an agreement on the proportion of revenue sharing.

$$
\phi \pi_{s2} \geq \pi_f
\tag{36}
$$

$$
(1 - \phi) \pi_{s2} \geq \pi_m + \pi_n
\tag{37}
$$

When ϕ meets the above conditions, the range of ϕ can be obtained by jointly solving Equations (36) and (37), $\phi \in \left[\frac{1}{4}, \frac{13}{16} \right]$. The overall revenue of the agricultural product supply chain in the centralized decision-making model is higher than that in the decentralized model. Moreover, the revenue distribution of farmer cooperatives is higher than that of the decentralized model, and the revenue distribution of manufacturers and retailers is higher than that of the decentralized model.

5. Discussion

In order to verify the validity of the theoretical model, the relevant parameter values will be set in combination with the actual survey data, and numerical simulation will be carried out through MATLAB. In order to avoid the influence of parameter value fluctuation on the conclusion of this paper, the parameter values are organized as follows: Considering that cereal agricultural products adopt the model of order-based production, taking "Wuchang rice" and ordinary rice, which means the rice in the market without brands, as examples, the average value of the research cases is mainly used regardless of special circumstances. After the dimensionless processing of case data, the basic values of the main parameters are shown in Table 2.

Table 2. Basic values of the main parameters.

Parameter	a	θ	C_i	C_j	β_i	β_j	μ	e	b	d	r
Basic value	60	40	3	1	0.1	0.2	10	6	6	3	1.5

5.1. The Impact of Market Potential Capacity on the Overall Profit of the Supply Chain

It can be seen from Figure 2 that the expansion of the potential market scale of characteristic agricultural products can significantly promote the overall profit of the supply chain under decentralized decision-making and centralized decision-making and has a more obvious effect on the overall profit of the supply chain under centralized decision-making. Under the same conditions, the overall profit of the agricultural product supply chain under centralized decision-making is always greater than that under decentralized decision-making, and the gap between the two will widen with the expansion of the potential market for agricultural products. The expansion of the potential market size of ordinary agricultural products will also increase the overall profits of the supply chain

under decentralized and centralized decision-making, but its promotion effect is not obvious compared with characteristic agricultural products. This is because the agricultural product supply chain dominated by farmer cooperatives takes characteristic agricultural products as its main business. Compared with ordinary agricultural products, the premium space of characteristic agricultural products is larger, and its potential market demand has a more significant impact on the overall profit of the supply chain. Under decentralized decision-making, the main goal of each node enterprise is to maximize its profit. Due to information asymmetry, trust crisis, fragile cooperation, and other reasons, it amplifies the bullwhip effect in the supply chain, and increases the transaction cost between node enterprises, resulting in a certain degree of loss in the overall profit of the supply chain. Under the centralized decision-making mode, reasonable pricing with the common goal of maximizing the overall profit of the supply chain can promote the cooperation of all subjects in the agricultural product supply chain, reduce the transaction cost in the process, and improve the overall profit of the supply chain.
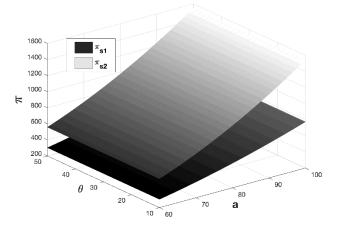

Figure 2. Effects of a and θ on π_{s1} and π_{s2}.

5.2. The Impact of Price Sensitivity on the Overall Profit of the Supply Chain

It can be seen from Figure 3 that the price sensitivity coefficient of characteristic agricultural products has a significant negative driving effect on profits under both decentralized and centralized decision-making. Price sensitivity refers to the change in the demand for a product caused by a price change. According to consumption demand theory, the higher the price sensitivity coefficient of a product, the greater the reduction in demand for a product with a price increase. The variation range of the price sensitivity coefficient of ordinary agricultural products is smaller than the variation range of the price sensitivity coefficient of characteristic agricultural products. Due to the feature of ordinary agricultural products' necessity for survival, the price sensitivity coefficient is low, and it will not have a significant negative effect on the profits of the supply chain. The research object of this paper is the agricultural product supply chain with farmer cooperatives as the core enterprise. This supply chain is mainly based on the sale of characteristic agricultural products, and characteristic agricultural products are the main growth point of the overall profit of the supply chain. Therefore, due to the increase in the price sensitivity coefficient of characteristic agricultural products, the demand for products decreases, which leads to a significant decrease in the overall profit of the supply chain. However, in this process, the overall profit of the supply chain under centralized decision-making is still greater than that under decentralized decision-making. The price sensitivity coefficient of consumers to characteristic agricultural products is bound to be higher than that of ordinary agricultural products. If the price of characteristic agricultural products changes too much or too frequently, it will improve the price sensitivity of consumers and affect the demand for characteristic agricultural products. All entities in the supply chain should cooperate to control the price of characteristic agricultural products within a reasonable

range to avoid a decline in the overall profit of the overall supply chain due to the sharp increase in price. Since consumers are not completely rational economic people, enterprises can adopt personalized customization and characteristic promotion services to enhance customer stickiness, reduce the price sensitivity coefficient of consumers to characteristic agricultural products, and reduce its negative impact on the overall profits of the supply chain. Supply chain coordination mechanisms such as quantity discounts can also be adopted. In the discount stage, product pricing tends to decrease, promoting small profits but the quick turnover of agricultural products. Through the above theoretical model, it can also be concluded that the optimal sales price of agricultural products under centralized decision-making is lower than that under decentralized decision-making. Therefore, with the increase in consumer price sensitivity coefficient, the optimal sales volume of agricultural products under centralized decision-making is higher than that under decentralized decision-making. Finally, the overall profit of the agricultural products supply chain under centralized decision-making is greater than that under decentralized decision-making.
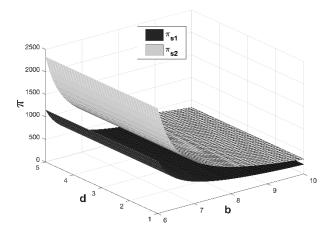

Figure 3. Effects of b and d on π_{s1} and π_{s2}.

5.3. The Impact of Quantity Loss Rate on the Overall Profit of the Supply Chain

Due to the vulnerability of agricultural products, there will inevitably be quantity loss in the process of product circulation and the profits in the supply chain will be affected. This paper assumes that the loss rate β is between 0 and 1. The quantity loss rate of characteristic agricultural products in the circulation process is generally lower than that of ordinary agricultural products due to their customized chemical processes such as fine packaging and brand building. It can be seen from Figure 4, that when the quantity loss rate of characteristic agricultural products is in the reasonable range of 0–0.3 and the quantity loss rate of ordinary agricultural products is in the range of 0.3–0.6, the overall profit under centralized decision-making will decrease slightly, and the overall profit of supply chain under decentralized decision-making will decrease slightly with the quantity loss rate, but the change is not significant. The increase in quantity loss rate will inevitably increase the actual cost of agricultural products and reduce the total profit when the sales price is certain. Due to farmers' aversion to risk, the income is uncertain, and the excessive quantity loss rate will reduce farmers' enthusiasm for production, resulting in the obstruction of the supply of characteristic agricultural products. The quantity of characteristic agricultural products decreases, and the retail price of characteristic agricultural products increases. Under a certain degree of price sensitivity, with the increase in price, consumers' demand for characteristic agricultural products decreases, resulting in the decline of the profits of the whole supply chain.
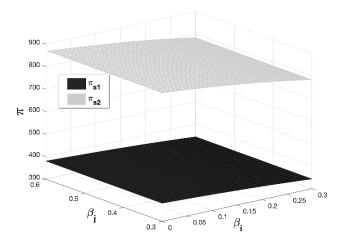
Figure 4. Effects of β_i and β_j on π_{s1} and π_{s2}.

5.4. The Impact of Characteristic Degree and the Characteristic Preference Coefficient on the Overall Profit of the Supply Chain

As can be seen from Figure 5, when other parameters are certain, with the improvement of the degree of agricultural product characteristics, the overall profit of the supply chain under decentralized model and centralized model increases, and the overall profit of the supply chain under centralized model is higher than that under decentralized model. Compared with ordinary agricultural products, characteristic agricultural products can create more profits for the supply chain of agricultural products due to the product premium brought by the degree of characteristics. Therefore, in the agricultural product supply chain dominated by farmer cooperatives, characteristic agricultural products should occupy a larger share in the main business, and the impact of agricultural product characteristics on the overall profit cannot be ignored. With the upgrading of people's consumption quality, the demand for agricultural products has changed from satisfying basic food needs to the pursuit of quality and brand, and the sensitivity to the characteristics of agricultural products has also increased. The supply chain of agricultural products urgently needs to transform the traditional business model, starting from the farmer cooperatives at the front of the supply chain. Farmer cooperatives should make full use of local advantageous natural resources and cultural characteristics, continuously improve the characteristics of their agricultural products, master the core endowment, occupy the leading position of the supply chain, and create more profits for the whole agricultural product supply chain.
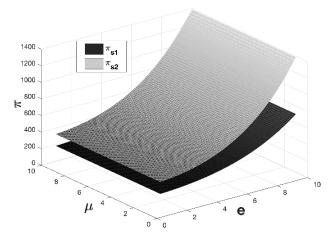

Figure 5. Effects of e and μ on π_{s1} and π_{s2}.

5.5. The Choice of Pricing Strategy

In the supply chain, it is necessary to make differential pricing for ordinary agricultural products and characteristic agricultural products. Subjects in the supply chain have more pricing power for characteristic agricultural products and receive more benefits from them. Based on the previous analysis, compared with pricing under decentralized decision-making, pricing under centralized decision-making can bring more benefits to the whole supply chain. When pricing under centralized decision-making, the price of characteristic agricultural products should increase with the improvement of the consumers' characteristic preference coefficient and the degree of agricultural product characteristics. However, due to the existence of consumers' price sensitivity, the price should not change too much or too frequently, which will affect the overall profit. Therefore, it is necessary to comprehensively consider the influence of multiple factors to adjust the price within a reasonable range. When pricing under centralized decision-making, subjects adopt income sharing contracts, which can realize the reasonable distribution of income and ensure that the income of each subject is higher than that under decentralized decision-making. Pareto mentioned in his research on economic efficiency and income distribution that Pareto improvement means making at least one person better without making anyone worse off. In other words, under the pricing model of centralized decision-making, the revenue of each subject is increased by implementing the revenue sharing contract and Pareto improvement is realized without reducing the revenue of any subject.

6. Conclusions

6.1. Main Conclusions

The pricing model in this paper is applicable to the three-level agricultural product supply chain dominated by farmer cooperatives. The supply chain operates ordinary agricultural products and characteristic agricultural products, but mainly characteristic agricultural products. This paper introduces the degree of agricultural product characteristics, and comprehensively considers the impact of various parameter changes on the pricing strategy of the supply chain, as well as the impact of different pricing models on the overall profit of the supply chain. Under the assumptions of this paper, it can be concluded that the overall profit of the supply chain obtained by pricing agricultural products through the decentralized decision-making model is lower than that created under centralized decision-making. The final sales pricing of agricultural products under the decentralized decision-making model is higher than that under centralized decision-making model. Under a certain price elasticity of demand, the decentralized decision-making model is not conducive to expanding the market share of agricultural products. Under decentralized or centralized decision-making, farmer cooperatives occupy the dominant power and master the pricing power, which is conducive to guiding the reasonable pricing of the supply chain and promoting the stable operation of the supply chain. Under certain conditions, the improvement of the degree of agricultural product characteristics can meet the personalized preference of consumers. In the face of consumers with a high characteristic preference coefficient, by improving the degree of agricultural product characteristics, the demand for agricultural products can be greatly increased, the overall supply chain of agricultural products can be improved, and the Pareto improvement of supply chain members can be realized. In the centralized decision-making model, the node enterprises in the supply chain can reach an agreement on the proportion of revenue sharing through the revenue sharing contract to ensure that their respective revenue is higher than that under the decentralized decision-making and achieve revenue coordination. Each node enterprise in the agricultural product supply chain should act as a rational community to make centralized decision-making and pricing to pursue the overall profit maximization of the supply chain. Through the revenue sharing contract, the conflict of interests between node enterprises can be avoided, and the reasonable distribution of revenue in the supply chain can be realized.

6.2. Research Enlightenment

In the agricultural product supply chain with farmer cooperatives as the core enterprise, the reasonable pricing of agricultural products by each node enterprise is of great significance to promote the reasonable distribution of profits in the supply chain and maintain the stable development of the agricultural product supply chain. The research conclusion shows that different decision-making models, the potential market scale of agricultural products, the degree of agricultural product characteristics, and the preference coefficient of agricultural product characteristics all have an impact on their pricing. The research conclusion provides a reference for the reasonable pricing of the supply chain, and draws the following conclusion:

Each node enterprise in the agricultural product supply chain with farmer cooperatives as the core enterprise should act as a rational community, establishing a strategic alliance for centralized decision-making based on the principle of maximizing the overall profit of the supply chain, and dynamically and reasonably price agricultural products according to the market demand forecast. When operating ordinary agricultural products and characteristic agricultural products at the same time, consumer preferences and price acceptance should be fully considered, and differentiated pricing should be implemented for products. The characteristics of agricultural products can bring more premium space for agricultural products and create more profits for the overall supply chain. Therefore, the agricultural product supply chain should strengthen the ability of brand building and strengthen the ability of brand maintenance. Furthermore, by making full use of the inherent conditions such as regional traditional culture, characteristic resources, and unique regional environment, farmer cooperatives improve the degree of agricultural product characteristics and increase the added value of agricultural products, ultimately maximizing the overall interests of the supply chain.

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