Research on Coordination for Green Supply Chain of Agricultural Products based on Compound Contract

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Keywords: Green Supply Chain; Consumer Demand; Supply Chain Coordination; Compound Contract.

Abstract: Considering consumer preference, product greenness, green R&D cost and other factors, this paper studies the coordination of two-level green supply chain composed of a single green agricultural producer and a single green agricultural retailer. The profit models of green supply chain members under different decision-making modes are constructed. According to the comparison of the optimal price and greenness of green agricultural products under different decision-making modes, it is found that cooperation can improve the overall revenue of the supply chain. Therefore, a hybrid contract of "revenue sharing-cost sharing" is constructed to coordinate the green supply chain of agricultural products, and the conditions for the implementation of the hybrid contract are discussed. The results show that the mixed contract can reduce the price of green agricultural products, improve the greenness and increase the market demand of green agricultural products; the "revenue sharing-cost sharing" mixed contract can effectively solve the "dual marginalization" effect, and a reasonable proportion of revenue sharing can enhance the collaborative ability among members of green agricultural products supply chain, and achieve the perfect coordination of green supply chain. Finally, an example is given to verify the effectiveness of hybrid contract in green supply chain of agricultural products.

1. Introduction

Green supply chain was proposed by Michigan State University's Manufacturing Research Association (MRC) in a research project called Environmentally Responsible Manufacturing in 1996 [1]. The green supply chain is a supply chain model that integrates environmental awareness into the whole process of R&D, packaging, transportation, consumption and disposal of products, improving resource utilization efficiency and reducing the negative impact of products on the environment. As people's awareness of food safety increases, green agricultural products gradually become people's choices.

In the green supply chain of agricultural products, the phenomenon that each member maximizes individual decision-making according to its own interests is widespread, resulting in the “double marginalization” effect, making it difficult for the supply chain to achieve optimal returns. In this context, it is of great practical significance to study the cooperative game and contract coordination between producers and retailers, and to improve the overall performance of agricultural products green supply chain. Gao Gengjun et al [2] studied the green supply chain contract coordination from the perspective of cost sharing, and found that the cost sharing-revenue sharing contract can effectively solve the "double marginalization" phenomenon; Jiang Shiying et al [3] established a product green Four kinds of green supply chain game models, on this basis, further establish the game under the revenue sharing contract; Ghosh et al [4] introduce cost sharing in green supply chain coordination, analyze cost sharing and supply chain decision The impact of Liao Kai [5] discussed the cooperation mechanism of supply chain considering consumer green preference; Wen Xingqi et al [6] considered the green preference of consumers and constructed a Stackelberg model among members of green supply chain based on government subsidy strategy And give the subsidy

effect of different subsidy strategies under the same government subsidy expenditure conditions; Barari [7] and so on through the design contract to make the green supply chain Pareto improved, but did not reach the Pareto optimal level; Wu Dongjing et al [8] established A secondary green supply chain dominated by manufacturers and retailers, considering the impact of both over-confidence on green supply chain decisions; Redness [9] will benefit from sharing contract introduction of fresh corn supply chain, to build a corn supply chain coordination model based on revenue-sharing contract with the buy-back contract.

In summary, the current research on green supply chain coordination only coordinates the supply chain to a certain Pareto improvement, and does not eliminate the phenomenon of "double marginalization". In this paper, considering the influence of price elasticity on the demand for green agricultural products, a centralized decision model, a Stackelberg game model and a hybrid contract model with income sharing factors and cost sharing factors are introduced to achieve the Pareto optimality of the green supply chain of agricultural products.

2. Research Hypothesis

Consider a green supply chain of single-channel agricultural products consisting of one manufacturer and one retailer. Producers produce green agricultural products according to environmental protection requirements and sell green agricultural products to retailers. The greenness of products increases with the increase of green inputs. Retailers Sell green produce to consumers. The relevant assumptions in this paper are as follows:

(1) Green agricultural producers master green core technology and are in a leading position in the supply chain game. Retailers belong to followers.

(2) Market demand is:

$$Q=\alpha\text{-}\beta p+\tau\theta$$

Q represents the market demand, α represents the market capacity of green agricultural products; β represents the demand price elasticity of green agricultural products, α and β are greater than 0; p represents the price of green agricultural products; θ represents the greenness of products; τ is the sensitivity coefficient of greenness of demand.

(3) The cost of producing green agricultural products by the manufacturer is c_m, and the research and development cost $c=\frac{1}{2}\eta\theta^2$, enerated to increase the greenness, η is the cost coefficient of greenness, greater than zero. Assuming the wholesale price is ω (p>ω), the producer's profit function can be expressed as:

$$\pi_M=（\omega-c_m)Q-\frac{1}{2}\eta\theta^2=（\omega-c_m)(\alpha-\beta p+\tau\theta)-\frac{1}{2}\eta\theta^2$$

The retailer's profit function can be expressed as:

$$\pi_R=(p-\omega-c_2)Q=(p-\omega-c_2)(\alpha-\beta p+\tau\theta)$$

3. Basic Model

3.1 Centralized Decision Model

Centralized decision-making is the ideal state of the green supply chain of agricultural products. The information of producers and retailers is completely shared and interconnected into one system. There is no green agricultural product settlement within the supply chain system. Only the sole decision makers exist, and the system determines the optimal product price. And greenness maximizes the profit of the entire supply chain, at which point the supply chain profit function is:

$$\pi_c=(p-c_m)(\alpha-\beta p+\tau\theta)-\frac{1}{2}\eta\theta^2 \quad (1)$$

Theorem 1: Under the centralized decision-making mode, the optimal pricing and optimal greenness of green agricultural products are:

$$p_c^* = \frac{\alpha\eta + c_m(\eta\beta - \tau^2)}{2\eta\beta - \tau^2}$$

$$\theta_c^* = \frac{\alpha\tau - c_m\tau\beta}{2\eta\beta - \tau^2}$$

The total profit of the supply chain is

$$\pi_c^* = \frac{\eta(\alpha - c_m\beta)^2}{2(2\eta\beta - \tau^2)}$$

Prove: According to formula (1), there are partial derivatives of p and θ

$$\frac{\partial^2 \pi_c}{\partial p_c^{\ 2}} = -2\beta$$

$$\frac{\partial^2 \pi_c}{\partial \theta_c^{\ 2}} = -\eta$$

The second-order Hessian matrix of π_c to p and θ is

$$\begin{vmatrix} -2\beta & \tau \\ \tau & -\eta \end{vmatrix}$$

First order master $-2\beta < 0$, when second order master $2\beta\eta - \tau^2 > 0$, Second-order Hessian matrix is negative, therefore p and θ have optimal solutions.

According to first order condition, $\frac{\partial \pi_c}{\partial p_c} = 0, \frac{\partial \pi_c}{\partial \theta_c} = 0$, We can get

$$p_c^* = \frac{\alpha\eta + c_m(\eta\beta - \tau^2)}{2\eta\beta - \tau^2}$$

$$\theta_c^* = \frac{\alpha\tau - c_m\tau\beta}{2\eta\beta - \tau^2}$$

The maximum profit of the green supply chain system of agricultural products under centralized decision is

$$\pi_C^* = \frac{\eta(\alpha - c_m\beta)^2}{2(2\eta\beta - \tau^2)}$$

3.2 Independent Decision Model

In the independent decision-making model, green agricultural producers and retailers act as independent stakeholders, and the game process is as follows: As the leader of the green supply chain, the producer first determines the product greenness: θ and wholesale price: ω, and the retailer is observing On the basis of the optimal wholesale price and greenness provided by the manufacturer, the price of the product is determined according to its principle of profit maximization. At this time, the profit function of the green agricultural product producer is:

$$\pi_{DM} = (\omega - c_m)(\alpha - \beta p + \tau\theta) - \frac{1}{2}\eta\theta^2 \tag{2}$$

The retailer's profit function is:

$$\pi_{DR} = (p - \omega)(\alpha - \beta p + \tau\theta) \tag{3}$$

Both sides form the Stackelberg game and are solved by the inverse induction method.

Theorem 2: In the independent decision model, the optimal price of green agricultural products, the optimal wholesale price and the optimal greenness are:

$$p_{_D}^{*}=\frac{3\alpha\eta+c_m\eta\beta-c_m\tau^2}{4\eta\beta-\tau^2}$$

$$\omega_D^{*}=\frac{2\alpha\eta+2c_m\eta\beta-c_m\tau^2}{4\eta\beta-\tau^2}$$

$$\theta_D^{*}=\frac{(\alpha-c_m\beta)\tau}{4\eta\beta-\tau^2}$$

Prove: In the first stage, retailers pursue their own profits and set the optimal retail price. First derivative obtained by equation (3) and we can get

$$p=\frac{\alpha+\tau\theta+\beta\omega}{2\beta}$$

In the second stage, the manufacturer sets the optimal wholesale price and the optimal greenness of green agricultural products to maximize their own profit. Find the Hessian matrix about θ and ω for equation (2),

$$\begin{vmatrix} -\beta & \frac{\tau}{2} \\ \frac{\tau}{2} & -\tau \end{vmatrix}$$

When $\beta\tau-\frac{\tau^2}{4}>0$, π_{DM} is a concave function for θ and ω, with the best product wholesale price and optimal greenness. According to the first-order condition,

$$\frac{\partial\pi_{DM}}{\partial\omega}=0,\frac{\partial\pi_{DM}}{\partial\theta}=0$$

We can get

$$\omega_D^{*}=\frac{2\alpha\eta+2c_m\eta\beta-c_m\tau^2}{4\eta\beta-\tau^2}$$

$$\theta_D^{*}=\frac{(\alpha-c_m\beta)\tau}{4\eta\beta-\tau^2}$$

The best retail price at this time is

$$p_D^{*}=\frac{3\alpha\eta+c_m\eta\beta-c_m\tau^2}{4\eta\beta-\tau^2}$$

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$$p_D^{*}=\frac{3\alpha\eta+c_m\eta\beta-c_m\tau^2}{4\eta\beta-\tau^2}$$

The maximum profit of the manufacturer is

$$\pi_{DM}=\frac{(\alpha-c_m\beta)^2\eta}{2(4\eta\beta-\tau^2)}$$

The maximum profit of the retailer is

$$\pi_{DR}=\frac{(\alpha-c_m\beta)^2\eta^2\beta}{(4\eta\beta-\tau^2)^2}$$

The total profit of the supply chain is

$$\pi_D=\frac{\eta(a-c_m\beta)^2(6\eta\beta-t^2)}{2(4\eta\beta-t^2)^2}$$

3.3 Comparison of Two Decision Models

Comparing theorem 1 and theorem 2, the following proposition can be derived.

Proposition 1: 1) $\theta_C^* > \theta_D^*$

2) $\pi_c > \pi_D$

Prove: 1) Because

$$2\eta\beta - \tau^2 < 4\eta\beta - \tau^2$$

So

$$\theta_C^* = \frac{\alpha\tau - c_m\tau\beta}{2\eta\beta - \tau^2} > \theta_D^* = \frac{\alpha\tau - c_m\tau\beta}{4\eta\beta - \tau^2}$$

2) Because

$$\frac{\pi_C}{\pi_D} = \frac{(4\eta\beta - \tau^2)^2}{(2\eta\beta - \tau^2)(6\eta\beta - \tau^2)}$$

$$\frac{\pi_C}{\pi_D} = \frac{(4\eta\beta - \tau^2)^2}{(2\eta\beta - \tau^2)(6\eta\beta - \tau^2)}$$

So

$$\pi_c > \pi_D$$

Proposition 1 shows that the optimal greenness and optimal profit of green agricultural products under decentralized decision-making are lower than the optimal level under centralized decision-making, indicating the existence of "double marginal effect". This indicates that the green supply chain of agricultural products has not reached the state of coordination at this time, and a reasonable contract is required to coordinate the green supply chain.

4. Revenue Sharing-cost Sharing Contract Model

Proposition 1 shows that improving the greenness of products under the decentralized decision-making model means that green agricultural producers must pay more and reduce the profits of producers. To this end, a revenue sharing-cost sharing contract is established, and the retailer shares part of the proceeds to the producer to obtain a lower wholesale price. At the same time, the retailer bears part of the green research and development cost of the manufacturer to reduce the cost burden of the producer. Under the coordination of the contract, the overall profit of the green agricultural product supply chain is equal to the profit under the centralized decision-making model, achieving a win-win situation for both parties.

By introducing a revenue sharing factor $\varphi \in (0,1)$ and a cost sharing factor $\xi \in (0,1)$, the green agricultural product retailer shares the proceeds to the green agricultural product retailer according to the ratio of $1-\varphi$, and shares the green research and development cost of the producer according to the proportion of ξ. At this point, the profit function of the green supply chain producer of agricultural products is

$$\pi_{TM} = [(1-\varphi)p + \omega - c_m](\alpha - \beta p + \tau\theta) - \frac{1-\xi}{2}\eta\theta^2 \tag{4}$$

Retailer profit function is

$$\pi_{TR} = (\varphi p - \omega)(\alpha - \beta p + \tau\theta) - \frac{\xi}{2}\eta\theta^2 \tag{5}$$

Theorem 3: If the revenue sharing-cost sharing contract is satisfied

$$\xi = 2\varphi$$

$$\omega = 2c_m$$

At this time, the green supply chain of agricultural products reached a state of coordination.

Prove: To achieve the coordination of the green supply chain of agricultural products, the decision of producers and manufacturers should be consistent with joint decision-making.

$$p_C^* = p_T^*, \theta_C^* = \theta_T^*$$

Finding the first-order partial derivative of p for equation (5) makes it zero.

$$p_T = \frac{\varphi(\alpha + \tau\theta) + \beta\omega}{2\varphi\beta}$$

Let $p_T = p_C^*$ we can get

$$\omega_T = \frac{\varphi(2c_m\eta\beta^2 - 2\tau\eta\beta\theta + \alpha\tau^2 - 2c_m\beta\tau^2 + \theta\tau^3)}{\beta(2\eta\beta - \tau^2)}$$

Substituting p_C^* and ω_T into equation (4), $\frac{\partial \pi_{TM}}{\partial \theta} = 0$

$$\theta_T = \frac{\tau(\alpha - c_m)[\eta\beta(2\varphi - 1) - 2\varphi\tau^2]}{(2\eta\beta - \tau^2)[\eta\beta(\xi - 1) - 2\varphi\tau^2]}$$

Let $\theta_T = \theta_C^*$ we can get

$$\xi = 2\varphi$$

At this time

$$\omega_T = \varphi c_m$$

Substituting $p_C^*, \theta_C^*, \omega = \varphi c_m$ into equation (4), let $\psi = \frac{2\varphi(\eta\beta - \tau^2)}{2\eta\beta - \tau^2}$, Then the revenue sharing and retailer profit of the green agricultural product producer under the revenue sharing-cost sharing contract are

$$\pi_{TM} = \frac{\varphi\eta(\alpha - c_m\beta)^2(\eta\beta - \tau^2)}{(2\eta\beta - \tau^2)} = \psi\pi_C$$

$$\pi_{TR} = \frac{\eta(\alpha - c_m\beta)^2[2(1-\varphi)\eta\beta - (1-2\varphi)\tau^2]}{2(2\eta\beta - \tau^2)^2} = (1-\psi)\pi_C$$

In order to coordinate the green supply chain coordination of agricultural products through the revenue sharing-cost sharing contract, it is necessary to ensure that the profit of green agricultural product producers and suppliers is not less than the respective profits before the coordination, that is, the contract is effective.

$$\begin{cases} \pi_{TM} = \psi\pi_C \geq \pi_{DM} \\ \pi_{TR} = (1-\psi)\pi_C \geq \pi_{DR} \end{cases} \tag{6}$$

The specific range of φ can be determined by equation (7). The specific value is determined by the manufacturer and the retailer, depending on the negotiation ability of the members of the green supply chain.

5. Numerical Study

In our numerical experiment, the related parameters have values as follow:

$$\alpha = 100, \beta = 1.5, \eta = 5, \tau = 1.5, c_m = 10, \varphi、\ \zeta \in (0,1)$$

At this time

$$2\beta\eta - \tau^2 = 12.75 > 0, \beta\tau - \frac{\tau^2}{4} = 6.39375 > 0$$

The condition for the revenue sharing-cost sharing contract that can be obtained from equation (6) is:

$$0.302 \le \varphi \le 0.5, \xi = 2\varphi$$

According to the hypothesis assignment, the parameter change results under different decision models can be obtained, as shown in Table 1.

Table 1. Aameter change results

Decision mode	φ	ξ	p	θ	ω	π_m	π_r	π
Centralized mode	N/A	N/A	43.33	10	N/A	N/A	N/A	1416.67
Independent mode	N/A	N/A	55.95	4.59	40.63	650.9	351.84	1002.74
Contract mode	0.35	0.7	43.33	10	3.5	1008.33	408.34	1416.67
	0.38	0.76	43.33	10	3.8	973.34	443.33	1416.67
	0.42	0.84	43.33	10	4.2	926.67	490	1416.67
	0.45	0.9	43.33	10	4.5	891.67	525	1616.67

As can be seen from the above table, compared with the centralized decision mode, the optimal profit of the green supply chain in the decentralized mode decreased by 413.93, and the optimal greenness decreased by 5.41. Proposition 1 was proved. Under the revenue sharing-cost sharing hybrid contract, the price of green agricultural products has been reduced compared with the decentralized decision-making model, but its greenness has been improved. The reduction in selling price and the increase in greenness have increased the demand for green agricultural products. Make up for the loss of revenue caused by the lower price. When φ changes within its value range (0.302, 0.5), the optimal profit of green supply chain producers and supply chains is higher than the decentralized decision-making model, and the total profit is always equal to the concentration model supply chain profit, achieve perfect coordination of the supply chain.

To more intuitively show the impact of sharing factor φ on the profit of green supply chain members, according to the data in Table 1, the results are shown in Figure 1.

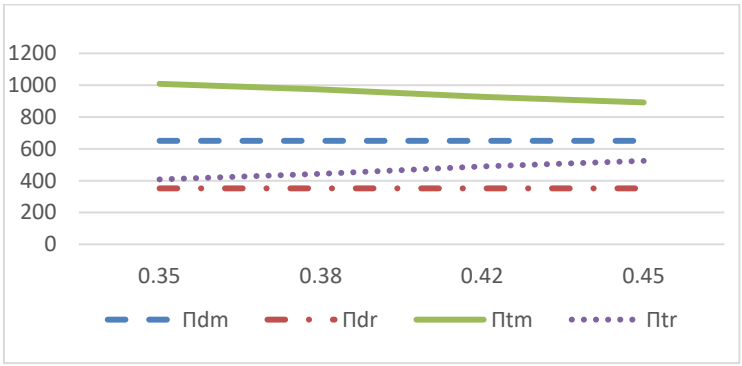

Fig. 1 The impact of φ change on the profit of supply chain members

It can be seen from Figure 1 that when the value of A changes constantly, as φ increases, the profit of the retailer increases, and the profit of the producer decreases, but it is higher than the two in the decentralized decision mode. The profit indicates that the Pareto improvement of both parties is realized under the revenue sharing-cost sharing contract.

6. Conclusion

This paper studies the cooperative game and contract coordination between green supply chain members for the two-level green supply chain composed of single green agricultural product producers and green agricultural product retailers. The research conclusions are as follows:

(1) The hybrid contract can reduce the price of green agricultural products, increase the greenness of green agricultural products, increase the market demand for green agricultural products, and make up for the decrease in revenue due to lower selling prices.

(2) Comparative analysis of centralized decision-making and decentralized decision-making, verifying the existence of the “double marginalization” effect in the green supply chain. The hybrid contract can effectively solve the "double marginalization" effect, so that the green agricultural product price and greenness reach the ideal state, and the members' income is equal to the centralized decision-making income, achieving the perfect coordination of the green supply chain.

Acknowledgments

This work was financially supported by Guangxi Philosophy and Social Science Fund Project “Study on the ‘Multi-mixed’ Logistics Model of Cross-border E-Commerce Agricultural Products in Guangxi” (17FJY009).

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