Coordinated Decision-Making of Supply Chain of Dual Channel Agricultural Products with Corporate Social Responsibility Based on Experimental and Mathematical Statistical Analysis

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Abstract—In recent years, the quality and supply of agricultural products has been the focus of national attention, especially under epidemic attacks, and agricultural companies can not only guarantee quality but also gain publicity by actively fulfilling their social responsibility. In this context, this paper investigates the impact of CSR on the profitability of dual-channel supply chains, and forms a model of coordination between centralized and decentralized decision-making and revenue-sharing contracts under the assumption of CSR by suppliers. Through the Stackelberg game and numerical analysis, the optimal decision of the supply chain under supplier CSR compliance is obtained. It is found that the level of supplier CSR compliance has a positive impact on supply chain prices and supply chain members' profits, and that revenue-sharing contracts can improve supply chain members' profits and effectively coordinate the supply chain.

Keywords-Dual-channel; agricultural product supply chain; revenue sharing; corporate social responsibility

1 INTRODUCTION

The supply and sale of agricultural products has always been a key concern for the country. In recent years, the social responsibility of agricultural enterprises has received increasing attention in order to promote the quality and quantity of agricultural products. The lack of corporate social responsibility in the supply chain may damage the corporate image and reduce consumers' trust in the company, affecting the operation of the entire supply chain. If suppliers of agricultural products take corresponding corporate social responsibility, it will help improve the quality of agricultural products and promote the sustainable development of the agricultural supply chain.

In terms of supply chain CSR, it mainly contains the social responsibility game between suppliers (manufacturers) and platforms(retailers) [1],[2],[3], governance mechanism of SCSR [4], and consideration of supply chain special factors [5]. In terms of coordinating dual-channel supply chain strategies, supply chain coordination is mainly achieved through price sensitivity contracts [6], compensation strategies [7], and revenue sharing contracts strategies [8],[9]. In contrast to the above literature, considering the social responsibility of suppliers, this paper models and analyzes the dual-channel supply chain under centralized decision making and decentralized decision making, and then studies the dual-channel supply chain coordination decision under the improved revenue sharing contract, and analyzes the conditions for dual-

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channel supply chain coordination under the social responsibility of agricultural suppliers, and the impact of suppliers' social responsibility on the dual-channel supply chain coordination decision of agricultural products. The impact of supplier social responsibility on the coordination decision of dual-channel agricultural supply chain is also analyzed.

2 DEFINITIONS AND MODELS

2.1 Model Description

This research considers a supply chain consisting of an agricultural supplier and a retailer, assuming that the supplier is socially responsible and the retailer is perfectly rational. The supplier produces only one type of agricultural product and the supplier sells through offline and online channels. In the offline channel, the supplier sells the agricultural product wholesale to the retailer at a certain offline wholesale price w, and the retailer sells it to the consumer at an offline sales price of p_r, and the offline demand is D_r. In the online channel, the supplier sells it online at a price of p_e through an online direct sales store, and the online demand is D_e. There are no multi-cycle sales, and losses from inventory and stock-outs of agricultural products are not considered, and the information of suppliers and retailers is fully symmetric. Also, the total demand in the market is stable, and the value is the sum of the offline volume of the retailer and the online direct sales volume of the produce supplier.

2.2 Centralized Decision-Making Model

In the centralized decision model, suppliers and retailers make decisions from a global perspective so that the overall revenue is optimal, where $D_r > 0$、$D_e > 0$.

The demand for the online direct sales channel and is

$$\begin{cases} D_e = (1-m)a - p_e + \beta p_r + \rho v\theta_0 \\ D_r = ma - p_r + \beta p_e + \rho v\theta_0 \end{cases} \quad (1)$$

where a is the market size of agricultural products, β is the price cross-elasticity between the two channels, m is the market demand share of offline channels, $\theta_0(0 < \theta_0 < 1)$ is the expected level of suppliers' social responsibility fulfillment, where v is the level of suppliers' corporate social responsibility fulfillment, and ρ is the coefficient of demand influenced by the level of CSR fulfillment.

The overall supply chain revenue function is

$$\pi = (p_r - c)D_r + (p_e - c)D_e - \frac{\lambda v^2}{2} \quad (2)$$

where c is the production cost of agricultural products and π is the overall benefit of centralized decision making, $\frac{\lambda v^2}{2}(0 < v < 1)$ is the cost of CSR fulfillment by suppliers[10], where λ>0 and the constraint （$k(v)' > 0, k(v)'' > 0$） is satisfied.

According to Eq. 2, form the Hessian matrix on p_r and p_e as follow:

$$\begin{bmatrix} \frac{\partial^2\pi}{\partial p_e^2} & \frac{\partial^2\pi}{\partial p_e \partial p_r} \\ \frac{\partial^2\pi}{\partial p_r \partial p_e} & \frac{\partial^2\pi}{\partial p_r^2} \end{bmatrix} = \begin{bmatrix} -2 & 2\beta \\ 2\beta & -2 \end{bmatrix}$$

It is easy to know that the value of the Hessian matrix is $4-4\beta^2$, and since $0<\beta<1$, $4-4\beta^2>0$, the Hessian matrix is negative definite, so there is an optimal solution p_r, p_e to make the maximum value of the return function. The optimal online direct sales price and offline retail price under centralized decision can be obtained as follows:

$$\begin{cases} p_e^* = \frac{(1-m+m\beta)a+c(1-\beta^2)+(\beta+1)\rho v\theta_0}{2-2\beta^2} \\ p_r^* = \frac{(\beta+m-m\beta)a+c(1-\beta^2)+(\beta+1)\rho v\theta_0}{2-2\beta^2} \end{cases}$$

Then:

$$\pi^* = \frac{2ma^2(1-m)+a^2\beta(2m^2-2m+1)}{4(1-\beta^2)} + \frac{\rho v\theta_0(a+\rho v\theta_0)}{2(1-\beta)} - \frac{c^2(\beta-1)+ac}{2} - c\rho v\theta_0 - \frac{\lambda v^2}{2} \quad (3)$$

Lemma 1: Under centralized decision making, considering the CSR of suppliers can make the most of the benefits of the dual-channel supply chain for agricultural products.

2.3 Decentralized Decision-Making Model

Under the decentralized decision-making model, the supplier first decides the online direct sales price p_e and the wholesale price w. Subsequently, the retailer decides the offline sales price p_r based on the supplier's price.

The retailers' benefits are:

$$\pi_r^D = (p_r - w)D_r = (p_r - w)(ma - p_r + \beta p_e + \rho v\theta_0)$$

The suppliers' benefits are:

$$\pi_e^D = (p_e - c)D_e + (w - c)D_r - \frac{\lambda v^2}{2}$$

$$= (p_e - c)[(1-m)a - p_e + \beta p_r + nv\theta_0] + (w - c)(ma - p_r + \beta p_e + \rho v\theta_0) - \frac{\lambda v^2}{2}$$

Based on the method under centralized decision making, we can obtain the optimal value as follows:

$$\begin{cases} p_e^D = \frac{\beta^2 c+ma-ma\beta-c-a-(\beta+1)\rho v\theta_0}{2\beta^2-2} \\ w_e^D = \frac{\beta^2 c+ma\beta-ma-a\beta-c-(\beta+1)\rho v\theta_0}{2\beta^2-2} \\ p_r^D = \frac{a\beta^2 m+2a\beta m+\beta^3 c+\beta^2 c-3ma-2a\beta-c\beta-c-(\beta^3-2\beta-3)\rho v\theta_0}{4\beta^2-4} \end{cases}$$

Based on the above equation we can find the optimal retailer and supplier benefits under decentralized decision making as follows:

$$\pi_r^D = \frac{(ma+c\beta-c+\rho v\theta_0)^2}{4} \quad (4)$$

$$\pi_e^D = \frac{2ma\beta+2a+\beta^2c-2am-c+(2\beta-2)\rho v\theta_0}{4} * \frac{\beta^2c+ma-ma\beta-c-a-(\beta+1)\rho v\theta_0}{2\beta^2-2} + \frac{4ac+3ma\beta c+\beta^2c^2-3mac-c^2+(c+c\beta)\rho v\theta_0}{8} - \frac{(ma+c\beta-c+\rho v\theta_0)*(ma+\rho v\theta_0)}{8} - \frac{\lambda v^2}{2} \quad (5)$$

Comparing the optimal online direct selling price p_e and offline sales price p_r under centralized and decentralized decision making, it can be obtained that

$$p_e^* = \frac{(1-m+m\beta)a+c(1-\beta^2)+(\beta+1)\rho v\theta_0}{2-2\beta^2} = p_e^D$$

$$p_r^* - p_r^D = \frac{(\beta^3-4\beta-5)\rho v\theta_0+am(1-\beta^2)+c(1-\beta)(\beta^2-1)}{4(1-\beta^2)} > 0$$

The optimal online direct sales price is equal under centralized and decentralized decision making, but the offline retail price will be higher under centralized decision making compared to the retailer's offline sales price p_r under decentralized decision making

Lemma 2: Under decentralized decision-making, supply chains can be optimal when suppliers are socially responsible.

Therefore, combining (3), (4) and (5), we can obtain the value of the difference between the optimal profit of the supply chain under centralized decision making and the optimal profit of the supply chain under decentralized decision making Δπ as follows：

$$\Delta\pi = \pi - \pi_e^D - \pi_r^D = \frac{[ma+c\beta+(\beta+1)\rho v\theta_0-c]}{16} > 0$$

From the above equation, we can know there is a double marginal effect in this supply chain, and a suitable supply chain contract needs to be designed to coordinate this supply chain.

3 REVENUE SHARING DECISION MODEL

Revenue sharing contract is a common supply chain coordination contract, which aims to build a revenue sharing mechanism to enable multiple parties in the supply chain to obtain reasonable profits. Compared with the common revenue sharing contract, the improved revenue sharing contract combines the characteristics of dual channels and considers two supply chain coordination methods in a dual-channel environment. On the one hand, the supplier shares the k_e（$0 < k_e < 1$） portion of the online revenue to the retailer after the sale is end in order to mitigate the channel conflict caused by the opening of the online produce sales channel. At the same time, the retailer shares the k_r（$0 < k_r < 1$） portion of the offline revenue to the supplier at the end of the sale in order to obtain a lower wholesale price for the produce. Therefore, this paper analyses the coordination of a dual-channel supply chain based on an improved revenue sharing contract.

In this dual-channel supply chain, the supplier first sets the online direct sales price and the offline wholesale price, and then the retailer sets the offline retail price based on the quotation given by the supplier and maximizing their own interests. The revenue functions of the supplier and the retailer are as follow:

$$\pi_e^R = [(1-k_e)p_e - c]D_e + (k_r p_r + w - c)D_r - \frac{\lambda v^2}{2}$$

$$\pi_r^R = [(1-k_r)p_r - w]D_r + k_e p_e D_e$$

we can get the solutions for the optimal price as follows:

$$p_e^{R*} = \frac{2(1-m)a+ma\beta+c\beta-c\beta^2+(\beta+2)\rho v\theta_0}{4(1-\beta^2)} + \frac{c}{2(1-k_e)} + \frac{\beta k_r(c\beta+ma-c+\rho v\theta_0)}{4(1-\beta^2)(1-k_e)}$$

$$w_e^{R^*} = \frac{(1-k_r)[ac\beta+(2-\beta^2-2\beta)c^2+2\beta c\rho v\theta_0]}{2c-2c\beta^2+\beta^2 c+ma\beta-\beta c+\beta\rho v\theta_0}$$

$$p_r^R = \frac{ma+2\beta p_e^{R*}+c-c\beta+\rho v\theta_0}{2}$$

Then

$$k_e = \frac{(1-k_r)(c\beta^2+ma\beta-\beta c+\beta\rho v\theta_0)}{2c-2c\beta^2+\beta^2 c+ma\beta-\beta c+\beta\rho v\theta_0}$$

Let $M = c\beta^2 + ma\beta - \beta c + \beta\rho v\theta_0$, $N = 2c - 2c\beta^2$, $\mathrm{H} = ac\beta + (2-\beta^2-2\beta)c^2 + 2\beta c\rho v\theta_0$, we can obtain the optimal revenue for retailers and suppliers under an improved revenue sharing pact as:

$$\pi_r^{R^*} = \left[(1-k_r)p_r^{R^*} - \frac{H(1-k_r)}{M+N}\right]D_r^* + \frac{(1-k_r)M}{M+N}p_e^{R^*}D_e^*$$

$$\pi_e^{R^*} = \left\{\left[1 - \frac{(1-k_r)M}{2c-M}\right]p_e^{R^*} - c\right\}D_e^* + \left[k_r p_r^{R^*} + \frac{H(1-k_r)}{2c-M} - c\right]D_r^* - \frac{\lambda v^2}{2}$$

Improved revenue sharing contracts enable supply chain coordination if the overall supply chain revenue is equal to the overall supply chain revenue under centralized decision making. The proof process is as follows:

Assuming the existence of coefficients$k_r(*)$, denote $F(k_r) = \pi - \pi_r^{R^*} - \pi_e^{R^*}$, then

$$F(k_r) = \frac{Mp_e^*}{M+N} - k_r\left\{\frac{Mp_e^*D_e^*}{M+N} + p_r^*D_r^*\right\}$$

since $\lim_{k_r\to 0} F(k_r) > 0$ $\lim_{k_r\to 1} F(k_r) < 0$,

then $\exists k_r \in (0.1)$ make $F(k_r) = 0$,

so, the improved revenue sharing contract enables supply chain coordination.

In addition, since $\frac{\partial k_e}{\partial v} = \frac{(1-k_r)\beta n\theta_0}{(M+N)^2} > 0, \frac{\partial k_r}{\partial v} = \frac{N\beta n\theta_0}{M^2} > 0$, we find that CSR can influence improved revenue-sharing contract decisions. As the level of CSR compliance increases, the revenue-sharing coefficients of retailers and suppliers also increase, and CSR has a greater impact on retailers' revenue-sharing decisions than on suppliers' revenue-sharing coefficients.

4 SIMULATION ANALYSIS

Based on the above equations, the numerical simulation results can be obtained as in Figure 1-Figure 4.

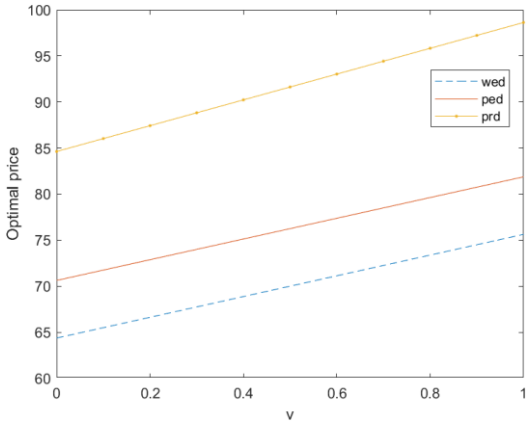

Fig. 1. The effect of v on optimal prices

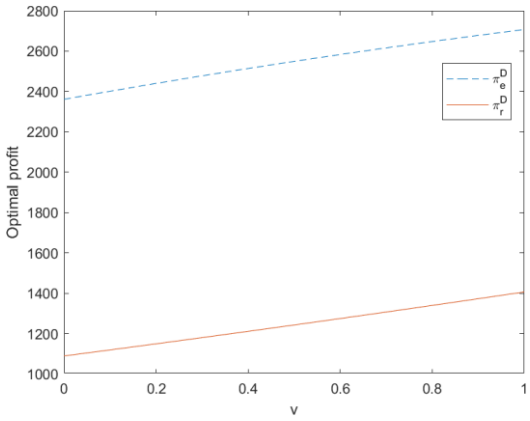

Fig. 2. The effect of v on supplier and retailer profits

Figure 1 illustrates that the optimal retail price, the optimal direct selling price and the optimal wholesale price are linear functions of the level of CSR compliance, with the supplier's level of CSR compliance having the greatest impact on the optimal retail price and the least impact on the optimal wholesale price. As the level of social responsibility of suppliers increases, the optimal retail price, the optimal direct sales price and the optimal wholesale price increase accordingly. Figure 2 shows that the optimal profit for both is a non-linear function of the supplier's CSR compliance level, and that the supplier's CSR compliance level v has a greater impact on the supplier's optimal profit than it does on the retailer's optimal profit.

Figure 3 illustrates that at the same level of fulfilment, as the retailer revenue sharing parameter k_r increases, the supplier's revenue under the improved revenue sharing contract gradually

decreases and the retailer's revenue gradually increases. The two lines of supply chain gains under collective decision overlap with the supply chain gains under the gain-sharing contract, further demonstrating the effectiveness of the gain-sharing contract. As can be seen from Figure 4, when the sharing factor $k_r \in (0.850,0.935)$, the difference in returns $\Delta\pi_e$ for suppliers and $\Delta\pi_r$ for retailers are positive, indicating that the existence of the revenue sharing factor k_r、$k_e \in (0,1)$ makes both sides of the supply chain under the revenue sharing contract revenue values are higher than those under decentralized decision making, and the dual-channel supply chain achieves coordination.

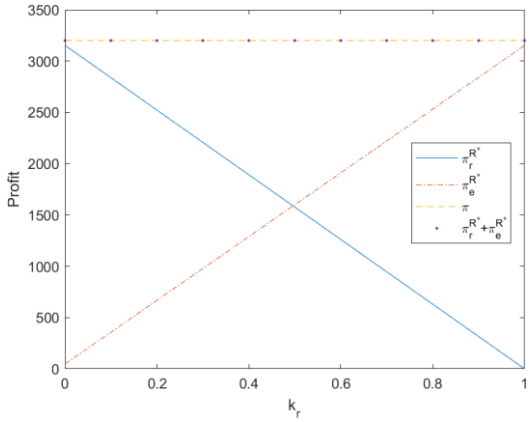

Fig. 3. The effect of k_r on supply chain member profits

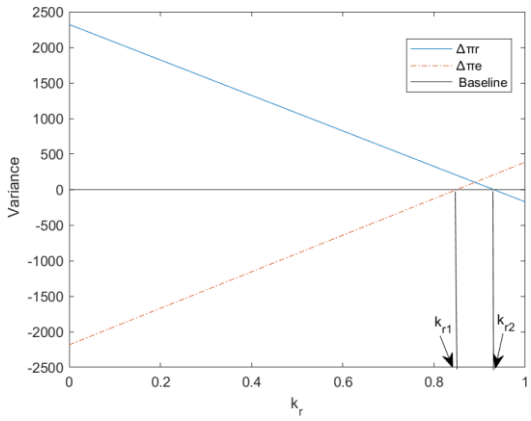

Fig. 4. The effect of k_r on profit variance

5 CONCLUSION AND FUTURE WORK

This paper investigates the coordination of dual-channel agricultural supply chains based on suppliers' corporate social responsibility by constructing an improved revenue-sharing contract model for dual-channel agricultural supply chains. The results of the paper show that under decentralized or centralized decision-making, the profitability of the supply chain can be

increased with the improvement of suppliers' social responsibility. In addition, when suppliers are socially responsible, the improved revenue sharing contract can achieve dual-channel agricultural supply chain coordination, and the improved revenue sharing contract can help improve the overall revenue of the dual-channel agricultural supply chain.

This paper considers a dual-channel supply chain consisting of one supplier and one retailer. However, in the actual dual-channel agricultural products supply chain, there are often multiple agricultural products suppliers and retailers, often forming a complex one-to-many, many-to-one or many-to-many sales model. Future research can further extend to explore the one-to-many or many-to-many dual-channel supply chain model.

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