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Profit Benefits Analysis of Fresh Food Supply Chain and Logistics Cooperation under Financial Constraints

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Abstract

This paper examines a three-tier agricultural supply chain consisting of a large fresh produce cooperative with bargaining power, a fresh produce e-commerce firm, and a third-party logistics firm under the premise of stochastic market prices, the fact that the fresh produce cooperative is in the early stages of its establishment, facing financial constraints, and that a bank provides financing to it, under the optimal decision of each of the three in terms of order price, optimal order quantity, and optimal service level of freshness preservation efforts, As well as in the case of external bank financing, fresh food e-commerce enterprises are faced with the choice of whether to cooperate with the logistics provider under the respective optimal decision variables, the optimal amount of profit. External financing can effectively improve the profit of the whole supply chain, and the cooperative financing model can reduce logistics cost, improve logistics efficiency, reduce risk, and promote the synergistic development of the supply chain, so as to achieve the maximisation of the overall profit of the supply chain. The numerical analysis of parameters is also carried out to provide decision-making reference for the third-level supply chain and increase profits.

Keywords

Fresh Produce; Third Party Logistics; Random Variables; Order Prices; External Financing.

1. Introduction

China is a large agricultural country, and agriculture is the lifeblood of the national economy; its development is directly related to the stability and development of society. Agricultural products are essential to people's lives, and agriculture is the primary industry in China. China's grain output per unit area is also gradually increasing. Even so, there are many uncertainties in agricultural production, especially the frequent fluctuations in market prices, the situation of "small production, big market", the global epidemic of new coronary pneumonia, drought, floods, earthquakes and other natural disasters can lead to a sharp decline in crop yields; in the end of the production, it may also be affected by the impact of stagnant sales. At the end of the production period, it may also be affected by slow-moving goods and other shocks. In recent years, the emergence of "contract farming"[1] has alleviated this predicament to a certain extent. At the same time, with the expansion of the scope of agricultural cultivation, it is difficult to store and preserve fresh agricultural products, etc[2]. With the development of science and technology, the third-party cold-chain logistics companies appeared in the market to solve this problem[3]. At the same time, fresh produce cooperatives in our country is still in the early stage

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of establishment, income is not stable, facing financial constraints, but also consider the three-tier supply chain to choose external financing to solve the funding problem first.

The following is a literature review on agricultural supply chains: T LI Tongjier and TANG Lixia examine order farming challenges and solutions in Guangxi's L County.[4] LUO Chongpu and GAO Qiang[5] explore new order agriculture models for high-quality development under rural revitalization. WANG Yafei and TANG Shuang[6] analyze the interactions between enterprises and farmers in agricultural industrialization.

In fresh agricultural product logistics, YANG Weidong et al. [7] discuss preservation issues, while Wei Guochen[8] emphasizes the development of cold chain logistics. Qin Yi and Guo Yingli[9] look at logistics models and development suggestions. For supply chain financing, YE Fei[10] et al. study farmers' financing choices under uncertainty, and CUI Xin et al.[11] analyze e-commerce supply chain decisions under stochastic demand. PENG HJ and PANG T.[12] investigate financing strategies for order agriculture under subsidies. Overall, the literature provides insights into optimizing agricultural supply chains and promoting agricultural industrialization and rural revitalization.

2. Problem Description and Assumptions

2.1. Problem Description

In this paper, we consider a three-tier order-based fresh produce agricultural supply chain system consisting of a large fresh produce production cooperative (f), an e-commerce enterprise (r), and a third-party logistics service provider (s), as the object of study. The large fresh produce production cooperative has bargaining power to decide the order wholesale price of fresh produce (w), and the market price is random. Therefore, the contract is signed first to decide the wholesale price, the production is finished, the fresh produce e-commerce enterprise acquires the agricultural products and processes and packages them, and decides its own order quantity, and the third-party logistics provider is responsible for providing the fresh transportation delivery service from the supplier to the enterprise and the consumer, and decides its own logistics freshness service level.

Since fresh produce cooperatives face financial difficulties in the early stage of establishment, and choose external financing from banks, and enterprises can choose to cooperate with third-party logistics, this paper considers two fresh produce supply chain models, as shown in the figure below.

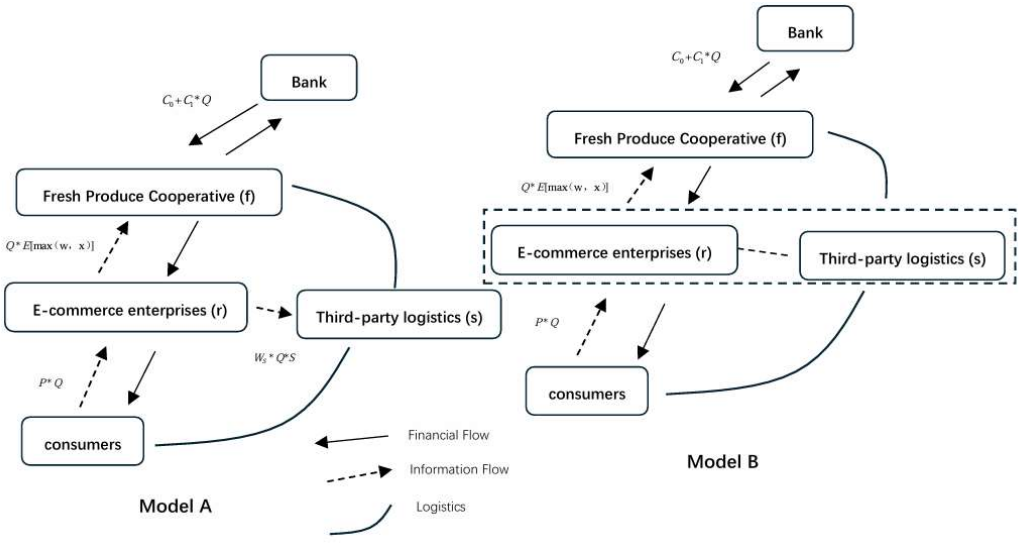

Fig.1 Models A and B

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2.2. Assumptions of the Problem

Before constructing the decision-making model of the order agriculture supply chain, the following basic assumptions and notation are presented.

Before production begins, the production cost of the farmer-producer cooperative is $C(Q)=C_0+C_1*Q$, C_0 is the fixed cost and $C_0 > 0$, C_1 is the unit input cost of growing a unit of fresh produce and $C_1 > 0$.

Because fresh products are difficult to keep fresh, the wholesale market price is also fluctuating frequently, assuming that the market price of fresh agricultural products is a continuous random variable x, where the probability distribution function and the probability density function are respectively $F(x)\geq 0$ and $f(x)\geq 0$, The mean value is $\bar{x}$, and for the sake of generality, this paper only considers the case of $\bar{x} > C_1$.

Prior to production, the fresh food e-commerce company and the fresh produce cooperative production cooperative signed a purchase contract, and at the end of production the maximum of both the order price and the wholesale market price as the purchase price for $max\{w,x\}$.

Table 1. The symbol summary

variable symbol	variable name
w	Order price
S	Level of preservation effort
Q	Order quantity
x	Random price
C_0	Fixed costs
C_1	Input costs per unit of produce
C_2	Business unit operating cost
W_S	Unit logistics price
θ	Preservation Effort Cost Factor
a	Asphyxiation Prices
b	Demand sensitization factor
t	Freshness service level sensitivity factor
f	Agricultural cooperative
r	Fresh food e-commerce business
s	Third-party logistics
$F(x)$	Probability distribution function
$f(x)$	Probability density function
π_f	Agricultural cooperative profit function
π_r	Profit of fresh food e-commerce firms
π_s	Third-party logistics profit function
r_f	Risk-free rate
r_e	Loan rate
L	Loan size

Fresh food e-commerce according to the ordering volume to determine the market price, its processing and packaging in the retail market will be sold, the market price function is $P=a-b*Q+t*S$, $a(a>0)$ said that the choking price, the significance of which is that if the retail price is higher than the a, then consumers will not buy this fresh agricultural products; $b(b\in(0,1))$ for the demand sensitivity coefficient, $\theta(\theta\in(0,1))$ said that the sensitivity to the market

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ordering volume; $t(t \in (0,1))$ said that the market price of the third-party logistics preservation of the level of sensitivity to the level of service.

The agricultural cooperative is in its early stages of establishment and does not have its own capital for the time being. Assuming that the bank's expected rate of return (risk-free rate of return) is r_f , the size of the farmer's financing is $L=C_0+C_1*Q$.the e-commerce firm, the farmer and the bank are risk-neutral, the cooperative farmer has limited liability, and the farmer and the firm aim to maximize their respective expected profits.

Due to the lack of financial management knowledge of the farmers, the farmers' cooperatives are not good at financial management as compared to the more organized and intensive banks and also do not have their own funds, but the banks have to take into account the cost of funds for lending out the funds.

The symbol summary table is shown in Table 1.

3. Model Building and Analysis

3.1. Analysis of Four Models

In the model (A), third-party logistics, fresh food e-commerce firms and members of fresh produce production cooperatives operate independently of each other in decision-making. Fresh produce cooperatives have a certain bargaining power to decide the price of product orders, but face financial constraints, e-commerce companies to decide the number of orders, logistics providers to decide the level of freshness services. Fresh food cooperatives do not have their own capital, so Cost 1234 borrows from the bank, pledges the order to the bank to obtain financing, and at the end of the selling season, the cooperative first pays back the bank loan with the sales money, and if there is still a balance, it is the cooperative's profit.

Since the bank's expected return is equal to the bank's risk-free return, it is described by the equation as follows:

$$Emin\left\{Q*\max(w,x),L*\left(1+{}^{\mathrm{r}_e}\right)\right\}=L*\left(1+{}^{\mathrm{r}_f}\right) \tag{1}$$

For the agricultural cooperative there are two situations, one is that the profit is only enough to repay the bank's loan or not enough to repay the loan, and the other is that there is a surplus after the profit has been used to repay the bank's loan, and the surplus is the net profit of the agricultural cooperative, so the profit of the agricultural cooperative can be expressed as follows:

$$E\left({}^{\pi_f}\right)=E\left\{Q*\max(w,x)-L\left(1+{}^{r_e}\right)\right\}^{+} \tag{2}$$

The profit model of the three is shown below:

$$E(\pi_f)=\underset{w^*}{Q*E[\max(w,x)]-L(1+r_f)}$$

$$\text{s.t.}\begin{cases}\max\limits_{Q^*}E(\pi_r)=\mathrm{P}*Q-Q*E[\max(w,x)]-W_s*Q*S-C_2*Q\\ s.t.\max\limits_{S^*}(\pi_s)=W_s*Q*S-\dfrac{1}{2}*\theta*S^2\end{cases}$$

Equation (1-1)

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In model (D), fresh produce cooperatives are also facing financial constraints, while the logistics provider cooperates with e-commerce enterprises and makes joint decisions, at which time the external financing profit model is shown below:

$$\max_{w_D^*} E(\pi_f)=E[\max(w,x)]*Q-L*(1+r_f)$$

$$\text{s.t. } \max_{Q_D^*,\ S_D^*} E(\pi_{rs})=\mathrm{P}*Q-Q*E[\max(w,x)]-\frac{1}{2}*\theta*\mathrm{S}^2-C_2*Q$$

Equation (1-2)

3.2. Model Solving and Parameter Analysis

The Steinberg game is a game-theoretic model for analyzing how multiple decision makers make choices in an interdependent environment. In the game, each participant's decision not only affects his or her own payoff, but also influences the outcomes of other participants. The key to the Steinberg game is to consider the interaction and mutual influence between participants. In the Steinberg game, participants are divided into two roles, the leader and the follower. The leader makes decisions first, while the followers react after observing the leader's decisions. The leader anticipates the responses of the followers when formulating strategies and accordingly formulates optimal strategies to maximize his or her benefits. Followers, in turn, choose their own optimal decisions based on the leader's strategy.

Solving each of these four equations by backward induction leads to the optimal decisions for each member of the supply chain as shown in the table below:

Table 2. Optimal Decision Table

Optimal decision variables	Mode (A)	Mode (B)
w^*	$\bar{x}+\int_0^{w_A^*}F(x)dx=\frac{a-C_2+C_1(1+r_f)}{2}$	$\bar{x}+\int_0^{w_B^*}F(x)dx=\frac{a-C_2+C_1(1+r_f)}{2}$
Q^*	$Q_A^*=\frac{\theta*(a-C_1(1+r_f)-C_2)}{2(2b\theta+2W_s^2-2tW_s)}$	$Q_B^*=\frac{\theta*(a-C_1(1+r_f)-C_2)}{2(2b\theta-t^2)}$
S^*	$S_A^*=\frac{W_S*(\mathrm{a}-\mathrm{C}_1(1+\mathrm{r}_f)-\mathrm{C}_2)}{2(2\mathrm{b}\theta+2W_S^2-2\mathrm{tW}_S)}$	$S_B^*=\frac{t*(a-C_1(1+r_f)-C_2)}{2(2b\theta-t^2)}$

At the same time we want to ensure that the supply chain members' profits are positive and the numerator denominator of the respective optimal profit value decision is greater than zero, so for different models the respective conditions are:

For model (A),the parameters are satisfied $t<\frac{b\theta+\frac{s^2}{}}{W_S}$; For model (B),the parameters are satisfied $t<\sqrt{2b\theta}$.

3.3. Impact Analysis

Proposition 1: The decision variable order price of fresh produce cooperatives varies in the opposite direction to the mean value of the random price $\bar{x}$ in the market.

When the mean value is larger, fresh produce cooperatives are often afraid of the uncertainty of future market prices, so they maintain their order prices at a reasonable level to maximize their expected profits. If the average market price $\bar{x}$ does not change, it shows a positive

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correlation with market choking prices, a negative correlation with cooperative costs, and a positive correlation with e-commerce costs.

Proposition 2: The effects of the parameters on the four optimal decision variables in the four models are shown below(the parameters are within reasonable limits.

$$\frac{\partial Q^*}{\partial t} > 0; \frac{\partial Q^*}{\partial b} < 0; \frac{\partial Q^*}{\partial \theta} < 0;$$
$$\frac{\partial S^*}{\partial t} > 0; \frac{\partial S^*}{\partial b} < 0; \frac{\partial S^*}{\partial \theta} < 0; \quad \frac{\partial Q^*}{\partial \mathrm{r}_f} < 0; \quad \frac{\partial S^*}{\partial \mathrm{r}_f} < 0;$$

For the optimal ordering quantity, which is inversely proportional to the market demand sensitivity coefficient, the higher the market demand sensitivity, the higher the ordering quantity resulting in higher prices, then consumers will reduce their purchases, and then fresh produce companies will reduce their costs accordingly in order to avoid inventory. Negative correlation with the freshness effort cost factor, also to reduce costs. Positively correlated with the insurance service level, the higher the freshness service level, the more consumers are willing to buy, so the e-commerce companies will increase their own ordering volume. For the level of preservation efforts of third-party logistics providers, it is positively correlated with the sensitivity coefficient of market demand, shows a positive correlation with the sensitivity coefficient of preservation service level, and shows a negative correlation with preservation costs.

For external bank financing, then, the risk-free rate will make order prices higher and e-commerce companies and third-party logistics decisions lower. That's because the higher the risk-free rate, the higher the level of the bank's credit interest rate, the higher the cost of the cooperative's loan, making the order price of fresh agricultural products increased accordingly, e-commerce enterprises and logistics companies to measure their costs and revenues, and accordingly reduce their decision-making variables to balance the lower profits.

4. Calculus Analysis

Next, an example analysis is carried out, referring to the existing literature and combining with the real situation, the model is analyzed by using an example, and the values of each parameter are assigned as shown in the table 3. Assuming that the stochastic market price of fresh produce obeys a uniform distribution [1.9], according to the proposition , we can find out at this time (A) (B) mode of fresh produce cooperative order price is $w^* = 4.13$.

Table 3. Parameter settings

Parameters	C_0	C_1	C_2	a	W_S	$\theta(theta)$	b	t	r_f
Values	1	2	1	10	0.65	0.8	0.3	0.1	5%

We substitute the above values into the external financing mode (A) and the external financing cooperation mode (B) decisions, respectively, and obtain the values of each decision variable and their respective corresponding expected profit values as shown in Table 4.

Table 4. Optimal solution table

Parameters	w^*	Q^*	S^*	π_f	π_r	π_s	π_{rs}	π
Mode (A)	4.13	3.14	0.38	14.8	2.95	0.53	---	14.26
Mode (B)	4.13	5.87	4.77	19.21	---	---	2.24	21.45

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The comparison shows that when cooperatives face financial constraints, fresh produce cooperatives under the cooperative model (B) can improve the overall profit of the supply chain, which indicates that cooperation with fresh produce e-commerce companies can help fresh produce cooperatives to obtain higher profits. And it can increase the ordering volume of e-commerce companies as well as the level of insurance services in the optimal decision.

Therefore, we need to choose the appropriate mode for the mode selection, fresh produce cooperatives need to choose the appropriate mode according to their own situation and the characteristics of the supply chain. If the fresh produce e-commerce companies are willing to cooperate and the cooperation can bring higher profits, then the cooperative mode (B) is a better choice. The three parties in the supply chain should choose whether or not to cooperate based on their own needs.

The market prices of fresh produce (28 vegetables and 6 fruits) combined with the market prices from January 2022 to December 2024 are analyzed for further examples，The official data obtained by querying the Ministry of Agriculture and Rural Development is shown in the Appendix。

As can be seen from the data, the average monthly price of fresh fruits and vegetables in the past two years is 6.5 yuan/kg, and its price range is between [4.9], due to the particularity of the price of fresh products, received seasonal weather and other effects approximate to obey the uniform distribution, therefore, combined with the previous assumptions of the parameter, according to the optimal solution obtained by the game, we can get the optimal decision-making calculation of the decision-making variable of the cooperative of fresh agricultural products. In addition, according to the information, it can be seen that China's cold chain logistics freight generally to the road refrigerated trucks and railroad cold chain transportation as the basic transportation, for fresh fruits and vegetables are also generally to the refrigerated trucks as a means of transport, refrigerated trucks transport basically the general price of general in 0.5 yuan / kg to 1 yuan / kg, for the railroad cold chain transportation, the price of the price of the cold chain transportation is generally in the range of 0.3 yuan / kg -0.5 yuan / kg. Therefore, we take the cold chain transportation of the Therefore, we take the price of cold chain transportation as 0.5 yuan/kg for example analysis, and the rest of the parameters are shown above.

Table 5. Table of Optimal Solutions for Specific Values

Parameters	w^*	Q^*	S^*	π_f	π_r	π_s	π_{rs}	π
Mode (A)	6.55	3.14	0.38	14.76	3.00	0.54	---	18.30
Mode (B)	6.55	5.87	0.73	28.66	---	---	---	29.34

As with the previous results, in the context of constrained bank funding, the profit of fresh produce cooperatives under the cooperative mode (B) is higher than that of the independent mode (A), indicating that cooperating with fresh produce e-commerce companies improves profits and optimizes supply chain efficiency. As banks finance cooperatives, they are able to scale up production and improve overall efficiency. Fresh produce e-commerce companies also have higher profits under the cooperative model. Therefore, when fresh produce cooperatives face financial constraints, they can choose the appropriate model, for example, fresh food e-commerce companies can choose to cooperate with logistics providers.

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5. Conclusion

This paper investigates the supply chain optimal decision-making problem under the premise of market price stochasticity, where fresh produce cooperatives face financial constraints needing bank funding as well as signing an order price agreement with a fresh produce e-commerce company, and fresh produce e-commerce companies face the question of whether or not to cooperate with third-party logistics providers. According to the Stackelberg game, the fresh produce cooperative as a leader, the fresh produce e-commerce company and the logistics provider as a follower decide, in turn, the order price at which they expect to maximize their profit, as well as the order quantity and freshness preservation strength. In this process, two different supply chain models were constructed.

It was found that when agricultural cooperatives face financial constraints, having cooperation can improve the overall profit to the supply chain and the profit of the cooperatives compared to when e-commerce companies have no cooperation. Meanwhile, market demand sensitivity, preservation effort level cost coefficient, and market preservation service sensitivity all affect the decision variables. When the market demand is more sensitive to price, model (A) is more favorable to the overall profit of the supply chain because the third-party logistics enterprises can operate independently and are not affected by the profit of the e-commerce enterprises, thus ensuring the stability of the supply chain. When the market demand is less sensitive to price, the cooperation model (B) is more favorable, because e-commerce enterprises can cooperate with logistics enterprises to better control logistics costs and increase product prices by improving the strength of capital preservation, thus increasing profits. Of course, the financing cost also affects the profit of the supply chain, so it is necessary to reasonably control the financing scale and interest rate. Numerical analysis also shows that choosing different supply modes according to different parameters can improve profits. Therefore, fresh produce cooperatives should choose the appropriate mode according to their own situation and supply chain characteristics in order to maximize profits. Overall, fresh produce cooperatives should choose the appropriate supply chain model according to their own situation and market environment. In addition, supply chain members need to strengthen cooperation and work together to improve logistics efficiency and reduce logistics costs in order to maximize the overall profit of the supply chain.

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