The optimization of Three-echelon Agricultural Supply Chain under Crop Revenue Insurance

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Abstract. As the agricultural supply chain of is vulnerability due to the dual effects of natural disaster and marketable risk, the paper deals with the optimization of agricultural supply chain by introducing the crop revenue insurance for the first time. Firstly, this paper established the profit model of supply chain without any insurance. Then the crop revenue insurance is introduced into the supply chain, and the impact of supply chain is discussed and profit optimization of the supply chain with yield insurance and crop revenue insurance is analyzed as well. Finally, a numerical example is used to verify the results. The study shows that the supply chain system can be optimized through crop revenue insurance based on the principle of sharing insurance cost and claim, which can make up profit loss of natural risk and market price risk.

1 Introduction

China is the large agricultural nation since the ancient times. Agriculture is the foundation of our country's economy. In recent years, however, agricultural planting industry are facing the more complex risks that include the irresistible natural risk and the market price risk. In addition, the independently small farmers unit is the main organization mode of China's agricultural planting, and the mode is not only small in scale, but also low efficiency and more difficult to avoid the fluctuation of risks. Duing the risks, the supply chain is unstable, and even rupture. Therefore improving the supply chain's ability to resist risk and reduce the external risk such as natural risk and marketable risk is play a vital significance for the supply chain stable.

Since the agricultural risk events can bring about huge impact on the normal operation of supply chain and the supply chain risk management has become a hotspot in the research of the supply chain. YJ. Zhou et al. [1] firstly, reviewed risk identification and management process of the research results at home and abroad. Then, points out that strengthen the recognition of risk in supply chain and reinforce the quantitative risk assessment research, moreover, tighten up the management of risks' feedback mechanism in the dynamic environment. B. Schuster [2] pointed out that risks can be modified by buying insurance, and be reduced by signing contract terms. Moreover, he also proposed that use derivatives to reduce market risk, such as futures, options and forward. B. Dan et al. [3] designed a new risk compensation mechanism that the bad weather will not break the coordination state of the supply chain and motivate producers input the optimal level of agricultural materials. To a certain extent, the risk compensation mechanism can reduce the adverse weather's influence and improve the stability of the supply chain. Ling et al. [4] demonstrated that share the risks of output and demand in the contract can not only increase the profits of all members, at the same time also make mutual coordination and promote development of supply chain. Yang and Li [5], put forward agricultural insurance can be divided into yield

insurance and revenue insurance, and agricultural insurance can be used as a way to transfer risks and improving the capacity of natural disaster risk management in our country.

In [6-8], the authors summarized the experience of foreign crop revenue insurance. Cao et al. [9] demonstrated the yield insurance can realize further optimize agricultural products supply chain under the natural risk. In [10-14], the authors considered the supply and demand uncertainty of the agricultural product that introduce options contracts to increase the agricultural products supply chain flexible to avoid risk. Above all, the importance of supply chain risk management has become increasingly obvious. Experts and scholars used a variety of methods and studied the supply chain risks from different angles to take further steps to transfer risks. Though the foreign scholars in the agricultural products supply chain has carried out a lot of research of the risk management, but the study of China's agricultural products is relatively poor, especially use the agricultural insurance to transfer the agricultural supply chain risk research are even less.

Using the agricultural insurance to transfer the risks is the important measure to reduce supply chain profit loss. Most of the studies focused on the production of agricultural insurance and summarized the experience of foreign crop revenue insurance, but the research that in the quantitative analysis of the impact of supply chain profit under the crop revenue insurance is still in a blank state. With the principle of sharing insurance cost and claim, the innovation of this paper is that introduced crop revenue insurance in three-level agricultural supply chain for the first time, and demonstrated that the crop revenue insurance can realize the further optimization of the supply chain, and the crop revenue insurance can also inspire dealers and distributors to increase quantity. In addition, this paper can also provide a basis gist for the supply chain risk management decision makers.

2 Problem descriptions

There is a single cycle model of three-level supply chain that composing a producer M , a distributor D and a retailer R . The retailer that faced with the market demand is a random variable x and its density function and distribution function are $f(x)$ and $F(x)$. Before the start of production cycle, firstly, the retailer makes the revenue sharing contract with the distributor, and then determines the quantity q_r . Secondly the distributor makes the revenue sharing contract with the supplier, and decides its wholesale quantity q_d . Finally, according to the quantity, the supplier determines its investment yield A . The supplier's production yield is α times more than q into production, $A=(1+\alpha)q, 0<\alpha<0.5$.

At the beginning of production, according to principle of sharing cost L and claim H , members of the supply chain decision to place the crop revenue insurance, and the insurance company will pay out in claim after the end of the production. In the selling season, the producer supplies agricultural products T , moreover the retailer expect sales S and retail price p .

Using β to describe the different damage degree of agricultural products under the different natural risk., but the supplier's actual output affected by natural risk and the available supply to the distributor is T , $T=(1+\alpha)(1-\beta)q$, the retailer expects sales S

$$S = \int_0^T xf(x)dx + \int_T^{+\infty} Tf'(x)dx = T - \int_0^T F(x)dx \quad (1)$$

The following assumptions are assumed to hold for this model.

- (1) All decision makers are risk neutral and perfectly rational, in addition, this paper don't consider stock losses and the rest of the products of the salvage value is zero.
- (2) If the supply chain's makers decide to place insurance, they will place the insurance for all production.
- (3) $q_r=q_d=q$.
- (4) Agricultural products market is a completely competitive market, and the retail price p is decided by the market price.

The subscript M , D and R respectively represent the supplier, distributor and retailer. The farm production cost c_0 . c_1 , c_2 and c_3 respectively represent the supplier, distributor, retailer marginal cost. The retailer and distributor income share coefficient are λ_1 , λ_2 . And the expected profit π .

3 The three-echelon supply chain profit model without insurance

In this situation, revenue sharing contract are used to coordinate the supply chain. In the model, the distributor is at a low wholesale prices w_1 to buy agricultural products from the supplier, and promises to give the supplier $1-\lambda_1$ proportion of earnings in return. Then the retailer take a lower wholesale at w_2 to gain the production from the distributor, and promises to give the distributor $1-\lambda_2$ proportion of earnings in return. So the profit model of overall profit, retailer, distributor and supplier can be as below.

$$\pi_{I1} = pS - (c_1 + c_2 + c_3)(1+\alpha)(1-\beta)q - c_0(1+\alpha)q \quad (2)$$

$$\pi_{R1} = \lambda_2 pS - (c_3 + w_2)(1+\alpha)(1-\beta)q \quad (3)$$

$$\begin{aligned} \pi_{D1} = & \lambda_1 [w_2(1+\alpha)(1-\beta)q + (1-\lambda_2)pS] \\ & - (c_2 + w_1)(1+\alpha)(1-\beta)q \end{aligned} \quad (4)$$

$$\begin{aligned} \pi_{M1} = & w_1(1+\alpha)(1-\beta)q - c_0(1+\alpha)q \\ & + (1-\lambda_1)[w_2(1+\alpha)(1-\beta)q + (1-\lambda_2)pS] \\ & - c_1(1+\alpha)(1-\beta)q \end{aligned} \quad (5)$$

Lin et al. [15] demonstrated that only the revenue-sharing contract parameters meet the conditions that $w_1 = \lambda_1 B - \lambda_1 c_3 - c_2$, $w_2 = \lambda_2 B - c_3$, $\pi_{R1} = \varphi_1 \pi_{I1}$, $\pi_{D1} = \varphi_2 \pi_{I1}$, $\pi_{M1} = (1 - \varphi_1 - \varphi_2) \pi_{I1}$. The supply chain can achieve coordination, $\varphi_1 = \lambda_2$, $\varphi_2 = \lambda_1(1 - \lambda_2)$, $c = c_1 + c_2 + c_3$, $B = [cA + c_0(1+\alpha)]/A$, $A = (1+\alpha)(1-\beta)$.

4 The three-echelon supply chain profit model with insurance

In order to reduce the effects of natural risk and marketable risk of supply chain profit, Decision makers can make a good use of the crop revenue insurance to transfer risks at external, and then, achieve the goal of both natural and marketable risk management. With the contract of sharing cost and claim, they appointed the sharing proportion. The retailer, distributor and supplier's sharing proportion respectively are φ_1 , φ_2 , $1-\varphi_1-\varphi_2$. Finally the supplier represents the supply chain to sign a insurance contract with the insurance company.

Reference to American ARP-HPE[14], the agricultural crop revenue insurance's claim rules as follows.

(1) Guaranteed income per unit area = the average yield of history * forecast price * security level. This article assumes that security level is 70%.

(2) The supply chain participants should pay insurance premium of each production cycle and $K\omega_S P_S/t$. The security level is K . ω_S on behalf of the insurance premium rate. The security price P_S .

(3) According to the actual income of harvest, the insurance company will compensate the part that under the guaranteed income which specified in the insurance contract. The claim expression is $N_S [(1+\alpha)qKp_S - p(1+\alpha)(1-\beta)q]V$. the coefficient of claim N_S . Difference growth period of the highest standard of compensation V .

$$N_S = \begin{cases} 1 & p(1-\beta) < p_S K \\ 0 & p(1-\beta) \geq p_S K \end{cases}$$

$$V = \begin{cases} 1 & \beta < 0.9 \\ V(i) & \beta \geq 0.9 \end{cases}$$

Adding the crop revenue insurance to the supply chain, so the profit model of overall profit, retailer, distributor and supplier can be as below.

$$\pi_{I2} = pS - (c_1 + c_2 + c_3)(1 + \alpha)(1 - \beta)q - c_0(1 + \alpha)q + E \quad (6)$$

$$\pi_{R2} = \lambda_2 pS - (c_3 + w_2)(1 + \alpha)(1 - \beta)q + \varphi_1 E \quad (7)$$

$$\pi_{D2} = \lambda_1 [w_2(1 + \alpha)(1 - \beta)q + (1 - \lambda_2)pS] - (c_2 + w_1)(1 + \alpha)(1 - \beta)q + \varphi_2 E \quad (8)$$

$$\pi_{M2} = w_1(1 + \alpha)(1 - \beta)q - c_0(1 + \alpha)q + (1 - \lambda_1)[w_2(1 + \alpha)(1 - \beta)q + (1 - \lambda_2)pS] - c_1(1 + \alpha)(1 - \beta)q + (1 - \varphi_1 - \varphi_2)E \quad (9)$$

$$E = -H + L, H = (1 + \alpha)qKp_s\omega_s \\ L = N_s[(1 + \alpha)qKp_s - p(1 + \alpha)(1 - \beta)q]V$$

5 The analysis of the crop revenue insurance on the optimization of supply chain profit

Comparing with the model of the third and fourth sections, and get the following propositions.

Proposition1. The supply chain decision makers place the crop revenue insurance, and when β increases to the condition that the actual revenue less than the guaranteed income, the profit of total supply chain, retailer, distributor and supplier will be advanced with the growth of β

proof.

$$\frac{\partial \pi_{I1}}{\partial \beta} = p \frac{\partial S}{\partial \beta} + c(1 + \alpha)q = (1 + \alpha)q[p(F(T) - 1) + c]$$

$0 \leq F(T) \leq 1, -1 \leq F(T) - 1 \leq 0, p \gg c, \frac{\partial \pi_I}{\partial \beta} < 0$ With the increase of β , the profit of total supply chain

without insurance will reduce.

$$\frac{\partial \pi_{I2}}{\partial \beta} = (1 + \alpha)q[p(F(T) - 1) + c] + N_s p(1 + \alpha)qV \\ = (1 + \alpha)qp[F(T) - 1 + c + N_s V]$$

$$p(1 - \beta) \geq p_s K, N_s = 0, \frac{\partial \pi_{I2}}{\partial \beta} = \frac{\partial \pi_{I1}}{\partial \beta}$$

$$p(1 - \beta) < p_s K, N_s = 1, \frac{\partial \pi_{I2}}{\partial \beta} < 0 < \frac{\partial \pi_{I1}}{\partial \beta}.$$

Proving by the same methods, and gained that the profit of retailer, distributor and supplier would be advanced with the growth of β

Proposition2. The supply chain decision makers placed the crop revenue insurance, and when marketable risk lead to lower price to the condition that the actual revenue less than the guaranteed income, the profit of total supply chain, retailer, distributor, supplier will be advanced with the decrease of retail price p

proof. $\frac{\partial \pi_{I1}}{\partial p} = S$, $\frac{\partial \pi_{I2}}{\partial p} = S - N_s(1 + \alpha)(1 - \beta)qV$, $S > 0$, $\frac{\partial \pi_{I1}}{\partial p} > 0$. With the decrease of p , the total profits of supply

chain without insurance is reduce.

$$p(1-\beta) \geq p_s K, N_s = 0, \quad 0 < \frac{\partial \pi_{I2}}{\partial p} = \frac{\partial \pi_{I1}}{\partial p}.$$

$$p(1-\beta) < p_s K, N_s = 1, \quad \frac{\partial \pi_{I2}}{\partial p} < 0 < \frac{\partial \pi_{I1}}{\partial p}.$$

Proving by the same methods, and gained that the profit of retailer, distributor,supplier would be advanced with the decrease of p .

6 Numerical study

In this section, the paper first use an example of Soybean production in Heilongjiang province, and describe the experimental parameters used in the numerical solutions. Then analyze these results and compare and contrast the performance of the channel without insurance and with the crop revenue insurance.

Assuming that the demand is a normal distribution function $x=\sigma$, $\sigma \sim N(200,8)$ $\alpha=0.03$, $p=7$ yuan/kg, $\sigma=200$ t, $c_0=1.5$ yuan/kg, $c_1=0.15$ yuan/kg, $c_2=0.15$ yuan/kg, $c_3=0.15$ yuan/kg. The average yield is 2000 kilograms per mu, $P_s=7$ yuan/kg, $K=70\%$, $\omega_s=6\%$ per mu.

According to the model in the third and fourth quarters, the paper consider the influence of natural risk on the profit of the supply chain. And then, the channel profit assessment of the insurance is implemented by "with-and-without comparison method".

Fig. 1. Natural risk impact on the overall profit.

The Figure1 shows that the profit of the participants in the supply chain that without insurance, with the increase of β the profit will reduce. $\beta > 0.8$ the profit of supply chain participants are negative, and the natural risk threat to the supply chain's profit. But the supply chain place the crop revenue insurance, although has premiums, through share premium and claim ,and the insurance’s characteristics of low cost and high claims, its impact on the supply chain profit is very small. On the contrary with the increase of β , the gap between the income and actual income increase, and members of the supply chain profit will increase slightly, so under the effect of the natural risk, the crop revenue insurance can optimize the supply chain profit.

Fig. 2. Marketable risk impact on the overall profit.

The Figure 2 shows that the profit of the participants in the supply chain without insurance, with the marketable risk lead to lower price ,the profit of supply chain fail sharply ,and the marketable risk threat to the supply chain's profit. But the supply chain place the crop revenue insurance, with the increase of the marketable risk lead to lower price, members of the supply chain profit will increase slightly, so under the influence of the marketable risk, the crop revenue insurance can optimize the supply chain profit.

7 Conclusion

According to the principle of sharing cost and claim, this article introduces the crop revenue insurance into the three-level agricultural supply chain, and discuss the impact on supply chain profit. In the demonstration part, first of all discuss the situation that the supply chain do not have insurance ,the revenue sharing contract was used to optimize the supply chain cooperation between members ,and make the supply chain in the coordination state that the overall profit achieve the optimal. Then, based on the revenue sharing profit model, and join the crop revenue insurance to the model and draw the following conclusion. The crop revenue insurance is able to transfer part of the risk to outside, and the claims of the crop revenue insurance can make up the loss profit that caused by the natural risk and marketable risk. Therefore the supply chain on the basis of the coordination of revenue sharing contract is able to realize the further optimization.

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