Research on Supply Chain Coordination of Fresh Agricultural Products under Agricultural Insurance

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Abstract. Based on the fact that the current fresh agricultural products are susceptible to natural risks and the coordination of supply chain is poor, This paper constructs the supply chain profit model under the two models of natural risk and agricultural insurance, Firstly, studying the coordination function of the supply chain system under Two-part Tariff; Then discussing the setting and claiming mechanism of agricultural insurance, compares the influence of agricultural insurance on supply chain profit and supply chain coordination; Finally, giving an example to validate the model results and give decision - making opinions. Research shows that the supply chain of fresh agricultural products can coordinated under Two-part Tariff, but the supply chain cooperation is poor in the natural risk , need to further stabilize and optimize the supply chain; When the risk factor is less than the non-participation insurance coefficient, not to participate in agricultural insurance is conducive to maintaining the coordination of the supply chain system; When the risk coefficient exceeds the non-participation insurance coefficient, the introduction of agricultural insurance can not only effectively manage the natural risks, but also help to improve the coordination of the supply chain system.

1 Introduction

Fresh agricultural products are closely related to the lives of the residents of vegetables, fruits, meat, aquatic products, milk, etc, occupy an important position in the daily life, but it has a characteristics about perishable, long production cycle, vulnerable impacted of the external environmental [1]. By the products' own characteristics and the impact of the external environment, fresh agricultural products supply chain is more unstable than the average product supply chain in the coordination. Specific performance for the uncontrollable natural risk are the uncertain supply of products, the unbalanced distribution of profits among supply chain members, the low coordination of the supply chain system, eventually leading to damage to the interests of consumers and members [2, 3].

China Federation of Logistics and Purchase defining the supply chain coordination as a application process management methods in the enterprise decision-making and planning, which produce a coordinated production, marketing, market effective management mechanism, thereby enhancing the overall operational efficiency of enterprises. While the supply chain's coordination can lower inventory levels, enhance information sharing, improve communication between members to maintain strategic co-operation between the partners, etc [4].

Supply chain contract as an effective business cooperation model, not only makes the overall coordination level of the supply chain increase, but also makes the supply chain members to achieve "win-win", has been widely recognized theorists and the business community [5] Therefore, this paper uses the contract to coordinate the supply chain and achieve the initial stability of the supply chain system.

A large number of scholars have shown that the revenue sharing contract, the option contract and the two charge contract can coordinate the supply chain system, but the Two-part Tariff has obvious advantages in the cooperation of the stable supply chain members [6]. So this paper uses Two-part Tariff to coordinate the supply of fresh agricultural products. Literature [7] made a detailed introduction about Two-part Tariff and its application, literature [8] describes the Two-part Tariff on the industrial supply chain coordination role. However, few scholars at home and abroad to study the Two-part Tariff's coordination role on the fresh agricultural supply chain system, for example, Wang Yu [9] used Two-part Tariff to coordinate the secondary supply chain of fresh agricultural products, but not to the coordination of three-level supply chain, so this paper uses Two-part Tariff to achieve the coordination of supply chain and the initial stability of member cooperation.

Under the influence of natural risks, the loss of fresh agricultural products in China is serious, Due to natural disasters caused by agricultural disasters reached more than 30 billion in Xinjiang each year[10], 134 million mu of vegetable crops affected, 83 million acres of disaster, 7.3 million mu of crops, but the insured farmers less than 10% in HeBei Province from November 2015 to January 2016[11], which result the supply chain members of the profit declined and the cooperation collapsed, supply chain coordination declines. Therefore, how to reduce the degree of natural damage to protect the profits of stakeholders to become another problem at all levels of the supply chain members. The agricultural insurance is designed for accidental factors such as natural disasters, after the occurrence of natural disasters, the manufacturer by paying low insurance premiums to obtain high claims to cover losses. Some scholars have verified that agricultural insurance can not only effectively manage natural risks, but also increase the profits of producers. Such as Yao Shoufu [12] quantitative analysis the economic effects about the development of China's agricultural insurance by the 1982-2014 insurance data, which shows that the agricultural insurance not only increase the farmers benefit, but also stable product production. Li Yaqi, etc. [13] selected 1985-2014 agricultural insurance premiums, compensation and agricultural output data to do a Co-integration test, which concluded that agricultural insurance premiums and compensation has a weak positive effect on agricultural output. However, there are few literatures study the effect of agricultural insurance on agricultural product supply chain, such as Cao Wujun [14] based on the option contracts and agricultural insurance to achieve the supply chain coordination and optimization in the secondary supply chain of farm produce under natural risk, but not to the three-level supply chain.

Based on previous studies, this paper studies the supply chain system of fresh agricultural products, which is composed of single producer, distributor and retailer. The paper discusses the coordination function of the Two-part Tariff to the supply chain system under the natural risk; and then introduces agricultural insurance into the fresh agricultural products three supply chain profit model; analyzes the impact of agricultural insurance on the quantity and profit of supply chain system; finally, an example is given to validate the model results and give decision - making opinions.

2 Problem description and assumptions

This paper studies the three-level supply chain system of fresh agricultural products, which consists of a single supplier(S)-distributor (D)-retailer(R). The retailer has an order opportunity before the sales season. The relevant assumptions are as follows:

Hypothesis 1: Supply chain members are fresh and rational risk, only to discuss a production cycle's activities, regardless of transport losses, inventory costs and management costs;

Hypothesis 2: Natural risks occur only in the process of agricultural production, which produces a threat to production, does not affect product quality, the supplier bears the loss.

Hypothesis 3: t_1 is the time interval at which the supplier delivers the product to the distributor, t_2 is the time interval at which the distributor will ship the product to the retailer, t is the time interval at which a retailer's product reaches the consumer, $t_1 + t_2 + t \leq T_0$, T_0 is the longest product life cycle, so $t \in (0, T_0 - t_1 - t_2)$, assumed

$$T = T_0 - t_1 - t_2.$$

Hypothesis 4: Freshness of fresh agricultural products decreased with the increase of transportation time of supply chain members and was affected by the degree of fresh effort of supply chain members. Based on the freshness iteration formula of fresh agricultural products in Ref. [15], it is assumed that the freshness factor of fresh agricultural products of retailers at the appropriate temperature is $\theta_{(i)} = 1 - \eta * \left(\frac{(1 - k_{s1} * \tau_s) * t_1^2 + (1 - k_{d1} * \tau_d) * t_2^2 + (1 - k_{r1} * \tau_r) * t^2}{T_0^2} \right)$, η is the agricultural products' maximum value of the natural attenuation. $\tau_i \in (0, 1)$ is the freshness level of member i ($i = 1$ indicates the Supplier, $i = 2$ indicates the Distributor, $i = 3$ indicates the Retailers), k_{i1} is the freshness of the degree of preservation of the sensitivity coefficient.

Hypothesis 5: For the supply chain, only concerned about whether consumers buy and the capacity of the entire market, Reference [16] in the consumer utility function, set it to $U_{(t)} = U_0 - \alpha * p + \beta * \theta_{(t)}$, U_0 is the initial cognitive value of the product to the consumer, α , β are sensitive coefficient about consumers of fresh agricultural products price and freshness, $\alpha + \beta = 1$. Only then $U_{(t)} > 0$, consumers will choose to buy products, or give

up the purchase, assumed δ is the market size measure, at any time t , the retailer's market demand is $D(t) = \delta p(U_{(t)} > 0)$, so $D_{(t)} = \delta * P * (U_0 - \alpha * P + \beta * \theta_{(t)}) > 0 = \delta * (1 - \alpha * P + \beta * \theta(t))$ In a sales cycle T within

the supply chain system, the total demand is $Q = \int_0^T \delta * (1 - \alpha * p + \beta * \theta_{(t)}) dt$,

$$\text{assumed } M_1 = \beta * T * (1 - \eta * \frac{t_1^2 + t_2^2 + \frac{1}{3} * T^2}{T_0^2}), \quad A_r = \beta * T * \eta * \frac{k_{r1} * T^2}{3 * T_0^2}, \quad A_d = \beta * T * \eta * \frac{k_{d1} * t_2^2}{T_0^2},$$

$$A_s = \beta * T * \eta * \frac{k_{s1} * t_1^2}{T_0^2}, \text{ so the actual demand of the supply chain system is } Q = \delta * ((1 - \alpha * p) * T + M), \text{ assumed}$$

$$M = M_1 + A_s * \tau_s + A_d * \tau_d + A_r * \tau_r.$$

Hypothesis 6: When the supply chain members take fresh, there must have the cost of fresh inputs and the degree of freshness preservation is positively related to the cost of preservation, Ref. [17] is used to express the cost function and combined with the article required, assumed the fresh-keeping cost function of member i in case j ($j = 1$ indicates natural risk, $j = 2$ indicates agricultural insurance) is $c_{ij} = \frac{1}{2} * k_{i2} * \tau_{ij}^2$, $k_{i2} > 0$ is the effect of preservation effort on the cost of preservation, the formula shows that the higher the degree of preservation efforts to preserve the higher the cost. τ_{ij} is the level of freshness effort of member i under mode j .

Hypothesis 7: Assume that the natural risk coefficient is μ , Q is the order quantity of the retailer, the actual

production of the supplier is $\frac{Q}{1-\mu}$.

Hypothesis8: The supplier estimates the natural risk factor for the product is $\bar{\mu}$, Δ is the non-participation insurance coefficient. When $\bar{\mu} \leq \Delta$, the risk is small, the supplier does not buy insurance, at this point, the supply chain system's optimal order quantity and the degree of preservation efforts to change small, which treated as invariant. When $\bar{\mu} > \Delta$, the risk is bigger, the supplier purchases agricultural insurance, so the insurance decision-making

coefficient value is $k_{\mu} = \begin{cases} 0, \bar{\mu} \leq \Delta \\ 1, \bar{\mu} > \Delta \end{cases}$.

Other related symbols: Q is the retailer's order quantity, p is the product per price, c_i is the unit production cost of the member i , assume $C = c_1 + c_2 + c_3$, π_1 and π_2 are the overall profit function of the supply chain under the natural risk and agricultural insurance, π_{i1} 、 π_{i2} are the profit function of the supply chain member i ($i = r, i = d, i = s$) based on the two-part Tariff under the natural risk and the agricultural insurance. w_{2j} , w_{1j} represent the wholesale price of the distributor to the retailer and the manufacturer to the distributor in the natural risk and the agricultural insurance.

3 Supply chain coordination of fresh agricultural products

3.1 Research on the coordination of the supply chain system under natural risk

Researching a fresh agricultural products supply chain, which are composed of supplier, distributor and retailers. From the literature [18] shows that non-contract under decentralized decision-making supply chain's efficiency is low, there is a double marginal effect between the supply chain members, while the two-part Tariff can not only eliminate the double marginal effects of the supply chain, but also stabilize the cooperative relationship of members. Therefore, this chapter uses two-part Tariff to coordinate the supply chain of fresh agricultural products. The decision-making process is retailers according to their objective function and the reaction function of supplier and distributor to determine the channel fee paid to the distributor f_{r1} , the selling price of the product p_1 , the degree of preservation effort τ_{r1} , then distributor according to their objective function and the reaction function of supplier and retailer to determine the channel fee paid to the supplier f_{r1} , the selling price of the product w_{21} , the degree of preservation effort τ_{d1} , finally, the supplier according to the reaction function of distributor and retailer determine the selling price of the product w_{11} , the degree of preservation effort τ_{s1} .

The expected profit function of the retailer is:

$$\max \pi_{r1}(p_1) = (p_1 - c_3 - w_{21})Q_1 - c_{r1} - f_{r1}$$

$$s.t. \begin{cases} (w_{21}) \in \arg \max \pi_{d1} = (w_{21} - c_2 - w_{11})Q_1 - c_{d1} + f_{r1} - f_{d1} \\ (w_{11}) \in \arg \max \pi_{s1} = (w_{11} - \frac{1}{1-\mu})Q_1 - c_{s1} + f_{d1} \end{cases}$$

The total profit of supply chain system is

$$\pi_1 = (p_1 - C - \frac{\mu}{1-\mu} * c_1)Q_1 - c_{r1} - c_{d1} - c_{s1} \quad (1)$$

Two-part Tariff can achieve a necessary and sufficient coordination of supply chain conditions:

Proposition 1 If the retailer, distributor, supplier's profit is an affine function of the total profit of the supply chain system, the supply chain is said to be coordinated under the two-part Tariff.

Proof: For the profits of the supply chain system, the second-order Hessian matrix of π_1 in formula (1) is:

$$H = \begin{bmatrix} \frac{\partial^2 \pi_1}{\partial p_1^2}, \frac{\partial^2 \pi_1}{\partial p_1 \partial \tau_{i1}} \\ \frac{\partial^2 \pi_1}{\partial \tau_{i1} \partial p_1}, \frac{\partial^2 \pi_1}{\partial \tau_{i1}^2} \end{bmatrix} = \begin{bmatrix} -2\alpha T, \delta A_i \\ \delta A_i, -k_{i2} \end{bmatrix}$$

As a result of the matrix is $-2 * \alpha * T < 0$, when $2 * \alpha * T * k_{i2} - \delta^2 * A_i^2 > 0$, Order Hessian matrix is negative, at

this point π_1 is a concave function about p_1 and τ_{i1} , indicating that there is a unique p_1 and τ_{i1} to maximize the profit of the supply chain system. Many parameters are solved from the first-order optimality condition

$$\frac{\partial \pi_1}{\partial p_1} = 0, \frac{\partial \pi_1}{\partial \tau_{r1}} = 0, \frac{\partial \pi_1}{\partial \tau_{d1}} = 0, \frac{\partial \pi_1}{\partial \tau_{s1}} = 0.$$

The optimal retail price of the supply chain system is:

$$p_1 = \frac{T + M_1 + \alpha * T * (C + \frac{\mu}{1-\mu} * c_1) + A_r * \tau_{r1} + A_d * \tau_{d1} + A_s * \tau_{s1}}{2\alpha T}$$

The optimal degree of freshness preservation for retailers is:

$$\tau_{r1} = \frac{\delta * A_r (T + M_1 - \alpha * T * (C + \frac{\mu}{1-\mu} * c_1))}{2 * \alpha * T * k_{r2} - \delta (A_r^2 + \frac{A_d^2 * k_{r2}}{k_{d2}} + \frac{A_s^2 * k_{r2}}{k_{s2}})}$$

The optimal dilution effort of the distributor is:

$$\tau_{d1} = \frac{\delta * A_d (T + M_1 - \alpha * T * (C + \frac{\mu}{1-\mu} * c_1))}{2 * \alpha * T * k_{d2} - \delta (A_d^2 + \frac{A_r^2 * k_{d2}}{k_{r2}} + \frac{A_s^2 * k_{d2}}{k_{s2}})}$$

The optimal degree of freshness preservation of the supplier is:

$$\tau_{s1} = \frac{\delta * A_s (T + M_1 - \alpha * T * (C + \frac{\mu}{1-\mu} * c_1))}{2 * \alpha * T * k_{s2} - \delta (A_s^2 + \frac{A_r^2 * k_{s2}}{k_{r2}} + \frac{A_d^2 * k_{s2}}{k_{d2}})}$$

At the same time when the members of the supply chain coordination at all levels, the wholesale price of distributors

is $w_{21} = \frac{1}{1-\mu} c_1 + c_2$, the supplier's wholesale price is

$$w_{11} = C + \frac{1}{1-\mu} c_1 - \frac{T + M_1 + A_s * \tau_{s1} + A_d * \tau_{d1}}{\alpha T}$$

At this point the optimal order quantity of the supply chain system is

$$Q_1 = \frac{\delta (T + M_1 - \alpha * T * (C + \frac{\mu}{1-\mu} * c_1) + A_r * \tau_{r1} + A_d * \tau_{d1} + A_s * \tau_{s1})}{2}$$

The maximum profit function of the supply chain system is

$$\pi_1 = (p_1 - C - \frac{\mu}{1-\mu} * c_1) * Q_1 - \frac{1}{2} k_{r2} * \tau_{r1}^2 - \frac{1}{2} k_{d2} * \tau_{d1}^2 - \frac{1}{2} k_{s2} * \tau_{s1}^2$$

So the retailer's profit function is $\pi_{r1} = \pi_1 - f_{r1}$

The distributor's profit function is $\pi_{d1} = 2\pi_1 + f_{r1} - f_{d1}$

The supplier's profit function is $\pi_{s1} = -2\pi_1 + f_{d1}$

That is to say, the profits of retailers, distributors and supplier are the affine functions of supply chain coordination profit under the Two-part Tariff, therefore, the optimal quantity Q_1 for the retailer is the optimal demand of the system and the supply chain system allocates the profit by adjusting the contract parameter f_{r1} and f_{d1} , the supply chain in Two-part Tariff is coordinated.

It is worth noting that $\tau_{ij} \in (0,1)$, $2 * \alpha * T * k_{i2} - \delta^2 * A_i^2 > 0$, so this article is discussed under the condition of

$T + M_1 - \alpha T (C + \frac{\mu}{1-\mu} * c_1) \geq 0$, it also means $C \leq \frac{T + M_1}{\alpha T} - \frac{\mu}{1-\mu} * c_1$, when $\tau_{ij} \geq 1$, freshness efforts can only

take 1, when $0 < \tau_{ij} < 1$, τ_{ij} takes the optimal solution.

Corollary 1: The fixed channel fee changes do not affect the supply chain cooperation in certain range, which was only the revenue game between supply chain members.

Prove: According to the profit function of retailers, distributors, suppliers, assume the channel fee charged by the manufacturer to the distributor in general is f_{r1} , the channel fee charged by the distributor to the retailer is f_{d1} , f_{r1} and f_{d1} satisfies the requirement that the profits of all members of the supply chain under the contract are greater than the

profits without contract, if the manufacturer to the distributor fees charged to increase the $f_{r1} + \Delta f$, f_{d1} unchanged, the retailer's profits decline, the distributor's profits rise, the supplier's profits remain unchanged, supply chain partnerships remain unchanged. It can be seen, fixed channel fee is the supply chain members of the game between the gains.

Corollary 2: With the increase of natural risk coefficient μ , supply chain system profits down, supply chain system is not coordinated.

Prove: In the other conditions remain unchanged, with the increase of natural risk coefficient μ , product prices down, preservation efforts to decline, the optimal order quantity of the supply chain system decreases, supply chain's overall profit decline, supply chain system is not coordinated.

Based on the analysis of supply chain model of fresh agricultural products under the Two-part Tariff, the following conclusions are drawn:

Conclusion 1: The Two-part Tariff can not only coordinate the supply chain of fresh agricultural products, but also to stabilize the cooperation between supply chain members.

From proposition 1 and corollary 1, Two-part Tariff can effectively eliminate the double marginal effect of supply chain, so that supply chain members achieve a win-win situation and achieve the coordination of the supply chain system. At the same time in the Two-part Tariff under the coordination of the fresh agricultural supply chain, downstream members of the upstream members of the order to pay a certain fixed channel fee, and then lower the wholesale price of access to upstream goods, making members of their respective profits will be greater than the profits without contracts, in the actual transaction in a fixed channel to do the profit protection, the transaction between members is not easy to interrupt; and the lower wholesale price will encourage members to produce or order more products, which is not only has theoretically meaningful but also has practical significance in the cooperative relation of the stable supply chain members.

Conclusion 2: Under the natural risk, the cooperation relationship of the supply chain of fresh agricultural products coordinated is low by Two-part Tariff.

Once the natural risk coefficient increases from the corollary2, supply and demand at all levels of the supply chain change, supply chain coordination declines. Therefore, introduced agricultural insurance in the coordination of fresh agricultural supply chain as a risk management tool, through the low payment of insurance premiums to obtain high claims to make up for losses in order to achieve a coordinated supply chain system at all levels of members of the further stable cooperation.

3.2 Research on the coordination of the supply chain system under agricultural insurance

Suppose that producers engaged in the production of fresh produce are able to circumvent the risks by purchasing product yield insurance. According to the "Insurance Practice of Planting Industry of China People's Property Insurance Co" insurance and claims rules, the policy of premium payment and claims for fresh agricultural products yield insurance is as follows:

Insurance Premium: In reference to the literature [19] under the incentive of government subsidies, the purchase of insurance for each production cycle when the producer only pay unit insurance $20\% * w * c_B$ (Per kilogram), among them, w is the premium rate, c_B is the unit yield insurance amount. Assume that the fresh yield of agricultural product yield insurance is $\Delta Q = (1 - \Delta) * Q$, Δ is the non-participation insurance coefficient, which is part of the supplier supply Q , then the supplier to the insurance company's insurance costs $0.2 * w * c_B * \Delta Q$.

As the natural risk factor is μ , the actual production of the supplier is $\frac{Q}{1 - \mu}$.

Claims: The insurance company according to the actual yield of the supplier and the insurance production of the difference between the compensation, the specific rules are as follows:

When $\mu \leq \Delta$, the insurance company does not compensate.

When $\mu > \Delta$, the insurance companies according to the actual output of agricultural production and insurance production of the difference between compensation, by the agricultural insurance claims rules can be obtained that the insurance company claims H for the supplier of the expression is:

$$H = k_0 * (\Delta Q - (1 - \mu) * Q) c_B = k_0 * (\mu - \Delta) * Q * c_B$$

Among them k_0 is the claim coefficient, $k_0 = \begin{cases} 0, \mu \leq \Delta \\ 1, \mu > \Delta \end{cases}$, The actual insurance company to the manufacturer's claim

amount is: $H - 0.2 * w * c_B * \Delta Q = (k_0 * (\mu - \Delta) - 0.2 * w * (1 - \Delta)) * Q * c_B$

Assumed that $B = (k_0 * (\mu - \Delta) - 0.2 * w * (1 - \Delta)) * c_B$ is insurance factor, the actual insurance company to the supplier claims amount $B * Q$. It is shows that Agricultural insurance claims is lower than the producer's normal production income, which is also a strategy of the insurance company for incentives to purchase insurance in the event of disaster can take positive measures to save the loss.

Under the above agricultural insurance rules, according to the supply chain coordination function of the Two-part Tariff, agricultural insurance is applied to fresh agricultural products supply chain, the decision-making process is as described in above3. Establishing agricultural insurance under the supply chain decision-making model, the overall profit function of the supply chain system is:

$$\pi_2 = (p_2 - C - \frac{\mu}{1 - \mu} * c_1 + k_\mu * B) * Q_2 - c_{r2} - c_{d2} - c_{s2}$$

The expected profit function of retailer is:

$$\max \pi_{r2}(p_2) = (p_2 - c_3 - w_{22}) * Q_2 - c_{r2} - f_{r2}$$

$$s.t. \begin{cases} (w_{22}) \in \arg \max \pi_{d2} = (w_{22} - c_2 - w_{12}) * Q_2 - c_{d2} + f_{r2} - f_{d2} \\ (w_{12}) \in \arg \max \pi_{s2} = (w_{12} - \frac{1}{1 - \mu} c_1 + k_\mu * B) * Q_2 - c_{s2} + f_{d2} \end{cases}$$

The same decision-making process as Proposition 1 is used to obtain the parameters of the supply chain in the case of purchasing agricultural insurance, as shown in Proposition 2

Proposition 2: The contract parameters of the supply chain system coordination under the agricultural insurance are as follows:

The optimal selling price of agricultural products is:

$$p_2 = \frac{T + M_1 + \alpha * T * (C + \frac{\mu}{1 - \mu} * c_1 - k_\mu * B) + A_r * \tau_{r2} + A_d * \tau_{d2} + A_s * \tau_{s2}}{2\alpha T}$$

The optimal degree of freshness retention for retailers is:

$$\tau_{r2} = \frac{\delta * A_r (T + M_1 - \alpha * T * (C + \frac{\mu}{1-\mu} * c_1 - k_\mu * B))}{2 * \alpha * T * k_{r2} - \delta (A_r^2 + \frac{A_d^2 * k_{r2}}{k_{d2}} + \frac{A_s^2 * k_{r2}}{k_{s2}})}$$

The optimal dilution effort of the distributor is:

$$\tau_{d2} = \frac{\delta * A_d (T + M_1 - \alpha * T * (C + \frac{\mu}{1-\mu} * c_1 - k_\mu * B))}{2 * \alpha * T * k_{d2} - \delta (A_d^2 + \frac{A_r^2 * k_{d2}}{k_{r2}} + \frac{A_s^2 * k_{d2}}{k_{s2}})}$$

The optimal degree of freshness of the supplier is:

$$\tau_{s2} = \frac{\delta * A_s (T + M_1 - \alpha * T * (C + \frac{\mu}{1-\mu} * c_1 - k_\mu * B))}{2 * \alpha * T * k_{s2} - \delta (A_s^2 + \frac{A_r^2 * k_{s2}}{k_{r2}} + \frac{A_d^2 * k_{s2}}{k_{d2}})}$$

The supplier's wholesale price is:

$$w_{12} = \frac{1}{1-\mu} c_1 + c_2 + k_\mu * B$$

The wholesale price of the distributor is:

$$w_{22} = C + \frac{1}{1-\mu} * c_1 - \frac{T + M_1 + A_s * \tau_{s2} + A_d * \tau_{d2}}{\alpha T} - k_\mu * B$$

At this point the optimal order quantity of the supply chain system is:

$$Q_2 = \frac{\delta (T + M_1 - \alpha * T * (C + \frac{\mu}{1-\mu} * c_1 - k_\mu * B) + A_r * \tau_{r2} + A_d * \tau_{d2} + A_s * \tau_{s2})}{2}$$

The maximum profit function of the supply chain system is:

$$\pi_2 = (p_2 - C - \frac{\mu}{1-\mu} * c_1 + k_\mu * B) * Q_2 - \frac{1}{2} k_{r2} * \tau_{r2}^2 - \frac{1}{2} k_{d2} * \tau_{d2}^2 - \frac{1}{2} k_{s2} * \tau_{s2}^2$$

The retailer's profit function is: $\pi_{r2} = \pi_2 - f_{r2}$

The profit function of the distributor is: $\pi_{d2} = 2\pi_2 + f_{r2} - f_{d2}$

The profit function of the supplier is: $\pi_{s2} = -2\pi_2 + f_{d2}$

It is worth noting that $\tau_{i2} \in (0,1)$, including 0 and 1, when $\tau_{i2} \geq 1$, freshness efforts can only take 1, when $0 < \tau_{i2} < 1$, τ_{i2} takes the optimal solution.

Corollary 3: When the supplier estimates the natural risk factor $\bar{\mu} \leq \Delta$, if the actual natural risk factor $\mu \leq \Delta$, the optimal decision of the supply chain is not changed; if the actual natural risk factor $\mu > \Delta$, the entire supply chain profits decline.

Prove: When the supplier estimates the natural risk factor $\bar{\mu} \leq \Delta$, the supplier is not insured, if the actual natural risk factor $\mu \leq \Delta$, from hypothesis 7, at this point the optimal retail price of agricultural insurance, the optimal degree of preservation efforts, the optimal demand, supply chain members at all levels of profit are the same as natural risk. That is to say when the supplier estimates the natural risk factor $\bar{\mu} \leq \Delta$ and the actual natural risk factor $\mu \leq \Delta$, which makes the optimal decision of the supply chain is not changed. If $\mu > \Delta$, the supplier's actual supply and demand for a serious inconsistency, which eventually leading to insufficient supply of suppliers, the entire supply chain profits decline.

Corollary 4: When the supplier estimates the natural risk factor $\bar{\mu} > \Delta$, if the actual natural risk factor $\mu \leq \Delta$, the supply chain overall profit decline, which is not conducive to supply chain coordination; if the actual natural risk factor $\mu > \Delta$, agricultural insurance can not only effectively manage natural risks, but also increase the supply chain as a whole and members of the income at all levels, help to strengthen the coordination of the supply chain.

Proof: When the supplier estimates the natural risk factor $\bar{\mu} > \Delta$, if the actual natural risk factor $\mu \leq \Delta$, the supplier is insured, suppliers pay more insurance costs, making the cost of the supply chain rise, the profits decline, which is not conducive to supply chain coordination. If the actual natural risk factor $\mu > \Delta$, take any number $\bar{\mu} \in (\Delta, 1)$, due to the introduction of agricultural insurance claims amount in $\bar{\mu}$, so $\tau_{i2} > \tau_{i1}$, $p_2 > p_1$, $w_{21} > w_{22}$, $w_{11} > w_{12}$, thus making $Q_2 > Q_1$, $\pi_2 > \pi_1$. Which means the supply chain system's profit under agricultural insurance is than the profit under natural risk, supply chain members at all levels of profits also become larger, the agricultural insurance can not only manage the natural risk effectively, but also can increase the profit for the whole supply chain and the members at all levels, which is helpful to strengthen the coordination of the supply chain system.

Corollary 5: With the natural risk factor μ increases, the decline of the profit of the supply chain system under the natural risk is larger than that of the agricultural insurance under the supply chain. Supply chain coordination under the agricultural insurance increased compared to the supply chain under natural risks,

Prove: In the agricultural insurance mode, with the natural risk factor μ increases, because the manufacturer has been the amount of agricultural insurance claims,

the rate of decline in the supply chain profits compared to the natural risk of supply chain profits decline is slower. Therefore, agricultural insurance under the supply chain coordination has increased under the natural risk of supply chain system coordination.

Based on the analysis of supply chain coordination model of fresh agricultural products under agricultural insurance and Two-part Tariff, the following conclusions are drawn:

Conclusion 3: The agricultural insurance is introduced into the fresh agricultural product supply chain under Two-part Tariff, supply chain coordination can be realized again by setting contract parameters;

Conclusion 4: The introduction of agricultural insurance not only can effectively manage the natural risks, but also increase the supply chain as a whole and members of the income levels, making the supply chain coordination increased.

From the inference (3) (4) (5) shows, agricultural insurance to make up for the lack of the supply chain system profits declined, part of the natural risk is transferred to insurance institutions outside the supply chain, reduce the risk of natural risks on the supply chain system, increase the supply chain as a whole and members of all levels of income, making the supply chain coordination increased.

4 Case study

In order to more clearly reflect the two charges and agricultural insurance system on the supply chain coordination role, the results of the above model are validated by onion. Suppose a region of the onion supply chain is composed of a supplier, a large fresh wholesaler, a retailer (such as a supermarket), the market size of onion in this area is roughly

measured $\delta = 10000$ (kg). Other variables in the model: $c_3 = 0.3$ RMB/kg, $c_2 = 0.5$ RMB/kg, $c_1 = 1.2$ RMB/kg,

$t_1 = 3$ day, $t_2 = 2$ day, $T = 10$ day, $\eta = \alpha = \beta = 0.5$, $k_{r1} = 0.1$, $k_{d1} = 0.2$, $k_{s1} = 0.3$, $k_{r2} = 50$, $k_{d2} = 80$, $k_{s2} = 100$.

According to the insurance company claims, the onion claim parameter is $w = 4\%$, $c_B = 0.5$ RMB/kg. Insurance claims are calculated on the basis of natural disasters occur in the maturity of crops.

4.1 Research on the coordination of supply chain

Substituting the above variables into the models in Sections 3.1 and 3.2, when the risk factor is determined, the optimal parameters and profit of the supply chain system under natural risks and agricultural insurance are obtained, the conclusion is: Under certain conditions, whether the agricultural insurance, supply chain members achieved a win-win fee system are in the Two-part Tariff, the supply chain system achieved effective coordination.

4.2 Supply chain coordination and optimization analysis

According to the relevant models given in Sections 3.1 and 3.2, $0 < \tau_{ij} \leq 1$ ($i = r, d, s$). Using Matlab to calculate the sensitivity coefficient for the supply chain coordination of fresh agricultural product under Two-part Tariff and agricultural insurance.

(1) Under the agricultural insurance, with the natural risk coefficient μ increases, agricultural insurance under the supply chain orders and profits are down, but the decline is not the same. As shown in Figure 1 below, when the natural risk coefficient μ in 0.1 step size gradually close to the non-participation insurance coefficient $\Delta = 0.2$, the order quantity of the supply chain rises slowly with about 260Kg for the step, the profits of the supply chain system gradually increased to about 190 yuan for the step. When the natural risk coefficient μ in 0.1 step away from the non-participation insurance coefficient $\Delta = 0.2$, the order quantity of the supply chain rises slowly with about 400Kg for the step, the profits of the supply chain system gradually increased to about 220 yuan for the step. Which means with the increase of natural risk coefficient μ , agricultural insurance supply chain orders and profits are down, the actual life of the risk factor is too large, the supplier in order to avoid risks, generally do not produce such products.

Fig. 1. Optimal order quantity and profit graph of supply chain system under agricultural insurance.

(2) When the coefficient of natural risk is less than the non-participation insurance coefficient ($\mu \leq \Delta$), the order quantity and profit of supply chain under natural disasters are larger than those of agricultural insurance. As shown in Figure 2 and Figure 3, when the non-participation insurance coefficient $\Delta = 0.1$, the disaster loss coefficient gradually increases to 0.1 in 0.01 steps, the order quantity and profit of the supply chain under the natural disaster are all bigger than the order quantity and profit under the agricultural insurance. But with the increase of the natural risk coefficient μ , in natural risk, the order quantity of the supply chain rises slowly with about 300Kg for the step, the profits of the supply chain system gradually increased to about 300 yuan for the step. In agricultural insurance, the order quantity of the supply chain rises slowly with about 200Kg for the step, and gradually close to the natural risk of supply chain under the order quantity, the profits of the supply chain system gradually increased to about 150 yuan for the step, and gradually close to the natural risk of supply chain profits. That is to say, when the natural risk coefficient is less than the non-participation insurance coefficient, due to the supplier to pay insurance costs, and insurance companies do not give claims, which making agricultural insurance under the cost of supply chain systems rise. The order quantity and profit of supply chain under agricultural insurance are all less than the order quantity and profit of supply chain under natural disaster. At this point the supplier is not suitable for insurance.

Fig. 2. $\mu < \Delta$ The Optimal Order Quantity of Supply Chain Under Natural Risks and Agricultural Insurance.

Fig. 3. $\mu < \Delta$ The Profit of Supply Chain Under Natural Risks and Agricultural Insurance.

(3)When the coefficient of natural risk is greater than the non-participation insurance coefficient ($\mu > \Delta$), the order quantity and profit of the supply chain under the agricultural insurance are all larger than the order quantity and profit under the natural risk. As shown in Figure 4 and Figure 5, when the non-participation insurance coefficient $\Delta = 0.1$, the natural risk coefficient increases gradually from 0.1 by 0.01 for the steps, the order quantity and profit of the supply chain under the agricultural insurance are all larger than the order quantity and profit under the natural risk. But with the increase of the natural risk coefficient μ , in natural risk, the order quantity of the supply chain rises slowly with about 400Kg for the step, the profits of the supply chain system gradually increased to about 300 yuan for the step; in agricultural insurance, the order quantity of the supply chain rises slowly with about 300Kg for the step, the profits of the supply chain system gradually increased to about 200 yuan for the step. That is to say, when the natural risk coefficient exceeds the non-participation insurance coefficient, the insurance company will reduce the cost of the supply chain system under the agricultural insurance, and the order quantity and profit of the supply chain under the agricultural insurance are all larger than the order quantity and profit under the natural risk. At this point the supplier chooses to purchase agricultural insurance.

Fig. 4. $\mu \geq \Delta$ The Optimal Order Quantity of Supply Chain Under Natural Risks and Agricultural Insurance.

Fig. 5. $\mu \geq \Delta$ The Profit of Supply Chain Under Natural Risks and Agricultural Insurance

4.3 Application strategy of fresh agricultural products

Through an example analysis, with the increase of natural risk coefficient, the agricultural supply chain of agricultural insurance not only avoids natural risks, but also slows down the supply chain as a whole and the interests of its members, and makes the supply chain coordination increase .Here are three fresh agricultural products supply chain application strategy:

(1)Using Two-part Tariff to achieve supply chain coordination and supply chain members of the stable cooperation, first set the parameters to satisfy either Proposition 1 or Proposition 2, then the two sides to negotiate a fixed channel fee, and finally to achieve the overall coordination of the supply chain and the stability of cooperation between members.

(2)In the supply chain operation process to join the agricultural insurance in order to reduce the natural risk damage of supply chain system profit. Part of the damage is transferred to the insurance company. At the same time, due to the addition of agricultural insurance, the supply chain members are more stable in the cooperative relationship.

(3)In practice, agricultural insurance not only makes the supply chain as a whole and the members of the natural risk increases, the interest decline slowed down, but also promote the information construction of the fresh agricultural product supply chain, improving the degree of information sharing, making the supply chain members of information symmetry, and ultimately to ensure the overall coordination of the supply chain.

5 Conclusion

This paper discusses optimal supply chain decision and supply chain coordination of fresh agricultural products, combined with the actual situation, using fresh iteration relation of fresh agricultural products, comprehensive use of inventory theory, utility theory, cooperative game, for a fresh agricultural products three supply chain, which consist suppliers, distributors, and retailers. The paper focuses on the coordination of Two-part Tariff under the agricultural insurance system to the supply chain system, research shows: ① the Two-part Tariff contract can not only coordinate the supply chain of fresh agricultural products, but also stable supply chain members of the cooperative relations, but under natural risks, the coordination of fresh agricultural products supply chain system is low. ②Agricultural insurance can not only effectively manage natural risks, but also increase the supply chain system benefits, and further strengthen the coordination of the supply chain system. At the same time, this paper demonstrates that whether there is Two-part Tariff under the agricultural insurance system to coordinate the supply chain and supply chain cooperation relationship changes by an example based on the model, which has theoretical guidance and practical significance for deeper research on supply chain coordination and supply chain cooperation. Because this article only single insurance for suppliers, the practice will involve the supply chain to other members of the various insurance. Therefore, it is the next research direction to study the coordination of multi-member and multi-member agricultural insurance supply chain.

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