

The Optimization Model Analysis of the New Agricultural Order Cooperation Mode

Yuquan Cui*, Bingjie Liu, Xiuxiu Li

School of Mathematics, Shandong University, Jinan, China

*Corresponding author

ABSTRACT

This paper put forward a new cooperative mode of agricultural order and constructed a new order agriculture optimization model. Firstly, an agricultural cooperative was established in which farmers are shareholders based on the proportion of the land area. Then the cooperative obtained profits by signing purchase contracts with agricultural purchasing companies and used part of the profits to distribute dividends to farmers. The new order agricultural supply chain optimization model of "farmers + cooperatives + sales companies" was constructed and the corresponding constraint optimization model under CVaR was established and discussed. The general analysis proved that the new agricultural order model proposed in this paper has strong practical significance.

Keywords: Cooperation mode, Optimization model, CVaR risk measurement criteria

1. INTRODUCTION

With the deepening of China's rural economic system reform, poverty alleviation has been on the agenda. The application of order agriculture with the nature of forward transaction is of great significance. Contract agriculture, also known as contract agriculture [1], effectively connects farmers with the market through contracts. Recently, many scholars have studied the risk characteristics of agriculture order [2-7]. Meantime, the scattered farmers often passively accept additional contracts provided by agriculture-related enterprises with market monopoly [8,9]. In essence, it is a lack of sound interest risk mechanism [10]. Therefore, a coordinated contract mechanism is needed between farmers and contracting companies.

It is found that considering the participation of cooperatives can not only ensure the benefits of farmers and reduce the risks of farmers, but also improve the order performance rate and increase the interests of the signing companies [11,12]. Furthermore, some scholars have improved the agricultural order contract model by adding contract restrictions [13-15]. Based on the previous research results, this paper proposed a new order agriculture model of "farmers + cooperatives + sales companies" based on the "company + farmer" order agriculture.

2. MODEL DESCRIPTION AND ASSUMPTIONS

The total cooperative land area of cooperatives is S and farmers become shareholders in cooperatives according to the proportion of the land area. After the sales season, the cooperative pays dividends to farmers according to the

proportion. In order to ensure the real benefits of farmers, the cooperative will also provide farmers with a fixed income M yuan per unit area. The type and quantity of crops to be planted shall be determined by the cooperatives and the cooperative society shall plant and manage a variety of crops, assuming that the yield of each crop is $Q_i (i=1, \dots, N)$. In addition, cooperatives need to employ workers for labor. The workers' wages are positively correlated with the output of agricultural products planted. The coefficient is c_{i3} . That is, the total

wages of workers provided by cooperatives are $\sum_{i=1}^N c_{i3} Q_i$.

It is assumed that the total number of cooperative workers is a among which b farmers are employed ($0 \leq b \leq a$). The cooperative and the sales company sign the sales contract in accordance with the principle of "purchase with guarantee and follow the market". There are the following assumptions.

1) The market demand of the i th ($i=1, \dots, N$) agricultural product is x_i . x_i is a non-negative random variable where its distribution function is $F(\cdot)$ and its density function is $f(\cdot)$.

2) The price assumptions for the i th ($i=1, \dots, N$) agricultural product are as follows.

The order price is w_i^r . The market sales price is w_i . w_i is the non-negative random variable where $w_i \in [A_i, B_i]$ and $G(\cdot)$ is its distribution function, $g(\cdot)$ is its density function. Therefore, the cooperative and the sale company's contract purchase price is $\max(w_i^r, w_i)$. The market sales price is p_i^m . p_i^m is a

non-negative random variable where its distribution function is $H(\cdot)$ and its density function is $h(\cdot)$. The cost function to grow the i th ($i = 1, \dots, N$) agricultural product is $C(Q_i)$.

The revenue of the cooperative, the farmers and the sales company are given as follows [16].

$$\pi_e = \varphi \sum_{i=1}^N [Q_i \max(w_i^r, w_i) - C(Q_i) - c_{i3} Q_i] - MS. \quad (1)$$

$$\pi_f = (1 - \varphi) \sum_{i=1}^N [Q_i \max(w_i^r, w_i) - C(Q_i) - c_{i3} Q_i] + MS + \frac{b \sum_{i=1}^N c_{i3} Q_i}{a}. \quad (2)$$

$$\pi_m = \sum_{i=1}^N [p_i^m \min(Q_i, x_i) - Q_i (w_i^r, w_i)]. \quad (3)$$

Here, farmers refer to all farmers participating in the cooperative. For a single farmer, assuming the farmer's land area is S_1 and the farmer applies to be a worker to plant agricultural products, the farmer's income is

$$\pi_{f1} = \frac{S_1}{S} (1 - \varphi) \sum_{i=1}^N [Q_i \max(w_i^r, w_i) - D(Q_i)] + MS_1 + \frac{\sum_{i=1}^N c_{i3} Q_i}{a} \quad (4)$$

3. THE DECISION MODEL

The cooperative was assumed to be risk-averse. CVaR was used to measure the average return of the cooperative [17]. The definition of CVaR is

$$CVaR_\eta(g(x, y)) = \max_{v \in R} \left\{ v + \frac{1}{\eta} E[\min(g(x, y) - v, 0)] \right\}$$

. Then consider further the decision-making behaviour of cooperatives and farmers.

Recall that the cooperative income function is Eq.1. Where φ and M are set by the cooperative and S is the total land area of all farmers participating in the cooperation. Therefore, CVaR can be calculated for the return function of the i th product, i.e. $\pi_i = Q_i \max(w_i^r, w_i) - C(Q_i) - c_{i3} Q_i$.

Let $g(Q_i, v) = v + \frac{1}{\eta} E[\min(\pi_i - v, 0)]$. Note

that $D(Q_i) = C(Q_i) + c_{i3} Q_i$. Substituting π_i into g , then

$$g(Q_i, v) = v - \frac{1}{\eta} \int_{w_i^r}^{w_i^r} [v - (Q_i w_i^r - D(Q_i))]^+ dG(w_i) - \frac{1}{\eta} \int_{w_i^r}^{w_i^r} [v - (Q_i w_i^r - D(Q_i))]^+ dG(w_i).$$

The following three cases are discussed to find the maximum of $g(Q_i, v)$.

(a) When $v < Q_i w_i^r - D(Q_i)$, it can be obtained

$$\text{that } g(Q_i, v) = v \text{ and } \frac{\partial g(Q_i, v)}{\partial v} = 1 > 0.$$

(b) When $Q_i w_i^r - D(Q_i) \leq v < B_i Q_i - D(Q_i)$, it can

$$\text{be obtained that } \frac{\partial g(Q_i, v)}{\partial v} = 1 - \frac{1}{\eta} G\left(\frac{v + D(Q_i)}{Q_i}\right).$$

Furthermore,

$$\frac{\partial g(Q_i, v)}{\partial v} \Big|_{v=Q_i w_i^r - D(Q_i)} = 1 - \frac{1}{\eta} G(w_i^r),$$

$$\frac{\partial g(Q_i, v)}{\partial v} \Big|_{v=B_i Q_i - D(Q_i)} = 1 - \frac{1}{\eta} G(B_i) < 0.$$

(c) When $v > B_i Q_i - D(Q_i)$,

$$\text{similarly, } \frac{\partial g(Q_i, v)}{\partial v} = 1 - \frac{1}{\eta} G(B_i) < 0.$$

Let v^* be the optimal solution that maximizes the return function $g(Q_i, v)$. By analyzing the above three cases, $g(Q_i, v)$ is concave with respect to v . Hence the following discussion can be obtained.

$$\text{When } 1 - \frac{1}{\eta} G(w_i^r) \leq 0,$$

i.e. $0 < G^{-1}(\eta) \leq w_i^r$, $v^* = w_i^r Q_i - D(Q_i)$ can be obtained.

$$\text{When } 1 - \frac{1}{\eta} G(w_i^r) > 0, \text{ i.e. } w_i^r < G^{-1}(\eta) \leq B_i, v^* \text{ can}$$

be obtained by solving the equation

$$1 - \frac{1}{\eta} G\left(\frac{v^* + D(Q_i)}{Q_i}\right) = 0. \quad \text{That}$$

$$\text{is } v^* = Q_i G^{-1}(\eta) - D(Q_i).$$

Then substitute v^* into the return function. It can be obtained that

$$g(Q_i, v) = \begin{cases} w_i^r Q_i - D(Q_i), & 0 < G^{-1}(\eta) \leq w_i^r \\ w_i^r Q_i - \frac{1}{\eta} \int_{w_i^r}^{G^{-1}(\eta)} (w_i - w_i^r) Q_i dG(w_i) - D(Q_i), & w_i^r < G^{-1}(\eta) \leq B_i \end{cases} \quad (5)$$

For cooperatives, the total revenue function can be summarized as follows.

$$\pi_e = \begin{cases} \varphi \sum_{i=1}^N (w_i^r Q_i - D(Q_i)) - MS, & 0 < G^{-1}(\eta) \leq w_i^r \\ \varphi \sum_{i=1}^N (w_i^r Q_i - D(Q_i)) - MS - \varphi \sum_{i=1}^N \left(\frac{1}{\eta} \int_{w_i^r}^{G^{-1}(\eta)} (w_i - w_i^r) Q_i dG(w_i) \right), & w_i^r < G^{-1}(\eta) \leq B_i \end{cases} \quad (6)$$

When $0 < G^{-1}(\eta) \leq w_i^r$, the decisions of farmers and the cooperative are discussed below. The similar discussion when $w_i^r < G^{-1}(\eta) \leq B_i$ will not be repeated in this paper.

3.1. The Decision-making Behavior of Farmers

Similar as the article[19], the income function of individual farmers can be expressed as $\pi_{f2} = Q \max(w, w^r) - C(Q)$. Where Q is the agricultural production of the individual farmer, q is the unit output of the agricultural product, w is the market purchase price of the agricultural product, w^r is the order price contracted between the individual farmers and the sales companies, and $C(Q) = c_0 + c_1 Q + c_2 Q^2$ is the cost function about the production Q .

For an individual farmer, if he has no labor force, he will definitely choose to join the cooperative. So this paper assumed that the farmer has a labor force. The following constraint model can be established.

$$\begin{aligned} \min z &= MS_1 \\ \text{s.t.} \quad & -\pi_e < 0, \\ & \pi_{f2} - \pi_{f1} < 0. \end{aligned}$$

Assuming the planting area of farmers is $S_1 = S/n$ ($n > 1$), the model can be rewritten as follows.

$$\begin{aligned} \min z &= MS_1 \\ \text{s.t.} \quad & MnS_1 - \varphi \sum_{i=1}^N (Q_i w_i^r - D(Q_i)) < 0, \quad (7) \end{aligned}$$

$$\begin{aligned} S_1 q \max(w^r, w) - C(S_1 q) - MS_1 - \sum_{i=1}^N c_{i3} Q_i / a \\ - \frac{1}{n} (1 - \varphi) \sum_{i=1}^N [Q_i \max(w_i^r, w_i) - D(Q_i)] < 0. \end{aligned} \quad (8)$$

Where $C(Q_i)$ is the cost of the agricultural production Q_i . And $C(Q_i)$ is assumed as the quadratic function of Q_i . That is $C(Q_i) = c_{i0} + c_{i1} Q_i + c_{i2} Q_i^2$. c_{i0} is the fixed cost of the i th agricultural product such as the lo

ss of production machinery. c_{i1} is the input cost coefficient of the i th agricultural product including seeds, fertilizers and so on. c_{i2} is the effort cost coefficient.

It is easy to see that the following equation $L(S_1, \lambda, \mu) = z + \lambda(-\pi_e) + \mu(\pi_{f2} - \pi_{f1})$ is the Lagrangian function of the model in Eq.6. And the KKT conditions are as follows.

$$\begin{aligned} \frac{\partial L(S_1, \lambda, \mu)}{\partial S_1} &= \mu(q \max(w^r, w) - c_1 q - 2c_2 q^2 S_1 - M) \\ &+ M + \lambda(Mn) = 0. \end{aligned} \quad (9)$$

$$\frac{\partial L(S_1, \lambda, \mu)}{\partial M} = S_1 + \lambda(nS_1) + \mu(-S_1) = 0. \quad (10)$$

$$\lambda(-\pi_e) = 0, \quad \lambda \geq 0. \quad (11)$$

Since the income of cooperatives must be greater than zero, i.e. $-\pi_e < 0$. It can be obtained from Eq.11 that $\lambda = 0$. Substituting $\lambda = 0$ into Eq.9 and Eq.10,

$$M + \mu(q \max(w^r, w) - c_1 q - 2c_2 q^2 S_1 - M) = 0$$

and $S_1 + \mu(-S_1) = 0$ can be obtained. Then $\mu = 1$ and the following corollary can be gotten.

Corollary 1: If the parameters M , φ and Q_i are set by the cooperative,

meeting $M > \frac{q\varphi(\max(w^r, w) - c_1)}{2}$ and

$$\frac{Mn(\max(w^r, w) - c_1)}{2c_2 q} - \varphi \sum_{i=1}^N (Q_i w_i^r - D(Q_i)) < 0,$$

the minimum land area that farmers choose to participate

in the cooperative is $S_1 = \frac{\max(w^r, w) - c_1}{2c_2 q}$.

3.2. The Decision-making Behavior of the Cooperative

As for the cooperatives, the following constraint model can be established similarly.

$$\begin{aligned} \min z &= MS - \phi \sum_{i=1}^N (Q_i w_i^r - D(Q_i)) \\ \text{s.t. } \{ & Q \max(w^r, w) - C(Q) - MS_1 - \sum_{i=1}^N c_{i3} Q_i / a - \\ & \frac{1}{n} (1 - \phi) \sum_{i=1}^N [Q_i \max(w_i^r, w_i) - D(Q_i)] \} < 0 \quad (12) \\ & - \sum_{i=1}^N c_{i3} Q_i < 0, \end{aligned}$$

The Lagrangian function is $L(Q_i, \lambda, \mu) = z + \lambda(\pi_{f2} - \pi_{f1}) + \mu \left(- \sum_{i=1}^N c_{i3} Q_i \right)$

where $\pi_{f2} - \pi_{f1} < 0$ is the short form of the first constraint in the model. Its KKT conditions can be obtained similar to the former case. Since the cooperatives want farmers to join, they will make the benefits of farmers joining cooperatives greater than the benefits of individual farmers by setting parameters, i.e. $\pi_{f2} - \pi_{f1} < 0$. From the KKT condition, $\lambda = 0$.

Furthermore, the corollary can be obtained.

Corollary 2: If the parameters that the cooperative set meet

$$\sum_{i=1}^N \left(\frac{(w_i^r - c_{i1} - 2c_{i3})(w_i^r - c_{i1})}{4c_{i2}} - c_{i0} \right) > \frac{MS}{\phi} \quad \text{and}$$

$$M > \frac{q\phi(\max(w^r, w) - c_1)}{2}, \quad \text{the benefit of farmers}$$

participating in the cooperatives will be greater than the benefit of individual farmers. And the cooperatives can obtain the optimal yield of maximum

$$\text{benefit } Q_i = \frac{w_i^r - c_{i1}}{2c_{i2}} \quad (i = 1 \dots N).$$

Thus, the cooperative can calculate the optimal production for each crop to gain maximum profits while farmers can also decide the minimum land area to gain more benefits. In this way, farmers can choose to join cooperatives with confidence, which provides a strong theoretical basis for the establishment of cooperatives.

When $w_i^r < G^{-1}(\eta) \leq B_i$,

$$\pi_e = \phi \sum_{i=1}^N \left[w_i^r Q_i - \frac{1}{\eta} \int_{w_i^r}^{G^{-1}(\eta)} (w_i - w_i^r) Q_i dG(w_i) - D(Q_i) \right] - MS$$

is the revenue function of the cooperative? The decision of the cooperative and the farmers can be similarly discussed. The discussion will not be detailed here; the following two conclusions are provided.

Corollary 3: If the parameters set by the cooperative

$$\text{meet } M > \frac{q\phi(\max(w^r, w) - c_1)}{2} \quad \text{and}$$

$$\sum_{i=1}^N [w_i^r Q_i - D(Q_i)] - \frac{1}{\eta} \int_{w_i^r}^{G^{-1}(\eta)} (w_i - w_i^r) Q_i dG(w_i) > \frac{Mn(\max(w^r, w) - c_1)}{2c_2 q \phi},$$

the minimum land area that farmers choose to participate in the cooperative to benefit more

$$\text{is } S_1 = \frac{\max(w^r, w) - c_1}{2c_2 q}.$$

Corollary 4: If the parameters set by the cooperative meet

$$M > \frac{q\phi(\max(w^r, w) - c_1)}{2} \quad \text{and}$$

$$\frac{w_i^r - c_{i1} - p}{2c_{i2}} (2(w_i^r - c_{i1} - c_{i3}) - (w_i^r - c_{i1} - p)^2 - 2p) - c_{i0} > \frac{MS}{\phi}$$

where $P = \frac{1}{\eta} \int_{w_i^r}^{G^{-1}(\eta)} (w_i - w_i^r) dG(w_i)$, the output of

agricultural products obtained by cooperatives under the premise of ensuring farmers to join cooperatives

$$\text{is } Q_i = \frac{w_i^r - c_{i1} - \frac{1}{\eta} \int_{w_i^r}^{G^{-1}(\eta)} (w_i - w_i^r) dG(w_i)}{2c_{i2}}.$$

4. CONCLUSION

This paper put out a "farmers + cooperative + sales companies" agricultural products supply chain model. CVaR analysis was used to obtain specific benefits of cooperatives under different degrees of risk aversion. By using Lagrange function analysis of cooperatives and farmers decision-making behavior, the minimum land area that farmers choose to participate in the cooperative to benefit more can be obtained under different conditions. According to the analysis on the establishment of the cooperative, there are many advantages can be seen. The cooperative can ensure its own interests and can also ensure the profits of farmers. The introduction of the new agriculture order mode can improve the rural farmers signing rate and performance rate of booking farming, providing a better solution to the problem of the rural poor people outing of poverty. With the rapid development of the society, many young people choose to go out to start their own businesses. As a result, there are more and more old people and children left behind in rural areas in China. Most of them have weak labor ability. It can be seen that cooperative mode order agriculture will become more and more mainstream. This paper provided a theoretical basis for the establishment of cooperatives.

However, the analysis was carried out in an ideal state. In fact, there are many uncertainties in real life such as the specific game behavior between cooperatives and sales companies, the competition between cooperatives and cooperatives. The uncertainties will have an impact on the decision-making of cooperatives. These problems can be further studied.

REFERENCES

- [1] Rehber E. Vertical coordination in the agro-food industry and contract farming: A comparative study of Turkey and the USA[R]. Food Marketing Policy Center, University of Connecticut, 2000(2).
- [2] Guo Jinyong, Empirical research on farmers' cooperative behavior in agricultural product marketing -- based on the investigation of farmers in Jiangxi province, first ed., China agricultural press, Beijing, 2009.
- [3] Wang Aiyong, Xia Ying, Problem and countermeasure in breaking a contract are studied in the industrialization of agricultural managing, J. Grain Issues Research, 2007(1):17-21.
- [4] Wei Fuquan, Yuan Lihuang, Comparison of agricultural orders at home and abroad and enlightenment from foreign experience, J. World Agriculture, 2010(7):12-14.
- [5] Ma Jiujie, Xu Xuegao, Market structure and contract agricultural performance analysis, J. Agricultural economy, 2006(2): 37-42.
- [6] Sun Liangyuan, Zhang Yueheng, Characteristics and risk management of agricultural risks in transitional period, J. Agricultural economy, 2001(8): 20-26.
- [7] Liu Jing, Comparison and selection between option market and order agriculture in risk prevention of agricultural products market, J. Agricultural economy, 2012(5): 124-126.
- [8] Huang Zuhui, Jiang Wenhua, Institutional perspective of agriculture and rural development -- theoretical review and application analysis, first ed., China agricultural press, Beijing, 2002(10): 180-188.
- [9] Fu Xiaxian, Problems and system innovation in agricultural industrialization management, J. Journal of Zhejiang University, 2004(5): 5-12.
- [10] Xue Zhaosheng, The guidance and application of option theory to order agriculture, J. Chinese agricultural economy, 2001(2): 73-76.
- [11] Zhang Yanping, Implementation and Factors Influencing Contract Farming Based on "Farmer + Cooperative + Company" —A Case Study of Napa Cabbage Contract in Jiaozhou of Shandong Province, J. Journal of Jianxi Agricultural University: Social Sciences Edition, 2012(4):6-12.
- [12] Zhou Liquan, Cao Liquan, Commodity contract is superior to factor contract-taking the contract selection in agricultural industrialization as an example, J. Economic Research, 2002(1).
- [13] Fu Hongyong, Dan Bin. Study of contract mechanism for "company + farmer" pattern based on weather option, J. Journal of Systems Engineering, 2015(6): 768-778.
- [14] Fei Ye, Qiang Lin, Yina Li, Coordination for contract farming supply chain with stochastic yield and demand under CVaR criterion, J. Operational Research, 2017(6).
- [15] Guo Hongdong, Study on order arrangement and performance mechanism of agricultural leading enterprises and farmers, first ed., China agricultural press, Beijing, 2005.
- [16] Giannoccaro, Pontrandolfo, Supply Chain Coordination by Revenue Sharing Contracts, J. International Journal of Production Economics, 2004(4): 131-139.
- [17] Yang L, Xu M H, Yu G, et al. Supply Chain Coordination with CVaR Criterion, J. Asia-Pacific Journal of Operational Research, 2009, 26(1): 135-160.
- [18] Rockafeller T.R., Uryasev S. Optimization of Conditional Value-at-risk, J. Journal of Risk, 2000, 2(3): 21-24.
- [19] Ye Fei, Lin Qiang. Supply chain coordination for "company + farmer" contract-farming with CVaR criterion, J. Systems Engineering—Theory and Practice, 2011(3): 450-460.
- [20] Lai Yanlian, He Guoping, The Optimal Method, first ed., Tsinghua University Press, Beijing, 2008(12): 169-179.