Uncertain demand of farming-enterprise supply chain coordination based on the option contract

Xiangyang Ren*, Yu Ren, Qingmei Li

School of Economics and Management, Hebei University of Engineering, Guangming South Str.199, 056038 Handan, P.R.China

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Abstract

The paper sets up a single-cycle and two-level supply chain model of single rural cooperative and multiple retail enterprises, based on subsidies of option price to combined contract, with the profits maximization of the whole farming-enterprises' supply chain and each member as the goal. It gives the best order quantity and the profits of the whole supply chain and each member under two circumstances, centralized decision and decentralized decision. It also obtains conditions to achieve supply chain coordination. Finally, the paper verifies the model through an example.

Keywords: Farming-enterprise supply chain, Option contract, Price subsidy contract, Supply chain coordination

1 Introduction

In recent years, agricultural industrialization operation mode revealed gradually, farming-enterprise supply chain consisting of rural cooperative and enterprise is the most basic one. This can reduce the circulation, shorten the circulation time, thereby reducing the procurement costs of enterprises, meanwhile to address slow selling problem of the rural cooperative's agricultural product. However, because the industrialization of agriculture is still relatively low, various of systems are not perfect and the contract lack of flexibility and others. That led to the phenomenon of default occur frequently. This will not only damage the interests of the rural cooperative, but also damage the interests of enterprises even coordination is far from discernible.

In order to make the profits of the whole supply chain and two sides of farming-enterprise have increasing and then realize supply chain coordination, many researchers research it from different aspects in different ways. Foreign scholars research it in the following areas, Research on the agricultural products supply chain coordination, such as: Gigler [1] has defined agricultural products' two features in appearance and quality. And have optimization study on the agricultural supply chain using dynamic programming. Cai [2] have coordinated research on agricultural supply chain in the business forms of remote transport's FOB price. Philip [3] consider it can prevent the risk of agriculture by using financial derivative instruments, and seeking for the optimal solution combination of contract farming using time sequence and dynamic multi-period model. Research on options contracts in the supply chain coordination applications, such as: Cachon [4] discussed channels coordination problems of optimal options contracts and managing wholesale price contract in single suppliers and single retailers system, assuming that suppliers' cost is public information while the demand is the retailer's private information. Wang [5] proposed another type of option contract, in this contract assuming the option execution amount in the second phase can be less than or more than the purchase volume of the first stage of the option, and obtained the optimal strategy from the options buyer's view. Fugate [6] has coordinated multi-stage supply chain related to the market demand forecast constantly updated using quantity flexibility contract, and has discussed the effect from the forecast quality and the flexible level to optimal decision. Research on one to many supply chain coordination, such as: Cachon [7] built a supply chain model containing n retailers, respectively analysed coordinating role of the revenue-sharing contract for the supply chain when n retailers compete only on the order quantity, compete only on price, or compete both on order quantity and price, and got that revenue sharing contract can coordinate the supply chain in the first two competition but it cannot make the supply chain coordination in case of the third competition. Domestic scholars research in the following aspects, research on the agricultural products supply chain coordination, such as: Bai [8] introduced the option mechanism in the agricultural products supply chain, established the decision-making mode of each decision-making body under the supply chain coordination that achieve the coordination of agricultural supply chain. Zheng [9] respectively researched that applied option contract to two-level supply chain model of single rural cooperative and single enterprise under asymmetric information and government participation. Research on options contracts in the supply chain coordination applications, such as: Hu

* ***Corresponding author*** e-mail: boyrenxy@126.com

[10] introduced one-way and two-way option under the premise of market demand is uncertain and analysed the influence of two kinds of options to two-level supply chain flexibility contract consists of single seller and single suppliers, and got the sellers and suppliers optimal decisions under two options contract. Zhu [11] constructed a three-level supply chain model of a single suppliers, single retailers and a single sellers under the premise of demand is uncertain and coordinate the model by applying option repurchase combined contract and gives the optimal decision of supply chain and each member of the supply chain. Research on the coordination of one to many supply chain, such as: Sun [12], constructed a two- level supply chain model of single suppliers and multiple retailers under the premise of demand is uncertain, characterized competition between retailers by the use of Cournot competition, and proposed a linear contract and achieved the coordinate of supply chain by the application of this contract. Wu [13], constructed a two- level supply chain model of single suppliers and multi retailers by the premise of unexpected events lead to changes in market demand and production costs and analysed optimal decision of supply chain and each member of the supply chain under unexpected events, and revenue sharing contract has been improved so that it has anti-burst. This paper research the two- level supply chain model of single rural cooperative and multiple retail enterprise under the premise of demand is uncertain by the application of option price subsidies combined contract on the base of previous studies on agricultural supply chain coordinator, application of options contract coordination and one to many supply chain model.

2 Model symbols and basic assumptions

2.1 MODEL SYMBOL

w^d : Under the Option Contract, wholesale price of per unit of product of each retail enterprises given by rural cooperative;

c : Rural cooperative production costs of per unit of product;

c' : Rural cooperative processing costs of units remaining products;

c_o : The purchase price of per unit of product options;

$\pi M_i c_o$: The interest cost of retail enterprises by buying the option $i=1,2,\cdots,n$;

c_e : Execution price of per unit of product options;

p_i : Retail enterprise i's retail price of unit of product, $i=1,2,\cdots,n$;

Q_i : Retail enterprise i's fixed order quantity, $i=1,2,\cdots,n$;

M_i : The purchase amount of option of retail enterprise i, $i=1,2,\cdots,n$;

c_i' : Retail enterprise i's processing costs of the remaining units of the product, $i=1,2,\cdots,n$;

g : Retail companies' out of stock losses of per unit of product

m : The price subsidies of remaining products in unit that rural cooperative offered to retail enterprises;

Demand function for the retail enterprises: $D_i = D_o - \alpha p_i + \sum_{j\neq i}^{n} \beta_j p_j$, $i=1,2,\cdots,n$, $\beta_j > 0, \alpha > \beta_j$.

D_o : The respective maximum demand of n retail enterprises. It is a random variable;

$F(x)$: Distribution function of the largest market demand D_o;

$f(x)$: Probability density function of the largest market demand D_o;

$F(x)$: Differentiable, continuous incremented, and $F(0)=0, \quad \mu = \int_0^{\infty} xf(x)dx$;

μ : Mean of the largest market demand D_o;

α : Consumer's price sensitivity coefficient;

β_j : Influence coefficient of market demand from retail enterprises j to retail enterprises i;

If the order quantity of retailer i is Q_i, when $Q_i \le D_i$, $Q_i \le x - \alpha p_i + \sum_{j\neq 1}^{n} \beta_j p_j$, $x \ge Q_i + \alpha p_i - \sum_{j\neq 1}^{n} \beta_j p_j$ then the sales volume of retail enterprises i is Q_i; when $Q_i > D_i$, $Q_i > x - \alpha p_i + \sum_{j\neq 1}^{n} \beta_j p_j$, $x < Q_i + \alpha p_i - \sum_{j\neq 1}^{n} \beta_j p_j$ then the sales volume of retail enterprises i is D_i.

So the expectations sales volume of retail enterprise i's products is: $S(Q_i) = \mathrm{E}\left[\min(Q_i, D_i)\right]$

$$= \int_0^{Q_i+\alpha p_i-\sum_{j\neq i}^{n}\beta_j p_j} xf(x)dx + \int_{Q_i+\alpha p_i-\sum_{j\neq i}^{n}\beta_j p_j}^{\infty} Q_i f(x)dx$$

$$= Q_i - \int_0^{Q_i+\alpha p_i-\sum_{j\neq i}^{n}\beta_j p_j} F(x)dx$$

Expectations remaining amount of retail enterprise i's products is:

$$I(Q_i) = \mathrm{E}\left[\max(Q_i - D_i, 0)\right]$$

$$= \mathrm{E}\left[\max\left(Q_i + \alpha p_i - \sum_{j\neq i}^{n}\beta_j p_j - x, 0\right)\right]$$

$$= \int_0^{Q_i+\alpha p_i-\sum_{j\neq i}^{n}\beta_j p_j} \left(Q_i + \alpha p_i - \sum_{j\neq i}^{n}\beta_j p_j - x\right) f(x)\,dx$$

$$= \int_0^{Q_i+\alpha p_i-\sum_{j\neq i}^{n}\beta_j p_j} F(x)dx = Q_i - S(Q_i)$$

Expectations shortage of retail enterprise *i*'s products $L(Q_i)=\mathrm{E}[\max(D_i-Q_i,0)]$

$$=\mathrm{E}\left[\max\left(x-\alpha p_i+\sum_{j\neq i}^{n}\beta_j p_j-Q_i,0\right)\right]$$

is:

$$=\int_{Q_i+\alpha p_i-\sum_{j\neq i}^{n}\beta_j p_j}^{\infty}\left(x-\alpha p_i+\sum_{j\neq i}^{n}\beta_j p_j-Q_i\right)f(x)dx$$

$$=\mu-S(Q_i)$$

2.2 THE BASIC ASSUMOTION

Make the following assumptions to the relationship between parameters:

(1) $c<w^c<p_i$, $c<w^d<p_i$, rural cooperatives wholesale price is higher than its cost of production to ensure that the profits of rural cooperatives, retail enterprises retail price is higher than its wholesale price that is to ensure it is profitable to retail business.

(2) $(1+\tau)c_o+c_e>w^d$, the purchase price of the option plus the exercise price is more than the wholesale price that making when retail companies get the elasticity of supply by options the same time that was encouraged using wholesale prices to order products.

(3) $(1+\tau)c_o+m<w^d+c_i'$, to ensure the validity of the option.

(4) $m<w^d$, retail companies cannot benefit from price subsidies directly.

(5) Assuming rural cooperatives and each retail enterprises are risk-neutral and completely rational and both of them are making decision according to their own expectations profit maximization principle.

3 Centralized decision-making farming-enterprises supply chain model under the option contract

Centralized decision-making model is researching the farming-enterprises supply chain as a whole. It is assumed that a centralization unit for unified management to all members of the supply chain and decision makers to arrange the rural cooperative's product and each retail enterprises order with the objective that the whole supply chain to maximize profits.

Under the centralized decision-making, the whole profit expectation of farming-enterprise is:

$$\Pi'^{D}=\sum_{i=1}^{n}\{p_iS(Q_i+M_i)-c_i'I(Q_i)-c'[I(Q_i+M_i)-I(Q_i)]-gL(Q_i+M_i)-c(Q_i+M_i)\}$$

$$=\sum_{i=1}^{n}[(p_i+c'+g)S(Q_i+M_i)+(c_i'-c')S(Q_i)-(c+c_i')Q_i-(c+c')M_i] \quad (1)$$

$$=\sum_{i=1}^{n}\left[(p_i+g-c)(Q_i+M_i)-(p_i+g+c')\int_0^{Q_i+M_i+\alpha p_i-\sum_{j\neq i}^{n}\beta_j p_j}F(x)dx-(c_i'-c')\int_0^{Q_i+\alpha p_i-\sum_{j\neq i}^{n}\beta_j p_j}F(x)dx-g\mu\right]$$

Formula (1): The first item represents: sales revenue of agricultural products. The second item represents: the cost of processing of the retail enterprises' remaining agricultural. The third item represents: cost of processing of rural cooperative's remaining agricultural. The fourth represents losses of out of stock. The fifth represents: production costs.

Solving the first derivative to Q_i+M_i in formula (1):

$$\frac{\partial\Pi'^{D}}{\partial(Q_i+M_i)}=(p_i+g-c)-(p_i+g+c')F\left(Q_i+M_i+\alpha p_i-\sum_{j\neq i}^{n}\beta_j p_j\right).$$

Solving the second derivative to Q_i+M_i in formula (1): $\frac{\partial^2\Pi'^{D}}{\partial(Q_i+M_i)^2}=-(p_i+g+c')f\left(Q_i+M_i+\alpha p_i-\sum_{j\neq i}^{n}\beta_j p_j\right)\leq 0$.

Thus Π'^{D} is concave function to Q_i+M_i, so:

$$(Q_i+M_i)^*=F^{-1}\left(\frac{p_i+g-c}{p_i+g+c'}\right)-\alpha p_i+\sum_{j\neq i}^{n}\beta_j p_j. \quad (2)$$

4 Decentralized decision farming-enterprise supply chain model based on option contracts

In decentralized decision supply chain, retailers often determine the order with their own profit-maximization as a criterion. The order cannot achieve overall optimization of agricultural products supply chain. In order to realize the coordination of agricultural products supply chain. As a leader, rural cooperative must enact terms of options that have incentive effect to the retailers, in order to make the optimal order quantity of retailers' and agricultural products supply chain equal.

Expectations of exercise options:

$$\int_{Q_i}^{Q_i+M_i}(D_i-Q_i)f(D_i)dD_i+\int_{Q_i+M_i}^{+\infty}M_i f(D_i)dD_i$$

$$=M_i-\int_{Q_i}^{Q_i+M_i}F(D_i)dD_i=M_i-\int_{Q_i+\alpha p_i-\sum_{j\neq i}^{n}\beta_j p_j}^{Q_i+M_i+\alpha p_i-\sum_{j\neq i}^{n}\beta_j p_j}F(x)dx$$

$$=M_i-\left[\int_0^{Q_i+M_i+\alpha p_i-\sum_{j\neq i}^{n}\beta_j p_j}F(x)dx-\int_0^{Q_i+\alpha p_i-\sum_{j\neq i}^{n}\beta_j p_j}F(x)dx\right]$$

$$=S(Q_i+M_i)-S(Q_i)$$

In decentralized decision supply chain, profit model of retailers:

$$\Pi_{Ri}^{D} = p_i S(Q_i + M_i) + mI(Q_i) - w^d Q_i - (1+\tau)M_i c_o - c_e[S(Q_i + M_i) - S(Q_i)] - gL(Q_i + M_i) - c_i' I(Q_i)$$
$$= (p_i + g - c_e)S(Q_i + M_i) - (m - c_e - c_i')S(Q_i) + (m - w^d - c_i')Q_i - (1+\tau)M_i c_o - g\mu$$
$$= (p_i + g - c_e)\left[Q_i + M_i - \int_0^{Q_i + M_i + \alpha p_i - \sum_{j\neq i}^{n} \beta_j p_j} F(x)dx \right] + (m - w^d - c_i')Q_i -$$
$$(m - c_e - c_i')\left[Q_i - \int_0^{Q_i + \alpha p_i - \sum_{j\neq i}^{n} \beta_j p_j} F(x)dx \right] - (1+\tau)M_i c_o - g\mu \quad . \quad (3)$$
$$= (p_i + g - w^d)Q_i - (p_i + g - c_e)\int_0^{Q_i + M_i + \alpha p_i - \sum_{j\neq i}^{n} \beta_j p_j} F(x)dx +$$
$$[p_i + g - c_e - (1+\tau)c_o]M_i + (m - c_e - c_i')\int_0^{Q_i + \alpha p_i - \sum_{j\neq i}^{n} \beta_j p_j} F(x)dx - g\mu$$

In (3), the first one: agricultural products sales revenue of retail enterprise *i*; the second one: subsidy of the residual agricultural products from rural cooperative to retail enterprise *i*; the third one: fixed ordering cost of retail enterprise *i*; the forth one: option purchase cost and interest costs of retail enterprise *i*; the fifth one: option execution cost of retail enterprise *i*; the sixth one: shortage cost of retail enterprise *i*; the seventh one: processing cost of the residual agricultural products of retail enterprise *i*.

Expectation profit of rural cooperative:

$$\Pi_{N}^{D} = \sum_{i=1}^{n} \{ w^d Q_i + (1+\tau)M_i c_o + c_e[S(Q_i + M_i) - S(Q_i)] - c'[I(Q_i + M_i) - I(Q_i)] - c(Q_i + M_i) - mI(Q_i) \}$$
$$= \sum_{i=1}^{n} \{ (w^d - c - m)Q_i + [(1+\tau)c_o - c' - c]M_i + (c_e + c')S(Q_i + M_i) + (m - c_e - c')S(Q_i) \} \quad . \quad (4)$$
$$= \sum_{i=1}^{n} \{ (w^d - c - m)Q_i + [(1+\tau)c_o - c' - c]M_i + (c_e + c')S(Q_i + M_i) + (m - c_e - c')S(Q_i) \}$$
$$= \sum_{i=1}^{n} \left\{ (w^d - c)Q_i + [(1+\tau)c_o + c_e - c]M_i - (c_e + c')\int_0^{Q_i + M_i + \alpha p_i - \sum_{j\neq i}^{n} \beta_j p_j} F(x)dx + (c_e + c' - m)\int_0^{Q_i + \alpha p_i - \sum_{j\neq i}^{n} \beta_j p_j} F(x)dx \right\}$$

In (4), the first one: sales revenue of rural cooperative benefited from retail enterprises fixed order; the second one: sales revenue of put option and interest costs of rural cooperative; the third one: sales revenue of rural cooperative benefited from retail enterprises option execution; the forth one: processing cost of the residual agricultural products of rural cooperative; the fifth one: production cost of rural cooperative; the sixth one: subsidy from rural cooperative to retail enterprises.

Calculate the first and the second order partial derivative of Q_i and M_i in (3):

$$\frac{\partial \Pi_{Ri}^{D}}{\partial Q_i} = (p_i + g - w^d) - (p_i + g - c_e)F\left(Q_i + M_i + \alpha p_i - \sum_{j\neq i}^{n} \beta_j p_j \right) + (m - c_e - c_i')F\left(Q_i + \alpha p_i - \sum_{j\neq i}^{n} \beta_j p_j \right)$$
$$\frac{\partial \Pi_{Ri}^{D}}{\partial M_i} = p_i + g - c_e - (1+\tau)c_o - (p_i + g - c_e)F\left(Q_i + M_i + \alpha p_i - \sum_{j\neq i}^{n} \beta_j p_j \right)$$
$$\frac{\partial^2 \Pi_{Ri}^{D}}{\partial Q_i^2} = -(p_i + g - c_e)f\left(Q_i + M_i + \alpha p_i - \sum_{j\neq i}^{n} \beta_j p_j \right) - (c_e + c_i' - m)f\left(Q_i + \alpha p_j - \sum_{j\neq i}^{n} \beta_j p_j \right) \leq 0$$
$$\frac{\partial^2 \Pi_{Ri}^{D}}{\partial M_i^2} = -(p_i + g - c_e)f\left(Q_i + M_i + \alpha p_i - \sum_{j\neq i}^{n} \beta_j p_j \right) \leq 0$$

It is clearly that Π_{Ri}^{D} is concave function about Q_i and M_i.

$$Q_i^D = F^{-1}\left(\frac{c_e+(1+\tau)c_o-w^d}{c_e+c_i'-m}\right)-\alpha p_i+\sum_{j\neq i}^{n}\beta_j p_j, \tag{5}$$

$$M_i^D = F^{-1}\left(\frac{p_i+g-c_e-(1+\tau)c_o}{p_i+g-c_e}\right)-F^{-1}\left(\frac{c_e+(1+\tau)c_o-w^d}{c_e+c_i'-m}\right). \tag{6}$$

The whole expectation profit of farming-enterprise supply chain:

$$\Pi^D=\sum_{i=1}^{n}\Pi_{Ri}^{D}+\Pi_N^D. \tag{7}$$

5 The coordination of farming-enterprise supply chain

To achieve the coordination of farming-enterprise supply chain, rural cooperative must make price policy that has incentive effect to the retailers. So it can make the optimal decision of retail enterprises and the decision of supply chain coordination corresponding.

$$\frac{p_i+g-c}{p_i+g+c'}=\frac{p_i+g-c_e-(1+\tau)c_o}{p_i+g-c_e}. \tag{8}$$

From (8), the coordination of farming-enterprise supply chain must satisfy:

$$c_o=\frac{(p_i+g-c_e)(c+c')}{(1+\tau)(p_i+g+c')}. \tag{9}$$

To make the supply chain coordinating, retail prices from all retail enterprises must be equal (at this time, all the retail enterprises accept the same contract).

To make the supply chain coordinating completely, it must adjust contract parameter to realize arbitrary allocation of supply chain profit between rural cooperative and retail enterprises.

Suppose that:

$$p_i+g-w^d=\lambda_i(p_i+g-c), \tag{10}$$

$$p_i+g-c_e-(1+\tau)c_o=\lambda_i(p_i+g-c), \tag{11}$$

$$p_i+g-c_e=\lambda_i(p_i+g+c'), \tag{12}$$

$$c_i'+c_e-m=\lambda_i(c_i'-c'). \tag{13}$$

It can be known from the hypothesis relationship among parameters: $0\le\lambda_i\le 1$.

From (1) and (10) to (13), (3) can be expressed as:

$$\begin{aligned}\Pi_{Ri}^{D}&=\lambda_i(p_i+g-c)(Q_i+M_i)\\&-\lambda_i(p_i+g+c')\int_0^{Q_i+M_i+\alpha p_i-\sum_{j\neq i}^{n}\beta_j p_j}F(x)dx\\&+\lambda_i(c_i'-c')\int_0^{Q_i+\alpha p_i-\sum_{j\neq i}^{n}\beta_j p_j}F(x)dx-g\mu\\&=\lambda_i\Pi_i'^{D}-(1-\lambda_i)g\mu\end{aligned}. \tag{14}$$

So the profit of rural cooperative Π_N^D can be expressed as:

$$\Pi_N^D=\sum_{i=1}^{n}\left[(1-\lambda_i)\Pi_i'^{D}+(1-\lambda_i)g\mu\right]. \tag{15}$$

6 Empirical analysis

The paper takes a supply chain composed of a rural cooperative and two retail enterprises from Handan city for example to prove. With a lot of surveys, the trading process of the rural cooperative and the two retail enterprises is as follows: Before the selling season, rural cooperative gives the wholesale price of the product w^c (without option contract), w^d (with option contract), purchase price of option c_o, exercise price of option c_e and subsidy of residual products from retail enterprise m. The two retail enterprises decide the fixed-order quantity Q_i and option purchase quantity M_i, according to profit maximization. In the selling season, retail enterprises decide whether to implement option or not, and the quantity of exercise option. After the selling season, if retail enterprises have residual products, the rural cooperative will give some subsidy.

The parameters and the parameter values, as Table 1 shows:

TABLE 1 The parameters and the parameter values

Parameter	w^c	w^d	c	c'	τ	p_1	p_2
Value	19	20	12	0.5	0.1	32	32
Parameter	c_1'	c_2'	g	m	α	β_1	β_2
Value	2	2	2	10	2	0.5	0.5

Suppose market demand is $x\sim N(100,30)$ normal distribution, $c_o=2$, solve the model by using Matlab.

(1) In centralized decision farming-enterprise supply chain based on options contracts, from (1) and (2), the optimal order quantity of the retail enterprises and the optimal profit of the farming-enterprise supply chain are: $(Q_1+M_1)^*=62.57$; $(Q_2+M_2)^*=62.57$; $\Pi'^{D}=2050.34$.

(2) In option contract coordination farming-enterprise supply chain, the optimal fixed order quantity, the optimal option purchase quantity of retail enterprises $i(i=1,2)$, the optimal profit of the whole supply chain and the profit of each members can be calculated according to (8) ~ (15): $Q_1^D = 52.55$; $Q_2^D = 52.55$; $M_1^D = 10.02$; $M_2^D = 10.02$; $\Pi_{R1}^D = 603.08$; $\Pi_{R2}^D = 603.08$; $\Pi_N^D = 422.09 + 422.09 = 844.18$; $\Pi^D = 2050.34$.

It is clearly that option contract can make farming-enterprise supply chain coordinated.

7 Conclusions

The paper established a two-stage supply chain model of one rural cooperative and many retail enterprises, taking into account several factors, such as the product cost of rural cooperative, the processing cost of the remaining product and shortage loss of retail enterprises. It realized the coordination of supply chain, by studying the model from centralized decision and decentralized decision, with option price subsidy joint contract. Some meaningful conclusions are arrived with the guidance of this conclusion,, the two sides of the supply chain can improve the efficiency of supply chain operation, reduce supply chain cost, realize the sustainable development and cooperation for a long time .They can finally share risks and profits, achieve the ideal level of supply chain management.

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Authors

Xiangyang Ren, born on February 11, 1979, Leting County, Hebei Province, P.R.China

Current position, grades: an associate professor.
University studies: Ph.D in Management Science and Engineering (2009) from China University of Mining and Technology, Beijing, P.R.China.
Scientific interests: different aspects of artificial intelligence and supply chain management. **Publications:** Enterprise Emergency Logistics Capability Index System Construction Based on Rough Set Theory, ICIC Express Letters, Part B: Applications, 2013; Study on Evaluation of Enterprise Emergency Logistics Capacity Based on Rough Set, Logistics Technology, 2013; Study on Benefit Allotment of Agricultural Produce Supply Chain Based on Game Model, Logistics Technology, 2013.

Yu Ren, born on January 25,1990, Handan city, Hebei Province, P.R.China

Current position, grades: a graduate student of Logistics Engineering at School of Economics and Management, Hebei University of Engineering, Han Dan, Hebei Province, P.R.China.
University studies: Bachelors Degree in Management (2013) from Hebei University of Engineering, Handan, P.R.China.
Scientific interests: different aspects of logistics and supply chain management.

Qingmei Li, born on May 18, 1984, Shijiazhuang city, Hebei Province, P.R.China

Current position, grades:graduate student of Logistics Engineering at School of Economics and Management, Hebei University of Engineering, Han Dan, Hebei Province, P.R.China.
University studies: Bachelors Degree in Management (2010) from Hebei University of Engineering, Handan, P.R.China.
Scientific interests: different aspects of logistics and supply chain management.