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Research on the Biomass Power Contract of "Company +Farmer" Under Default Risk

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Abstract

We research the biomass power generation problem in the perspective of farmer contracting supply chain. By establishing a mathematical model and under the random yield and demand, a multiple farmer contract with a biomass power generation company problem in a two-level supply chain is researched in this paper. We propose different mechanisms in two situations: under default risk and no default risk. And compare the optimal decision in different contracts. We find that the famers' optimal input amount is always linear to the company's order quantity; The company and farmers' optimal decision quantity will both be improved under no default risk. However, the optimal input quantity by farmers will decrease with the increases of the compensation ratio in this situation.

Key words: Supply chain; farmer contracting; Biomass power generation; Contract-default

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INTRODUCTION

Energy is the pillar of the development of the national economy. And play an important role in maintaining the rapid economic development and improvement of people's living standards. Statistics shows that since 2006, the ratio of fossil fuels consumption is up to 87.9% to the total energy consumption in the world, of which the proportion of China is as high as 93.8%. China's oil reserves are very small, proven reserves are only 1.3% of the world's total reserves. Since 1993, domestic oil production has been in short supply, China has become a net oil imports country with an increasing demand. Based on the rich media, lean oil, less gas characteristics of fossil energy resources. China's main energy dependence is coal which annual consumption in China is the second in the world. Wood Mackenzie, an energy research firm, said in a published report that although a series of measures to reduce coal consumption have been introduced and implemented, China's annual coal consumption will rise to 7 billion tons by 2030, which is twice of the current annual consumption. As China's largest stockpile and the most widely distributed non-renewable strategic resources, coal plays an important role in the development of economy in China. However, relying on the development of non-renewable energy will encounter bottlenecks in the future.

The renewable energy, which is abundant and green, comes into our vision because of the shortage of fossil fuels. Research on the use of renewable energy has also been rapidly developed. Whether traditional fossil fuels or renewable energy, they all play an important role in the field of power generation. According to the US Energy Information Administration (EIA) report, the world's fastest growing energy consumption will be in terms of electricity supply. EIA estimates that the global power generation will achieve an average annual growth rate of 2.3% by 2035.

Although China is developing a series of policies to reduce the dependence on coal electricity, but it can't curb the demand for coal. The use of coal power generation has caused some urgent problems, including the environmental pollution and the Greenhouse effect. Aware of the negative impact of coal electricity, there have been many countries focus on the development of renewable energy power generation. Denmark began to use biomass energy since 1970. And in 1989, Denmark's straw power generation project had been able to achieve profitability. However, China's biomass power generation is still in the development stage.

China is a big agricultural country with nearly 70% of the peasant population. China's rural areas are also hidden in a huge biomass energy resource in the context of the vast agricultural land area. Biomass energy can be raw materials for crop stalks, trees, etc. while because of the low use of straw, cereal leather and other biomass energy in China's rural area. China has a very substantial potential in the biomass power generation industry. The Chinese government has begun to pay attention to the development of renewable energy power generation projects, and has stated that the renewable energy power generation will rise to an important level in the power supply system. With the support of government, there have been many attempts on building biomass power plants in China. The biomass power generation installed capacity in Anhui, a large agricultural province, has reached 278MW, generating capacity of 153MW·h per year. Henan Province also has a unique natural resource in developing the biomass power generation with an average 70 million tons annually straw production. However, due to the lack of experience, high production cost and the instability in the supply of raw materials, the vast majority of biomass power companies are at a loss. We'll focus on the problems listed above by researching a two-echelon supply chain with farmers and the biomass generation company.

1. LITERATURE

In the traditional power generation companies, coal is closely related to the upstream industry. While due to the instability of coal price and the determined price of electricity. The coal contract price negotiation is extremely fierce. And the conflict caused by the profit is becoming more and more difficult. The biomass power contract of "Company +Farmer" will provide a viable solution to the conflict.

Research on the contract farming supply chain has been developed rapidly. He et al. (2008) analyzed the supplier and the manufacture's profit under yield and demand uncertainty. They discussed the different revenue in the centralized model, no risk sharing model and risk sharing model. Hu et al. (2013) analyzed the optimal order strategy for the manufacturer under a two-echelon supply chain with yield and demand uncertainty. Centralized model and decentralized model are established to study the expected revenue of the supply chain. And a revenue sharing order contract is proposed to coordinate the supply chain. Zhang (2009) established a tripartite, farmer, government and the company, coordination mechanisms based on the distribution of farmers in China through the big system theory. A contract incentive and profit return mechanism were proposed to reduce operating cost and maximize the profit of the whole supply chain. But all models are established on the assumption that the farmer is a single group. Huh et al. (2012) researched the expected profit of an agriculture product manufacturer with multiple farmer supply chain under demand uncertainty. Three different models were discussed to estimate the best choice for the manufacturer. It's find that the manufacturer's maximum profit will be achieved in reneging-contract. But it neglected the influence of the farmers' optimal input quantity the supply chain. Huang et al. (2012) further researched the coordination mechanism of rewards and punishments and revenue-return contracts in the three-stage biomass supply chain which is consisted of energy company, production base and farmers to achieve the maximum expected profit to all parties in the supply chain. With the development of biomass energy, some scholars have begun to study the biomass power contract of "Company +Farmer" supply chain. Nasiri et al. (2009) analyzed a three-stage supply chain consists of farmer, electricity generation company and the electricity consumer to investigate the optimal strategy for them with incentive. Wang (2001) expands the model and analyzed the game strategy between the farmers, the middle purchaser and the power generation enterprise. The dynamic game under complete information and incomplete information (uncertainty of straw quality) biomass electricity supply chain are analyzed respectively. The government subsidy and some detailed-costs are considered into the model to estimate the revenue of the supply chain. We can find that there is rarely research on the biomass power contract of "Company +Farmer" under default risk. Because of the short-sighted characteristic of farmers, the default situation often occurs in reality. A suitable mechanism design for the supply chain under default risk is worthy of further study. So we established a biomass power contract of "Company +Farmer" supply chain under default risk based on the model of Fuzhan Nasiri and Woonghee Tim Huh's. The influence of the default risk to the optimal order and input decision is further studied in this paper.

The rest of the paper is organized as follows. Section 3 will set different models in two situations. Section 4 is the analysis of the models. And we summarize the results in Section 5.

2. MODEL

In this paper, we research a farm-contracting supply chain with a single biomass power generation company and multi-farmer. The decision of the company and each farmer is based on the maximization of their own profit. The supply chain structure is shown in Figure 1. Since the area of arable land per household in the rural area is allocated by the population in China. We assume that the land area per household is the same. And the optimal input amount is the same for each farmer, too. The company will propose a certain contract order quantity based on the contract price to farmers before the realization of the biomass. And the demand for biomass power is variable. Farmers will decide an optimal input quantity according to company's order, operation cost and the contract price which are random yield. Some assumptions and symbols in are listed below.

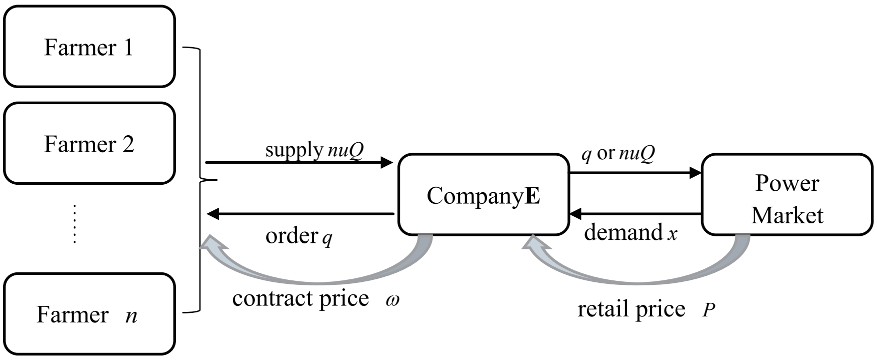

Figure 1
The Structure of the Supply

Assumptions:

(a) Power generation company and farmers' decisions are based on maximizing their own profit.
(b) Farmers' operating cost are positively related to the input amount, and the total operating cost is CQ.
(c) The excess biomass produced by the farmer has no salvage value.
(d) The information between farmers and the power generation company is complete and reciprocal.

Related symbols:

Deterministic parameters

- F Farmer
- E Power company
- n Famer numbers
- C Farmers' operating cost
- C_e Emergency order price for material
- ω Contract price
- P Electricity sales price in the biomass power generation market
- y Company's operating cost
- α The compensation ratio of the power generation company to the emergency order cost ($0< \alpha < 1$)
- $\pi_{\#}^{\theta}$ The profit function of the main party of supply chain. θ for different parties, # for different mechanism.

Stochastic parameters

- u The random yield variable of the material with density function f(u) and cumulative distribution function $F(u)$, $E[u]=\bar{u}$
- x The random demand variable of the biomass power with density function $g(x)$ and cumulative distribution function $G(x)$, $E[x]=\bar{x}$
- v The random conversion rate of the biomass power with density function $h(v)$ and cumulative distribution function H(v), $E[v]=\bar{v}$

Decision variables

- Q The amount of every farmer input, Q^* is the optimal decision
- q The amount of company ordered, q^* is the optimal decision

2.1 Centralized Model

The centralized model is used as a benchmark model for comparison. The supply chain profit function is:

$$\pi_0=P\cdot E_{\mathrm{u},x,v}[\min\{nuvQ_0,x]-nCQ_0-E[ynuQ_0v] \quad . \tag{1}$$

Lemma 1. The supply chain profit is concave in Q_0, and the optimal Q_0^* satisfies:

$$\int_0^{\infty} v\int_0^{\infty} u\int_{nuQ_0v}^{\infty} g(x)\mathrm{d}xf(u)\mathrm{d}uh(v)\mathrm{d}v=\frac{C+y\overline{uv}}{P} \quad . \tag{2}$$

2.2 The Production and Order Strategy Under No Default Risk

In this case, the company will always procure q to product the biomass electricity. While $q>nuQ$, the emergency order will be operated to fulfill the unmet order. The emergency order price is $C_e(C_e>C)$. Three mechanisms are researched in this part.

2.2.1 Famers Bear the Emergency Order Cost

While $q>nuQ$, the farmer will bear all the emergency order cost. And the famer's profit function is:

$$\pi_{11}^{F}=\omega\cdot q-C_{e}\cdot E_{u}[(q-nuQ_{11})]-nCQ_{11}. \tag{3}$$

The first part is the revenue from the contract. The second part is the emergency order cost. The third part is the operation cost.

Lemma 2. π_{11}^{F} is concave in Q_{11}, and the optimal Q_{11}^{*} satisfies:

$$\int_{0}^{\frac{q}{nQ_{11}}}uf(u)\mathrm{d}u=\frac{C}{C_{e}}. \tag{4}$$

From (4) we know that for $\int_{0}^{m}uf(u)\mathrm{d}u=H(m)$, $\frac{\partial H(m)}{\partial m}=mf(m)>0$. Thus $H(m)$ is a monotonically increasing function, and there is a unique solution for $\frac{q}{nQ_{11}}$ in (4).

If $Q_{11}^{*}=M_{11}q$, then M_{11} is a constant parameter related to C,C_e, $f(\cdot)$ and n. M_{11} increases with the increase of C_e, and decreases with the increase of C and n.

Lemma 2 denotes that the famers' input Q_{11} amount is linear to the company's order quantity q. The proportional coefficient is M_{11} which is determined by the operation cost, emergency order price and the number of farmers.

The company's expected profit is

$$\pi_{11}^{E}=P\cdot E_{x,v}[\min\{qv,x\}]-\omega\cdot q-E[yqv]. \tag{5}$$

The first part is the sales revenue. The second part is the contract-procurement cost. The third part is the production cost.

Lemma 3. The company's expected profit π_{11}^{E} is concave in q_{11}. and the optimal q_{11}^{*} satisfies

$$\int_{0}^{\infty}\int_{qv}^{\infty}vg(x)\mathrm{d}xh(v)\mathrm{d}v=\frac{\omega+\bar{yv}}{P}. \tag{6}$$

2.2.2 Famers and Company Share the Emergency Order Cost

In this mechanism, the company will share the emergency order cost with farmers. While $q>nuQ$, the company will share α part of the cost. And farmers will bear the left 1－α part cost. Then the farmers' expected profit is

$$\pi_{12}^{F}=\omega\cdot E_{u}[\min\{nuQ_{12},q\}]-(1-\alpha)C_{e}E_{u}[(q-nuQ_{12})^{+}]-nCQ_{12}. \tag{7}$$

The first part is the revenue from the contract. The second part is the emergency order cost farmers bear. The third part is the operation cost.

Lemma 4. π_{12}^{E} is concave in Q_{12}, and the optimal Q_{12}^{*} satisfies

$$\int_{0}^{\frac{q}{nQ_{12}}}uf(u)\mathrm{d}u=\frac{C}{\omega+(1-\alpha)C_{e}}. \tag{8}$$

If $Q_{12}^{*}=M_{12}q$, then M_{12} is a constant parameter related to C,
$_e$, α ,ω , $f(\cdot)$ and n. M_{12} increases with the increase of C_e and ω, and decreases with the increase of C, α and n.

The company's expected profit is

$$\pi_{12}^{E}=P\cdot E_{x,v}[\min\{qv,x\}]-\alpha C_{e}E_{u}[(q-nuQ_{12})^{+}]-\omega\cdot E_{u}[\min\{nuQ_{12},q\}]-E[yqv]. \tag{9}$$

The first part is the sales revenue. The second part is the emergency order cost company bear. The third part is the contract-procurement cost. And the last part is the production cost.

Lemma 5. The company's expected profit π_{12}^{E} is concave in q_{12}. and the optimal q_{12}^{*} satisfies

$$\int_{0}^{\infty}\int_{qv}^{\infty}vg(x)\mathrm{d}xh(v)\mathrm{d}v=\frac{\omega+\bar{yv}+(\alpha C_{e}-\omega)\int_{0}^{1/nM_{12}}(1-nuM_{12})f(u)\mathrm{d}u}{P}. \tag{10}$$

We can know that q_{12}^{*} is decreases with the increase of α. Since the larger α, the higher cost the company share.

2.2.3 Famers and Company Share the Yield Risk

In this case, farmers will compensate for company's replenishment cost when $q>nuQ$. The compensation coefficient is b. While the company will compensate for farmers' excessive output with compensation coefficient t.

Then the farmers' expected profit function is

$$\pi_{13}^{F}=\omega\cdot E_{u}[\min\{nuQ_{13},q\}]-b\,E_{u}[(q-nuQ_{13})^{+}]+t\,E_{u}[(nuQ_{13}-q)^{+}]-nCQ_{13}. \tag{11}$$

The first part is the revenue from the contract. The second part is the compensate cost to the company. The third part is the compensation from the company. And the last part is the operation cost.

Lemma 6. π_{13}^{F} is concave in Q_{13}, and the optimal Q_{13}^{*} satisfies

$$\int_{0}^{\frac{q}{nQ_{13}}}uf(u)\mathrm{d}u=\frac{C-tu}{\omega+b-t}. \tag{12}$$

If $Q_{13}^{*}=M_{13}q$, then M_{13} is a constant parameter related to C, b , t , ω , $f(\cdot)$ and n. M_{13} increases with the increase of b and ω, and decreases with the increase of Cand n.

The company's expected profit is

$$\pi_{13}^{E}=P\cdot E_{x,v}[\min\{qv,x\}]+bE_{u}[(q-nuQ_{13})^{+}]-tE_{u}[(nuQ_{13}-q)^{+}]-C_{e}E_{u}[(q-nuQ_{12})^{+}] \\ -\omega\cdot E_{u}[\min\{nuQ_{13},q\}]-E[yqv] \ . \tag{13}$$

The first part is the sales revenue. The second part and third part are the compensation from and to the farmers, respectively. The forth part is the emergency order cost. The fifth part is the contract-procurement cost. And the last part is the production cost.

Lemma 7. The company's expected profit π_{13}^{E} is concave in q_{13}. and the optimal q_{13}^{*} satisfies

$$\int_{0}^{\infty}\int_{qv}^{\infty}vg(x)\mathrm{d}xh(v)\mathrm{d}v=\frac{\omega+y\bar{v}+(\omega+b-t-C_{e})\int_{0}^{1/nM_{13}}(1-nuM_{13})f(u)\mathrm{d}u+t\int_{0}^{\infty}(1-nuM_{13})f(u)\mathrm{d}u}{P}\ . \tag{14}$$

2.3 The Production and Order Strategy Under Default Risk

Default risk is common in contract farming supply chain because of the short-sighted farmers. Therefore, farmers will take no responsibility for the short of the biomass material. Two different situations are discussed in this part.

No emergency order. The company will buy $\min\{nuQ_{21},q\}$ from farmers.

The company bear the emergency order cost. The company will make up for the shortage of the biomass material.

2.3.1 No Emergency Order

Farmers will not make up for the shortage in this model if $q>nuQ$.

Then the farmers' expected profit function is

$$\pi_{21}^{F}=\omega\cdot E_{u}[\min\{nuQ_{21},q\}]-nCQ_{21}\ . \tag{15}$$

The first part is the revenue from the contract. And the second part is the operation cost.

Lemma 8. π_{21}^{F} is concave in Q_{21}, and the optimal Q_{21}^{*} satisfies

$$\int_{0}^{\frac{q}{nQ_{21}}}uf(u)\mathrm{d}u=\frac{C}{\omega}\ . \tag{16}$$

If $Q_{21}^{*}=M_{21}q$, then M_{21} is a constant parameter related to C, ω , $f(\cdot)$ and n. M_{21} increases with the increase of ω, and decreases with the increase of Cand n.

The company's expected profit is

$$\pi_{21}^{E}=P\cdot E_{u,x,v}[\min\{qv,x,nuQ_{21}v\}]-E\{(\omega\cdot E_{u}+yv)[\min\{nuQ_{21},q\}]\}\ . \tag{17}$$

The first part is the sales revenue. The second part is the contract-procurement cost and the production cost.

Lemma 9. The company's expected profit π_{21}^{E} is concave in q_{21}. and the optimal q_{21}^{*} satisfies

$$\int_{0}^{\infty}\int_{\frac{1}{nM_{21}}}^{\infty}\int_{qv}^{\infty}vg(x)\mathrm{d}xf(u)\mathrm{d}uh(v)\mathrm{d}v+\int_{0}^{\infty}\int_{0}^{\frac{1}{nM_{21}}}\int_{nuM_{21}qv}^{\infty}nuM_{21}vg(x)\mathrm{d}xf(u)\mathrm{d}uh(v)\mathrm{d}v \\ =\frac{(\omega+y\bar{v})[1-\int_{0}^{\frac{1}{nM_{21}}}(1-nuM_{21})f(u)\mathrm{d}u]}{P}\ . \tag{18}$$

2.3.2 The Company Bear the Emergency Order Cost

Different with the previous model. The company will make up for the shortage material when $q>nuQ$.

Then the farmers' expected profit function is same with the previous one

$$\pi_{22}^{F}=\omega\cdot E_{u}[\min\{nuQ_{22},q\}]-nCQ_{22}\ . \tag{19}$$

Lemma 10. π_{22}^{F} is concave in Q_{22}, and the optimal Q_{22}^{*} satisfies

$$\int_{0}^{\frac{q}{nQ_{22}}}uf(u)\mathrm{d}u=\frac{C}{\omega}\ . \tag{20}$$

If $Q_{22}^{*}=M_{22}q$, Then the company's expected profit is

$$\pi_{22}^{E}=P\cdot E_{x,v}[\min\{qv,x\}]-C_{e}E_{u}[(q-nuQ_{12})^{+}]-\omega\cdot E_{u}[\min\{nuQ_{22},q\}]-E[yqv]\ . \tag{21}$$

The first part is the sales revenue. The second part is the emergency order cost. The third part is the contract-procurement cost. And the last part is the production cost.

Lemma 11. The company's expected profit π_{22}^{E} is concave in q_{22}. and the optimal q_{22}^{*} satisfies

$$\int_{0}^{\infty}\int_{qv}^{\infty}vg(x)\mathrm{d}xh(v)\mathrm{d}v=\frac{\omega+y\bar{v}+(C_{e}-\omega)\int_{0}^{1/nM_{12}}(1-nuM_{12})f(u)\mathrm{d}u}{P}. \tag{22}$$

3. ANALYSIS

3.1 The Comparison of *M*

(a) $M_{21}=M_{22}$; (2) $M_{11}>M_{21}$; (3) $M_{12}>M_{21}$.

(b) Because the farmers don't have to make up for lack of biomass under default risk situation. We can know $M_{21}=M_{22}$ from Formula (16) and (20).

(c) Because of the monotonically increasing of $H(m)=\int_0^m uf(u)\mathrm{d}u$ and $C_e>\omega$, $M_{11}>M_{21}$ is approved according to Formula (4) and (16).

(d) For $0<\alpha<1$ and the monotonically increasing of $H(m)=\int_0^m uf(u)\mathrm{d}u$. It's obviously that $M_{12}>M_{21}$ according to formula (8) and (16). We find that model 3.2.2 would be equal to model 3.3.2 when $\alpha=1$.

The M can be considered as the risk sharing ratio for farmers in different mechanisms. Farmers will input more to meet the requirement from the company when M is large. It means that farmers will take the majority of the responsibility for material shortage risk. On the contrary, farmers will input less to meet the same requirement from the company when M is small. Farmers is willing to input more under no default risk compare to the other situation because of high emergency order cost.

Since the compensation efficient α is uncertain, we can't compare the level of M_{11} and M_{12}. If α satisfies $\omega+(1-\alpha)=C_e$. The farmers will face the same situation in model 3.2.1 and model 3.2.2. When α is high enough to meet $\omega+(1-\alpha)>C_e$.. The farmers will share more emergency order cost and input more to meet the company's requirement. However, if $\omega+(1-\alpha)<C_e$. The company will share the majority of the emergency cost. And farmers have no motivation to improve their input in this situation.

3.2 The Comparison of the Optimal Order Quantity

(a) $q^*_{11}>q^*_{22}$; (2) $q^*_{12}>q^*_{22}$;

(b) since q^*_{11} satisfies

$$\int_0^\infty\int_{qv}^\infty vg(x)\mathrm{d}xh(v)\mathrm{d}v=\frac{\omega+y\bar{v}}{P}\ .$$

and q^*_{22} satisfies

$$\int_0^\infty\int_{qv}^\infty vg(x)\mathrm{d}xh(v)\mathrm{d}v=\frac{\omega+y\bar{v}+(C_e-\omega)\int_0^{1/nM_{12}}(1-nuM_{12})f(u)\mathrm{d}u}{P}\ .$$

For $C_e>\omega$ and

$$(C_e-\omega)\int_0^{1/nM_{12}}(1-nuM_{12})f(u)\mathrm{d}u>.$$

We can know that $q^*_{11}>q^*_{22}$ according to the cumulative distribution function of $G(x)$. It's denoted that the company will reduce the order quantity if the emergency order cost is born by the company alone.

(c) We can see that $q^*_{12}>q^*_{22}$; from formula (10) and (22) for the same reason ibid .

Also, if α satisfies $\alpha C_e-\omega=0$.The compensation price to the farmers is equal to the contract price. The company's optimal order quantity is equal ($q^*_{11}=q^*_{12}$). When α is high enough to meet $\alpha C_e-\omega>0$. The company will reduce the order quantity to avoid the high compensation cost. On the contrary, the company will increase the order quantity if $\alpha C_e-\omega<0$.

3.3 The Comparison of the Optimal Input Quantity

(a) $Q^*_{11}>Q^*_{22}$,

(b) $Q^*_{12}>Q^*_{22}$.

We can get the conclusion from equation $Q=Mq$. This is consistent with common sense. The farmers will input more to meet the requirement because of the high cost of emergency order.

From Formula (4) and (8) we can see that

$$\begin{cases} Q^*_{11}=Q^*_{12} \text{ if } \alpha C_e-\omega=0\ . \\ Q^*_{11}>Q^*_{12} \text{ if } \alpha C_e-\omega>0\ . \\ Q^*_{11}<Q^*_{12} \text{ if } \alpha C_e-\omega<0\ . \end{cases}$$

It means that when the company improves the compensation level α. The farmers will decrease their input quantity. This is deviate from our common sense. The reason for that is the order quantity will decrease by the company if α is high because of the high emergency order cost company share. And the farmers will decrease their input quantity faced with a lower order quantity, respectively.

CONCLUSION

We research the biomass power generation problem in the perspective of farmer contracting supply chain. By establishing a mathematical model and under the random yield and demand, a multiple farmer contract with a biomass power generation company problem in a two-level supply chain is researched in this paper. We propose five different mechanisms in two situations: under default risk and no default risk. And compare the optimal decision in different contracts. We find that: (a) The famers' optimal input amount is always linear to the company's order quantity. And the proportional coefficient is determined by some certain constant and the contract mechanisms. (b) The company and farmers' optimal decision quantity will both be improved under no default risk. Because the farmers will share the emergency order cost with the company and try to avoid pay this by improving the input quantity. (c) The optimal input quantity by farmers will decrease with the increases of the compensation ratio because of the decrease of the order quantity. However, the agriculture product is seasonality and low-quality. Besides, there is transportation and inventory cost in reality. More factors can be considered into the model in the future.

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