The Impact of Loan Risk Compensation Policy in the Short Food Supply Chain: Is Blockchain-Enabled Financing More Efficient?

Purpose – This study aims to explore conditions for the application of blockchain-enabled financing versus traditional prepayment. It seeks to understand how a short food supply chain can choose more efficient financing pattern under loan risk compensation policy, crucial for designing an optimal short food supply chain.

Design/Methodology – Employing Stackelberg game, decisions of the short food supply chain regarding the adoption of different financing patterns are modeled. The theoretical model's outcomes are validated using data from the Ministry of Agriculture and Rural Affairs of China, including publicly available market prices and costs of soybeans and wheat over the past decade. Adjusted market prices are derived using consumer price index for residential prices to eliminate the impact of inflation.

Findings – The loan risk compensation rate, prepayment discount rate, blockchain-enabled financing interest rate, and distribution of crop output create three distinct scenarios, prompting members of the short food supply chain to form various financing pattern preferences. Simultaneously, loan risk compensation effectively improves supply chain performance. Moreover, the impact of risk compensation is more pronounced at lower output rates.

Originality/Value – This research emphasizes that the blockchain-enabled financing pattern is not always dominant. Government departments can shape the financing pattern preferences of supply chain members by adjusting risk compensation rate, thereby promoting the application of the blockchain-enabled financing pattern. This paper contributes to the literature on the adoption of blockchain technology for financing short food supply chain by delving into the issue of financing pattern selection.

Keywords: short food supply chain; risk compensation; supply chain finance; upstream capital constraints; blockchain

Paper type Research paper

1. Introduction

High natural and market risks in short food supply chain operations (Nakandala *et al.*, 2017), imperfect rural credit and risk management (Gow and Swinnen, 2001), the mismatch between the benefits and risks of providing loans, and insufficient credit incentives from banks, resulting in credit rationing (Kundid and Ercegovac, 2011). To relieve the "risk-return" imbalance of financial institutions, the government should establish special funds for loan risk compensation to minimize the risk and cost of agriculture-related loans by loss sharing or cost subsidies. For example, Kunshan City, Jiangsu Province, established a 50 million RMB special fund for agricultural loan risk compensation called "Kunnong Loan". It can assist the new type of agricultural operating entity withstanding planting risks and raise the cash required for agricultural production and operation more easily and at a reduced cost.

The efficient transmission of government compensation to the final beneficiary is a significant challenge. Some of the intended benefits of policy subsidies are not automatically passed on to the final recipients (Wang *et al.*, 2008). Due to its power advantage, the core firm can capture a portion of the anticipated benefits of the subsidy under the prepayment. Instead of that, it would be better to improve the effectiveness of risk subsidy policies by adopting a new blockchain-enabled financing pattern (Dong *et al.*, 2023) that directly subsidizes the risk taker, i.e., subsidizes the core business. The above article, however, does not theoretically explore the differences in risk compensation among different financing patterns. Research on blockchain-enabled financing under risk subsidies is especially important, given the role that risk subsidies play in providing incentives for the use of digital technologies like blockchain in short food supply chains. Enterprises in the supply chain can select different financing pattern according to comparison with blockchain-enabled financing, which can help short food supply chain enterprises decide the right financing options under government risk subsidies.

Specificly, this article compares *the traditional prepayment pattern* (called "*T-pattern*") to *the blockchain-enabled financing pattern* (called "*B-pattern*") in a short food supply chain that includes a financially constrained farmer, an acquirer, and a core enterprise. The farmer can use two financing patterns: the traditional prepayment (it receives funds from the acquirer) and the blockchain-enabled financing pattern (it receives bank loans with a guarantee from the core enterprise). For the two financing patterns, the government supplements the losses of the acquirer and the core firm, respectively, when the farmer experiences bankruptcy.

The former pattern is prevalent in two-tier supply chain financing (Zhao and Huchzermeier, 2019). Due to the deep-tier supply chain visibility barrier (Agrawal *et al.*, 2024), the prepayment in a three-tier supply chain cannot leverage core firms to help finance secondary suppliers. For instance, in a short food supply chain consisting of farmers, buyers, and core enterprises, farmers typically cannot access affordable bank loans with the support of the core enterprise's credit, as farmers lack a direct transactional relationship with the core enterprise. The blockchain-enabled supply chain finance pattern can just overcome these shortcomings (Dong *et al.*, 2023; Liu *et al.*, 2023). Nevertheless, given the distinct compensation targets of the loan risk compensation policy in the two financing patterns and variations in the operational processes of these patterns, a comprehensive analysis of the optimal profit variances among members of the short food supply chain in different scenarios becomes imperative. This analysis aims to empower enterprises in making well-informed choices regarding the suitable financing pattern.

The contributions of our study are as follows. First, the risk-free case is currently taken into account in numerous blockchain financing research. Our analysis takes into account the bankruptcy risk associated to the stochastic character of farmers' output. We derive the optimal decision for a short food supply chain under the loss risk compensation policy. Second, different from downstream funding constraints (Liu et al., 2023), our research considers that the blockchain-enabled financing pattern is introduced in the short food supply chain with upstream funding constraints. Under the comparison of two different financing patterns, we innovatively explore the impact of factors such as output uncertainty and compensation rate on the preference of supply chain members' financing patterns. To help the capital-constrained short food supply chain in selecting the best financing plan.

The rest of the article is organized as follows. Section 2 summarizes the literature review. Section 3 sets out the model framework and describes the two financing patterns. The supply chain game models under the two financing patterns are then analyzed separately, and equilibrium solutions are obtained. Section 4 compares the supply chain members' returns and examines the threshold at which the risk compensation rate becomes effective. Section 5 investigates the effects of financing interest rates and risk compensation rates on the choice of supply chain financing options. Section 6 presents the conclusions and outlook of the article.

2. Literature Review

2.1 Upstream financial constraints

Our paper is related to the literature that studies upstream funding constraints. On the non-agricultural side, for example, Tunca and Zhu (2018) studied the impact of buyer-mediated financing on supply-side funding constraints, arguing that it can reduce loan rates and wholesale prices and compare it to commercial loan options. Kouvelis and Zhao (2018) studied the problem of funding constraints for both suppliers and retailers, where suppliers can use bank loans. Kouvelis and Xu (2021) also analyzed bank loans, recourse versus non-recourse factoring, and reverse factoring. They found that reverse factoring is only sometimes the preferred option for suppliers despite its many advantages. In agriculture, scholars also focused on the impact of risks such as adverse weather and natural disasters on agricultural output (Miao *et al.*, 2016; Yu *et al.*, 2022). For example, Yi *et al.* (2021) studied the impact of bank financing in a supply chain consisting of "farmer + platform intermediary " in a supply chain consisting of "farmer + platform intermediary" with both bank financing and intermediary-guaranteed financing patterns. However, these articles are based on secondary supply chain analysis and do not consider the financial constraints in deep-tier supply chains. Although Dong *et al.* (2023), Liu *et al.* (2023) studied the capital constraint problem in deep-tier supply chains, they focused on the downstream capital constraint problem. An *et al.* (2023) and Zhao *et al.* (2024) examined the effectiveness of blockchain technology in solving the problem of financial constraints as well as the problem of financial fraud, respectively, but did not consider the impact of loan loss subsidy. The subsidy, however, is crucial to stimulate lenders' initiative and alleviate the financial constraint problem of agri-related firms, especially in agri-related loans.

2.2 Agricultural Supply Chain Operations Management

This work also addresses two streams in operations management. On the one hand, our paper is related to the literature on agricultural supply chain operations management that examines the impact of uncertain agricultural yields on various decisions. Kazaz (2004) examined production planning with stochastic yields and demand in the olive oil industry. Subsequently, Kazaz and Webster (2011) studied the impact of output-related transaction costs on the optimal choice of selling prices and yields under agricultural supply uncertainty. Anderson and Monjardino (2019) studied novel contracts that could coordinate agricultural supply chains under yield risk to understand the relationship between yields, fertilizers, and weather. However, this literature does not address the content of financial constraints and subsidy mechanisms.

On the other hand, there is a growing body of research on operations management - this literature examines government subsidies in different contexts (Alizamir et al. ,2019; Ye et al. ,2021; Guo et al., 2022). For example, for the farmer subsidy aspect of the supply chain, Guda et al. (2021) studied the Guaranteed Support Price scheme (GSP). The scheme supported farmers and the poor by purchasing agricultural products at attractive prices and redistributing the products to the poor at subsidized prices. Shi *et al.* (2021) studied the impact of yield insurance and government premium subsidies on farmers when there is uncertainty in output risk. They concluded that yield insurance and premium subsidies might cause a decline in returns per unit area. ChintTalli and Tang (2022) compared and analyzed two types of government subsidies, cost subsidies, and minimum support prices, and found that both subsidies could increase yields. However, cost subsidies were more effective.

In addition, interventions such as government subsidies have also been studied in the context of firms' financial constraints. For example, Akkaya et al. (2021) compared the effects of two policy instruments, taxes, and subsidies, on the adoption of new methods and found that a zero-expenditure policy does not lead to a decline in social welfare when producers face financial constraints during the transition phase to new methods. Jin et al. (2022) studied the effects of two government support policies, loan guarantees and interest subsidies, on financially constrained manufacturing firms and found that both policies are conducive to higher output and economic performance. Our work differs from theirs in that we focus on government intervention under the risk of borrower insolvency. This government intervention depends on the lender's loan losses, which have received minimal attention.

In table 1, the literature in the review has been categorized to highlight the differences in this study. We focus on the comparison of financing models in a three-tier short food supply chain and consider the impact of risk compensation rates. In studies comparing financing models, they usually only compare the differences in optimal decisions between different financing models without considering the changes brought about by the impact of risk. In our study, loss risk compensation is introduced based on the bankruptcy risk associated with output uncertainty. In particular, our study is carried out in a three-tier supply chain, further dissecting the impact of loss risk compensation rate on supply chain members.

Table 1： Categorized literature.

Referennce	Supply chain	Financial constraints	Subsidy	Blockchain
Tunca and Zhu (2018)	Two tiers	Y	N	N
Kouvelis and Zhao (2018)	Two tiers	Y	N	N
Kouvelis and Xu (2021)	Two tiers	Y	N	N
Yi et al. (2021)	Two tiers	Y	N	N
Dong et al. (2023)	Deep tiers	Y	N	Y
Liu et al. (2023)	Deep tiers	Y	N	Y
An et al. (2023)	Deep tiers	Y	N	Y
Zhao et al. (2024)	Deep tiers	Y	N	Y
Kazaz (2004)	Two tiers	N	N	N
Kazaz and Webster (2011)	Two tiers	N	N	N
Anderson and Monjardino (2019)	Two tiers	N	N	N
Alizamir et al. (2019)	Two tiers	N	Y	N
Ye et al. (2021)	Two tiers	N	Y	N
Guo et al., 2022	Two tiers	N	Y	N
Guda et al. (2021)	Two tiers	N	Y	N
Shi et al. (2021)	Two tiers	N	Y	N
ChintTalli and Tang (2022)	Two tiers	N	Y	N
Akkaya et al. (2021)	Two tiers	Y	Y	N
Jin et al. (2022)	Two tiers	Y	Y	N
This research	Deep tiers	Y	Y	Y

Note: Y means yes, N means no.

3. Problem Statement

3.1 Mode Description

Now we start to introduce two financing patterns. Consider a short food supply chain consisting of the farmer who lacks capital and the well-funded acquirer and core enterprise. The farmer faces the pressure of no initial capital and must resort to external financial support to maintain production.

(1) Traditional Prepayment pattern

The process between the three parties in the short food supply chain under the traditional prepayment is as follows. **1)** The core enterprise needs to purchase agricultural products from the acquirer at a specific price. **2)** The acquirer buys agricultural products from the farmer at a specific price. At the same time, part of the payment is made in advance based on a specific discount rate to meet the funds required by the farmer for production. **3)** The farmer decides their planting area. During harvesting, it supplies agricultural products to the acquirer while the acquirer pays the purchase price. If the total payment is not enough to deduct the advance, the farmer goes bankrupt, and after the bankruptcy, the farmer's profit is zero. Then the acquirer will bear the loss and receive compensation from the government; otherwise, the farmer can also receive the remaining payment after deducting the prepayment and interest. **4)** The acquirer supplies the agricultural products to the core enterprise. **5)** The core enterprise processes and packages the agricultural products and sells them to consumers.

(2) Blockchain-Enabled Financing pattern

Based on the characteristics of blockchain, such as tamper-evident, the farmer can pass their transaction information to the core enterprise. Then the core enterprise can guarantee the remote farmer after confirming the farmer's credit. As a result, the farmer can obtain a loan from the bank for production. At the end of the period, the farmer pays the principal and interest of the loan to the bank. We call it a blockchain-enabled financing pattern.

The process between the three parties in the short food supply chain under this model is as follows. **1)** The core enterprise purchases agricultural products from the acquirer at a specific price. **2)** The acquirer buys agricultural products from the farmer at a specific price. **3)** The core enterprise obtains the farmer's transaction information and confirms the farmer's credit status. **4)** The core enterprise provides a guarantee for the farmer. **5)** The farmer borrows from the bank under the guarantee of the core enterprise, and the bank provides loan funds for him after approval. **6)** With the support of loan funds and the acquirer's purchase price, the farmer decides on the planting area. **7)** The product is supplied to the acquirer during the harvest season. If the total payment is not enough to pay the principal and interest of the bank loan, the farmer will go bankrupt, and the farmer's profit will be zero after bankruptcy. The unpaid principal and interest of the loan will be borne by the core enterprise and compensated by the government; otherwise, the farmer will also receive the remaining purchase price after deducting the principal and interest of the loan. **8)** The core enterprise purchases all the agricultural products from the acquirer, processes, packages the agricultural products, and then sells the agricultural products to the consumers in the market.

3.2 Parameter Descriptions and Assumptions

Table 2 defines the relevant parameters.

Table 2: Parameter List.

Parameters	Definition
General Parameters	
x	Agricultural output rate
c	Coefficients of the quadratic cost function
p	Agricultural market price
N	Maximum possible market price (intercept of the inverse demand curve)
b	Price sensitivity of the inverse demand function
t	Loan risk compensation rate
r_a	Prepayment discount rate
r_b	Bank loan interest rate in blockchain-enabled financing
π^f	The farmer's profit
π^s	The acquirer's profit
π^m	The core enterprise's profit
Decision variables	
q	The farmer's planting area
ω_1	The acquirer's purchase price
ω_2	The core enterprise's purchase price

We made the following assumptions to characterize realistic financing patterns further and simplify the game model.

1) Assume that the agricultural output rate x is a continuous random variable with a density function of $f(x)$ and a normal distribution function of $F(x)$. The agricultural output rate x has mean μ ($L \le \mu \le H$)and standard deviation σ, Where L represents the minimum output rate, which can even be zero in the event of a disaster, and H represents the maximum output rate.

2) Drawing on previous studies (Niu *et al.*, 2016; Ye *et al.*, 2020), let the production cost function be $C(q) = cq^2$, and the market price of agricultural products satisfy $p = N - bqx$, where qx represents the amount of agricultural output.

3) Due to government financial constraints, we assume a government compensation rate $t \in [0,1]$. For differentiation, it is assumed that, prior to the discussion section, the government compensation rates are uniform across both financing patterns.

4) Without considering the moral hazard of the three parties, it is assumed that the farmer does not default but has limited funds and goes bankrupt if there are not enough funds to repay the loan. Similar to article (Jing and Seidmann, 2014), assume that the initial capital of the farmer is zero.

5) The superscripts f, s, and m represent the farmer, acquirer, and core enterprise, respectively, and * denotes the optimal solution. T and B subscripts represent the traditional prepayment and the blockchain-enable financing pattern, respectively.

3.3 Modeling and Equilibrium

Given the existence of output risk, if the agricultural output rate falls below a specific value, the farmer may not be able to repay the loan funds, resulting in the loss of farm-related loans for the acquirer or the core enterprise. To this end, the supply chain decision model with two financing patterns in the case of farmers' bankruptcy risk is discussed below.

3.3.1 Traditional Prepayment pattern

(1) The farmer's decision making

The expected profit function of the farmer is as follows.

$$\pi_T^f\left(q_T\right)=E\left[q_T x\omega_{T1}-cq_T^2(1+r_a)\right]^+ \tag{1}$$

where $z^+=\max(z,0)$, $q_T x\omega_{T1}$ represents the payment for the sale of agricultural products received by the farmer from the acquirer. And $cq_T^2(1+r_a)$ is the principal and interest on the loan, i.e., the funds the farmer needs to repay the acquirer.

When $q_T x\omega_{T1}\le cq_T^2(1+r_a)$, the farmer is insolvent. For the convenience of calculation, note that $x_T=cq_T(1+r_a)/\omega_{T1}$ denotes the critical point of bankruptcy of the farmer. Therefore, from equation (1), the expected profit function of the farmer is

$$\pi_T^f\left(q_T\right)=\int_{x_T}^{H}(q_T x\omega_{T1}-cq_T^2(1+r_a))f(x)dx \tag{2}$$

From equation (2), the first-order derivative is equal to zero, and we have

$$q_T^*=\frac{\omega_{T1}x_{T0}}{c(1+r_a)} \tag{3}$$

Where $x_{T0} = \dfrac{HF(H) - \int_{x_T}^{H} F(x)dx}{2F(H) - F(x_T)}$.

(2) The acquirer's decision making

If $x > x_T$, then the acquirer will have no loss; if $x \le x_T$, the acquirer's loss is $cq_T^{*2}(1+r_a) - q_T^* x\omega_{T1}$. Thus, the acquirer loss can be expressed as $\theta_1 = cq_T^2(1+r_a) - E\min\left(cq_T^2(1+r_a), q_T x\omega_{T1}\right)$, and $t\theta_1$ is the amount of government compensation for the acquirer loss.

Therefore, the acquirer's expected profit is

$$\pi_T^s\left(\omega_{T1}\right) = E\left[q_T x\omega_{T2} - q_T x\omega_{T1} - \theta_1 + t\theta_1\right] \tag{4}$$

where $q_T x\omega_{T2}$ represents the payment received by the acquirer from the core enterprise.

q_T^* is substituted into equation (4), and after simplification, we get

$$\begin{aligned}\pi_T^s\left(\omega_{T1}\right) = \frac{x_{T0}}{c(1+r_a)}[&\mu(\omega_{T2} - \omega_{T1})\omega_{T1} - (1-t)\omega_{T1}^2(\int_L^{x_T} F(x)dx \\ &+LF(L) - x_{T0}F(L))]\end{aligned} \tag{5}$$

From equation (5), the first-order derivative is equal to zero, and we have

$$\omega_{T1}^* = \frac{\mu\omega_{T2}}{2\mu + 2(1-t)k_T} \tag{6}$$

where $k_T = \int_L^{x_T} F(x)dx + LF(L) - x_{T0}F(L)$.

(3) The core enterprise's decision making

The core enterprise's expected profit is

$$\pi_T^m\left(\omega_{T2}\right) = E\left[pq_T x - q_T x\omega_{T2}\right] \tag{7}$$

where $pq_T x$ is the sales revenue of the core enterprise.

Substituting equation (3) and equation (6) into equation (7), and simplifying, we get

$$\pi_T^m\left(\omega_{T2}\right) = \frac{\mu^2 x_{T0}}{c(1+r_a)[2\mu + 2(1-t)k_T]}\{N\omega_{T2} - \omega_{T2}^2 - \frac{b(\mu^2+\sigma^2)x_{T0}\omega_{T2}^2}{c(1+r_a)[2\mu+2(1-t)k_T]}\} \tag{8}$$

From equation (8), the first-order derivative is equal to zero, and we have

$$\omega_{T2}^{*}=\frac{Nc(1+r_a)[\mu+(1-t)k_T]}{\varepsilon} \tag{9}$$

where $\varepsilon=2c(1+r_a)[\mu+(1-t)k_T]+b(\mu^2+\sigma^2)x_{T0}$.

Substituting equation (9) into equation (3) and equation (6), we get

$$q_T^{*}=\frac{N\mu x_{T0}}{2\varepsilon} \tag{10}$$

$$\omega_{T1}^{*}=\frac{N\mu c(1+r_a)}{2\varepsilon} \tag{11}$$

Substituting q_T^*, ω_{T1}^* and ω_{T2}^* into equation (2), equation (5) and equation (8), we get

$$\pi_T^{f*}=\frac{N^2\mu^2 x_{T0}c(1+r_a)Z}{4\varepsilon^2} \tag{12}$$

$$\pi_T^{s*}=\frac{N^2\mu^2 x_{T0}c(1+r_a)[\mu+(1-t)k_T]}{4\varepsilon^2} \tag{13}$$

$$\pi_T^{m*}=\frac{N^2\mu^2 x_{T0}}{4\varepsilon} \tag{14}$$

where $Z=HF(H)-x_{T0}F(H)-\int_{x_{T0}}^{H}F(x)dx$.

3.3.2 Blockchain-Enabled Financing Pattern

(1) The farmer's decision making

The expected profit function of the farmer is as follows.

$$\pi_B^f(q_B)=E\left[q_B x\omega_{B1}-cq_B^2(1+r_b)\right]^+ \tag{15}$$

where $q_B x\omega_{B1}$ represents the payment from the acquirer. And $cq_B^2(1+r_b)$ is the principal and interest on the bank loan, i.e., the funds the farmer needs to repay the bank.

When $q_B x\omega_{B1}\le cq_B^2(1+r_b)$, the farmer is insolvent. Same as prepayment, note that $x_B=cq_B(1+r_b)/\omega_{B1}$ denotes the critical point of bankruptcy of the farmer under B-pattern. Therefore, from equation (15), the expected profit function of the farmer under B-pattern is

$$\pi_B^f(q_B)=\int_{x_B}^{H}(q_B x\omega_{B1}-cq_B^2(1+r_b))f(x)dx \tag{16}$$

From equation (16), the first-order derivative is equal to zero, and we have

$$q_B^* = \frac{\omega_{B1} x_{B0}}{c(1+r_b)} \tag{17}$$

where $x_{B0} = \dfrac{HF(H) - \int_{x_B}^{H} F(x)dx}{2F(H) - F(x_B)}$.

(2) The acquirer's decision making

The acquirer's expected profit is

$$\pi_B^s(\omega_{B1}) = E(q_B x \omega_{B2} - q_B x \omega_{B1}) \tag{18}$$

where $q_B x \omega_{B2}$ represents the core enterprise payment.

The q_B^* is substituted into equation (18), and after simplification, we get

$$\pi_B^s(\omega_{B1}) = \frac{x_{B0}\mu(\omega_{B2} - \omega_{B1})\omega_{B1}}{c(1+r_b)} \tag{19}$$

From equation (19), the first-order derivative is equal to zero, and we have

$$\omega_{B1}^* = \frac{\omega_{B2}}{2} \tag{20}$$

(3) The core enterprise's decision making

If $x > x_B$, then the core enterprise has no loss; if $x \le x_B$, the loss is $cq_B^2(1+r_b) - q_B x \omega_{B1}$. Thus, the loss under B-pattern can be expressed as $\theta_2 = cq_B^2(1+r_b) - E\min\left[cq_B^2(1+r_b), q_B x \omega_{B1}\right]$, and $t\theta_2$ is the amount of government compensation for the core enterprise loss.

Therefore, the core enterprise's expected profit is

$$\pi_B^m(\omega_{B2}) = E[pq_B x - q_B x \omega_{B2} - \theta_2 + t\theta_2] \tag{21}$$

where $pq_B x$ is the sales revenue of the core enterprise.

Substituting equation (17) and equation (20) into equation (21), and simplifying, we get

$$\begin{aligned}\pi_B^m(\omega_{B2}) = \frac{x_{B0}}{4c(1+r_b)}\{2\mu(N - \omega_{B2})\omega_{B2} - \frac{b(\mu^2+\sigma^2)x_{B0}\omega_{B2}^2}{c(1+r_b)} \\ -(1-t)\omega_{B2}^2[\int_L^{x_B} F(x)dx + LF(L) - x_{B0}F(L)]\}\end{aligned} \tag{22}$$

where $k_B = \int_L^{x_B} F(x)dx + LF(L) - x_{B0}F(L)$.

From equation (22), the first order derivative is equal to zero, and we have

$$\omega_{B2}^{*}=\frac{Nc\mu(1+r_b)}{\delta} \tag{23}$$

where $\delta=c(1+r_b)[2\mu+(1-t)k_B]+b(\mu^2+\sigma^2)x_{B0}$.

Substituting ω_{B2}^{*} into equation (17) and equation (20), we get

$$q_B^{*}=\frac{N\mu x_{B0}}{2\delta} \tag{24}$$

$$\omega_{B1}^{*}=\frac{Nc\mu(1+r_b)}{2\delta} \tag{25}$$

Based on the expression for the critical point in x_B and x_T, we know that the value of the critical point depends on the distribution function of the x so that we can obtain $x_B=x_{B0}=x_T=x_{T0}, k_B=k_T$. For ease of illustration, the subsequent use of k denotes k_B and k_T.

Substituting q_B^{*}, ω_{B1}^{*} and ω_{B2}^{*} into equation (18), equation (19) and equation (22), we get

$$\pi_B^{f*}=\frac{N^2\mu^2x_{B0}c(1+r_b)Z}{4\delta^2} \tag{26}$$

$$\pi_B^{s*}=\frac{N^2\mu^3x_{B0}c(1+r_b)}{4\delta^2} \tag{29}$$

$$\pi_B^{m}\left(\omega_{B2}\right)=\frac{N^2\mu^2x_{B0}}{4\delta} \tag{30}$$

4. Results Analysis

4.1 Character of Equilibrium

In this section, we try to answer: the differences in equilibrium decisions under different financing patterns, including farmers' equilibrium acreage and purchase and procurement prices of agricultural products.

Proposition 1 There are critical values.

(1) When $\frac{\varepsilon}{\delta}>1$, $q_B^{*}>q_T^{*}$;

(2) When $\frac{\varepsilon}{\delta}>\frac{1+r_a}{1+r_b}$, $\omega_{B1}^{*}>\omega_{T1}^{*}$;

(3) When $\frac{\varepsilon}{\delta}>\frac{1+r_a}{1+r_b}[1+\frac{(1-t)k}{\mu}]$, $\omega_{B2}^{*}>\omega_{T2}^{*}$.

Proof of proposition 1: Proposition 1 can be obtained by comparing the planting area and purchase prices under the two financing patterns.

Proposition 1 shows that the value of $\frac{\varepsilon}{\delta}$ plays a vital role in the supply chain decision under both financing patterns. Moreover, a higher $\frac{\varepsilon}{\delta}$ value will result in a larger optimal acreage for the farmer and higher purchase prices for the acquirer and core enterprise under the B-pattern.

Next, we examined the preferences of three supply chain parties for financing patterns.

Proposition 2 Between the two financing patterns,

(1) When $\frac{\varepsilon}{\delta} > \sqrt{\frac{1+r_a}{1+r_b}}$, the farmer prefers B-pattern;

(2) When $\frac{\varepsilon}{\delta} > \sqrt{\frac{1+r_a}{1+r_b}[1+\frac{(1-t)k}{\mu}]}$, the acquirer prefers B-pattern;

(3) When $\frac{\varepsilon}{\delta} > 1$, the core enterprise prefers B-pattern.

Proof of proposition 2: Let the profit of supply chain members in B-pattern be greater than that in T-pattern, which proves proposition 2.

Proposition 2 illustrates that supply chain members can adopt different financing patterns according to local conditions to use government subsidies to obtain maximum benefits effectively. Furthermore, high $\frac{\varepsilon}{\delta}$ can achieve a win-win situation for the farmer, acquirer, and core enterprise under the B-pattern. Given the complexity of the model, a more detailed analysis of the preferences is presented later in the next section.

4.2 Threshold for risk compensation to work

With the risk of bankruptcy, the farmer will go bankrupt if it encounters a disaster that results in a lower crop output rate. Based on $x_B = x_{B0} = x_{T0} = x_T$ it is known that when the output rate is lower than x_{B0} , there is $\theta_1 > 0$ and $\theta_2 > 0$; otherwise, the loan risk loss is 0. Inherent Proposition.

Proposition 3 Regardless of whether the T-pattern or the B-pattern is used, government compensation can reduce the losses of the acquirer or the core firm when the output rate $x < x_{B0}$. Otherwise, no government compensation is required.

Proposition 3 shows that the farmer will go bankrupt when $x < x_{B0}$ i.e., the acquirer (core firm) will have the risk of losing the advance (guarantee) and will need to be compensated by the government; otherwise, no compensation is required. It can be seen that $x = x_{B0}$ is the turning point of whether government compensation can work. Although financing patterns may stimulate the farmer to plant more or less, the bankruptcy tipping point is not related to the choice of financing pattern, not to the farmers' loan capital, but only to the distribution of output rates.

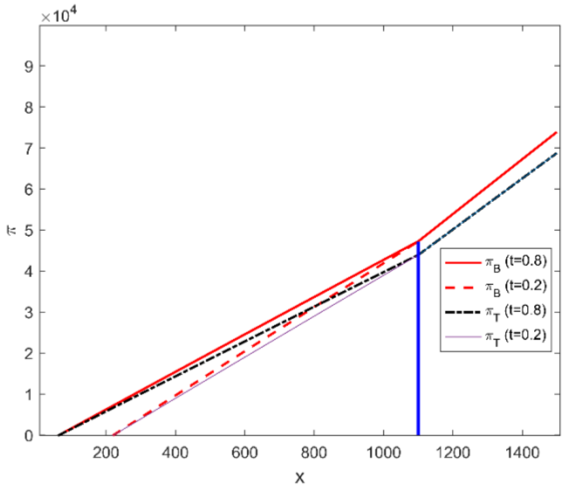

Figure 1. The effect of t and x on π.

Note: $N = 7.343, c = 243.723, r_a = 0.1, r_b = 0.02, b = 0.000008701, \mu = 2185, \sigma = 498$

In addition, we investigate the impact of changes in output rate x and risk compensation rate t on the total returns of the short food supply chain under different financing patterns. As shown in Figure 1, $x = 1100.82$ is the dividing line. At this point, it can be found that: to the right of the dividing line, different values of t do not affect the total revenue of the short food supply chain. That is because when the output rate is greater than $x = 1100.82$, there is no possibility of bankruptcy for the farmer, so loan risk compensation does not play a role. On the left side of the dividing line, the total return of the supply chain under both financing patterns increases as t increases, and the lower the output rate x , the more significant the effect of t on the total return of the short food supply chain.

5. Discussion of short food supply chain financing pattern options

The preference for optimal financing pattern to supply chain members may be different. Constrained by the power advantage of the core firms, the financing pattern of SMEs can only rely on the choice of the core firms.

For convenience, based on proposition 2 , the preference thresholds for the farmer and the acquirer are noted as $\lambda_1 = \sqrt{\frac{1+r_a}{1+r_b}}$, $\lambda_2 = \sqrt{\frac{1+r_a}{1+r_b}[1+\frac{(1-t)k}{\mu}]}$ .The parameter h represents the upper limit of $\frac{\varepsilon}{\delta}$. Therefore, there are three scenarios of financing options as follows.

(1) Scenario 1: $1 < \lambda_1 < \lambda_2 < h$

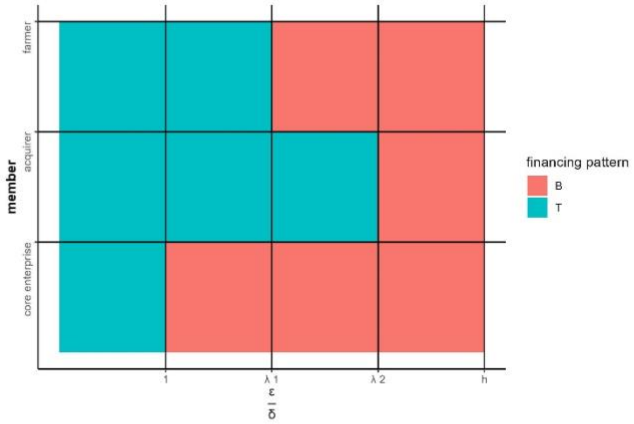

Figure 2. Preference of financing pattern selection in scenario 1.

As shown in Figure 2, in this scenario, if $\frac{\varepsilon}{\delta} \in (\lambda_2, h)$, the B-pattern is more beneficial to all three members of the supply chain. If $\frac{\varepsilon}{\delta} \in (\lambda_1, \lambda_2)$, the B-pattern is more beneficial to the farmer and the core enterprise.

In the case of $\frac{\varepsilon}{\delta} \in (1, \lambda_1)$, both the farmer and the acquirer prefer the T-pattern because they are relatively more profitable under this financing pattern. However, the core companies prefer the B-pattern. If the core enterprise selects its supply chain members based on this mode, the farmer and acquirer, who are on the weaker side of the supply chain, will have to compromise - and their returns will suffer as a result.

To protect the farmers' profit, the government can force the core enterprise to choose the T-pattern by adjusting the compensation rate. Specifically, it can give different risk compensation rates according to different financing patterns so that the following corollary can be made.

Corollary 1 When $\frac{\varepsilon}{\delta} \in (1, \lambda_1)$, the financing pattern preference of the core enterprise can not be forced to shift.

Proof of corollary 1: When considering two financing patterns with different compensation rates, let $\pi_T^{m*} > \pi_B^{m*}$, we obtain $\frac{\varepsilon}{\delta} < 1$, which contradicts the premise assumption $\frac{\varepsilon}{\delta} \in (1, \lambda_1)$. It proves corollary.

As shown in Figure 2, the case of $\frac{\varepsilon}{\delta} < 1$ should be disregarded. Because $\lambda_1 > 1$ in scenario 1 proves that $\frac{\varepsilon}{\delta} > 1$ holds constant.

(2) Scenario 2: $\lambda_1 < 1 < \lambda_2 < h$

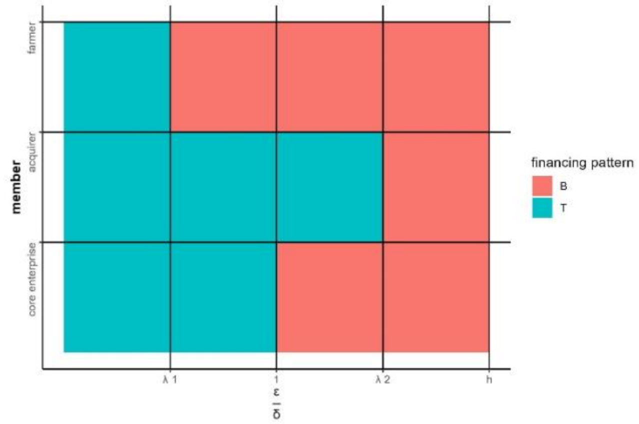

Figure 3. Preference of financing pattern selection in scenario 2.

As shown in Figure 3, in this scenario, if $\frac{\varepsilon}{\delta} \in (0, \lambda_1)$, all the members of the short food supply chain prefer the T-pattern. If $\frac{\varepsilon}{\delta} \in (\lambda_2, h)$, all the members of the short food supply chain prefer the B-pattern. If $\frac{\varepsilon}{\delta} \in (1, \lambda_2)$, both the core enterprise and the farmer prefer the B-pattern. However, the acquirer is forced to choose the B-pattern due to the strength advantage of the core enterprise. It is important to note that in case $\frac{\varepsilon}{\delta} \in (\lambda_1, 1)$, only the farmer prefers B-pattern because it has higher returns in this mode. Therefore, if we want to protect the farmer's income, the government department can force the acquirer and the core enterprise to choose the B-pattern of the supply chain by adjusting the risk compensation rate. Therefore, the following inference can be drawn.

Corollary 2 When $\frac{\varepsilon}{\delta} \in (\lambda_1, 1)$, if the government's risk compensation rate for both T and B-patterns satisfies condition $t_T < 1 + \frac{k}{\mu} - \frac{1+r_b}{1+r_a}\left[\frac{k}{\mu} + \frac{1-t_B}{2}\right]$, it can force the core firm to shift its financing pattern preference from T to B.

Proof of corollary 2: When considering two financing patterns with different compensation rates, let $\pi_T^{m*} < \pi_B^{m*}$, corollary 2 can be proved.

(3) Scenario 3: $\lambda_1 < \lambda_2 < 1$

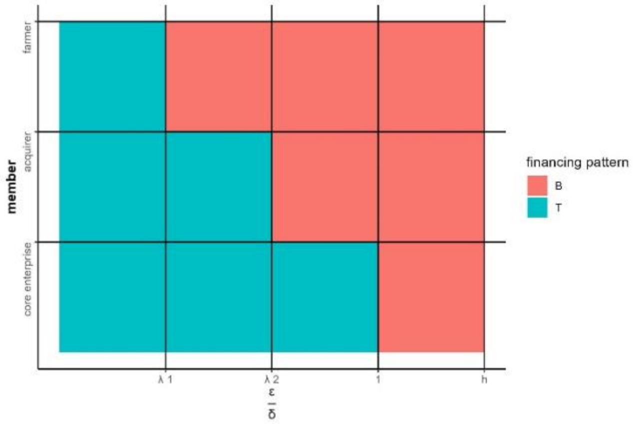

Figure 4. Preference of financing pattern selection in scenario 3.

As shown in Figure 4, in this scenario, we need to pay attention to the $(\lambda_1, 1)$ interval when it is better for the farmers to choose the B-pattern. However, the core firm prefers the T-pattern. Forced by the power advantage of the core business, the farmer's profits can only be damaged. At this point, the risk compensation can be adjusted to force the acquirer and the core enterprise to choose the B-pattern of the supply chain. The corollary is the same as scenario 2, except that each supply chain member has a different financing pattern preference. It is not repeated here.

6. Conclusion

Based on the problem of the farmer's financial constraints in the short food supply chain, this paper examines the differences between the traditional prepayment and the blockchain-enabled supply chain finance mode, as well as the preferences for financing pattern selection. It provides an in-depth analysis of the role of loan risk compensation. On the one hand, we offer theoretical guidelines for choosing the appropriate financing pattern for short food supply chains when bankruptcy risk is considered. On the other hand, we offer a reference basis for designing loan risk compensation strategies, thereby accelerating the deployment of blockchain technology in short food supply chain financing. Specifically, the following is a summary of the article's key points:

(1) The decision of short food supply chain members under different financing patterns is influenced by factors such as the financing interest rate, the cost, and the output distribution. By the critical value expression we established, the higher the critical value, the greater the area planted by farmers under the blockchain-enabled financing pattern and the greater the purchase prices. The firm's decision under the new financing pattern may be inferior to the traditional prepayment at lower critical values.

(2) Government risk subsidies improve the performance of the short food supply chain and are more effective at low output rates. Nevertheless, they are only effective when output rates are below the farm's bankrupt threshold. Although the results above demonstrate that the farmer's equilibrium acreage varies across financing patterns, the farmer's bankruptcy thresholds are not affected by the financing pattern. They are only connected to the output distribution of crops. It also shows that when the farmer is subject to bankruptcy risk, the losses incurred by lenders differ depending on the financing pattern. A formerly higher-yielding financing option may lead to increased losses. Consequently, it is vital to select the most suitable mode of financing based on the circumstances.

(3) We provide each party's preferred financing pattern depending on the range of the critical value expression we established. We consider that the core enterprise may compel weaker parties to alter their mode choice preferences in light of its powerful advantages. We provide a range of loan risk compensation rates under different scenarios to change the core enterprise's financing pattern preference to stimulate the adoption of innovative technologies.

7. Management implications

In the field of supply chain financing, small and medium-sized enterprises (SMEs) often face various challenges in obtaining bank loans due to lack of collateral. While blockchain-based financing present opportunities, they are not always superior to traditional models, especially when faced with the risk of loan losses. This paper suggests two management implications. First, short food supply chain practitioners should consider the two financing modes and the applicable conditions of government subsidy policies, in light of seasonal climate and changes in production costs, to choose an appropriate financing mode for improved performance. Second, the government should monitor whether risk compensation rates in subsidy policies are affecting supply chain practitioners' financing choices in unintended ways, potentially creating barriers to the adoption of blockchain technology. To further promote new technology adoption, the government could also consider offering targeted subsidies for blockchain-based financing modes.

8. Limitations and future work

In this paper, the research has some limitations that can be addressed in future work. Firstly, only the blockchain-enabled financing option based on company guarantee was covered in our article. Future studies can investigate additional supply chain financing patterns allowed by blockchain technology, such as reverse factoring and accounts receivable. Secondly, this study only considered yield uncertainty. Future research could take into account uncertainties on both the supply and demand sides to better understand the complexities of short food supply chains. Lastly, the results concentrate on the distinctions between modes resulting from risk compensation. Additional elements, such as price subsidies, income subsidies, and precise poverty alleviation, can be considered in subsequent research.

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