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Evolutionary Game Analysis of Blockchain Technology Preventing Supply Chain Financial Risks

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Abstract: Because of the risks existing in supply chain finance, taking accounts receivable factoring business as the research object, this paper uses the evolutionary game method to analyzes the factors affecting the decision-making of the participants in supply chain finance, constructs an evolutionary game model between small and medium-sized enterprises and financial institutions, and analyzes the mechanism of blockchain to solve the financial risks of the supply chain by comparing the changes of evolutionary stability strategies before and after the introduction of blockchain technology. This paper aims to reduce financing risks by analyzing the mechanism of blockchain technology in supply chain finance. It is found that, firstly, blockchain technology can reduce the credit risk of financial institutions and solve financing problem. Credit risk plays a decisive role in whether financial institutions accept financing business decisions. Blockchain technology can reduce the operational risk of financial institutions and improve the business income of financial institutions. Secondly, the strict regulatory environment formed by blockchain technology makes the default behavior of small and medium-sized enterprises and core enterprises in a high-risk state at all times. No matter the profit distribution proportion that small and medium-sized enterprises can obtain through collusion, they will not choose to default, which effectively solves the paradox that small and medium-sized enterprises cannot obtain loans from financial institutions despite the increased probability of compliance. Then, the evolutionary game between financial institutions and small and medium-sized enterprises is balanced in that financial institutions accept business applications, small and medium-sized enterprises abide by the contract, and the convergence effect is better. Therefore, blockchain technology not only reduces the financing risk of financial institutions but also helps to solve the financing problems of small and medium-sized enterprises.

Keywords: blockchain; supply chain finance; account receivable factoring; evolutionary game

1. Introduction

The increasing competition forces enterprises in the supply chain to establish business alliances based on the commonality of commodity flow, capital flow, and information flow, aiming to reduce costs and improve competitive strength [1]. However, in the transaction process of the alliance, the increased difficulty of risk control caused by information asymmetry has led financial institutions to raise the threshold for enterprises to finance, thus increasing the difficulty of financing for alliance enterprises [2]. Supply chain finance (SCF) originates from this background, which provides a new way to solve the financing difficulties of small and medium-sized enterprises (SMEs) and reduce the financing risk of financial institutions.

Although SCF provides a feasible way to solve the financing difficulties of enterprises, the problems such as insufficient information penetration in the whole chain, weakening data quality, low payment and settlement efficiency, and shallow credit transmission levels [3], increase the credit risk of financial institutions. Therefore, financial institutions

must pay more credit investigation cost to evaluate the credit status of enterprises before lending [4]. The basic features of blockchain technology such as decentralization, traceability, tamper-proof, and smart contract [5,6] have effectively broken the information barriers within and between organizations [7] and provided a new idea for preventing and solving the risk issues in SCF [8]. Relevant research has shown that there are four main ways for blockchain technology to promote the development of SCF: (1) distributed records solve information asymmetry; (2) data traceability improves enterprise supervision; (3) the decentralized characteristics increases the efficiency of clearing and settlement; (4) smart contract technology resolves operational risk [9]. SCF has three financing modes: accounts receivable, inventory pledge, and prepaid accounts. In different financing businesses, the mechanism of blockchain technology is different [10]. However, the research on the utilization of blockchain technology in SCF mainly focuses on mechanism design [11,12], application optimization [13–15], and technology optimization [10,16–18]. In addition, some studies have analyzed the mechanism of blockchain technology to optimize SCF in combination with specific cases, and designed new financial management solutions, which confirmed that blockchain technology is beneficial to improving the efficiency of business operations [19,20]. The research on the mechanism of employing blockchain technology to prevent risks in SCF is not sufficient.

SCF mainly involves three subjects: SMEs, core enterprises, and financial institutions. As the supplier of traded commodities, SMEs initiate financing business applications to financial institutions after the core enterprises confirm the receipt and form accounts receivable vouchers. Therefore, SMEs are also the demand side of funds. As the demanders of traded commodities, core enterprises issue accounts receivable vouchers and provide financing guarantees for SMEs. Financial institutions are the suppliers of funds in SCF. After evaluating the credit level of SMEs and core enterprises, they decide whether to provide funding. The decision-making behavior of each subject in SCF is a dynamic and repeated process. On the one hand, the default of SMEs will have an impact on whether the core enterprises continue to cooperate with them in the later stage, and then affect the performance choice of SMEs. On the other hand, whether financial institutions are willing to make loans depends not only on whether SMEs have core enterprises as guarantees and the credit situation of core enterprises, but also on the early credit situation of SMEs. Therefore, each subject needs to make repeated choices based on historical data and realistic conditions so that the system may eventually present various equilibrium states. There are mainly credit risks and operational risks in this process. Different types of risks will have different degrees of impact on the decision-making. In combination with the decision-makers different behavior tendencies, clarifying the mechanism and conditions of blockchain technology to reduce risks and to affect the decision-making of participants is the premise for the rational application of blockchain technology. Based on the limited rationality of participants, the evolutionary game emphasizes the dynamic process of equilibrium evolution. By analyzing equilibrium solutions, the evolutionary game can provide a reliable method for studying the action mechanism of blockchain technology in SCF.

At present, there are many game studies on the application of blockchain technology to SCF by starting with pledge business [21], and this paper will also follow this practice. Accounts receivable factoring is a common product in SCF. It has important practical value for solving the shortage of operating funds of enterprises. Accounts receivable factoring business can effectively make up for the SME's funding gap [22]. The factoring business of accounts receivable can be divided into two modes: with recourse and non-recourse. Some studies have built a non-recourse factoring financing model for accounts receivable [23]. Most studies show the impact of account receivable factoring business on supply chain performance and SMEs financing strategies [24–27]. However, the existing research ignores the sequence of repayment date and due date of accounts receivable in the process of real pledges, as well as the differences between core enterprises or SMEs, which violates the embodiment of the practical value of SCF. In addition, most existing studies sort out the

influencing factors of financing participants' decision-making in a static way [28], ignoring the sequence between financial institutions' credit investigation and their decision-making, and did not highlight the action mechanism of blockchain technology in the game process.
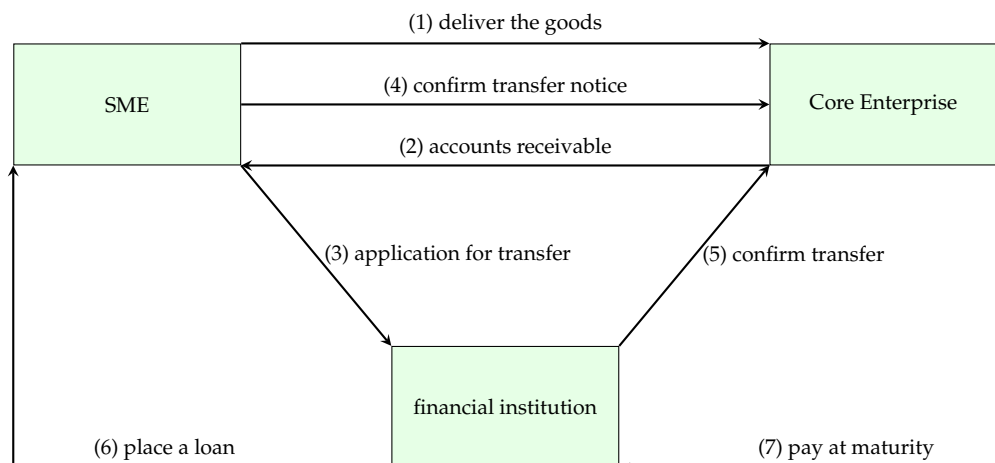
Therefore, this paper takes the accounts receivable factoring business as the research object, applies the evolutionary game analysis method, divides the default behavior of SMEs into two types: unilateral default and collusion with core enterprises, and analyzes the evolutionary stability strategy (ESS) between financial institutions and SMEs. By comparing the stability of the equilibrium strategy before and after introducing blockchain technology, this paper defines the main factors affecting the decision-making process and the mechanism that how blockchain technology makes the system stable by resolving risks.

The rest parts of this paper are organized as follows. In Section 2, the basic problems studied in this paper are described, and assumptions are presented. Game models before and after the introduction of blockchain technology into SCF are established and analyzed in Section 3. A numerical example in agricultural supply chain ASC are presented in Section 4 to verify our results from the models. Section 5 concludes the paper and puts up the main conclusions.

2. Problem Description and Basic Assumptions

2.1. Problem Description

In the factoring business of accounts receivable (with right of recourse), SMEs transfer accounts receivable certificates issued by core enterprises to financial institutions and the claims on accounts receivable are transferred. The business process is shown in Figure 1.
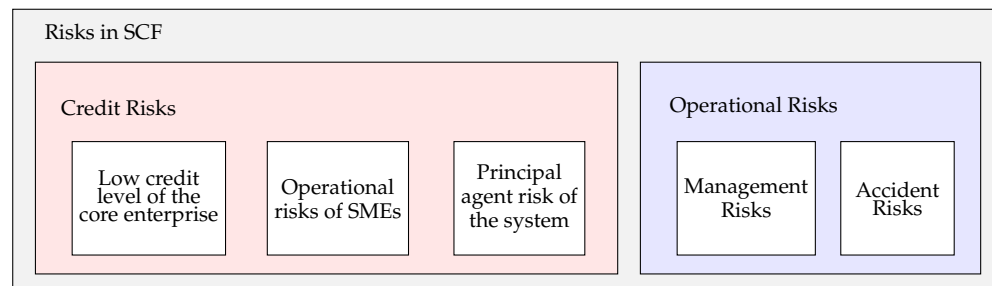

Figure 1. The process of accounts receivable factoring business.

There are 7 main procedures in the process of accounts receivable factoring business in the SCF.

(1) The SME signs up supply contract with the core enterprise;

(2) After the SME delivered the goods, the core enterprise confirms the receipt, and signs the accounts receivable;

(3) The SME initiates factoring business with the financial institution, transfers the accounts receivable and opens factoring collection accounts;

(4) The SME notifies the core enterprise to confirm that the creditor's rights in the accounts receivable have been transferred;

(5) The financial institution confirms to the core enterprise;

(6) The financial institution reviews contracts and invoices, then issues payments after confirming that the transaction exists;

(7) The core enterprise pay the amount in full on the due date.

The factoring business of accounts receivable mainly involves credit risks and operational risks as shown in Figure 2.

Figure 2. Risks in factoring business of accounts receivable in SCF.

The consensus mechanism of the blockchain technology can reduce risks and provide low-cost financing services for enterprises in the supply chain [8]. As the main risk source, credit risk mainly includes three aspects.

(1) Low credit level of the core enterprise. The essence of the factoring of accounts receivable is that the core enterprise uses its credit as the guarantee for credit endorsement. Financial institutions accept SMEs financing services based on the operating conditions and credit ratings of core enterprises. The risks generated by core enterprises stem from their operations and their credit level. Therefore, when there is a problem with the core enterprise's operating ability or credit level, it often brings the basic risk to the whole business.

(2) Operational risks of SMEs. In the factoring business of accounts receivable, although there is credit endorsement with the accounts receivable of core enterprises as collateral, the main body of loan repayment is still SMEs. If the debt repayment capabilities of SMEs is low, SMEs may choose to default because they are unable to repay the payments, and the financing risk of financial institutions increases. Therefore, the debt repayment capabilities of SMEs will affect the recovery of loan amounts.

(3) Principal-agent risk of the system. When the core enterprise grant loans, SMEs might collude with the core enterprise to conceal the real cooperative relationship and credit status, and then forge false contracts, bills, and certificates to defraud bank funds. The problem of information asymmetry makes it difficult for financial institutions to accurately evaluate their business, and thus wrongly grant loans to the high-risk business as a low-risk business.

Operational risks in the accounts receivable factoring business mainly include management risks and accidents that may occur during the business promotion. The complexity of the business transaction process makes its processing is highly dependent on manual completion, which has the problems of high business cost, high operational risk, and low income.

Credit risks and operational risks caused by information asymmetry make it difficult for financial institutions and SMEs to determine whether their choice optimize their returns [29,30]. Therefore, financial institutions might choose to accept or decline the applications of SMEs' factoring business by considering credit risks and operational risks, and SMEs may choose to comply to maximize their profits or not. In addition, the credit of the core enterprise also plays an important role. It may not pay to the bank-designated account by the payment promise, but choose to collude with SMEs. Therefore, the "not comply" of SMEs includes two possibilities: SMEs themselves default and collude with core enterprises.

Blockchain technology is based on the transaction accounting rules generated between mutually distrustful nodes, which strengthens the credit value of the supply chain structure and effectively resolves the credit risk and operational risk in the factoring business of accounts receivable. On the one hand, blockchain technology can reduce manual intervention. It digitizes paperwork-dependent procedures through smart contract technology, so as to improve business efficiency and reduce operational risk. On the other hand, for the credit risk in the business, if the enterprise changes the data or tampers with the existing information after default, it will pay a high cost. If an enterprise's breach of contract is found, the whole-network broadcasting characteristics of blockchain technology will cause

huge losses to the enterprise's reputation. Moreover, blockchain technology provides strong proof for the transaction of new funds. The transaction records generated will permanently exist in the credit history of the enterprise. If SMEs apply for financing again after default, it will be difficult to be trusted again. Thus, the essence of SCF risk is the existence of information asymmetry. Blockchain technology can effectively solve the problem of information asymmetry. It only needs fewer platform use fees, so that participants can obtain the benefits brought by information sharing. Specifically, financial institutions relying on blockchain technology can reduce credit investigation costs, improve business efficiency, reduce financing risks, and then reduce operation costs and risk losses. And, SMEs improve the availability of loans by standardizing their behavior.

2.2. Basic Assumptions and Model Parameters

The loan repayment behavior of SMEs can be divided into compliance and non-compliance [22], but the reasons why SMEs choose to default is still not clarified. Although a non-recourse account receivable financing model has been constructed [23], most financial institutions will choose a recourse account receivable financing model due to risk considerations. In addition, the existing research ignores the sequence between financial institutions' credit investigation and their decision-making, and does not highlight the action mechanism of blockchain technology in the game process. Therefore, according to the factoring process in SCF, we make the following assumptions.

(1) In real business, accounts receivable financing mostly occurs in the upstream of the supply chain [31]. Therefore, we only discuss the business system composed of SMEs, core enterprises, and financial institutions in the upstream of the supply chain.

(2) The financial institution has two strategies: accept or decline the accounts receivable financing application of the SME. Let the probabilities be x and $1 - x$, respectively. The SME also has two strategies: compliance or non-compliance. Suppose the probabilities are y and $1 - y$, respectively. When the SME chooses to abide by the contract, it fulfills the contract with the core enterprise and supplies products to the core enterprise on time with qualified quality and quantity. When the SME chooses not to abide by the contract, it may construct a false transaction contract with the core enterprise to defraud loans (assuming the probability of occurrence is α), or it unilaterally fails to perform or fully perform the supply contract with the core enterprise (assuming the probability of occurrence is $1 - \alpha$).

(3) Suppose the total amount of accounts receivable is R. When the SME applies for factoring financing of accounts receivable to financial institutions, financial institutions first conduct credit audits on the SME and the related core enterprise. Assuming that the cost of credit review is C_b. After the audit, if the financial institution chooses to accept the factoring financing business of accounts receivable, it will pay a loan of kR (k generally 70–80%) to the SME. At the same time, the SME transfers accounts receivable vouchers to financial institutions, and the creditor's rights have been transferred. If the financial institution chooses to decline the factoring financing business of accounts receivable after credit investigation for the SME and the related core enterprise, the financial institution can use the amount of kR for other businesses (such as short-term loans), and the yield is assumed to be r_b.

(4) It is assumed that the rate of return of the SME during normal production is r_p. The cost of producing the goods required by the contract is C. The SME may default or abide by the contract after receiving loans from financial institutions. When the SME defaults and jointly defrauds loans with the core enterprise, the benefit distribution ratio obtained by SME is assumed to be $P(0 < P < 1)$. If the SME defaults unilaterally, the core enterprise will repay the debt in an amount lower than the nominal value, and the SME will pay the remaining amount (based on the recourse of the financial institution). The default of the SME will cause it to lose the opportunity of follow-up cooperation with the core enterprise. Suppose that the total cost paid by the SME is C_p.

(5) Blockchain technology can carry out transaction endorsement and guarantee verification beyond the third party, and pass the credit of core enterprises layer by layer,

so as to help the SME finance and improve the income of the whole supply chain. Driven by the blockchain, the information is highly transparent, and the information acquisition cost of each subject in the supply chain is almost zero. Therefore, it is assumed that the default cost of SMEs after using blockchain technology is C'_p and $C'_p \to \infty$. Moreover, in this situation, the financial institution does not need to pay the credit investigation cost C_b. Instead, the financial institution needs to pay the construction and maintenance cost M of the blockchain platform, but $M \ll C_b$.

Based on the above assumptions, related symbols and definitions are further described as follows:

R: the amount of accounts receivable;

k: the bank pledge rate;

r_p: the return rate after successful financing of SMEs;

C_p: the default costs of SMEs;

C'_p: the default cost of SMEs driven by blockchain technology;

C: the production costs of SMEs;

C_b: the credit investigation cost of financial institutions;

r'_b: the deposit rate of financial institutions;

r_b: the loan interest rate of financial institutions;

x: the probability when financial institutions choose to accept the factoring application;

y: the probability of SMEs choosing to keep the contract;

α: the probability that SMEs choose to collude when they do not comply;

P: the ratio of profit distribution to SMEs in collusion;

M: the blockchain platform maintenance fee.

3. The Model

3.1. Before Applying Blockchain Technology

3.1.1. Construction of the Game Matrix

In this game, the financial institution has two actions: accept or not accept the business application. The SME will or will not comply with the contract. In addition, the SME may or may not collude with the core enterprise when the SME does not comply with the contract. Therefore, there are 6 possible results in this game.

Result 1: When the financial institution accepts the factoring application, the financial institution will pay the credit investigation cost C_b and the deposit interest kRr'_b within the corresponding period. If the SME delivers the goods according to the contract (abide by the contract), the factoring business is carried out normally, and the financial institution recovers the accounts receivable according to the factoring business at maturity, resulting in income $(1-k)R$. Therefore, the net income of the financial institution is $(1-k)R - C_b - kRr'_b$ in this case. On the other hand, the SME obtains loans kR for production. The income generated is $kR(1 + r_p)$ and the production cost is C. Therefore, the net income of the SME is $kR(1 + r_p) - C$ in this case.

Result 2: When the financial institution accepts the factoring application, but the goods delivered by the SME fail to be produced according to the contract standards, so that the core enterprise cannot carry out normal processing. The core enterprise will only deliver the amount lower than the book value to the financial institution, and the insufficient part needs to be paid by the SME which will be included in the default cost C_p. Therefore, in this case, the net income of financial institutions is not affected, but the net income of the SME will decrease. Their net income is $(1-k)R - C_b - kRr'_b$ and $kR(1 + r_p) - C - C_p$, respectively.

Result 3: When the financial institution accepts factoring applications, and the SME and the core enterprise jointly defraud loans, the transaction contract is false and the transaction background does not exist. At maturity, the loan becomes bad debt and the financial institution cannot recover it. In this case, the financial institution will lose the debt of kR paid when accepting the business application and the deposit interest kRr'_b within the corresponding period. Due to false transactions, the SME does not need to submit

commodities to core enterprises, so they have no corresponding production cost C, and will obtain the part of production income $kRP(1 + r_p)$ generated by the loan. Therefore, the income of the financial institution and the SME are $-kR(1 + r'_b) - C_b$ and $kRP(1 + r_p)$, respectively.

Result 4: When the financial institution decides to decline the factoring application after the credit investigation, but the SME delivers the goods according to the contract (abide by the contract), and the core enterprise pays the payment by the due date. The income generated by the loan kR that the financial institution should have paid is $kR(r_b - r'_b)$, but the credit investigation cost C_b needs to be paid, so the net income of the financial institution is $kR(r_b - r'_b) - C_b$. The SME recovers the loan R at maturity, so their net income is $R - C$.

Result 5: When the financial institution decides to decline the factoring business application after the credit investigation, the SME unilaterally breaches the contract. At this time, the goods cannot be produced according to the contract standard. The core enterprise will repay the loan in an amount lower than the nominal value, and the rest will be borne by the SME, which will be included in the default cost C_p. Therefore, the income of the financial institution and the SME is $kR(r_b - r'_b)$ and $R - C - C_p$, respectively.

Result 6: When the financial institution decides to decline the application for factoring business after credit investigation, and there is no joint loan fraud between the SME and the core enterprise, the earnings of the financial institution and the SME are $kR(r_b - r'_b) - C_b$ and zero, respectively.

To sum up, the return matrix of the financial institution and the SME under different situations before applying the blockchain technology is concluded in Table 1.

Table 1. The return matrix before introducing blockchain technology.

		SME		Compliance
		Non Compliance $(1 - y)$		
		Collusion(α)	**Non Collusion $(1 - \alpha)$**	**(y)**
B	Accept	$-kR(1 + r'_b) - C_b$	$(1 - k)R - C_b - kRr'_b$	$(1 - k)R - C_b - kRr'_b$
A	(x)	$kRP(1 + r_p)$	$kR(1 + r_p) - C - C_p$	$kR(1 + r_p) - C$
N	Decline	$kR(r_b - r'_b) - C_b$	$kR(r_b - r'_b) - C_b$	$kR(r_b - r'_b) - C_b$
K	$(1 - x)$	0	$R - C - C_p$	$R - C$

3.1.2. Replication Dynamic Equation of the Financial Institution

Let $E_{(x)}$ be the financial institution's expected return when accepting the factoring business application and $E_{(1-x)}$ be its expected return when not accepting. And $\bar{E}_x$ be its average return. Then,

$$
\begin{aligned}
E_{(x)} = {} & y[(1 - k)R - C_b - kRr'_b] \\
& + (1 - y)\{\alpha[-kR(1 + r'_b) - C_b] + (1 - \alpha)[(1 - k)R - C_b - kRr'_b]\}
\end{aligned}
\tag{1}
$$

$$
\begin{aligned}
E_{(1-x)} = {} & y(kR(r_b - r'_b) - C_b) \\
& + (1 - y)\{\alpha[kR(r_b - r'_b) - C_b] + (1 - \alpha)[kR(r_b - r'_b) - C_b]\}
\end{aligned}
\tag{2}
$$

$$
\bar{E}_x = xE_{(x)} + (1 - x)E_{(1-x)}
\tag{3}
$$

Replication dynamics equation is

$$
\begin{aligned}
F(x) = \frac{\mathrm{d}x}{\mathrm{d}t} &= x(E_{(x)} - \bar{E}_x) \\
&= x(1 - x)(y\alpha + 1 - k - kr_b - \alpha)R
\end{aligned}
\tag{4}
$$

Solve $F(x) = 0$, we can get the stationary point of the differential equation as follows:

$$x_1^* = 0, \quad x_2^* = 1 \tag{5}$$

$$y^* = \frac{k + kr_b + \alpha - 1}{\alpha} \tag{6}$$

Equation (6) indicates that $\dfrac{\partial F(x)}{\partial x} = 0$ always holds when the probability of the SME choosing to abide by the contract is y^*. That is, the state will not change due to external changes. In this case, no matter what value x takes, it is always the solution of the equation $F(x) = 0$, and all x are equilibrium points. That is, all states are stationary.

According to the stability of the differential equation, if $y \neq y^*$, the evolutionary stability strategy needs to satisfy $F(x^*) = 0$ and $F'(x^*) < 0$ at the same time.

When $y > y^*$, $F'(1) < 0$, so $x = x_2^* = 1$ is an evolutionary stable strategy. That is, when the probability of the SME choosing to keep the contract is greater than y^*, the system will eventually evolve into the equilibrium state of the financial institution accepting factoring business application.

When $y < y^*$, $F'(0) < 0$, so $x = x_1^* = 0$ is an evolutionary stable strategy. That is, when the probability of the SME choosing to keep the contract is less than y^*, the system will eventually evolve into the equilibrium state of the financial institution declining factoring business application.

The core of replication dynamics is that the number of individuals who adopt more successful strategies in the group will gradually increase. It can be seen from Equation (6) that the choice of the financial institution has nothing to do with the cost of credit investigation, that is, the key to whether the financial institution accepts factoring applications is credit risk. Therefore, although blockchain technology improves the income of financial institutions by reducing operational risk, the key to the decision of financial institutions lies in the impact of blockchain on credit risk.

It can be further found from Equation (6) that the pledge rate k of the financial institution is positively correlated with the probability y that the SME chooses to abide by the contract. This is because the pledge rate of the financial institution mainly depends on the credit degree and business terms of the SME. On the one hand, the SME with high credit has low risks, the financial institution is more willing to accept factoring applications, and the pledge rate is increased. On the other hand, considering long-term cooperation, the SME will also choose to standardize their behavior in order to maintain their high credibility in financial institutions. In addition, the collision probability α is negatively correlated with y. When α increases, the probability of the SME choosing collusion to defraud loans increases, but the possibility of the SME choosing to abide by the contract decreases. This also shows that collusion plays a decisive role in credit risk, and the occurrence of a breach of contract is mainly caused by collusion.

3.1.3. Replication Dynamic Equation of the SME

The expected return of the SME is assumed to be $E_{(y)}$ when they are fully compliant, and $E_{(1-y)}$ when they are not. The average return is denoted as $\bar{E}_y$.

$$E_{(y)} = x[kR(1 + r_p) - C] + (1 - x)(R - C) \tag{7}$$

$$
\begin{aligned}
E_{(1-y)} = {} & x\{\alpha[kRP(1 + r_p)] + (1 - \alpha)[kR(1 + r_p) - C - C_p]\} \\
& + (1 - x)[(1 - \alpha)(R - C - C_p)]
\end{aligned}
\tag{8}
$$

$$\bar{E}_y = yE_{(y)} + (1 - y)E_{(1-y)} \tag{9}$$

The replicator dynamics equation is

$$F(y) = \frac{dy}{dt} = y(E_{(y)} - \bar{E}_y)$$
$$= y(1-y)\{x[\alpha R[k(1+r_p)-1] - \alpha k R P(1+r_p)]$$
$$+ C_p + \alpha R - \alpha C - \alpha C_p\}$$

(10)

Let $F(y) = 0$, then

$$y_1^* = 0, \quad y_2^* = 1$$

(11)

$$x^* = \frac{\alpha R - \alpha C + (1-\alpha)C_p}{\alpha R[k P(1+r_p) - k(1+r_p) + 1]}$$

(12)

Therefore, Equation (11) and Equation (12) is the stationary point of the differential equation. Since $x > 0$, then $P > 1 - \frac{1}{k(1+r_p)}$.

Equation (12) indicates that $\frac{\partial F(y)}{\partial y} = 0$ always exists when the probability of the financial institution accepting the application is x^*. That is, the state will not change due to external changes. In this case, no matter what y takes, it is always the solution of the equation $F(y) = 0$, and all y are equilibrium points. That is, all states are stationary.

According to the stability of the differential equation, if $x \neq x^*$, the ESS needs to satisfy $F(y^*) = 0$ and $F'(y^*) < 0$.

When $x < x^*$, $F'(1) < 0$, so $y^* = 1$ is an evolutionary stable strategy, that is, when the probability of the financial institution accepting the factoring application is less than x^*, the system will eventually evolve into the SME choosing to abide by the contract.

When $x > x^*$, $F'(0) < 0$, so $y^* = 0$ is an evolutionary stable strategy, that is when the probability of the financial institution accepting business application is greater than x^*, the system will eventually evolve into the SME defaulting.

In addition, when $P > 1 - \frac{1}{k(1+r_p)}$, it can be seen from Equation (12) that when α is smaller, x is larger. Therefore, if the financial institution is risk-averse, the financial institution is less likely to accept the factoring business application of the SME. However, if the financial institution is still willing to accept the business application, the SME will tend to seize the opportunity. The SME will consider comprehensively the long-term benefits generated by subsequent cooperation and choose to abide by the contract. When the financial institution is more likely to accept the factoring application of the SME, the SME will decide to default under the temptation of the high-profit distribution obtained by collusion.

It can be further found from Equation (12) that both C_p and r_p are positively correlated with x. The increase of r_p means that the profits of the SME after obtaining loans are greater. At this time, in order to improve the loan willingness of the financial institution, the SME is more likely to provide real transactions. If r_p decreases, the profits of the SME after obtaining loans will also decrease. When profits are getting smaller and smaller, the SME is more and more inclined to conceal or cheat and provide false business transactions. At this time, in order to ensure the authenticity of accounts receivable provided by the SME, the financial institution will increase the punishment to enterprises. However, in order to improve x (that is, to improve the probability that the SME provides real business), r_p needs to be reduced and C_p needs to be increased. Therefore, when the risk loss caused by concealment or fraud by the SME is greater than the income, the SME will not easily make concealment or fraud after comprehensively considering its actual operation status and repayment ability. At this time, if the SME is aware of its poor operating conditions, it will not choose to obtain loans through the way of accounts receivable factoring with recourse, which also reduces the credit risk of the financial institution.

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On the one hand, through the replication dynamic differential equation of financial institutions, it can be concluded that the probability of the SME choosing to abide by the contract is small, and the risk-aversion financial institution tends not to accept business applications. On the other hand, through the replication dynamic equation of the SME, it can be concluded that the smaller the probability of the financial institution accepting business applications, the greater the probability of the SME choosing to abide by the contract. Therefore, this means that the smaller the probability of the SME choosing to abide by the contract, the larger financial institutions will accept business applications. This is a paradox that is contrary to the decision-making of the financial institution. This is because it is difficult for the financial institution to supervise due to the problem of information asymmetry. When the compliance probability of the SME increases, the credit of the SME increases, and the financial institution is more and more inclined to accept business applications. However, when the proportion of income that can be distributed by the SME in collusion increases, the SME can obtain higher profits through collusion. Therefore, it will take risks to choose default, the probability of compliance gradually decreases, and the possibility of the financial institution accepting the business application decreases again. This has formed a strange circle of "the financial institution does not accept business applications → the probability of compliance of the SME increases → the credit of the SME in the financial institution increases → the financial institution tends to accept the business application → the proportion of benefits distributed by the SME collusion increases → the probability of default of the SME increases → the financial institution does not accept the business application". This circle makes the system unable to stabilize.

3.1.4. Analysis of Equilibrium State and Stability Strategy of Evolutionary Game

Based on the above analysis, the evolutionary game system has five equilibrium points: $E_1(x_1^*, y_1^*)$, $E_2(x_1^*, y_2^*)$, $E_3(x_2^*, y_1^*)$, $E_4(x_2^*, y_2^*)$, $E_5(x^*, y^*)$.

Taking the derivatives of Equation (4) and (10) respectively, we can get the following Jacobian matrix.

$$J = \begin{bmatrix} \dfrac{\partial F(x)}{\partial x} & \dfrac{\partial F(x)}{\partial y} \\ \dfrac{\partial F(y)}{\partial x} & \dfrac{\partial F(y)}{\partial y} \end{bmatrix} \tag{13}$$

where

$$\frac{\partial F(x)}{\partial x} = (1 - 2x)(\alpha y + 1 - k - kr_b - \alpha)R \tag{14}$$

$$\frac{\partial F(x)}{\partial y} = \alpha x(1 - x)R \tag{15}$$

$$\frac{\partial F(y)}{\partial x} = y(1 - y)\alpha[k(1 + r_p) - 1 - kP(1 + r_p)]R \tag{16}$$

$$\frac{\partial F(y)}{\partial y} = (1 - 2y)[x(k(1 + r_p) - 1)\alpha R - x\alpha kRP(1 + r_p) + C_p + \alpha(R - C - C_p)] \tag{17}$$

Next, we calculate determinant value $\det J$ and trace value matrix $\mathrm{tr} J$ of equilibrium points $E_1, \cdots, E_5$, and to judge the stability of the equilibrium point of the evolutionary game. The results are shown in Table 2.

Table 2. Stability judgment and analysis of equilibrium point of accounts receivable factoring business before applying blockchain technology.

	Conditions	Equilibrium Point	Sign of det$J$	Sign of tr$J$	Judgement
Case I	$P_l < P < P_u$	E_1	−	U	SP
		E_2	−	U	SP
		E_3	+	U	UP
		E_4	+	-	ESS
		E_5	+	0	CP
Case II	$P > P_u$	E_1	−	U	SP
		E_2	−	U	SP
		E_3	−	-	SP
		E_4	−	U	SP
		E_5	+	0	CP

Note: $P_l = 1 - \dfrac{1}{k(1+r_p)}$; $P_u = \dfrac{\alpha R[k(1+r_p)-1] + \alpha(R-C-C_p) + C_p}{\alpha k R(1+r_p)}$; U—Uncertain; SP—Saddle Point; UP—Unstable Point; ESS—Evolutionary Stable Strategy; CP—Central Point.

It can be seen from Table 2 that the system may not reach stable equilibrium through long-term evolution. Whether it can achieve the ESS combination that the financial institution accepts the factoring application and the SME abides by contracts depends on factors such as interest distribution ratio P, joint loan fraud probability α, return on normal production r_p, and default cost C_p.

3.2. After Applying Blockchain Technology

After introducing blockchain technology in SCF, the main changes include: first, the blockchain platform maintenance cost M replaces the credit investigation cost C_b of the financial institution. Second, the blockchain increases the default cost of the SME, denoted it as C'_p.

The return matrix of the financial institution and the SME under different situations after applying blockchain technology is concluded in Table 3.

Table 3. The return matrix after introducing blockchain technology.

		SME		
		Non Compliance $(1-y)$		**Compliance**
		Collusion (α)	**Non Collusion $(1-\alpha)$**	**(y)**
B A	Accept (x)	$-kR(1+r'_b) - M$ $kRP(1+r_p)$	$(1-k)R - M - kRr'_b$ $kR(1+r_p) - C - C'_p$	$(1-k)R - M - kRr'_b$ $kR(1+r_p) - C$
N K	Decline $(1-x)$	$kR(r_b - r'_b) - M$ 0	$kR(r_b - r'_b) - M$ $R - C - C'_p$	$kR(r_b - r'_b) - M$ $R - C$

Similar to the above analysis process, after the introduction of blockchain technology, the game system has five equilibrium points: $E_1(x^*_{1B}, y^*_{1B})$, $E_2(x^*_{1B}, y^*_{2B})$, $E_3(x^*_{2B}, y^*_{1B})$, $E_4(x^*_{2B}, y^*_{2B})$, $E_5(x^*_B, y^*_B)$, where

$$x^*_{1B} = 0, x^*_{2B} = 1$$
$$y^*_{1B} = 0, y^*_{2B} = 1$$
$$x^*_B = \frac{\alpha(R-C) + (1-\alpha)C'_p}{\alpha R[kP(1+r_p) - k(1+r_p) + 1]}, y^*_B = \frac{k(1+r_b) + \alpha - 1}{\alpha}$$

The corresponding Jacobian matrix is

$$J = \begin{bmatrix} \dfrac{\partial F(x)}{\partial x} & \dfrac{\partial F(x)}{\partial y} \\ \dfrac{\partial F(y)}{\partial x} & \dfrac{\partial F(y)}{\partial y} \end{bmatrix} \tag{18}$$

where

$$\frac{\partial F(x)}{\partial x} = (1 - 2x)(\alpha y + 1 - k - kr_b - \alpha)R \tag{19}$$

$$\frac{\partial F(x)}{\partial y} = \alpha x(1 - x)R \tag{20}$$

$$\frac{\partial F(y)}{\partial x} = y(1 - y)\alpha[k(1 + r_p) - 1 - kP(1 + r_p)]R \tag{21}$$

$$\frac{\partial F(y)}{\partial y} = (1 - 2y)[x(k(1 + r_p) - 1)\alpha R - x\alpha kRP(1 + r_p) + C'_p + \alpha(R - C - C'_p)] \tag{22}$$

The results of stability of the equilibrium point of the evolutionary game are shown in Table 4.

Table 4. Stability judgment and analysis of equilibrium point of accounts receivable factoring business.

Conditions	Equilibrium Point	Sign of det$J$	Sign of tr$J$	Judgement
	E_1	−	U	SP
	E_2	−	U	SP
$P_l < P < P_u$	E_3	+	U	UP
	E_4	+	−	ESS
	E_5	+	0	CP

Note: $P_l = 1 - \dfrac{1}{k(1 + r_p)}$; $P_u = \dfrac{\alpha R[k(1 + r_p) - 1] + \alpha(R - C - C'_p) + C'_p}{\alpha kR(1 + r_p)}$; U—Uncertain; SP—Saddle Point; UP—Unstable Point; ESS—Evolutionary Stable Strategy; CP—Central Point.

3.3. Comparative Analysis

By comparing the system equilibrium states before and after the introduction of blockchain technology (Tables 2 and 4), the following results can be found.
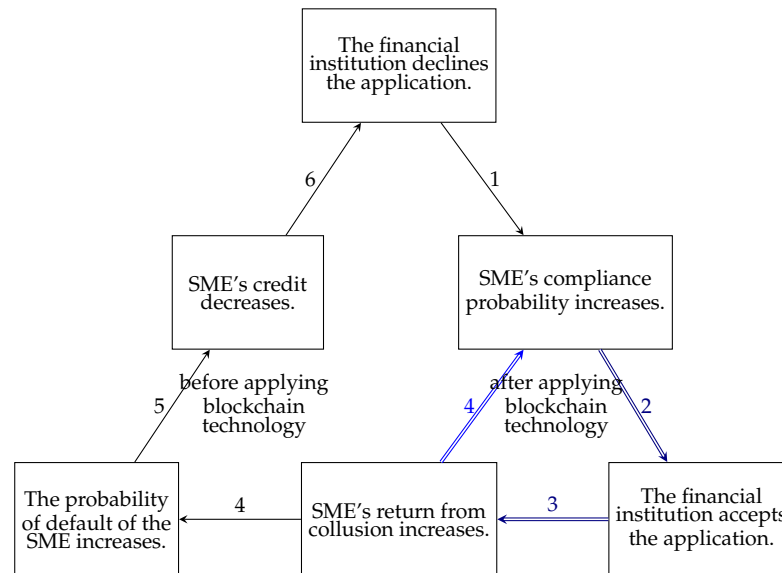
(1) The introduction of blockchain technology has cracked the paradox in SCF.

Before applying blockchain technology, when the profit distribution ratio P generated by the collision of the SME is low, the possibility of the SME choosing collusion is low. Therefore, the default probability of the SME decreases. At this time, the financial institution is more likely to accept the factoring application. However, the financial institution lacks positive means to prevent the occurrence of joint loan fraud. In this case, the risk aversion mechanism may fail. It means that when $P > P_u$, the strategy that the financial institution accepting mortgage applications and the SME abiding by the contract is no longer stable. Moreover, the larger the profit distribution ratio P obtained by the SME, the stronger its willingness to collude and the greater the possibility of default.

Due to the existence of information asymmetry, the penalty cost formulated by financial institutions tends to be below, and it is easy to treat the high-risk business as a low-risk one. Default cost C_p indirectly reflects the regulatory environment of financial institutions. Blockchain technology increases C_p to improve supervision by resolving the problem of information asymmetry. In this situation, the conspiracy will be in a high-risk state. No matter what the proportion of collusion distribution of the SME is, it will always be within the range of $[P_l, P_u]$.

Therefore, blockchain technology creates a strict regulatory environment by increasing default costs, thus controlling the proportion of collusive distribution of the SME and preventing the paradox of SCF. The beneficent cycle is: "the financial institution does

not accept business applications → the compliance probability increases → the financial institution accepts the application → the distribution proportion of benefits obtained by the SME collusion increases → the compliance probability increases → the financial institution accepts business applications". The mechanism of blockchain technology to resolve credit risk is shown in Figure 3.

Note: The cycle from 1 to 6 is the paradox before applying blockchain technology to SCF. The circle from 2 to 4 is the core beneficent cycle after applying blockchain technology to SCF.

Figure 3. The mechanism of blockchain technology to resolve credit risk.

(2) The default cost C_p of the SME plays a key role in the formation of stable strategy. From Table 2, P_u can be rewritten as

$$P_u = 1 - \frac{\alpha C - (1-\alpha)C_p}{\alpha k R(1+r_p)} \tag{23}$$

Hence, when C_p increases until $C_p > \frac{\alpha}{1-\alpha}C$ is established, the condition $P < P_u$ is easier to exist. However, in reality, the default probability α of the SME is usually high, so it is difficult for C_p to reach $\frac{\alpha}{1-\alpha}C$ before the application of blockchain technology. This makes $P < P_u$ difficult to exist. In addition, when the rate of return r_p obtained by the production of the SME increases, $P < P_u$ is easier to exist. The larger r_p is, the greater the profit of the SME. In order to improve the willingness of the financial institution to accept factoring applications, the SME is more likely to choose to abide by the contract. The greater the default cost C_p of the SME, the lower its default probability. At this time, the financial institution is more willing to accept factoring applications. If r_p is reduced, the profits obtained by the SME after obtaining loans will also be reduced, and the SME tends to cheat and increase the possibility of providing untrue business applications. In this case, in order to ensure the authenticity of accounts receivable provided by the SME, the financial institution will increase the punishment to the SME, and the possibility of default of the SME will be reduced. To sum up, default cost C_p plays a key role in the formation of stability strategy.

At present, existing studies have only concluded that blockchain technology reduces the probability of SMEs choosing to default and improves the financing efficiency of SMEs [10,12,14,19]. However, it did not analyze the reasons for the reduction in the probability of default, and the mechanism of blockchain technology. Compared with the existing research, this paper not only explains the mechanism of blockchain technology to resolve credit risk but also finds the reason why the system cannot reach equilibrium before apply-

ing blockchain technology. And found the critical value of the collusion distribution ratio in the case of default.

4. A Numerical Example

In this section, based on the case in [32], we discuss the impact of the introduction of blockchain technology in (ASC) finance to verify the relevant conclusions of this paper.

4.1. Background

The ASC is characterized by regionality, seasonality, the scattered connection of market subjects, uncertain output, many hierarchical nodes, and asymmetric information [33,34], which leads to the lengthening of the accounts receivable cycle of agricultural products farmers and the obvious tendency of subject immobilization.

In ASC, SMEs are mainly farmers who are responsible for the production and supply of agricultural products. After the harvest of agricultural products, they are regularly purchased and sold by the core enterprise. Since the production of agricultural goods have a long cycle, the core enterprise usually provides a guarantee for farmers to obtain loans from financial institutions (commercial banks) to encourage farmers' sustainable reproduction.

Based on the data of a real transaction, it is assumed that the book value of accounts receivable R is 1 million yuan. With the book value of accounts receivable as a pledge, farmers apply to commercial banks for factoring business. The deposit interest rate r'_b of commercial banks is 2%, the loan interest rate r_b is 4%, the credit rate k is 80%, and the credit investigation cost C_b is 0.01 million yuan. After the introduction of blockchain technology, commercial banks need to pay platform construction and cost M of 100 yuan. In addition, the yield rate r_p of farmers in normal production is 30%, and the corresponding production cost C is 0.6 million yuan. If the farmers unilaterally breach the contract, the core enterprise will repay part of the debt in an amount lower than the nominal value. The remaining part will be paid by the farmers. Moreover, farmers' breach of contract will result in the loss of opportunities for re-cooperation with core enterprises or other enterprises. At this time, the total price C_p paid by farmers is 0.7 million yuan.

4.2. Stability Analysis of Accounts Receivable Financing Mode before Introducing Blockchain Technology

Before the introduction of blockchain technology, it is assumed that the possibility of joint loan fraud between farmers and core enterprises is 90%. In this way, according to the calculation results of P_l and P_u, we take P as 30% for evolution simulation. The results are shown in Figure 4.

It can be seen from Figure 4 that at the beginning of the evolution period, commercial banks tend to decline farmers' pledge applications to avoid risks due to farmers' breach of contract. At this stage, the probability of commercial banks accepting pledge business converges to 0. With the advancement of system evolution and the gradual standardization of farmers' behavior, commercial banks choose to accept farmers' pledge applications to obtain higher income. At this stage, the probability of commercial banks accepting pledge applications converges to 1, and the probability of farmers' compliance converges to 1 as well. The system realizes evolutionary stability.
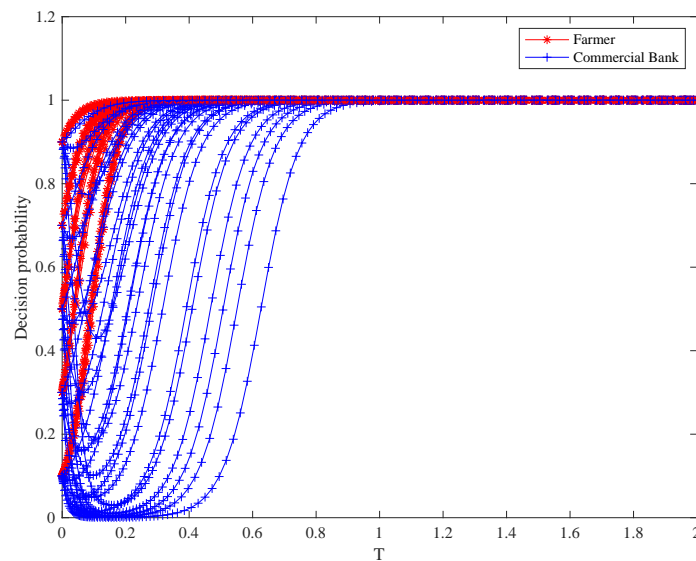
Figure 4. System evolution track before introducing blockchain Technology ($P = 30\%$).

When $P > P_u$, let $P = 53\%$. At this time, the evolution track of the system is shown in Figure 5.
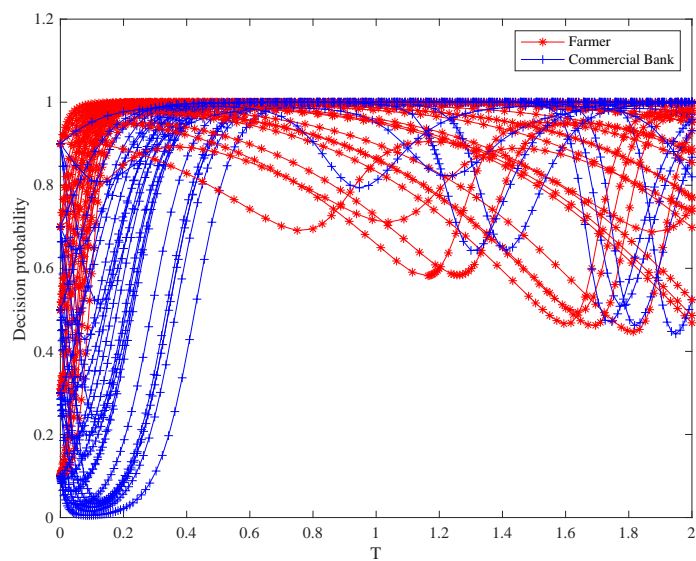

Figure 5. System evolution track before introducing blockchain Technology ($P = 53\%$).

It can be found from Figure 5 that due to the high proportion of benefit distribution obtained by collusion between farmers and core enterprises, farmers have a strong willingness to choose collusion. Therefore, commercial banks are less willing to accept farmers' pledge applications at the earlier period. In this case, farmers began to restrict their behavior to improve their credit to obtain loans from commercial banks. Commercial banks are more willing to accept business applications, but it also correspondingly improves the income that farmers can obtain by choosing collusion. After weighing the cost of default and the profit of loan fraud, more and more farmers will choose to default again. Therefore, the system is difficult to achieve stability in this case. In the reality that joint loan fraud can not be controlled easily, the cost of default C_p must be large enough to realize a stable state in which farmers choose not to default and commercial banks choose to accept pledge applications.

4.3. Stability Analysis of Accounts Receivable Financing Mode after Introducing Blockchain Technology

The highly transparent information under the blockchain technology and the non-tamperability based on timestamp technology make the punishment of farmers' breach of contract infinite. No matter what the benefit distribution ratio P generated by farmers' collusion is, farmers will not choose to breach the contract, and commercial banks are more willing to accept the application for factoring business. The default cost of farmers here is assumed to be 10 million yuan. After the introduction of blockchain technology, the dynamic evolution track of the cooperation strategy combination between farmers and commercial banks in accounts receivable factoring business is shown in Figure 6 ($P = 30\%$) and Figure 7 ($P = 53\%$).
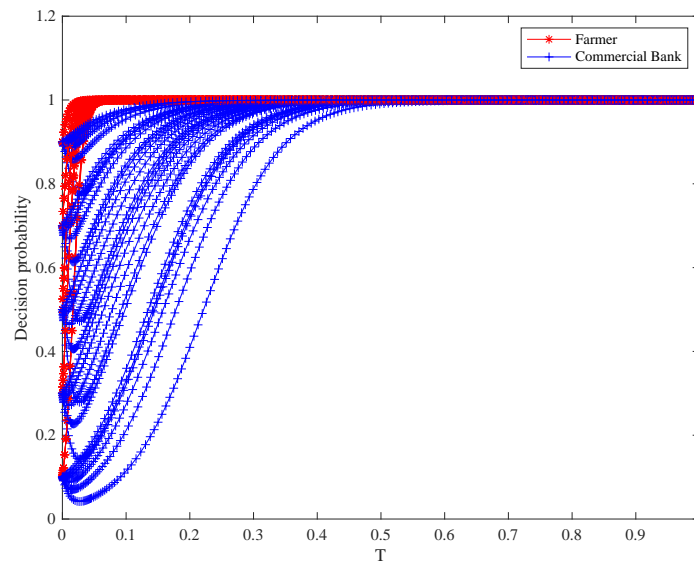

Figure 6. System evolution track after introducing blockchain Technology ($P = 30\%$).
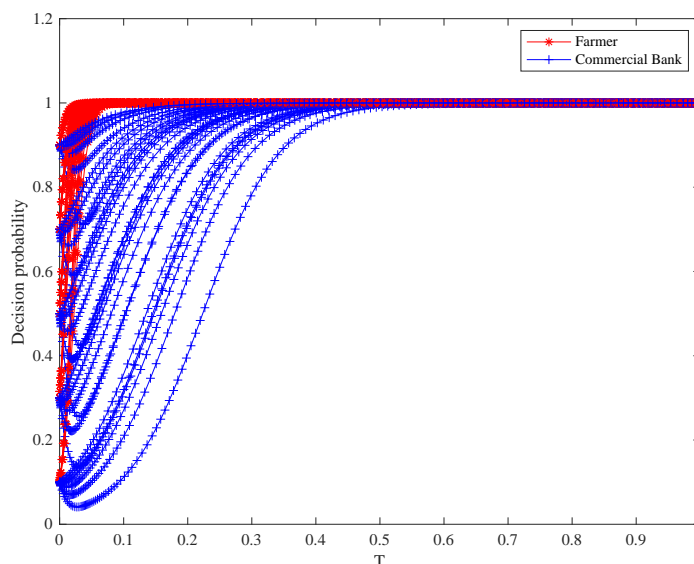

Figure 7. System evolution track after introducing blockchain Technology ($P = 53\%$).

It can be seen from Figures 6 and 7 that after the introduction of blockchain technology, no matter what the profit distribution ratio of collusion P is, the strategic choices of farmers and commercial banks converge to 1, that is, farmers choose to abide by the contract, and commercial banks tend to accept business applications. The strategy (1,1) becomes the system evolution stability strategy.

In addition, by comparing the system evolution trajectory before and after applying blockchain technology, it can be seen that the evolution path of all parties is more consistent after the introduction of blockchain technology. On the premise that blockchain technology is the guarantee, farmers standardize their behavior. Regardless of the external interest drive and the initial state of the strategy proportion adopted by all parties in the game, commercial banks and farmers will eventually converge to the strategy combination (accept, abide). It can be seen from Figure 4 that the convergence effect of the system is better than that of the evolution path in Figure 6. Therefore, the increase of punishment shortens the path of commercial banks not accepting applications in the early stage. And the greater the default cost C_p, the more the evolution path in Case II after the introduction of blockchain will tend to Case I.

5. Conclusions

This paper makes a game analysis on the dynamic evolution process of accounts receivable factoring business in SCF. By introducing blockchain technology, we find the following main conclusions.

(1) Credit risk and operational risk are the main sources of risk in SCF. The key to whether financial institutions accept factoring applications is credit risk. Blockchain technology only improves the income of financial institutions by reducing operational risk, and the key to the decision-making of financial institutions lies in the impact of blockchain on credit risk. The principal-agent risk plays a decisive role in credit risk, and the breach of contract is mainly caused by collusion.

(2) The pledge rate of financial institutions mainly depends on the credit level and loan terms of SMEs. On the one hand, SMEs with high credit have low risks, financial institution's willingness to lend has increased, and the pledge rate has increased. On the other hand, in the case of a certain proportion of collusion distribution, SMEs will choose to standardize their behavior to maintain their high credibility in financial institutions. When the profits obtained by SMEs after obtaining loans are reduced, they will tend to hide or cheat and provide untrue business transactions. At this time, in order to ensure the authenticity of business, financial institutions will increase the punishment to improve the default cost of SMEs. In this way, the risk of loss caused by concealment or fraud will be greater than the benefits. Therefore, SMEs will not easily make concealment or fraud after comprehensively considering their actual operation status and repayment ability.

(3) Blockchain technology creates a stricter regulatory environment by resolving the problem of information asymmetry. At this time, no matter how high the credit degree of SMEs is, and what proportion of profit distribution can be shared by collusion, the highly transparent business supervision environment built by blockchain technology has effectively solved the problem that the decision-making between SMEs and financial institutions can not reach a stable state. Thus, the credit risk in SCF with blockchain technology is reduced, the system tends to be stable through long-term evolution, and the decision-making time of subject evolution is shortened greatly. Financial institutions are more willing to accept business applications, which solves the financing problems of SMEs.

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