Evolutionary Game Analysis of Supply Chain Finance Receivables Financing for Financial Institutions and SMEs Considering Blockchain

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Abstract: The frequent occurrence of defaults and fraudulent loans in traditional supply chain finance seriously restricts the healthy development of financing businesses. The emergence of blockchain technology has created new opportunities to reduce the risk of enterprise default, improve the financing efficiency of lenders, and create a real and transparent trading environment. This article constructs an evolutionary game model of supply chain finance accounts receivable financing under blockchain technology, incorporating collusion behavior into the default decision-making of SMEs, exploring the evolutionary path of each participant and the stable equilibrium strategy of the model, and considering the impact of cost, punishment intensity and incentive factors on the decision-making of both parties. Using MATLAB software to conduct numerical simulation analysis to verify the deduced conclusions. The results show that there are certain barriers to adopting blockchain technology in the receivables financing model, and the introduction cost is an important factor restricting the application of technology. Reducing costs, increasing punishment intensity and incentives can strengthen the convergence of all participants towards the equilibrium point (access to the blockchain, keeping the promise), helping to achieve a win-win situation for all parties.

Keywords: Blockchain Supply Chain; Finance Accounts; Receivable Financing; Evolutionary Game

1 Introduction

SMEs account for over 90% of the total number of enterprises in China and are the backbone of our national economy. However, in the actual production activities, SMEs in the upstream of the supply chain hardly enjoy the dominant power, they often need to expand their production and operation activities through "credit sales", and a large number of accounts receivable bills seriously restrict the flow of cash flow of enterprises, limiting the further development of enterprises. In this environment, supply chain finance has emerged to provide a solution to the problem of difficult financing for SMEs[1,2]. Provide convenient and fast supply chain financial services for enterprises in the chain. However, the problems of information asymmetry, high cost of credit collection, complex offline processes, and low efficiency in the actual business process still cannot be effectively solved[3,4], and there are numerous phenomena of SMEs defaulting or even colluding with core enterprises[5], and HangQian Communication, a subsidiary of Yongwei Holdings, fraudulently obtained bank loans through fictitious accounts receivable with affiliated companies during 2018-2020, involving an amount of up to 220

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million RMB, This all reflects that there are still many shortcomings in the current accounts receivable financing business.

As blockchain technology continues to advance, its utility in empowering supply chain finance is becoming more and more obvious[6]. Based on the functions and characteristics of blockchain[7], it can effectively improve the information sharing of financing parties, inhibit the default of SMEs, and improve the efficiency of financing while reducing the cost of pre-loan credit collection and post-loan supervision of financing business, which brings new opportunities for realizing mutual win-win situation between banks and enterprises[8,9], and many scholars have also designed the process and architecture of blockchain financing platform[10,11]. Through reading the existing literature, we found that scholars have a clear understanding of the problems of the current supply chain finance receivables financing model, and have also put forward corresponding solutions. With the continuous development of blockchain technology, scholars are increasingly aware of the advantages of its application to accounts receivable financing business, but the focus of their research often lies in the technical and application aspects of blockchain, and the research on the construction of blockchain platform also focuses on the design of the theoretical framework, more qualitative analysis, and rarely the construction of mathematical models. Therefore, from a quantitative perspective, this paper constructs a game model for the evolution of accounts receivable financing in supply chain finance considering blockchain, focusing on the dynamic mechanism of financial institutions and SMEs in the financing process, to analyze the impact of considering blockchain technology on the final decision of both financial institutions and SMEs, to reduce the risk of default in accounts receivable financing and build a good supply chain finance ecology.

2 Blockchain-enabled game model for the evolution of accounts receivable financing

2.1 Model Assumptions and Description of Parameters

To effectively carry out the game evolution study, assumptions are made and parameters are set for the game evolution model involving financial institutions and SMEs on both sides (as shown in Table 1).

Assumption 1: The financial institutions and SMEs involved in the evolution of the game are all finite rational players, and their ultimate goal in repeating the game is to maximize their respective utility or self-interest.

Assumption 2: The interest rate of the loan provided by the financial institution is r_2, In the initial stage of the accounts receivable financing business, to obtain the real information of the financing enterprise, field investigation is needed, at this time, the credit cost of financial institutions is C_3, credit costs for financial institutions after accessing blockchain is C_4, As the information sharing degree is improved after accessing the blockchain, it becomes quicker to obtain the true information of the financing enterprise and the cost is relatively lower, therefore $C_4 < C_3$, the additional benefit of financial institutions after accessing blockchain due to the improvement of financing efficiency is S_2, The cost of accessing the blockchain platform is M.

Assumption 3: The amount of accounts receivable bills issued by core enterprises held by SMEs is R, the pledge rate of accounts receivable provided by the financial institution is k, The rate of return on investment when the SME obtains financing for normal production is r_1, The cost of production for the SME is C, The cost of default for SMEs is C_1, The cost of default for SMEs after accessing the blockchain is C_2, Since the default will be recorded on the chain and cannot be tampered with after acc-essing the blockchain, it will be very difficult to raise funds or find partners again af-terward, therefore $C_2 \gg C_1$, the incentive for the financial institution to keep the prom-ise of the SME after accessing the blockchain is S_1.

Assumption 4: Incentives for financial institutions when SMEs are trustworthy after accessing the blockchain—S_1 and the additional benefits to financial institutions due to increased efficiency in financing—S_2 will only be effective to the extent that the SME keeps the promise.

Assumption 5: After obtaining financing, the SME will have two scenarios: keep the promise and default. In the case of default, the probability that the SME chooses to collude with the core enterprise is $p(0 < p < 1)$, The probability that the SME does not choose to collude with the core enterprise (failing to deliver the goods to the core enterprise within the specified time or delivering substandard quality) is $(1-p)$.

Assumption 6: The probability that a financial institution chooses to access the blockchain is $x(0 < x < 1)$ and the probability of not accessing the blockchain is $(1-x)$ The probability that an SME will keep its promise is $y(0 < y < 1)$ and the probability of default is $(1-y)$.

Table 1. Parameter settings for the evolutionary model of the accounts receivable financing game

Parameters	Definition
R	Amount of accounts receivable held by SMEs
k	Accounts receivable pledge rate
r_1	SMEs carry out normal production when the Return on Investment
r_2	Interest rates for loans from financial institutions
p	SMEs in non-compliance Probability of collusion with core enterprises
C	Production costs for SMEs
C_1	Cost of default for SMEs
C_2	The cost of default for SMEs after accessing blockchain
C_3	Credit Costs for Financial Institutions
C_4	Credit Costs for Financial institutions after accessing blockchain
S_1	When SMEs keep their promises after accessing to blockchain Incentives for financial institutions
S_2	Additional benefits for financial institutions due to increased efficiency in financing after accessing blockchain
M	Cost of accessing a blockchain platform

2.2 Game evolution strategy choice and payoff matrix

Based on the previous assumptions and the parameter settings, there are six possible outcomes of the game between financial institutions and SMEs, based on which we construct the game payoff matrix (as shown in Table 2).

Table 2. Payoff matrix for the evolution of the game between financial institutions and SMEs

		SMEs		
		Keeping the Promise(y)	default$(1-y)$	
			Collusion(p)	Non-Collusion$(1-p)$
Financial Institution	Access (x)	$kRr_2 - C_4 - M + S_2$ $kR(r_1 - r_2) - C + S_1 - M$	$-kR - C_4 - M$ $kR(1 + r_1) - M$	$kRr_2 - C_4 - M$ $kR(r_1 - r_2) - C - C_2 - M$
	No access $(1-x)$	$kRr_2 - C_3$ $kR(r_1 - r_2) - C$	$-kR - C_3$ $kR(1 + r_1)$	$kRr_2 - C_3$ $kR(r_1 - r_2) - C - C_1$

3 Evolutionary game analysis

3.1 Evolutionary equilibrium points

From Table 2, we can obtain that the expected revenue function for financial institutions when they choose to access the blockchain is

$$E_{(x)} = y(kRr_2 - C_4 - M + S_2) + (1-y)[p(-kR - C_4 - M) + (1-p)(kRr_2 - C_4 - M)] \quad (1)$$

The expected revenue function for financial institutions when they choose not to access the blockchain is

$$E_{(1-x)} = y(kRr_2 - C_3) + (1-y)[p(-kR - C_3) + (1-p)(kRr_2 - C_3)] \quad (2)$$

According to the two equations above, we can obtain the average expected revenue of financial institutions as:

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

Based on the above equation, we then calculate the replicated dynamic equation for the financial institution as:

$$F_{(X)} = \frac{d_x}{d_t} = x(E_{(x)} - \bar{E}_x) = x(1-x)(yS_2 + C_3 - C_4 - M) \quad (4)$$

Let formula 4 = 0, which gives $x_1^* = 0, x_2^* = 1, y^* = \frac{C_4 - C_3 + M}{S_2}$ is the equilibrium solution to the financial institution replicated dynamic equation.

Using the same method, which gives $y_1^* = 0, y_2^* = 1, x^* = \frac{P(kR + kRr_2 + C + C_1) - C_1}{(p-1)(C_1 - C_2) + S_1}$ is the equilibrium solution to the SME replicated dynamic equation.

Through replicated dynamic equations for financial institutions and SMEs, we can ob-tain five equilibria which are $E_1(0,0), E_2(0,1), E_3(1,0), E_4(1,1), E_5\left(\frac{P(kR+kRr_2+C+C_1)-C_1}{(p-1)(C_1-C_2)+S_1}, \frac{C_4-C_3+M}{S_2}\right)$,Here it is necessary to satisfy both

$0 < \frac{P(kR+kRr_2+C+C_1)-C_1}{(p-1)(C_1-C_2)+S_1} < 1, 0 < \frac{C_4-C_3+M}{S_2} 1$, based on the previous assumption that $(p-1) < 0$, and because the cost of default for SMEs after accessing the blockchain C_2 is much greater than the previous cost of default C_1, and $S_1 > 0$, So $P(kR + kRr_2 + C + C_1) - C_1 > 0$, and $P(kR + kRr_2 + C + C_1) - C_1 < (p-1)(C_1 - C_2) + S_1$. In addition，s-ince $S_2 > 0$, so $(C_4 - C_3 + M) > 0$, and $C_4 - C_3 + M < S_2$.

3.2 Evolutionary equilibrium point analysis

The local stability analysis of the Jacobi matrix leads to the evolutionary stability strategy (ESS), so we take partial derivatives of the replicated dynamic equations for financial institutions and SMEs respectively, and obtain the Jacobi matrix as

$$J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} =$$

$$\begin{bmatrix} (1-2x)(yS_2 + C_3 - C_4 - M) & x(1-x)S_2 \\ y(1-y)[(p-1)(C_1 - C_2) + S_1] & (1-2y)\{x[(p-1)(C_1 - C_2) + S_1] \\ & -P(kR + kRr_2 + C + C_1) + C_1\} \end{bmatrix} \quad (5)$$

$$det(J) = a_{11}a_{22} - a_{12}a_{21} = (1-2x)(yS_2 + C_3 - C_4 - M)(1-2y)\{x[(p-1)(C_1 - C_2) + S_1] - p(k + kRr_2 + C + C_1) + C_1\} - x(1-x)S_2 * y(1-y)[(p-1)(C_1 - C_2) + S_1] \quad (6)$$

$$tr(J) = a_{11} + a_{22} = (1-2x)(yS_2 + C_3 - C_4 - M) + (1-2y)\{x[(p-1)(C_1 - C_2) + S_1] - p(kR + kRr_2 + C + C_1) + C_1\} \quad (7)$$

Substituting the points E_1, E_2, E_3, E_4, E_5 into the above equation to calculate the determinant $det(J)$ and the rank $tr(J)$ respectively, and the final calculation results are shown in Table 3.

Table 3. Stability analysis of equilibrium points in the evolution of receivables financing

equilibrium point	$det(J)$	$tr(J)$	Evolutionary results
$E_1(0,0)$	+	-	ESS
$E_2(1,0)$	+	+	Unstable point
$E_3(0,1)$	+	+	Unstable point
$E_4(1,1)$	+	-	ESS
$E_5(x^*, y^*)$		0	Saddle Point

Based on the calculations in Table 3, we can see that (no access to the blockchain, default) and (access to the blockchain, keep the promise) are the final evolutionary stabilization strategies(ESS). The phase diagram of the evolution of the game between financial institutions and SMEs is shown in Fig. 1.

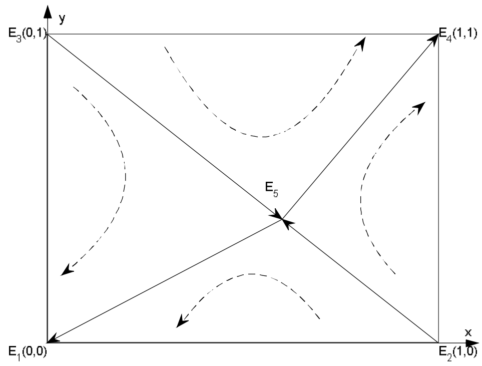

Fig. 1. Phase diagram of the evolution of the game between financial institutions and SMEs

By analyzing the evolutionary phase diagram, we can know that when the decisions of the two sides of the game fall in the zone $E_1E_2E_5E_3$ the game will evolve in the direction of $E_1(0,0)$ and the game evolves in the direction of $E_2E_4E_3E_5$ when the game will evolve in the direction of $E_4(1,1)$. Thus, the probability of the whole game system evolving depends on the position of coordinate $E_5(x^*, y^*)$, i.e. when $S_{E_2E_4E_3E_5} > S_{E_1E_2E_5E_3}$, the strategy adopted by the financial institution will be to access the blockchain and the strategy adopted by the SME will be to keep the promise. When $S_{E_2E_4E_3E_5} < S_{E_1E_2E_5E_3}$, the evolution will take place in the opposite direction. Where

$$S_{E_2E_4E_3E_5} = \frac{1}{2}(1-x^*)(1-y^*) = \frac{1}{2}\left[1 - \frac{P(kR + kRr_2 + C + C_1) - C_1}{(p-1)(C_1 - C_2) + S_1}\right]\left[1 - \frac{C_4 - C_3 + M}{S_2}\right]$$

4 Numerical simulation analysis

4.1 Evolution when parameters take on default values

To describe the evolution of both sides of the game in the process of receivables financing in supply chain finance more concrete and intuitive way, and to verify the conclusion that blockchain can enable receivables financing for SMEs derived from the above derivation, this paper uses $Matlab$ Before conducting the analysis, we need to assign values to the parameters and satisfy the assumptions in Chapter 2, and the default values of the specific parameters are as follows: $R = 50, k = 0.8, r_2 = 0.04, p = 0.9, C = 20, C_1 = 30, C_2 = 800, C_3 = 6$. $C_4 = 2, S_1 = 10, S_2 = 15, M = 10$, and the phase diagram of the evolution of the game when the parameters are set to the default values is obtained (as shown in Fig. 2).

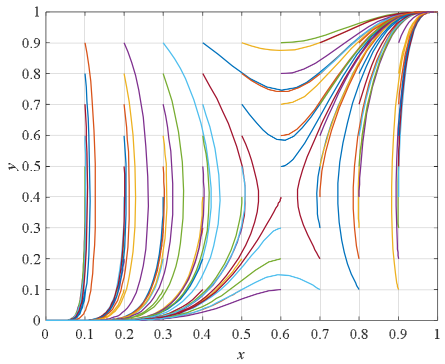

Fig. 2. Phase diagram of the evolution of the game when the parameters are set to their default values

Fixed with parameters set to default values x and values y, both fixed here at 0.5, by changing the x (financial institutions accessing the blockchain) and y (SMEs keeping the promise) to observe the evolution of both sides of the game by varying the values of $x = 0.1, 0.3, 0.5, 0.7, 0.9$, $y = 0.1, 0.3, 0.5, 0.7, 0.9$ respectively. (As shown in Fig. 3). We can see that at lower values, the model stable equilibrium strategy is (no accessing to the blockchain, defaulting), while when the values are increased to a certain level, the model stable equilibrium strategy changes to (accessing to the blockchain, keeping the promise), which confirms the evolutionary stable strategy calculated above (ESS). However, we can also see that the threshold value of the stable equilibrium strategy shift is high, which reflects the existence of certain barriers in the new model of "accounts receivable financing + blockchain".

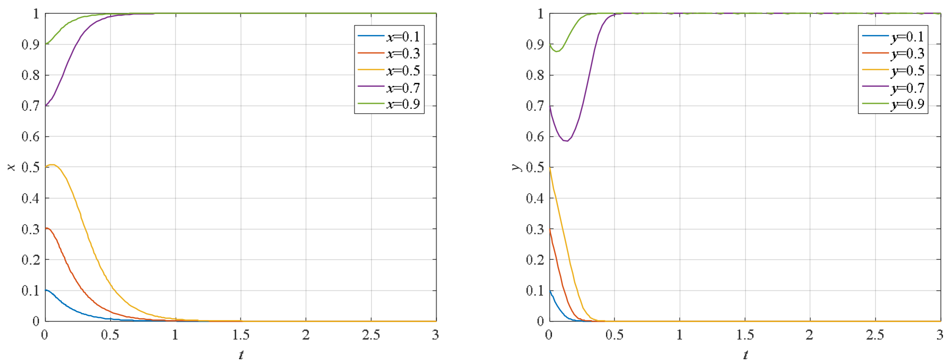

Fig. 3. Evolution of financial institutions and SMEs when parameters are set to default values

4.2 Evolution when parameter values are changed

(1) The cost of default for SMEs after accessing blockchain C_2

Assigning a value to the default cost for SMEs after accessing the blockchain $C_2 = 1000$, while ensuring that other parameters remain unchanged, the evolutionary phase diagram (shown in Fig. 4) is increased by 200 from the default value. By comparing Fig. 2 and Fig. 4, we can find that after increasing the default cost of SMEs after accessing the blockchain, more and more points move towards the point (1,1), As the cost of default increases, the probability of SMEs choosing to keep their contracts increases, and financial institutions are more willing to access the blockchain to monitor the production activities of SMEs, promoting the evolutionary equilibrium of the game.

(2) Incentives for financial institutions when SMEs keep their promises after accessing the blockchain S_1

Under the premise of ensuring other parameters remain unchanged, assigning the incentive of financial institutions when SMEs keep their promises after accessing the blockchain $S_1 = 20$, which is increased by 10 from the default value, the evolutionary phase diagram (as shown in Fig. 4), as S_1 increases, more points converge towards (1,1), for SMEs, choosing to be on the chain can gain additional benefits, more and more enterprises are willing to accept the blockchain platform for financing, and the strategy of SMEs tends to keep their promises, which also has a positive effect on financial institutions.

(3) Additional benefits for financial institutions due to increased efficiency in financing after accessing blockchain S_2

Assigning additional benefits for financial institutions due to increased financing efficiency after accessing the blockchain $S_2 = 30$, while ensuring that other parameters remain unchanged The evolutionary phase diagram (as shown in Fig. 4), which increases by 15 from the default value, shows that when S_2 increases, the strategy of financial institutions tends to access the blockchain, the strategy of SMEs tends to keep the promise, the additional benefit brought by the increase of financing efficiency drives the game to (1,1).

(4) Cost of accessing a blockchain platform M

Assigning a value to the cost of introducing the blockchain platform $M = 15$, while ensuring that the other parameters remain unchanged, which is increased by 5 from the default value, evolves the phase diagram (as shown in Fig. 4). Comparing Fig. 2 and Fig. 4, we find that increasing the cost of introducing a blockchain platform makes more and more points converge towards (0,0), so this parameter is an important factor that constrains whether financial institutions access the blockchain. In the early stage, when there are relatively few members on the chain and the cost to be borne by each member is higher, financial institutions' decisions tend to not access the blockchain, while SMEs' decisions tend to default as the possibility of counterfeiting through information differences increases.

(5) The amount of credit cost reduction for financial institutions after accessing the blockchain $(C_3 - C_4)$

Assigning the amount of credit cost reduction for financial institutions after accessing the blockchain $(C_3 - C_4) = 6$, while ensuring that other parameters remain unchanged, which is increased by 2 from the default value, evolves the phase diagram (as shown in Fig. 4). With the reduction of credit cost, the total cost of financial institutions to carry out receivables financing business decreases, the decision of financial institutions tends to access the blockchain, and the decision of SMEs tends to keep the promise, driving the evolution of the game to (1,1).

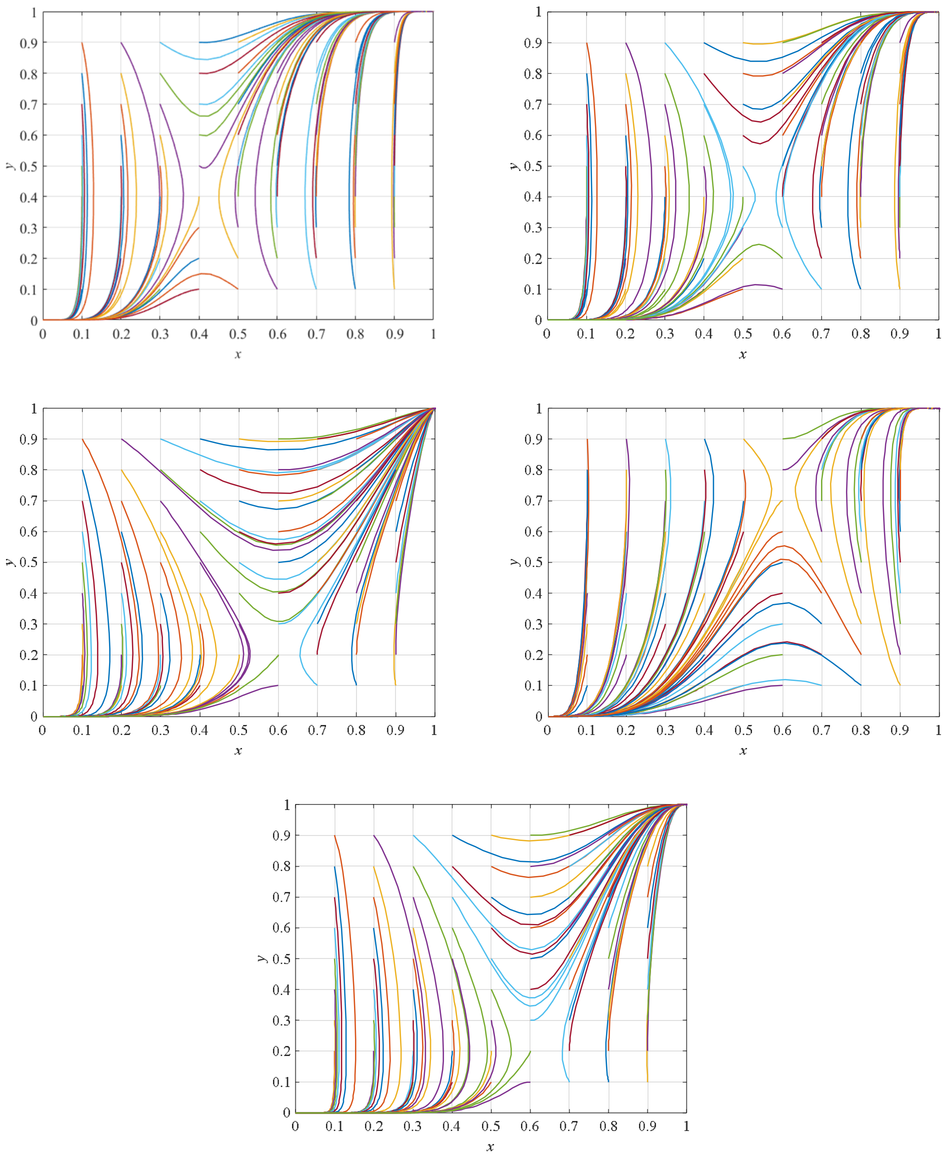

Fig. 4. Phase diagram of the evolution of the game when the parameters are changed

5 Conclusions

This paper constructs an evolutionary game model of financial institutions-SMEs in supply chain finance under blockchain technology, and incorporates collusion into the default decision of SMEs to analyze the impact of blockchain technology on the final decision of both sides of the game. Based on the above study, the following specific conclusions were obtained.

(1): There are certain barriers to the adoption of blockchain technology in the accounts receivable financing model, and the cost of introducing a blockchain platform is an important constraint to the application of the technology. When the initial strategy of the evolutionary game system takes a low value, the model stabilizes the equilibrium strategy towards $E_1(0,0)$ (no access to the blockchain, defaulting), while when the value increases to a certain level, the model stable equilibrium strategy moves towards the point$E_4(1,1)$ (access to the blockchain, keeping the promise). The balance between cost and utility is a key consideration to increase the willingness of all parties to participate and a key point to drive the future application of this technology.

(2): Financial institutions' incentives for SMEs to keep the promise and penalties for default are key factors driving the evolutionary game equilibrium after accessing the blockchain. The increase in penalty for default and the disclosure of historical transaction records can better supervise the production activities of enterprises and enhance their willingness to keep trust, and financial institutions are more willing to access blockchain to reduce the credit risk they may face when carrying out accounts receivable financing business; The compliance incentive can attract more financiers to participate in the process, relieving the pressure of stagnant accounts receivable and meeting the financing needs of enterprises while increasing the financing business volume of financial institutions. This helps to build a good environment for supply chain finance.

(3): The additional benefits of increased financing efficiency and reduced credit costs for financial institutions as a result of access to blockchain have a positive impact on the application of this technology. Through blockchain technology, financial institutions can effectively reduce the labor costs and operational risks associated with traditional credit investigations, improve the efficiency of their accounts receivable financing operations, and more efficiently address the "urgent needs" of SMEs, ultimately achieving a win-win situation for all parties.

Reference

[1] Xu Yangyang, Lei Quansheng. An overview of supply chain finance[J]. Guangxi Science,2021,28(06):547-556.

[2] Abraham Seidmann. Financing sourcing in a supply chain [J]. Decision support systems,2014,58(2):15-20 .

[3] Song Hua. Dilemma and breakthrough: challenges and trends in the development of supply chain finance[J]. China Circulation Economy,2021,35(05):3-9.

[4] Zhou Lei, Deng Yu, Zhang Yuyan. Analysis of the game of supply chain financial services for small and medium-sized enterprises under blockchain empowerment[J]. Financial Theory and Practice,2021(09):21-31.

[5] He Shan, Ma Xiaolin. Analysis of accounts receivable pledge financing based on supply chain finance[J]. Credit, 2018,36(10):89-92.

[6] Zhao Juan. Exploring the innovative path of fintech-enabled industrial chain financial upgrading[J]. Southwest Finance,2022(08):59-71.

[7] Deng Ke. The essence, landing conditions and application prospects of blockchain technology[J]. Journal of Shenzhen University (Humanities and Social Sciences Edition),2018,35(04):53-61.

[8] Guo Bing. Fintech reshapes accounts receivable financing[J]. China Finance, 2018(22):63-64.

[9] Wang Xiaoyan,Shi Yanan,Shi Xiumin. Exploration of blockchain-based supply chain accounts receivable financing model[J]. Finance and Accounting Newsletter,2021(14):141-144.
[10] Shi Xiufan. Blockchain-based business processing framework design for supply chain finance[J]. Finance and Accounting Monthly,2022(15):77-83.
[11] Ren Bo, Qiu Guodong. Overcoming collusive masking behavior: coupling intelligent blockchain and supply chain finance operational mechanisms[J]. China Circulation Economy,2022,36(03):35-47.