Scientific Research Publishing

Open Journal of Business and Management, 2022, 10, 3185-3201
https://www.scirp.org/journal/ojbm
ISSN Online: 2329-3292
ISSN Print: 2329-3284

Evolutionary Game Analysis of the Behavior Strategies of Participants in the Supply Chain Financial Credit Market under Government Subsidies

Shu Fang, Bao Feng

School of Economics, Guangxi University, Nanning, China
Email: fengbao1995@st.gxu.edu.cn

How to cite this paper: Fang, S., & Feng, B. (2022). Evolutionary Game Analysis of the Behavior Strategies of Participants in the Supply Chain Financial Credit Market under Government Subsidies. *Open Journal of Business and Management, 10*, 3185-3201.
https://doi.org/10.4236/ojbm.2022.106158

Received: September 28, 2022
Accepted: November 13, 2022
Published: November 16, 2022

Abstract

On the basis of clarifying the participants in the supply chain financial credit market and their credit behaviors, we use the evolutionary game theory to construct a tripartite evolutionary game model of credit for small and medium-sized enterprises (SMEs), core enterprises and financial institutions in the government subsidy environment, and analyze the equilibrium point. We also use numerical simulation to analyze the influence of changes in government subsidies and other factors and different initial conditions on the evolutionary results. The results show that: 1) The initial proportion of the active credit strategy selected by the game player has a significant impact on the evolution of the system; 2) Government subsidies have a great positive effect on the convergence of the credit system to the best stable state, but the function itself is not universal. Therefore, the government needs to rationally coordinate the subsidy quotas of participating entities in accordance with the actual situation, and provide targeted support and subsidies; 3) The higher the independent repayment rate of SMEs, the more the credit market converges to the best stable state.

Keywords

Government Subsidies, Supply Chain Finance, Credit Market, Evolutionary Game, Numerical Simulation

1. Introduction

Since 2020, the covid-19 shock has produced a fatal blow to Chinese SMEs. A large number of SMEs have closed down due to the broken capital chain, making

it more difficult for SMEs to survive. It is urgent to help SMEs in financing. Supply chain finance grants credit to core enterprises, which can effectively solve the problem of "financing difficulties" for small and medium-sized enterprises. In the process of China's epidemic slowing down and economic recovery and development, the development of supply chain finance will be an important means to restore the national economy. The credit issue is the central issue of supply chain finance. The business among small and medium-sized enterprises, core enterprises and financial institutions revolves around credit, and the strategic choices of various credit entities will affect the credit business. Further, the stability of the credit market greatly affects the development of the supply chain financial market.

Under the impact of the epidemic, there are also great risks in the development of supply chain finance. The supply chain finance credit market will also experience "failure" phenomena which require government to intervene. The various supply chain financial policies that have been issued mention that various methods should be adopted to encourage and protect the development of supply chain finance, and government subsidies are one of the important means. The development of the credit market of supply chain finance is a long-term and dynamic process. Therefore the game situation created by the evolutionary game method is more in line with the actual dynamics, and has certain reference significance for the government to effectively guide the supply chain finance.

In summary, this article intends to use the evolutionary game method to analyze the behavior of the credit market participants under government subsidies on the basis of clarifying the credit business behavior of the supply chain credit market participants. We construct a tripartite game matrix, analyze the evolution process of strategies, discuss the specific evolution mechanism of the credit market under government subsidies, and further use Matlab to perform numerical simulations to verify the accuracy of the model and deeply explore the specific effects of government subsidies on the evolution of the credit market. The conclusions of this article provide suggestions and references for the decision-making subsidies of relevant government departments, and help the development of supply chain finance.

The article is organized as follows: the second part is a review of existing relevant literature, the third part is an analysis of the credit behavior system of the supply chain financial credit market under government subsidies, the fourth part is the construction and analysis of the evolutionary game model, the fifth part is the numerical simulation analysis, and the sixth part is the conclusions and suggestions of the article.

2. Literature Review

In the field of supply chain finance research, Caniato et al. (2019) reviewed the history, current research and future research directions of supply chain finance. One of the important directions mentioned is the cost-benefit trade-off game

between different players and the design of the revenue distribution mechanism behind it. The literature in this area ranges from purely theoretical derivations to actual simulations with data. In theory, Liu et al. (2020) established the corresponding multi-party game model by using the meshless partial differential equation theory and the theories and methods of game theory and information economics, and explored the application of this game model in the multi-game of supply chain finance. Zhang (2022) studied the choice of supply chain financing of Chinese SMEs based on the theoretical model of Go game. In terms of specific applications, Yu and Rehman Khan (2021) studied the supply chain finance of green agricultural products under the background of Covid-19 by using the evolutionary game method, taking agricultural product suppliers and urban residents in the credit system as the two sides of the game. Yan et al. (2021) introduced core enterprises into the traditional accounts receivable financing mode and further analyzed the strategic decisions of banks, SMEs and core enterprises. Finally, the availability of the accounts receivable pledge financing model based on supply chain finance is proved by simulation analysis and evolutionary game theory. Both theory and simulation prove that the three parties can achieve a win-win situation. Li (2020) also showed that supply chain financing can effectively improve the probability of bank lending and reduce the moral hazard of small and medium-sized enterprises in the sports industry. Supply chain financing can not only alleviate the financing difficulties of small and medium-sized enterprises, but also improve the coordination of supply chain, ensure the strategic expansion of core enterprises, and realize the long-term development of the industry. When constructing game models, modern game theory has expanded from simple two-party interaction to three-party game, or even four-party game. The details considered are more and more complex and closer to reality. It is not difficult to conclude from the existing literature that evolutionary game theory is an important core theoretical tool to study supply chain finance.

However, in the existing literature, most of the research on government subsidies and supply chain finance has focused on making policy recommendations for the development of supply chain finance. Li (2011) analyzed the problems existing in China's supply chain finance, combined with the development experience of international supply chain finance, and put forward four policy recommendations to promote development. Wang et al. (2014) pointed out that SMEs need government policy guidance in supply chain innovation. Chang (2018) made policy recommendations on the development of China's foreign trade supply chain finance based on the perspective of the P2P industry. There are few studies on the evolution of the supply chain financial credit market under government subsidies, and the analysis of the strategic behavior of the credit market under government subsidies from the perspective of tripartite entities is even rarer.

In summary, firstly, the research on the evolution of multi-participant relationship in supply chain finance credit market is relatively rare. Credit market participants are mainly small and medium-sized enterprises, core enterprises

and financial institutions. In the past, most domestic scholars' research object on supply chain finance credit is often the game between any two sides of the above three parties, and rarely explores and analyzes the behavior strategy mechanism and evolution process of credit behavior from the perspective of the whole three parties. The second is the optimization research on the main body relationship of supply chain finance credit market, especially from the perspective of government subsidy and the internal optimization of the market, the optimization strategy of the main body relationship of supply chain finance credit market has not been discussed.

To explore the evolution of credit market under government intervention through evolutionary game method is more consistent with the dynamic characteristics in practice, which can have a deeper understanding of the evolution law of credit market and the behavior choice of participants, and has certain reference significance for the government to effectively guide supply chain finance. Based on this, this paper will systematically explore the shortcomings and deficiencies in the above research, hoping to enrich the theoretical connotation and application value of related research. Therefore, this paper will take small and medium-sized enterprises, core enterprises and financial institutions as the research subject of the credit market, consider the impact of government subsidies, build a three-party dynamic game model, explore the optimization strategy of the relationship between the main players in the credit market, and provide a reference for the sound development of the credit market and the formulation of relevant policies.

3. Supply Chain Financial Credit Behavior System under Government Subsidies

Participants in the credit market of supply chain finance include small and medium-sized enterprises, core enterprises and financial institutions, and the government intervenes as an external entity. In the market, the main entities with credit behavior are small and medium-sized enterprises, core enterprises, and financial institutions among which ineffective factors such as incomplete rationality and information asymmetry exist. Participants have different interest demands (Liu & Xia, 2018), and the effective operation of the supply chain financial market depends on the game of behavioral strategies between the participants.

Figure 1 shows the credit behavior system of the supply chain financial credit market under government subsidies. Due to problems such as the easy break of the capital chain of small and medium-sized enterprises, they tend to raise funds. Therefore, small and medium-sized enterprises are the initiators of financing (Hofmann, 2005). When SMEs are financing, they will pledge their accounts receivable or other pledges to obtain loans, and will repay the principal and interest after maturity. The core enterprise is the most critical part of supply chain finance. When SMEs initiate financing, the core enterprise will conduct a

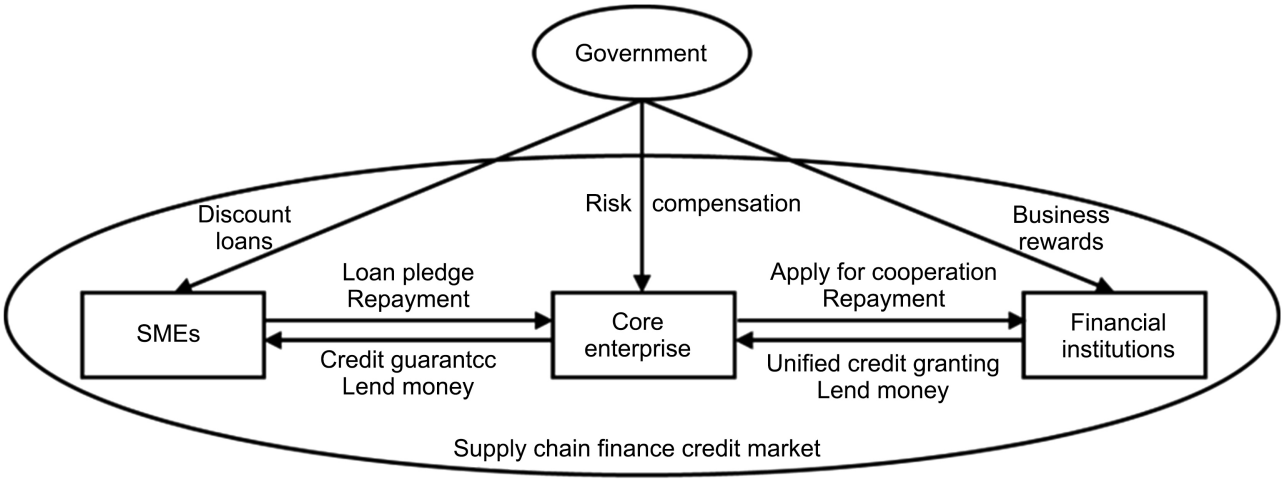

Figure 1. Supply chain financial credit behavior system under government subsidies.

credit evaluation of the SMEs, and will guarantee the SMEs for loan financing to financial institutions if the evaluation is qualified. Core companies will spend evaluation costs when conducting credit evaluations, and the benefits come from the timely interest of small and medium-sized enterprises. In addition, when the government provides risk compensation, they will actively seek cooperation from small and medium-sized enterprises. Financial institutions are the party that provides funds in supply chain finance. When small and medium-sized enterprises apply for loans, they will ask the core enterprises of the cooperation to evaluate whether they can obtain loans. Financial institutions will also spend a certain amount of evaluation costs when choosing core companies to cooperate with, and their income comes from the core companies' repayments. At the same time, when the government gives business incentives, they will open up more supply chain finance businesses.

Specifically, during the transaction process, SMEs can choose financing, that is, use orders, warehouse receipts or other pledges as pledges to make financing loans to core enterprises, thereby increasing their own capital circulation rate and promoting transactions with customers, but SMEs have to pay financing costs including search costs and pledge costs. If SMEs choose not to raise funds, they will continue the original transaction process. When the core enterprise chooses a guarantee, it obtains income through the interest after the loan expires, but it will pay a certain evaluation cost when rating the credit of the small and medium-sized enterprise. In addition, the core enterprise needs to bear the risk of the small and medium-sized enterprise not repaying the loan to a certain extent. When the core enterprise chooses not to guarantee, the core enterprise maintains its original income. When financial institutions choose to cooperate, they can obtain benefits through the interest-bearing repayment of core companies, but they will consume evaluation costs and supervision costs when they choose core companies. If they choose not to cooperate, they will maintain the original benefits.

4. Construction and Analysis of Evolutionary Game Model

4.1. Game Model Construction

Assumption 1: There are three types of game players in supply chain financial credit behavior: SME group A, core enterprise group B and financial institution C. The group members are limited rational and risk-neutral.

Assumption 2: In the tripartite game system of supply chain finance, SMEs consider their own operating conditions and have two strategic choices: lending and not lending. The core enterprise can choose to guarantee or not guarantee. Financial institutions can also cooperate or not. This article regards "financing", "guarantee" and "cooperation" strategies as active credit strategies, and vice versa as passive credit strategies. Assume that the proportion of small and medium-sized enterprises who choose the "loan" strategy is x ($0 \le x \le 1$), the proportion of the "no loan" strategy is $1 - x$; the proportion of core enterprises that choose the "guarantee" strategy is y ($0 \le y \le 1$), the proportion of choosing the "non-guaranteed" strategy is $1 - y$; the proportion of financial institutions choosing the "cooperative" strategy is z ($0 \le z \le 1$), and the proportion of choosing the "non-cooperative" strategy $1 - z$.

Assumption 3: The government does not directly participate in supply chain finance, but will intervene in the operation of supply chain finance through preferential policy support, such as loan discount support for small and medium-sized enterprises, risk compensation for core enterprises, and business reward support for financial institutions.

Based on the above assumptions, the payment matrix of tripartite game of supply chain finance and credit under government subsidies is constructed, as shown in Table 1. The parameters in the payment matrix are defined as follows: R_1, R_2 and R_3 are the basic benefits of smes, core enterprises and financial institutions not participating in supply chain finance respectively; r represents the new income of smes after financing; m represents the loan amount of small and medium-sized enterprises; i_1 represents the interest that smes need to pay to core enterprises, and i_2 represents the interest that core enterprises pay to financial institutions ($i_1 > i_2$); θ represents the probability of self-repayment of smes, and 1-θ represents the risk loss probability of core enterprises; k represents the income obtained by the core enterprise from the disposal of the collateral of the enterprise loan guaranteed when the smes fail to repay the loan as scheduled; T represents the access cost of smes seeking financing; C_1 represents the evaluation cost of core enterprises' loans to smes; C_2 represents the evaluation and supervision cost of financial institutions' participation in supply chain finance.

4.2. Model Construction and Solution

According to the above assumptions and the payout matrix of the mixed game strategy, a dynamic replication method is adopted to solve the problem. Assuming that the expected return when the SME adopts the "financing" strategy and

Table 1. Three-party game payment matrix of supply chain financial credit under government subsidies.

			Financial Institution	
		Core enterprise	Cooperation z	Non-cooperation 1-z
SMEs	Financing x	Guarantee y	$R_1+H_1+r-\theta(m+i_1)-T$, $R_2+i_1+H_2-C_1-(1-\theta)(m+i_1)+k-i_2$, $R_3+H_3+i_2-C_2$	R_1-T+H_1, R_2-C_1, R_3
		Non-guarantee 1 − y	R_1-T+H_1, R_2, R_3-C_2	R_1-T+H_1, R_2, R_3
	Non-financing 1 − x	Guarantee y	R_1, R_2-C_1, R_3-C_2	R_1, R_2-C_1, R_3
		Non-guarantee 1 − y	R_1, R_2, R_3-C_2	R_1, R_2, R_3

"no financing" are E_x and E_{1-x}, and the average expected return is set to be $\bar{E}_S$. The dynamic equation for the replication of the SME's choice of the "financing" strategy is obtained:

$$F(x)=\frac{\mathrm{d}x}{\mathrm{d}t}=x\left[E_x-\bar{E}_S\right]=x(1-x)\left[yzr-yz\theta(m+i_1)+H_1-T\right] \tag{1}$$

In the same way, the dynamic equation for copying the core enterprise's choice of "guarantee" strategy is calculated as:

$$\begin{aligned} G(y)&=\frac{\mathrm{d}y}{\mathrm{d}t}=y\left[E_y-\bar{E}_C\right] \\ &=y(1-y)\left[xz\left(i_1+H_2+k-i_2\right)-xz(1-\theta)(m+i_1)-C_1\right] \end{aligned} \tag{2}$$

Finally, the dynamic equation for copying the core enterprise's choice of "guarantee" strategy is calculated as:

$$H(z)=\frac{\mathrm{d}z}{\mathrm{d}t}=z\left[E_z-\bar{E}_D\right]=z(1-z)\left[xy\left(i_2+H_3\right)-C_2\right] \tag{3}$$

Combining the dynamic Equations (1), (2) and (3), we get the tripartite equations of credit under government subsidies, as shown in Equation (4):

$$\begin{cases} F(x)=\dfrac{\mathrm{d}x}{\mathrm{d}t}=x(1-x)\left[yzr-yz\theta(m+i_1)+H_1-T\right] \\ G(y)=\dfrac{\mathrm{d}y}{\mathrm{d}t}=y(1-y)\left[xz\left(i_1+H_2+k-i_2\right)-xz(1-\theta)(m+i_1)-C_1\right] \\ H(z)=\dfrac{\mathrm{d}z}{\mathrm{d}t}=z(1-z)\left[xy\left(i_2+H_3\right)-C_2\right] \end{cases} \tag{4}$$

4.3. Asymptotic Stability Analysis of the Model

Let the 3 equations in the dynamic Equations (4) $\frac{\mathrm{d}x}{\mathrm{d}t}=0$, $\frac{\mathrm{d}y}{\mathrm{d}t}=0$, and $\frac{\mathrm{d}z}{\mathrm{d}t}=0$. The partial equilibrium point of the credit equation system is obtained as $E_1(0, 0, 0)$, $E_2(1, 0, 0)$, $E_3(0, 1, 0)$, $E_4(0, 0, 1)$, $E_5(0, 1, 1)$, $E_6(1, 0, 1)$, $E_7(1, 1, 0)$, $E_8(1, 1, 1)$ and

$E_9\left(x^*, y^*, z^*\right)$, among which $E_9\left(x^*, y^*, z^*\right)$ is the solution of Equations (5).

$$\begin{cases} yz\left[r+\theta\left(m+i_1\right)\right]+H_1-T=0 \\ xz\left[i_1+H_2+k-i_2-\left(1-\theta\right)\left(m+i_1\right)\right]-C_1=0 \\ xy\left(i_2+H_3\right)-C_2=0 \end{cases} \tag{5}$$

Considering that the asymptotically stable solution of the multi-group evolutionary game replicating dynamic system must be a strict Nash equilibrium solution (Pang & Shen, 2018), while is not a strict Nash equilibrium solution, so only the equilibrium point needs to be considered. In the study of evolutionary games, the local stability of the Jacobian matrix of the system can be used to judge the stability of the equilibrium point of the group dynamic system (Friedman, 1998). The Jacobian matrix of the system obtained from the differential equation is:

$$J=\begin{bmatrix} \partial F/\partial x & \partial F/\partial y & \partial F/\partial z \\ \partial G/\partial x & \partial G/\partial y & \partial G/\partial z \\ \partial H/\partial x & \partial H/\partial y & \partial H/\partial z \end{bmatrix} \tag{6}$$

Using the Lyapunov method, the local stability of the equilibrium point of the differential equation can be judged (Guttalu & Flashner, 1988), and the local stability can be analyzed to obtain Proposition 1 to Proposition 4.

***Proposition* 1:** If $H_1<T$, $E_1(0, 0, 0)$ is the evolutionary stable strategy of the system, and this stable state is very unfavorable to the development of supply chain finance.

Proof: Substituting (0, 0, 0) into formula (6), the Jacobian matrix of E_1 is:

$$J=\begin{bmatrix} H_1-T & 0 & 0 \\ 0 & -C_1 & 0 \\ 0 & 0 & -C_2 \end{bmatrix}$$

According to the definition, we have $-C_1<0$ and $-C_2<0$. If $H_1<T$, that is, when the government's subsidy to SMEs is less than the financing cost of SMEs, all the characteristic values of the Jacobian matrix are less than 0. According to the Lyapunov indirect method, $E_1(0, 0, 0)$ is systematic ESS. In this stable state, SMEs choose "no financing", core enterprises choose "no guarantee", and financial institutions choose "no cooperation", which is very detrimental to the development of supply chain finance.

***Proposition* 2:** If $H_1>T$, $E_2(1, 0, 0)$ is an evolutionary and stable strategy of the system. In this stable state, SMEs choose "financing", core enterprises choose "no guarantee", and financial institutions choose "nocooperation".

Proof: The Jacobian matrix of E_2 is:

$$J=\begin{bmatrix} T-H_1 & 0 & 0 \\ 0 & -C_1 & 0 \\ 0 & 0 & -C_2 \end{bmatrix}$$

It is known that $-C_1 < 0$ and $-C_2 < 0$, if $H_1 > T$, that is, when the government subsidy is greater than the financing cost of small and medium-sized enterprises, all the characteristic values of the Jacobian matrix are less than 0. According to the Lyapunov indirect method, $E_2(1, 0, 0)$ can be obtained as the ESS of the system. In this stable state, only small and medium-sized enterprises take the initiative to raise funds, and the supply chain finance business cannot be carried out smoothly.

***Proposition* 3:** Regardless of the value of the parameter, E_3, E_4, E_5, E_6 and E_7 can only be unstable points or saddle points.

Proof: The Jacobian matrix of E_3 is:

$$J = \begin{bmatrix} H_1 - T & 0 & 0 \\ 0 & C_1 & 0 \\ 0 & 0 & -C_2 \end{bmatrix}$$

According to the judgment condition of Lyapunov's indirect method for ESS, if and only if the values on the diagonal of the Jacobian matrix of the equilibrium point are all negative numbers, the equilibrium point is ESS. In the Jacobian matrix of E_3, E_3 can only be an unstable point or a saddle point since $C_1 > 0$. When $H_1 > T$, E_3 is the saddle point; when $H_1 < T$ and $H_1 + C_1 > T + C_2$, E_3 is the unstable point; when $H_1 < T$ and $H_1 + C_1 < T + C_2$, E_3 is also the saddle point. In the same way, it is easy to prove that E_3, E_4, E_5, E_6 and E_7 can only be unstable points or saddle points.

***Proposition* 4:** When $r + H_1 > \theta(m + i_1) + T$, $i_1 + k + H_2 > C_1 + (1-\theta)(m + i_1) + i_2$ and $i_2 + H_3 > C_2$ are satisfied, $E_8(1, 1, 1)$ is the ESS of the system. At this time, the supply chain finance is developing towards the most ideal state.

Proof: The Jacobian matrix of E_8 is:

$$J = \begin{bmatrix} \theta(m + i_1) + T - r - H_1 & 0 & 0 \\ 0 & C_1 + (1-\theta)(m + i_1) + i_2 - i_1 - k - H_2 & 0 \\ 0 & 0 & C_2 - i_2 - H_3 \end{bmatrix}$$

When $r + H_1 > \theta(m + i_1) + T$, $i_1 + k + H_2 > C_1 + (1-\theta)(m + i_1) + i_2$ and $i_2 + H_3 > C_2$ are satisfied, the matrix eigenvalues are all less than 0. According to the Lyapunov indirect method, $E_8(1, 1, 1)$ is ESS at this time. The practical significance is that if the following three conditions are met at the same time, then $E_8(1, 1, 1)$ is an evolutionary stable strategy. 1) The sum of government subsidies to SMEs and the newly increased income after financing is greater than the sum of the loan principal and interest of SMEs and the access costs paid. 2) The government's risk compensation for the core enterprise guarantee plus the interest and pledged disposal income obtained after the core enterprise guarantee is greater than the core enterprise's evaluation cost. 3) The government's business rewards for cooperation with financial institutions plus the interest received during cooperation with financial institutions are greater than the evalua-

tion and supervision costs paid by financial institutions. In this stable state, SMEs choose financing, core enterprises choose guarantees, financial institutions choose cooperation, and supply chain finance moves toward the most ideal state.

5. Numerical Simulation Analysis

On the basis of theoretical analysis, we further explore the influence of the changes of various parameters in the tripartite model of supply chain finance and credit on the dynamic evolution of the system. In this section, the actual supply chain financial operation is used as a basic reference, and Matlabis used to numerically simulate the evolution process of interaction between small and medium-sized enterprises, core enterprises and financial institutions. Based on the actual situation, according to the China central bank's credit loan benchmark interest rate table for 2021 shown in Table 2, the 10-year annualized interest rate of the loan is 4.9%. Therefore, if the loan of SMEs is 400,000 for 10 years, the maturity interest is about 100,000, which is the benchmark to define the initial value of the simulation data.

For the convenience of analysis, the value of each parameter in the system is scaled down, assuming that the initial value of each parameter is: $R_1 = 1$, $R_2 = 1$, $R_3 = 1$; assuming that the loan m is 4, then the core enterprise interest is about 1. Assuming other internal parameters $r = 8$; $i_2 = 0.5$; $\theta = 50\%$; $k = 1.5$; $T = 2$; $C_1 = 0.3$; $C_2 = 0.3$. In addition, considering the actual government subsidy situation, risk compensation is the highest, financing subsidy is the second, and business rewards are the lowest. Assuming that the government's financing subsidy for small and medium-sized enterprises $H_1 = 0.6$, the risk compensation for core enterprises $H_2 = 1.2$, and the business rewards for financial institutions $H_3 = 0.3$, the above initial conditions meet the conditions of Proposition 1 and Proposition 4. Considering the randomness of the initial state, except for 4.1, the initial credit ratio of the participating subjects in the remaining studies is set to 0.5.

5.1. The Impact of Population Ratio on Evolutionary Results

The evolution phase diagram of the tripartite game system of supply chain finance credit is shown in Figure 2, where X, Y, and Z respectively represent the proportion of small and medium-sized enterprises that choose financing, the proportion of core business groups that choose guarantees, and the proportion of financial institutions that choose cooperation.

Table 2. 2021 China benchmark loan interest rate.

Time Span	Interest Rate (%)
Within a year	4.35
One year to five years	4.75
More than five years	4.90

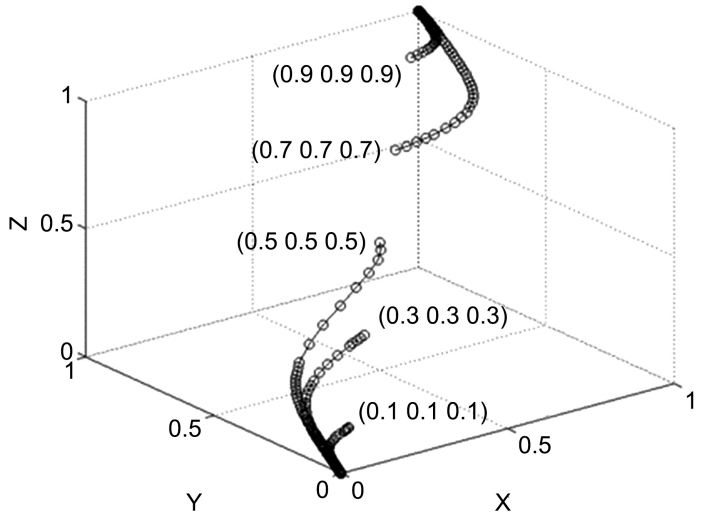

Figure 2. The influence of the initial proportion of the population on the result of system evolution.

As shown in **Figure 2**, under the initial conditions, the system has two evolutionary stable strategies (0, 0, 0) and (1, 1, 1), which verifies the analysis of Proposition 1 and Proposition 4. At the same time, the result of the final evolution of the system is related to the proportion of the initial population of the game player. In the initial state, the higher the proportion of active credit strategies selected by each game player, the higher the probability that the system will converge to a stable equilibrium point (1, 1, 1). Otherwise, the system will converge to a stable equilibrium point (0, 0, 0). The greater the probability, which indicates that in the initial credit system, the higher the proportion of active credit strategies adopted by each game subject, the more favorable it is for the development of supply chain financial services.

5.2. The Impact of Government Subsidies on Evolutionary Results

In the operation of the supply chain financial credit market, the government hopes to promote the completion of supply chain financial services in the form of subsidies, thereby promoting the smooth operation of the credit market. The influence of government subsidies on the evolution of the credit system is shown in **Figure 3** to **Figure 6**.

Figure 3 to **Figure 5** show that regardless of government subsidies to SMEs, core enterprises or financial institutions, they have a certain positive significance in promoting the achievement of supply chain financial services, and help the credit system to converge to an optimal and stable state (1, 1, 1). At the same time, as the amount of subsidies increases, the speed at which the credit system converges to (1, 1, 1) will continue to increase.

It can be seen from **Figure 3** to **Figure 6** that if the government subsidy amount to any participant in the system is too low or there is no subsidy, the system is difficult to converge to the point (1, 1, 1), and it will move towards

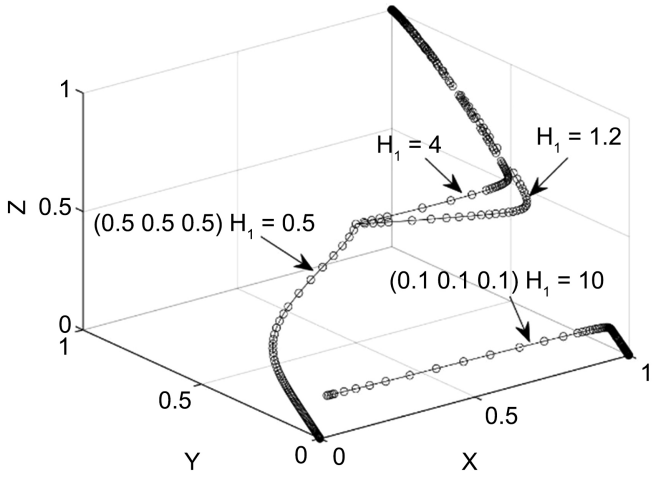

Figure 3. The impact of financing subsidies on the results of system evolution.

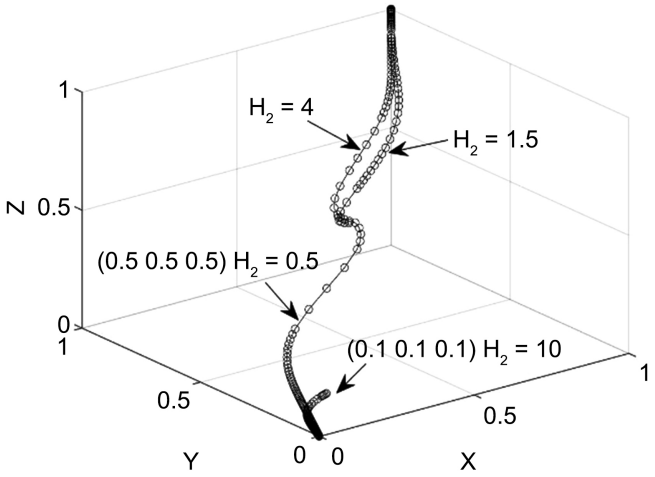

Figure 4. The impact of risk compensation on the results of system evolution.

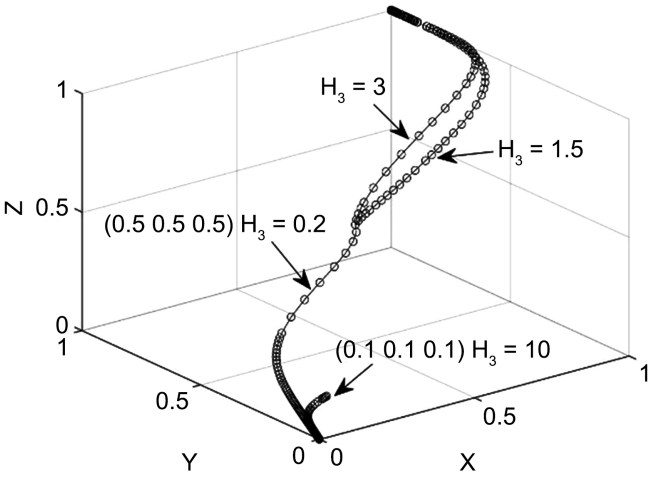

Figure 5. The impact of business incentives on the results of system evolution.

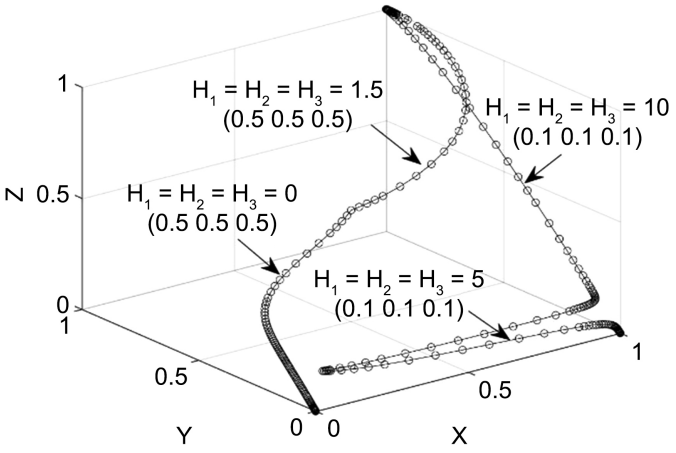

Figure 6. The impact of three types of subsidies on the results of system evolution.

(0, 0, 0). When the initial proportion of participants in the game system choosing active credit strategies is small, that is, when x, y, and z are all 0.1, the government will simultaneously increase subsidies to small and medium-sized enterprises, core enterprises, and financial institutions, which will help the system converge to (1, 1, 1), but the amount of subsidy needs to be large. Meanwhile, if the government only unilaterally increases risk compensation or business rewards, the system will not be able to converge to the (1, 1, 1) point. It should be noted that when the government unilaterally increases the financing subsidy or when the three subsidies are high, it will cause the system to converge to (1, 0, 0), indicating that SMEs are thirsty parties in the credit market and are vulnerable to market influence Even if the initial proportion of "financing" is low, as long as there is a certain amount of subsidies and profits, it will prompt them to raise funds.

Based on **Figure 3** to **Figure 6**, when the initial proportion of participating entities choosing active credit strategies is low, compared to blindly and unilaterally increasing the subsidy to a certain entity, if the government can rationally coordinate the subsidy quota for each participating entity, It will help the system converge to (1, 1, 1). From **Figure 6**, we can also know that when the initial proportion of participants choosing an active credit strategy is high, that is, when x, y, and z are all 0.5, without government subsidies, the credit system also cannot converge to the best state, but moves toward (0, 0, 0). Under the above conditions, if the government implements certain subsidies, the system can converge to (1, 1, 1) and evolve toward the best state, indicating that government subsidies have an important catalytic effect on the achievement of credit business.

5.3. The Impact of Government Subsidies on Evolutionary Results

In the process of supply chain finance credit, if SMEs, as borrowers, do not repay on time or directly fail to repay, it will cause certain troubles to core enterprises and financial institutions. The influence of the SME's independent repayment rate on the evolution of the credit system is shown in **Figure 7** and **Figure 8**.

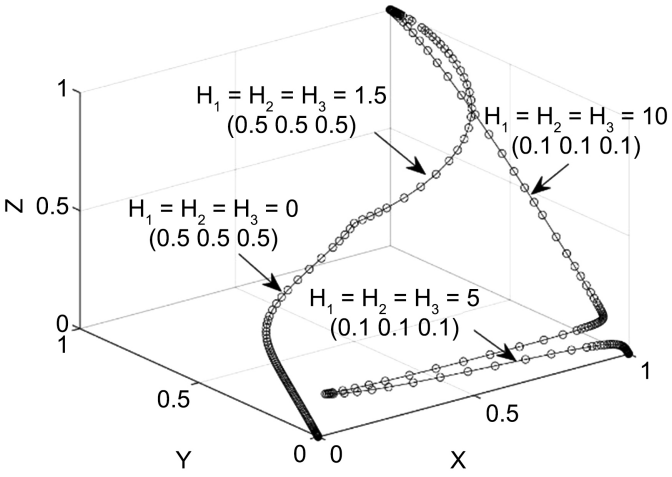

Figure 7. The influence of θ on the result of system evolution when there is no subsidy.

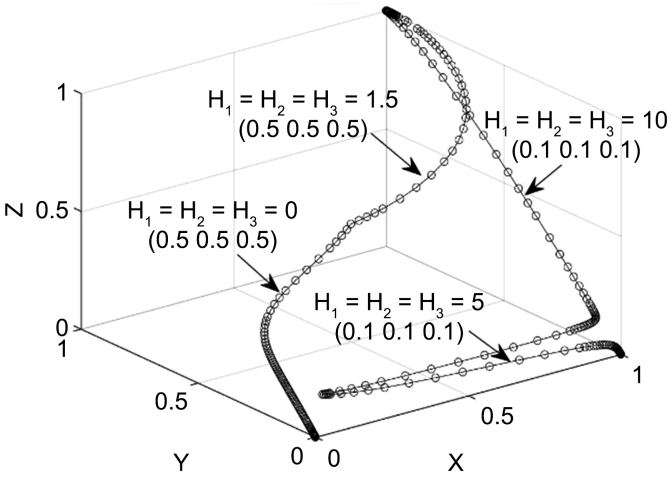

Figure 8. The influence of θ on the result of system evolution when there is subsidy.

Figure 7 shows the effect of θ on the evolution of the system when there is no government subsidy. It can be found that no matter how θ changes when there is no subsidy, the system always converges to (0, 0, 0). Figure 8 shows the effect of θ on the evolution of the system when there is government subsidy. From the simulation diagram, as θ increases, the system gradually evolves toward the point (1, 1, 1), and the larger θ, the faster the evolution speed. Based on Figure 7 and Figure 8, under the same conditions, government subsidies have a certain promotion for the system to converge to the best stable state.

6. Conclusion and Policy Recommendations

6.1. Conclusion

Based on the theory of supply chain finance and evolutionary game theory, the paper constructs a tripartite evolutionary game model of supply chain finance

credit for small and medium-sized enterprises, core enterprises and financial institutions under the environment of government subsidies, and uses the dynamic method to solve 8 evolutionary equilibrium points in the credit system. 8 points are analyzed by the Jacobian matrix method, and the effect of changes in the population proportion, government subsidies and repayment probability on the evolution of the credit system is explored through Matlab numerical simulation concluding the internal mechanism of the credit market evolution under the classic model of "small and medium-sized enterprises + core enterprises + financial institutions".

1) Credit system may evolve to the best stable state where small and medium-sized enterprises choose financing, core enterprises choose guarantees, and financial institutions choose cooperation if and only if $r+H_1>\theta(m+i_1)+T$, $i_1+k+H_2>C_1+(1-\theta)(m+i_1)+i_2$ and $i_2+H_3>C_2$; the key to the evolution lies in the initial population proportion of the credit system participants in choosing active credit strategies.

2) Government subsidies play a very positive role in the achievement of the supply chain financial credit business and the stable development of the credit market. When the system converges to the best stable point, if the government invests more, the faster the system converges. However, it should be noted that if the proportion of the initial population of the participants who choose the active credit strategy is small, blindly increasing the subsidy to one party will not have the best effect. Taking into account the fragility of small and medium-sized enterprises and the characteristics of the credit market, rational coordination of subsidies for all parties and targeted support and subsidies can effectively promote the stable development of the supply chain financial credit market.

3) The independent repayment rate of SMEs has a great influence on the achievement of credit business. In an environment with appropriate government subsidies, the higher the independent repayment rate of SMEs, the higher the proportion of core enterprises choosing guarantees, and the higher the proportion of financial institutions choosing cooperation, and the system will converge to the best stable state. However, in reality, due to improper capital flow and other reasons, the self-repayment rate of SMEs is not very high, and government subsidies cannot effectively increase the self-repayment rate. At this time, the government should strengthen supervision and formulate appropriate punishment mechanisms to promote the increase in the rate of voluntary repayment.

6.2. Policy Recommendations

In order to better promote the development of supply chain financial business and ensure the stability of the supply chain financial credit market, the following policy recommendations are put forward based on the above conclusions.

1) The government should attach importance to supply chain financial credit. The government should recognize the importance of supply chain financial credit to the development of small and medium-sized enterprises, establish relevant

departments or arrange personnel to pay attention to supply chain financial credit, actively understand the industry principles and development trends of the supply chain financial credit market, and improve the corresponding laws and regulations in the credit market.

2) The government should rationally coordinate subsidies based on the actual conditions of the credit market. Government subsidies have a great positive effect on the stable development of the credit market, but when granting subsidies, they must also be rationally coordinated according to the actual conditions of the credit market. Since SMEs are the weaker party in credit, the government can formulate relevant policies, such as granting an appropriate percentage of loans to SMEs as financing subsidies. The core enterprise is the backbone of credit, and the non-repayment behavior of small and medium-sized enterprises will cause greater losses to the core enterprise. Therefore, the risk compensation fee needs to be higher. Through the establishment of a risk compensation mechanism, an appropriate percentage of the loan amount is invested as risk compensation; as for financial institutions, the government may formulate business incentive mechanisms, such as granting financial institutions an appropriate percentage of the loan amount for supply chain financial services involved as incentives. In general, it is necessary to combine the actual credit market and local economic conditions, rationally coordinate, and formulate an appropriate amount as a subsidy, so that the stability and development of the supply chain financial credit market can be promoted most effectively.

3) Finally, the government should strengthen credit market supervision and establish appropriate punishment mechanisms. In reality, there will be many problems in the supply chain financial credit market, such as the involuntary repayment of small and medium-sized enterprises, which may not be effectively solved by subsidies alone. Therefore, the government can establish an appropriate punishment mechanism to punish SMEs who fail to repay on time according to the overdue time, and impose huge liquidated damages on non-repayment. In addition, macro-regulation of the entire supply chain financial credit market should be carried out, other violations in the credit system should be resolved in a timely manner, and relevant laws and policies should be adjusted accordingly through investigation and feedback to ensure the stability and development of the supply chain credit market.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Caniato, F., Henke, M., & Zsidisin, G. A. (2019). Supply Chain Finance: Historical Foundations, Current Research, Future Developments. *Journal of Purchasing and Supply Management, 25,* 99-104. https://doi.org/10.1016/j.pursup.2019.02.002

Chang, H. (2018). Research on the Financial Development of China's Foreign Trade Supply Chain—Based on the Perspective of P2P Industry. *Theory Monthly, No. 10,* 131-137. (In Chinese)

Friedman, D. (1998). On Economic Applications of Evolutionary Game Theory. *Journal of Evolutionary Economics, 8,* 15-43. https://doi.org/10.1007/s001910050054

Guttalu, R. S., & Flashner, H. (1988). A Numerical Method for Computing Domains of Attraction for Dynamical Systems. *International Journal for Numerical Methods in Engineering, 26,* 875-890. https://doi.org/10.1002/nme.1620260409

Hofmann, E. (2005). Supply Chain Finance: Some Conceptual Insights. In R. Lasch, & C. G. Janker (Eds.), *Logistik Management: Innovative Logistikkonzepte* (pp. 203-214). Deutscher Universitats-Verlag. https://doi.org/10.1007/978-3-322-82165-2_16

Li, S. (2011). Policy Recommendations for the Development of China's Supply Chain Financial Services. *Journal of Finance and Economics, No. 7,* 36-39. (In Chinese)

Li, S. (2020). Supply Chain Financing Strategy in Sports Industry Based on Game Theory. In V. Sugumaran, Z. Xu, & H. Zhou (Eds.), *Proceedings of the 2020 International Conference on Multi-Modal Information Analytics: Vol. 1: Application of Intelligent Systems in Multi-Modal Information Analytics* (pp. 143-149). Springer. https://doi.org/10.1007/978-3-030-51431-0_22

Liu, W., & Xia, L. (2018). Analysis on the Behavioral Strategy of Participants on Online Lending Market Based on Evolutionary Game Theory—A Trilateral Game Perspective. *China Management Science, No. 5, 169-177.* (In Chinese)

Liu, X., Peng, X., & Stuart, M. (2020). Multiparty Game Research and Example Analysis in Supply Chain Finance System Based on MPDE Theory. *Alexandria Engineering Journal, 59,* 2315-2321. https://doi.org/10.1016/j.aej.2020.02.023

Pang, Q., & Shen, Y. (2018). A Tripartite Evolutionary Game Analysis of Corruption under Limited Rationality. *Statistics and Decision, 34,* 36-40. (In Chinese)

Wang, F., & Su, D. (2014). Research on Financing Innovation and Guiding Policies of Small and Medium-Sized Enterprises Based on Supply Chain Finance Model. *Logistics Technology, 33,* 375-377. (In Chinese)

Yan, B., Chen, Z., Yan, C., Zhang, Z., & Kang, H. (2021). Evolutionary Multiplayer Game Analysis of Accounts Receivable Financing Based on Supply Chain Financing. *International Journal of Production Research, 2021,* 1-19. https://doi.org/10.1080/00207543.2021.1976432

Yu, Z., & Rehman Khan, S. A. (2021). Evolutionary Game Analysis of Green Agricultural Product Supply Chain Financing System: COVID-19 Pandemic. *International Journal of Logistics Research and Applications, 25,* 1115-1135. https://doi.org/10.1080/13675567.2021.1879752

Zhang, L. (2022). Analysis on the Choice of Supply Chain Financial Financing Mode Based on Game Theory Model. In V. Sugumaran, A. G. Sreedevi, & Z. Xu (Eds.), *The 4th International Conference on Multi-modal Information Analytics: Vol. 2: Application of Intelligent Systems in Multi-Modal Information Analytics* (pp. 1071-1076). Springer. https://doi.org/10.1007/978-3-031-05484-6_146