

The impact of credit guarantee on enterprises' willingness to undertake environmental responsibilities: Evidence from a dynamic evolutionary game model

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ABSTRACT

Evolutionary game is a powerful tool for exploring the interactive strategies of enterprises, governments, and third-party platform institutions that provide credit guarantees. In the context of big data and the Internet of Things, as more and more enterprises participate in the collective process of credit shaping, this series of platform-based credit ratings have a profound impact on the environmental willingness of enterprises. This article constructs an evolutionary game model of enterprise government with the introduction of credit guarantee mechanism, explores the evolution of participant behavior and their Evolutionary Stable Strategies (ESS), and uses MATLAB tools for evolutionary simulation to explore the impact of relevant parameters on the system evolution results. The results have shown that the selection of environmental protection strategies by enterprises is a dynamic process of continuous adjustment and optimization; The government can help the evolutionary game converge to an ideal state by providing reward subsidies and strengthening punishment measures; The intervention of credit guarantees has influenced the strategic choices of both parties, promoting the willingness of enterprises to actively fulfill their environmental responsibilities.

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1. Introduction

China has experienced more than 30 years of rapid economic development. However, the price of the economic boom is the excessive consumption of resources and the environment. Therefore, the Chinese government attaches great importance to environmental issues, and how to encourage company to actively implement environmental protection behaviors and improve the ability to reduce pollution and emissions is currently an urgent issue. Given the public good nature of the environment, government-enforced governance is considered the primary means to solve the pollution problem of company (Jordan, 1999; Perdue et al., 2003). Due to the poorly defined property rights of the environment, company often choose to avoid the responsibility of environmental governance in order to maximize their profits, leading to the failure of the market mechanism (Liu & Yang, 2025). Government market regulation is one of the effective policy tools to overcome market failure and promote sustainable economic growth (Bernauer & Koubi, 2006; Dong et al., 2021). Due to the limitation of government management radius and the complexity of environmental issues, local governments are unable to monitor the environmental behavior of company in real time. Under the dual pressure of regional development and performance evaluation, the government and company have the same goal, which is easy to form "government-enterprise collusion" and soften environmental regulations, but instead encourage company to violate the laws and regulations of emissions opportunistic behavior, resulting in the failure of government environmental regulation (Nazih et al., 2020; Zhang et al., 2023). In recent years, with the development of the digital economy, the government hopes to further strengthen the state's capacity in the social field by promoting credit mechanisms, complementing the effectiveness of existing legal norms, and improving the effectiveness of social governance beyond the order centrally provided by the government (Feng et al., 2023). The credit guarantee mechanism is introduced in the implementation of corporate environmental responsibility to play a restraining and incentivizing role, reduce the financial burden on the government, while alleviating the problem of capital turnover caused by corporate environmental responsibility, reduce the cost of corporate environmental responsibility, and encourage company to actively and voluntarily fulfill their

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environmental responsibility (Zuo, 2023). The supervisory effectiveness of credit guarantee mechanisms is derived from the “gaze”, a combination of a constantly observing system and a constantly observed sense of self (Hirth, 2014; Chen et al., 2025). The platform-led credit scoring mechanism transforms the traditional, empirical order of trust into data-based algorithmic control and accurate prediction, reconfiguring the traditional trust model (Jiang et al., 2019). Credit transactions are conducted between companies and third-party credit guarantee institutions, exchanging the small credit of companies for the large credit of third-party institutions (Luo, 2012). The fulfillment of environmental responsibility is a long-term repetitive market behavior, and in the process of accumulating credit. The accumulation of credit is a sunk cost, the greater the sunk cost, the greater the opportunity cost of losing trust in the process of fulfilling environmental responsibility, the greater the loss of trust in the enterprise (Li et al., 2024; Zhu et al., 2021; Dai et al., 2023). Therefore, the more credit accumulated by a company, the more they will pay attention to their own credit image, consciously abide by the rules and actively fulfill their environmental responsibilities (Qi et al., 2025; Higham, 2001).

This article incorporates the credit guarantee mechanism into the theoretical framework of the game between enterprises and governments regarding environmental responsibility. Construct a dynamic evolutionary game model among enterprises, governments, and credit guarantee institutions under regulatory mechanisms, and deeply explore the evolutionary mechanism of credit guarantee in enhancing corporate environmental willingness. At the same time, Matlab was used to analyze the strategic evolution theory and system stability of enterprises assuming environmental protection responsibilities, and simulation verification was conducted. It was found that in the scenario of credit guarantee intervention, enterprises are more willing to assume environmental protection responsibilities. The article provides an empirical explanation for building a collaborative environmental responsibility fulfillment supervision system with multiple stakeholders, and also provides a theoretical basis and decision-making support for solving other environmental problems.

2. Methods

Evolutionary Game Theory (EGT) has developed on the basis of Game Theory and has become a new research trend. The drawback of game theory is that it assumes that the parties to the game are perfectly rational, i.e., that all parties to the game are rational economic agents and achieve the best strategy in a game (Ding et al., 2023). However, in today's complex market economy, complete rationality is very difficult to achieve for real decision makers (Axelrod & Hamilton, 1981). The evolutionary game modifies this assumption and considers that the rationality of the game participants is limited and it is difficult to analyze the game comprehensively, which is reflected in the evolutionary game that the game participants must adjust dynamically in the long run to reach the equilibrium, and then the strategy adopted by the game parties is the Evolutionarily Stable Strategy (ESS). If the player deviates from this stable strategy, a new evolutionary game will emerge, and after adjustment, the equilibrium will be reached again. Assuming that the sample of subjects is Q , to simplify the description, let the subjects have only two strategies X and Y . The proportion of subjects who choose and two strategies in the sample is x and $1-x$, where $x \in (0,1)$. When the evolutionary game starts, the subjects in the sample will appear random competition, and the evolutionary game theory emphasizes the process of changing the proportion of subjects who choose a particular strategy in the sample Q . As time progresses, it can be expressed as a function of time: $x(t)$ and $x(1-t)$. The imitative learning process of each subject can form a replicative dynamic equation:

$$\frac{dx}{dt} = x(u_x - \bar{u}) \quad (1)$$

This equation describes the dynamics of replicators choosing strategy X , where x is the proportion of subjects choosing strategy X in the total sample Q , u_x is the return of choosing strategy X , and \bar{u} is the average return of the overall strategy. The rate of evolution is proportional to the expected difference in returns from different strategy choices.

Credit is closely related to the game, from the perspective of evolution and game to understand credit, you can use the classic model of game theory "prisoner's dilemma" to analyze. The model is set up to determine whether a company is actively engaged in environmental responsibility. If both companies promise to actively fulfill their environmental responsibilities, environmental pollution will be effectively managed, the producer's own reputation and social influence will increase, and environmental and social benefits will be improved; if one of the companies breaks its promise to actively fulfill its environmental responsibilities, then environmental management will be affected. There are costs associated with being active in environmental responsibility, so a party that is passive in environmental responsibility gains more than a company that is active in environmental responsibility. Suppose that both companies actively fulfill their environmental responsibilities, receiving a benefit of U_1 and paying a cost of C_1 ; if one does not fulfill and the other does, both receive a benefit of U_3 and the one that does still pays a cost of C_1 ; if both negatively fulfill their environmental responsibilities, they receive a benefit of U_2 ($U_2 < U_3 < U_1$) and pay no cost. Thus, the payoff matrix is as follows:

Table 1
Payment matrix for two companies

		Company 2	
		Actively fulfilling environmental responsibilities	Negative fulfillment of environmental responsibility
Company 1	Actively fulfilling environmental responsibilities	$U_1 - C_1, U_1 - C_1$	$U_3 - C_1, U_3$
	Negative fulfillment of environmental responsibility	$U_3, U_3 - C_1$	U_2, U_2

This is where a good credit relationship becomes one of the ways to solve this dilemma. The game, as it continues, has the potential for two companies to establish a credit relationship such that each party trusts the other party's decision to actively perform environmentally while adopting a performance strategy of their own. This requires one party to trust the other to make the decision to perform, while trusting the other to predict that they will also trust the other to perform their strategy. Trust becomes a condition for satisfying both parties' need for consistency. As perfectly rational people seeking to maximize their interests, there must be incentives or penalties to ensure that both parties honor their commitments to protect the environment. As the external environment changes, one of the parties may deviate from the commitment, and there are many factors that affect the stability of credit in economic activities. The introduction of a credit mechanism provided by a third-party platform can solve this problem of credit stability to a certain extent.

3. Evolutionary Game Model

3.1 Construction of the Evolutionary Game System (I)

First, we construct the evolutionary game model (I) with the game population as the producer and the government, and study the evolutionary steady-state equilibrium of the strategies of the two parties in the game without the credit rating participation scenario.

3.1.1 Basic Assumptions and Parameter Description

The parties involved in the evolutionary game are the producer group and the government group, both of which are finite rational subjects. The strategy set of the producer group is (active responsibility, negative responsibility), and the strategy set of the government group is (strong regulation, weak regulation).

Hypothesis 1: The probability of positive company performance is $x(0 \leq x \leq 1)$ and the probability of negative performance is $1 - x$; the proportion of strong government group regulation is $y(0 \leq y \leq 1)$ and the proportion of weak regulation is $1 - y$.

Hypothesis 2: The environmental protection fund paid by the enterprise is P , and the credit rating obtained by the enterprise by fulfilling its environmental responsibility and declaring it in the third-party platform organization is r . The cost of the enterprise when it actively fulfills its environmental responsibility and is consistent with its declaration is C_E . Therefore, the true cost of actively fulfilling its environmental responsibility is rC_E .

Hypothesis 3: The cost of strong government regulation is C_Q , and the cost of weak regulation is C_R . The cost of environmental regulation, which the government incurs when a company fails in its environmental responsibilities, is C_S . The government penalizes a company for failing in its environmental responsibilities under strong regulation with a fine of F . The government gives incentive subsidies to companies according to their environmental credit rating, and the percentage of subsidies under strong regulatory conditions is:

$$r_R = \begin{cases} r, & 0.6 \leq r \leq 1 \\ 0, & 0 \leq r \leq 0.6 \end{cases} \tag{2}$$

If the company's credit rating is $r \geq 0.6$, the subsidy ratio is r . If the company's credit rating is $r < 0.6$, the company is found to have a large amount of misreporting and is not subsidized. The subsidy rate under weakly regulated conditions is r_F . r_F is slightly higher than r_R because under weakly regulated government conditions, the audit is less stringent than under highly regulated conditions, and the company's credit rating is slightly higher than the true level.

Hypothesis 4: When an enterprise actively fulfills its environmental responsibility and self-declares, the government subsidy

is A . The subsidy obtained under the strong regulatory condition is $r_R A$, and the subsidy obtained under the weak regulatory condition is $r_F A$. The negative fulfillment of an enterprise's environmental responsibility or a breach of trust in the rating process will cause a loss of corporate reputation, and the loss of reputation under the strong regulatory condition is R_1 , and the loss of reputation under the weak regulatory condition is R_2 .

The specific meaning of the parameters is shown in Table 2:

Table 2
Description of main parameters

Parameter Symbols	Definition
P	Amount of environmental fund paid by company
R_1	Loss of credibility caused by companies' negative environmental responsibilities when government regulation is strong
R_2	Loss of credibility caused by companies' negative environmental responsibilities when government regulation is weak
r	Corporate Credit Rating
C_E	Costs when companies actively fulfill their environmental responsibilities versus declaring the situation consistent
rC_E	True cost for companies to fulfill their environmental responsibilities
r_R	Percentage of government subsidies in case of strong regulation
r_F	Percentage of government subsidy in case of weak regulation
A	Subsidies granted by the government when the enterprise actively fulfills its environmental responsibilities and the application situation is consistent
$r_R A$	Subsidies at the time of strong regulation
$r_F A$	Subsidies at the time of weak regulation
C_S	The government has to pay the cost of managing the environment for companies to negatively fulfill their environmental responsibilities
F	The government levies fines on companies for negatively fulfilling their environmental responsibilities during strong regulation
C_Q	Cost of regulation when government regulation is strong
C_R	Cost of regulation when government regulation is weak

3.1.2 Building an evolutionary game model

Based on the above assumptions and parameter settings, the benefit matrices of the company group and the government group under different strategies are:

Table 3
Matrix of government and company strategy choices and benefits

		Company	
		Actively (x)	Negatively ($1-x$)
Government	Strong Regulation (y)	$P - r_R A - C_Q, -P + r_R A - rC_E$	$P - C_S - C_Q + F, -P - R_1 - F$
	Weak Regulation ($1-y$)	$P - r_F A - C_R, -P + r_F A - rC_E$	$P - C_S - C_R, -P - R_2$

From the above benefit matrix, we can obtain the expected benefit U_{11} for a company to actively perform its environmental responsibility and the expected benefit U_{12} for a company to negatively perform its environmental responsibility:

$$U_{11} = y(-P + r_R A - rC_E) + (1-y)(-P + r_F A - rC_E) = -P - rC_E + [yr_R + (1-y)r_F]A \quad (3)$$

$$U_{12} = y(-P - R_1 - F) + (1-y)(-P - R_2) = -P - yR_1 - (1-y)R_2 - yF \quad (4)$$

The average benefits of company group is:

$$\bar{U}_1 = xU_{11} + (1-x)U_{12} \quad (5)$$

The expected benefits U_{21} of strong government regulation and the expected benefits U_{22} of weak regulation are:

$$U_{21} = x(P - r_R A - C_Q) + (1-x)(P - C_S - C_Q + F) = P - x r_R A - C_Q - (1-x)C_S + (1-x)F \tag{6}$$

$$U_{22} = x(P - r_R A - C_R) + (1-x)(P - C_S - C_R) = P - C_R - x r_R A - (1-x)C_S \tag{7}$$

The average benefits of government group is:

$$\bar{U}_2 = y U_{21} + (1-y) U_{22} \tag{8}$$

3.1.3 Constructing the replication dynamic equation

According to the Evolutionary Game Theory (EGT), the dynamic equation for the replication of the game of strategic choice between the corporate group and the government group is:

$$F(x) = \frac{dx}{dt} = x(U_{11} - \bar{U}_1) = x(1-x)(U_{11} - U_{12}) = x(1-x)[-r C_E + [y r_R + (1-y)r_F]A + y R_1 + (1-y)R_2 + y F] \tag{9}$$

$$F(y) = \frac{dy}{dt} = y(U_{21} - \bar{U}_2) = y(1-y)(U_{21} - U_{22}) = y(1-y)[C_R - C_Q - x(r_R - r_F)A + (1-x)F] \tag{10}$$

Let $\frac{dx}{dt}$ and $\frac{dy}{dt}$ be equal to 0 simultaneously, the local equilibrium point of the evolutionary game model replicating the dynamic equations is:

$(0, 0)$, $(1, 0)$, $(0, 1)$, $(1, 1)$, (x_0, y_0) , where

$$y_0 = \frac{r C_E - r_F A - R_2}{(r_R - r_F)A + F + R_1 - R_2} \tag{11}$$

$$x_0 = \frac{C_R - C_Q + F}{(r_R - r_F)A + F} \tag{12}$$

3.1.4 Equilibrium point and stability analysis

The equilibrium point of the replicated dynamic equations is not necessarily the system evolutionary stable strategy (ESS), and according to the method proposed by Friedman (1998), the stability of the equilibrium point can be obtained analytically using a Jacobi (Jacobian) matrix (denoted as J). The corresponding Jacobi matrix is given by:

$$J = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} = \begin{bmatrix} (1-2x)[-r C_E + [y r_R + (1-y)r_F]A + y R_1 + (1-y)R_2 + y F] & x(-1+x)[(r_R - r_F)A + F + R_1 - R_2] \\ y(-1+y)[(r_R - r_F)A + F] & (1-2x)[C_R - C_Q - x(r_R - r_F)A + (1-x)F] \end{bmatrix} \tag{13}$$

When satisfying: (1) $trJ = a_{11} + a_{22} < 0$; (2) $detJ = a_{11}a_{22} - a_{12}a_{21} > 0$

The equilibrium point of the replicated dynamic equation is stable, when there is an evolutionary stable strategy (ESS). First of all, the equilibrium point (x_0, y_0) can be excluded, because at this equilibrium point $trJ = a_{11} + a_{22} = 0$, condition (1) is not satisfied and the ESS cannot be reached. Therefore, only the other four local equilibrium points need to be considered, and the specific values of a_{11} , a_{12} , a_{21} , and a_{22} and the results of stability analysis are shown in Table 4.

Table 4
Specific values and stability analysis results at local equilibrium points

equilibrium points	a_{11}	a_{12}	a_{21}	a_{22}	trJ	$detJ$	Local stability
$(0, 0)$	$-r C_E + r_F A + R_2$	0	0	$C_R - C_Q + F$	Unsure	-	Unstable point
$(1, 0)$	$r C_E - r_F A - R_2$	0	0	$C_R - C_Q - (r_R - r_F)A$	Unsure	-	Unstable point
$(0, 1)$	$-r C_E + r_R A + R_1 + F$	0	0	$-C_R + C_Q - F$	Unsure	-	Unstable point
$(1, 1)$	$r C_E - r_R A - R_1 - F$	0	0	$-C_R + C_Q + (r_R - r_F)A$	Unsure	-	Unstable point

From the above analysis, it can be seen that the evolutionary game between the corporate group and the government group does not have an evolutionary stable strategy (ESS) in the situation without the intervention of the guarantee agency, and the game between the two parties always fails to reach a steady state.

3.2 Evolutionary game system (II) construction and game analysis

By evolving the evolutionary game model (I) constructed in 3.1, it is found that the producer and the government are constantly playing the game and cannot reach a stable equilibrium, so a credit guarantee agency is introduced in this section and a new evolutionary game system (II) is constructed under the participation scenario of the credit guarantee agency to determine whether there is an evolutionary steady-state equilibrium for the strategies of the two parties in the game.

3.2.1 New parameter description

When a credit guarantee agency is involved, the credit guarantee agency guarantees the enterprise. The government issues incentive funds in accordance with the results of self-declaration of company to fulfill their environmental responsibilities, after which the credit rating is reviewed, and if it is found that the enterprise's credit rating is not 1, some of the subsidy money is to be returned, and the enterprise has purchased a credit guarantee, and the subsidy money pursued by the government is paid by the guarantee company. When the government's strong supervision finds that the enterprise's declaration is not consistent with the actual performance, i.e., the credit rating is less than 0.6, a fine is also levied for the enterprise's breach of trust, and the fine will also be paid by the insurance company. The amount of credit guarantee collected by the credit guarantee agency is related to the credit rating of the enterprise in the previous year, and the amount of credit guarantee collected is lower if the credit rating is good in the previous year. When the credit guarantee agency intervenes, the added parameters are described in Table 5.

Table 5
Description of new parameters

Parameter Symbols	Definition
$(1-r_R)A$	Credit guarantee agencies pay out to the government for recovery subsidies
$(1-r)F_S$	Credit guarantee agencies pay out penalties to the government for corporate default in the event of strong government regulation
αA	The premium that a company has to pay is inversely proportional to the credit rating of the company in the previous year.

3.2.2 Constructing an evolutionary game model (II)

When credit guarantee agencies step in, the matrix of benefits for the company group and the government group is shown in Table 6.

Table 6
Matrix of corporate and government strategy choices and benefits under credit guarantee agency intervention

		Company	
		Actively (x)	Negatively ($1-x$)
Government	Strong Regulation (y)	$P - A - C_Q + (1-r_R)A + (1-r)F_S,$ $-P + A - rC_E - \alpha A$	$P - C_S - C_Q + F,$ $-P - R_1 - F$
	Weak Regulation ($1-y$)	$P - A - C_R + (1-r_F)A,$ $-P + A - rC_E - \alpha A$	$P - C_S - C_R,$ $-P - R_2$

The expected benefits U_{11}' for a company to actively fulfill its environmental responsibility and the expected benefits U_{12}' for a company to negatively fulfill its environmental responsibility under the new benefit matrix are:

$$U_{11}' = y(-P + A - rC_E - \alpha A) + (1-y)(-P + A - rC_E - \alpha A) = -P + A - rC_E - \alpha A \quad (14)$$

$$U_{12}' = y(-P - R_1 - F) + (1-y)(-P - R_2) = -P - yR_1 - (1-y)R_2 - yF \quad (15)$$

The average benefits of the company group is:

$$\bar{U}_1' = xU_{11}' + (1-x)U_{12}' \quad (16)$$

The expected benefits U_{21}' and U_{22}' of the government's choice of strong and weak regulation are:

$$U_{21}' = x(P - A - C_Q + (1 - r_R)A + (1 - r)F_S) + (1 - x)(P - C_S - C_Q + F) = P - xr_R A - C_Q + (1 - r)F_S - (1 - x)C_S + (1 - x)F \quad (17)$$

$$U_{22}' = x(P - A - C_R + (1 - r_F)A) + (1 - x)(P - C_S - C_R) = P - C_R - xr_F A - (1 - x)C_S \quad (18)$$

The average benefits of government group is:

$$\overline{U_2}' = yU_{21}' + (1 - y)U_{22}' \quad (19)$$

Construct the new replication dynamic equation:

$$G(x) = x(1 - x)(U_{11}' - U_{12}') = x(1 - x)[(1 - \alpha)A - rC_E + yR_1 + (1 - y)R_2 + yF] \quad (20)$$

$$G(y) = y(1 - y)(U_{21}' - U_{22}') = y(1 - y)[-x(r_R - r_F)A - C_R + C_Q + (1 - r)F_S + (1 - x)F] \quad (21)$$

The local equilibrium point of the new evolutionary game model replicating the dynamic equations is: (0,0), (1,0), (0,1), (1,1), (x₀', y₀'), where

$$y_0' = \frac{rC_E - (1 - \alpha)A - R_2}{F + R_1 - R_2} \quad (22)$$

$$x_0' = \frac{C_R - C_Q + F + (1 - r)F_S}{(r_R - r_F)A + F} \quad (23)$$

3.2.3 Evolutionary game stability analysis

According to the new replica dynamic equation, the corresponding Jacobi matrix is obtained in the same way:

$$J' = \begin{bmatrix} a_{11}' & a_{12}' \\ a_{21}' & a_{22}' \end{bmatrix} = \begin{bmatrix} (1 - 2x)[(1 - \alpha)A - rC_E + yR_1 + (1 - y)R_2 + yF] & x(-1 + x)[F + R_1 - R_2] \\ y(-1 + y)[(r_R - r_F)A + F] & (1 - 2x)[-x(r_R - r_F)A - C_R + C_Q + (1 - r)F_S + (1 - x)F] \end{bmatrix} \quad (24)$$

Similarly in the evolutionary game system (II) the equilibrium point (x₀', y₀') is not a system stability strategy, and the values of the other four equilibrium points and the results of stability analysis are shown in Table 7.

Table 7
Specific values and stability analysis results at local equilibrium points under the intervention of credit guarantee agencies

Equilibrium points	a ₁₁ '	a ₁₂ '	a ₂₁ '	a ₂₂ '	trJ'	detJ'	Local stability
(0,0)	-rC _E + (1 - α)A + R ₂	0	0	C _R - C _Q + F	Unsure	+	Unstable point
(1,0)	rC _E - (1 - α)A - R ₂	0	0	C _R - C _Q - (r _R - r _F)A + (1 - r)F _S	+	-	Unstable point
(0,1)	-rC _E + (1 - α)A + R ₁ + F	0	0	-C _R + C _Q - F	Unsure	-	Unstable point
(1,1)	rC _E - (1 - α)A - R ₁ - F	0	0	-C _R + C _Q + (r _R - r _F)A - (1 - r)F _S	-	+	Evolutionary Stable Strategy(ESS)

When a credit guarantee agency is involved, the evolutionary game between the enterprise group and the government group has a constant evolutionary stable strategy (ESS), and the strategy is (1,1). That is, when the enterprise group of electrical and electronic product manufacturers chooses to actively perform their environmental responsibilities and the government group chooses to strongly regulate, the game between the two parties appears to be stable.

4 Numerical example

4.1 Model simulation analysis

(1) When there is no credit guarantee agency intervention, and there is no evolutionary stable strategy (ESS) in the model (I);

according to the parameters and assumptions, the parameters are assigned as follows:

$$r=0.7, r_F=r+0.1, r_R=\begin{cases} r, 0.6 \leq r \leq 1 \\ 0, 0 \leq r \leq 0.6 \end{cases} \tag{25}$$

Here it is assumed that r_F is 0.1% higher than the real one.

Credit rating the values are 0 to 1; 1 means very good credit and 0.6 is the set starting point for government incentives and subsidies. Let $A=2, F=3, C_E=8, C_S=6, R_1=2.5, R_2=2.5, C_R=3, C_R=2$. The initial policy probabilities of the two parties are set as $x=0.5, y=0.4$. The simulation results are obtained as shown in Fig. 1.

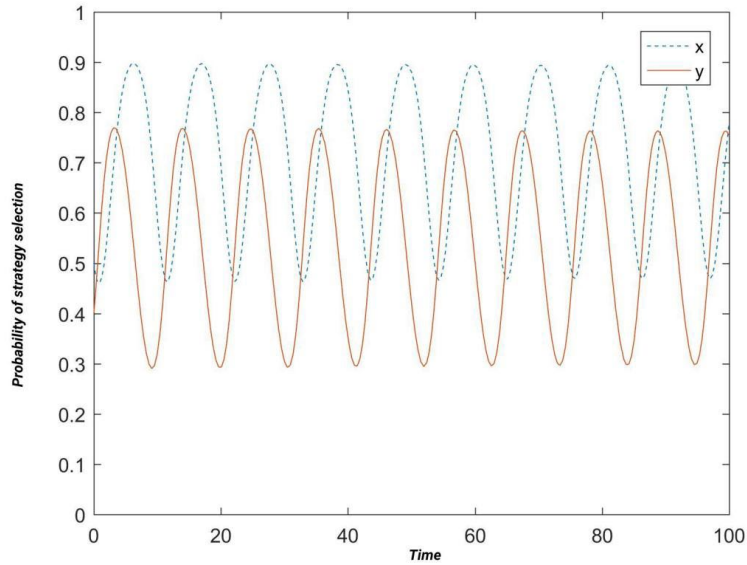


Fig. 1. Simulation results of model (I)

According to the evolutionary iteration steps, the proportion of active corporate responsibility and strong government regulation is constantly changing, and the trend is the same, both are in a cyclical oscillation state, there is no change to each other's strategy is, always can make their own strategy change to maximize returns, the game process is difficult to control, there is no stable evolutionary results.

(2) When the credit guarantee agency intervenes, the evolutionary game model (I) is improved into the evolutionary game model (II), and the evolutionary stable strategy(ESS) (1,1) appears in the evolutionary game model (II), in order to reflect the appearance of the stable evolutionary strategy is caused by the improvement of the model, the assignment values in the evolutionary game model (II) are the same as those in the evolutionary game model (I). The new parameter assignment is: $\alpha = 1 - r, F_S = 6$. At this time, the initial strategy probabilities of the two parties are also set to $x=0.5, y=0.4$. The simulation results are obtained, as shown in Fig. 2.

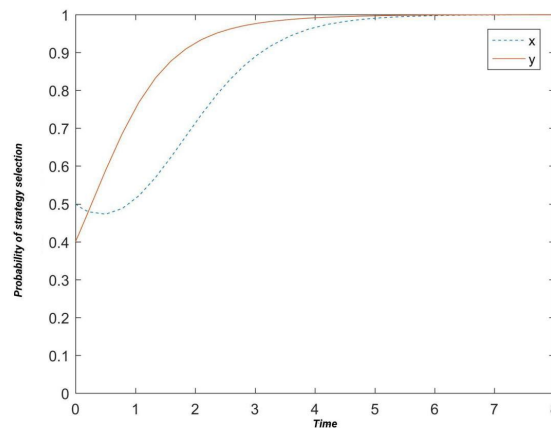


Fig. 2. Simulation results of evolutionary game model (II)

As can be seen in Fig. 2, the strategies x and y of both parties eventually evolve toward 1 in the scenario where the credit guarantee agency is involved. Where x has a tendency to evolve toward 0 at the beginning, but with the gradual increase of y , x also gradually evolves toward 1. This indicates that if the credit rating is used as a guarantee to constrain company to reward them for their trustworthiness and punish them for their failure, they may tend to fulfill their environmental protection strategy negatively at first, but with the increase of the probability of strong government regulation, they will gradually evolve to a positive fulfillment strategy. Both sides of the game to reach a stable state, that is, under the conditions of strong government regulation, the production company consciously and actively take responsibility for environmental protection.

4.2 Influence of parameter changes

From the above analysis, it is clear that credit guarantees motivate companies to actively fulfill their environmental responsibilities. Among them, the credit rating result r , the credit compliance incentive subsidy A , the proportion coefficient α of the premium paid by company to the credit guarantee agency and the government penalty F for company and the penalty F_s paid by the guarantee agency to the government for company's breach of trust are all important parameters that influence company's choice of strategy, and the impact of changes in the main parameters on company is analyzed specifically below.

(i) r is the enterprise credit rating, and the subsidy will be given only when the enterprise credit rating r is greater than or equal to 0.6, and when the enterprise's credit rating is less than 0.6, the subsidy is 0. According to the assigned value, the credit rating r is selected to change from 0.5 to 0.8, and the simulation image of the impact of the high or low credit rating r on the strategy choice of both the enterprise and the government is drawn, as in Fig. 3.

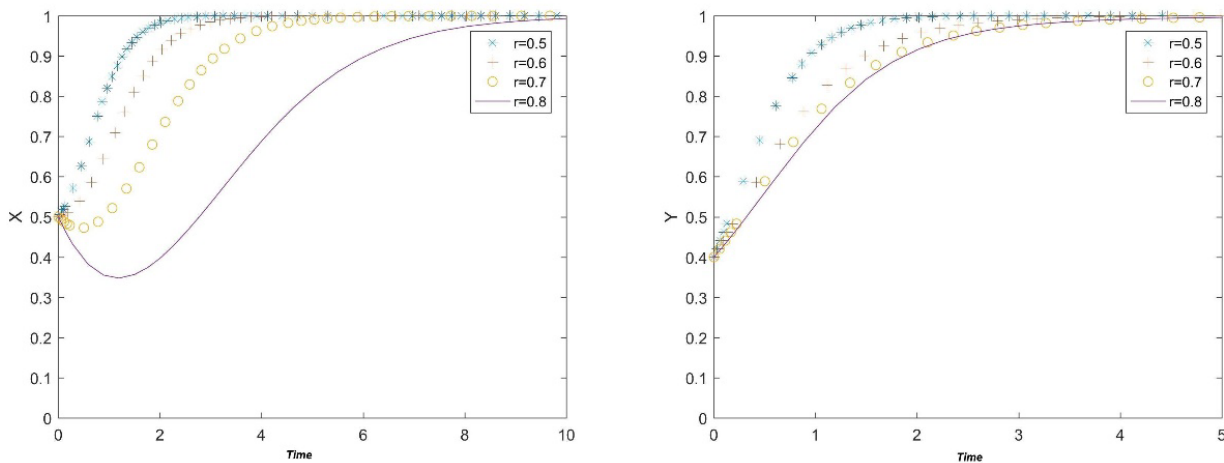


Fig. 3. Effect of credit rating r on the choice of strategy for both parties

As seen in Fig. 3, the rate of evolution of x and y to 1 gradually becomes slower as the credit rating r increases. The effect of the change in credit rating on the evolution of both x and y is significant. There is no incentive subsidy under strong government regulation when r takes the value of 0.5. Considering that r_F is 0.1 higher than the true r under weak regulation, there should be an incentive subsidy when r takes a value of 0.5 under weak regulation. It is obvious that the curve converges to 1 at a much faster rate than other values when r is 0.5. The lower the credit rating of an enterprise, the more the government tends to choose strong regulation to manage the behavior of the enterprise in fulfilling its environmental responsibility, and the company with low credit rating attempt to obtain greater incentive subsidies through lower costs. And when r is larger, the government tends to regulate more weakly; however, the curve of x tends to 1 at a slower rate than other values, and even tends to 0 at the beginning, which proves that when the credit rating of company is higher and they fulfill their environmental responsibility better, they are not incentivized enough to optimize their behavior more, however, with the change of time, after the government tends to regulate strongly, the company only gradually evolve towards the strategy of actively fulfilling their environmental responsibility.

(ii) A is the incentive subsidy given by the government when the enterprise actively fulfills its environmental responsibility in line with the application situation, and the subsidy is $r_R A$ for strong regulation and $r_F A$ for weak regulation. the variation of the selected parameter A from 2 to 5 is shown in Fig. 4.

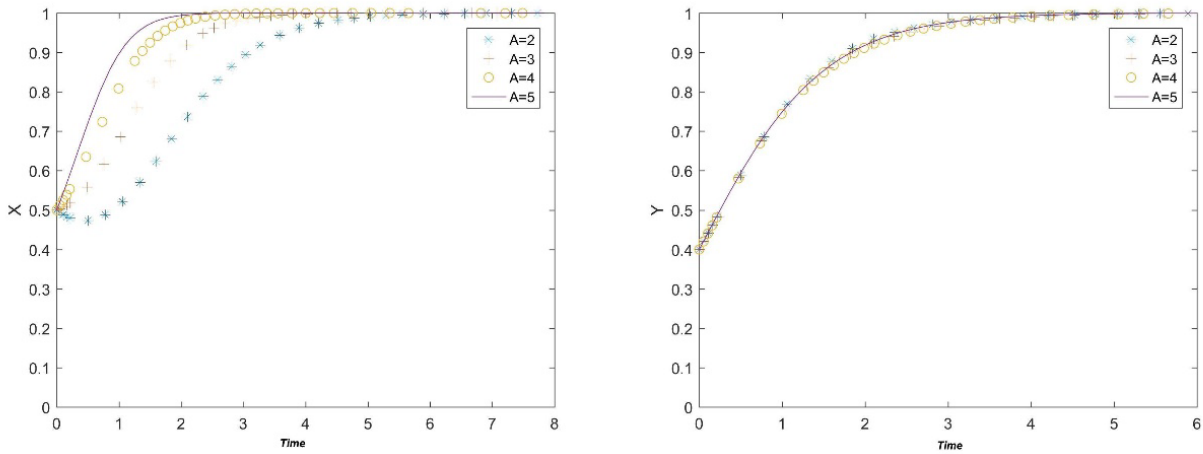


Fig. 4. Effect of incentive subsidy A on strategy choice of both parties

Similarly, as the incentive subsidy A increases, the rate of evolution of x and y to 1 becomes progressively slower. The change in incentive subsidy A has a significant effect on the evolution of x , but not on the evolution of y . The larger the A , the faster the rate of evolution of x to 1, i.e., as the amount of subsidy increases, the more willing companies are to actively fulfill their environmental responsibilities. When $A=2$, the curve evolves to 0 at the beginning, indicating that companies are reluctant to choose to actively fulfill their environmental responsibilities when the incentive subsidy is low. It is only due to the trend of strong government regulation that companies are forced to choose the strategy of actively fulfilling their environmental responsibility.

(iii) α is the coefficient of the proportion of premiums paid by the enterprise to the credit guarantee agency, which is inversely proportional to the credit rating r . The change in α from 0.15 to 0.3 is analyzed in Fig. 5, which shows that α has a greater impact on the evolution of x and a smaller impact on the evolution of y . The larger the α , the slower the rate of evolution of x to 1, i.e., as the percentage of premiums paid by company to credit guarantee agencies increases, the willingness of company to actively fulfill their environmental responsibility is reduced.

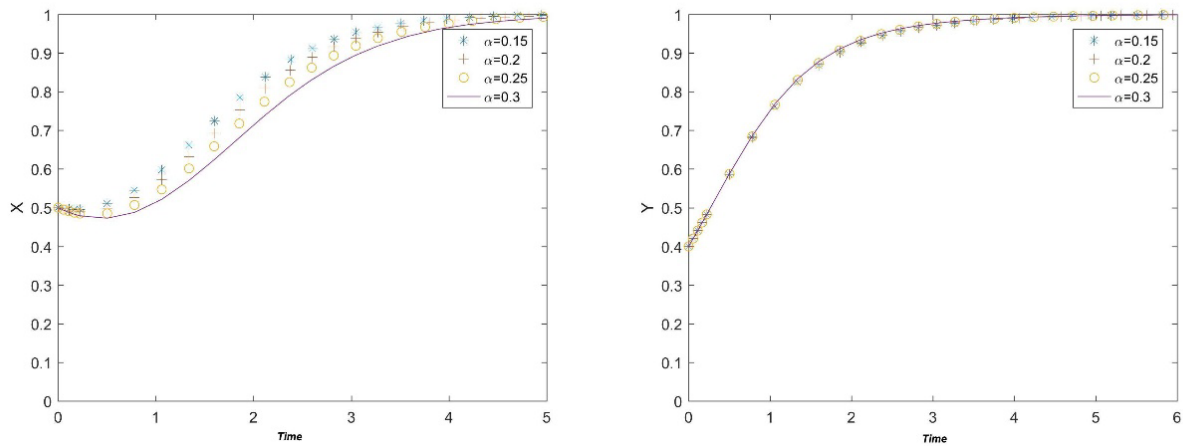


Fig. 5. Effect of premium factor α on the choice of strategy for both parties

(iv) F is the penalty levied by the government when the company negatively fulfills its environmental responsibility during strong government regulation. The value of the parameter F varies from 3 to 6, as shown in Fig. 6. From the figure, it can be seen that the change in the fine F has a more obvious effect on both the company and the government. the larger the F , the faster the rate of evolution of x and y to 1, indicating that as the fine increases, the company tends to be more active in fulfilling its environmental responsibility, and the government tends to be more strongly regulated.

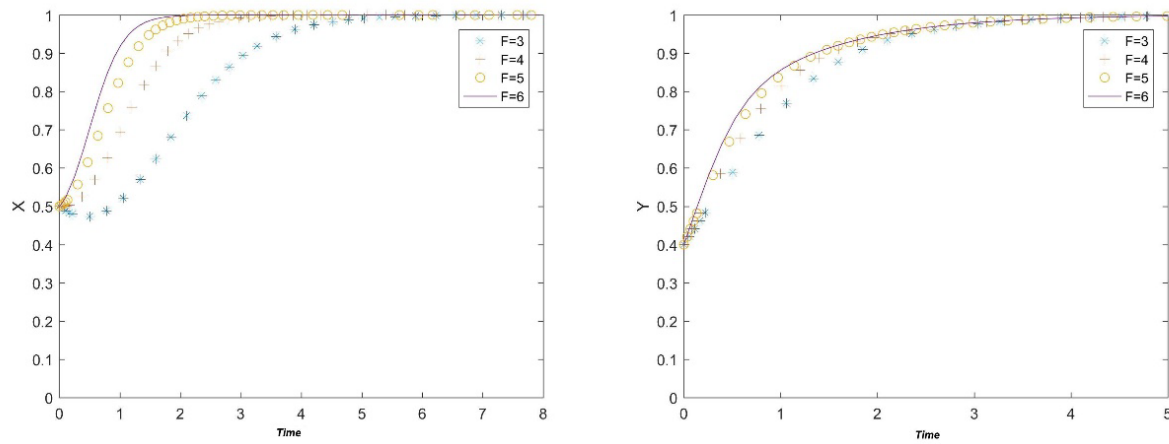


Fig. 6. Effect of penalty F on strategy choice of both parties

5. Conclusion

Based on evolutionary game theory, this paper explores the evolutionary process and equilibrium strategy conditions of company's and government's strategies for environmental responsibility and willingness to regulate the environment through the introduction of credit guarantee mechanisms. Using Matlab data simulation, we investigate the influence of relevant parameters on the evolution of the system and find that the credit rating result of the company, the incentive subsidy given by the government, the rate of credit guarantee and the penalty amount are the key factors affecting the willingness of a company to fulfill their environmental responsibility. The introduction of a credit guarantee mechanism into the supervision of a company's fulfillment of environmental responsibility is a participatory credit collection method. For the government, it achieves a new kind of empowerment by transferring certain powers to the rated company themselves; for the first enterprise, credit guarantee is an important self-regulatory measure. Credit guarantees offer a new dimension and possibility to complement state-led environmental oversight through the intervention of third-party institutions, reducing enforcement costs for the central government and increasing the willingness of companies to fulfill their environmental responsibilities.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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