Study on pre-loan evolutionary stable strategy of bank-enterprise for preventing moral hazard

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Abstract

Based on the information asymmetry between enterprises and banks at the stage of loan application, a replicator dynamic model of bank-enterprise evolution at the pre-loan stage was established and analysed by using the evolutionary game theory (EGT) and the stability theory of nonlinear differential equation. A numerical simulation was also performed in details, which displayed intuitively how banks and enterprises achieved stable cooperation through long-term evolution. The results showed that, to effectively prevent pre-loan moral hazard, it was vitally important for commercial banks to improve their screening ability, increase disguised costs of enterprises, and formulate proper sanctions and appropriate amounts of penalty as per the local loan atmosphere also with the profit which the loan investment projects will make.

Keywords: information asymmetry, evolutionary game, duplicator dynamic model, decision-making

1 Introduction

A principal-agent relationship can be used to describe the relationship between commercial banks and enterprises that they issue loans to. In the case of information asymmetry, enterprises may adopt some practices, which go against banks' fund security measures when pursuing maximum profit, causing undesirable moral hazard. From the submission of the loan application to the loan contract signing (i.e., the pre-loan stage), enterprises aiming to obtain the loan may lie about their actual financial situations, loan repayment abilities, credibility, and the size of the risks involved in the project to be invested in. Once the loan is approved, it is easy for bad debt to be created. Banks should be highly cautions in choosing appropriate enterprises applying for loan, and make the correct decisions to prevent moral hazard, which is very important.

Stiglitz and Weiss studied the issue of bank-enterprise decisions under the hypothesis of information asymmetry in which banks would limit their loan approval ratios, causing credit rationing. Stiglitz and Weiss concluded that if banks increased interest rates, debtors might be stimulated to make high-risk investments, causing bigger moral hazard [1]. Bester further explored the role of mortgages in bank-enterprise decisions, and concluded that proper selection of loan interest rates and mortgages could screen out high-risk contracts [2]. Blumberg analyzed the loan application situations of enterprises at start-up and found that the most important factors for loan rejection were: loan commitment, loan repayment sign, and the success rate of the project invested in [3]. Xiaohong Dong discussed that in single-stage credit decisions, the harm brought by moral hazard could be overcome by a certain amount of mortgages, but in the long-term, for cooperation between banks and enterprises, one method to overcome moral hazard for banks could be offering certain preferential measures to enterprises [4]. Yanxi Li constructed a universal model of bank-enterprise decisions to prevent moral risk by setting incentives [5]. Xintian Zhuang proposed a pricing model of loan interest rates, using the maximum principle under conditions of information asymmetry [6]. Sulin Pang studied moral risk aversion methods in the cases of combined and non-combined risks, and proved that sufficient mortgages and proper ration could reduce the pre-loan moral hazard of bank-enterprise decisions by creating a credit risk decision model [7, 8].

Literatures mentioned above chose to convert credit contracts into either an optimal control problem or a classic game, in order to find the optimal interest rate, ration, or mortgage value. Such methods generally have relatively strict assumed conditions that banks should be isolated from enterprises and they also should be required to be "rational entities". However, in reality, banks and enterprises belong to different groups and the individual decisions in a group may be affected by the decisions of others. So almost no "complete rationality" exists. The evolutionary game theory can help solve this kind of problems. The EGT is based on "bounded rationality", in which individual decisions are mutually influenced and realized through the processes of imitation, study and mutation, etc. With a dynamic analysis of the decision-making behaviours, the EGT can help to derive

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conclusions, which reflect real-world situations. Taylor was the first to propose the duplicator dynamic model based on the EGT [9]. The model, derived from biological evolution, combines an evolutionary stable strategy with a replicator dynamic to simulate population evolution processes and stable states. Many scholars have subsequently carried out researches on the model. In recent years, the EGT has been applied to economic management applications such as inter-enterprise cooperation [10]; industrial cluster competition and cooperation behaviour [11], financial innovation [12], and credit guarantee [13].

In terms of using EGT to solve practical problems, the existing literatures lack analysis of stable points in depth, and lack numerical simulation. Based on the EGT described in the literatures [14, 15] and the stability theory of nonlinear differential equation, this paper studies how banks design loan contracts and sanction mechanisms at the pre-loan stage, to help banks and enterprises reach a stable cooperation state through long-term evolution, while effectively preventing pre-loan moral hazard.

2 Evolutionary Game Model of Bank-Enterprise at the Pre-Loan Stage

2.1 MODEL CRITERIA AND PAY-OFF MATRIX OF BANK-ENTERPRISE AT THE PER-LOAN STAGE

At the loan application stage, commercial banks and enterprises applying for loan shall meet the following hypotheses:

Hypothesis 1: let the fund owned by the enterprise be W, the amount needed for the investment project be I, let the enterprise require a loan of B ($B = I - W$) from banks, let the rate of return after project success be r', and the profit be calculated by R ($R = (B+W)(1+r')$). Let the project success rate be p, let the rate of enterprise's default on repayments be s, let the loan interest rate be r, let the risk-free interest rate be ρ, let the value of the enterprise's mortgage to banks be C_0 ($C_0 < W$), and let the bank's examination cost be C_b.

Hypothesis 2: the enterprise applying for loan may make a decision of "applying based on facts" or "deceiving for loan" due to the moral hazard created by the bank-enterprise information asymmetry. Banks should make a decision of "approving the loan" or "rejecting the loan" by examining application materials.

Hypothesis 3: if the enterprise chooses to apply based on facts, but banks choose to reject the loan, banks and enterprises will suffer the respective opportunity losses of OL_b ($OL_b = (r-\rho)B$) and OL_e ($OL_e = (r'-r)B$). If the enterprise chooses to "deceive for loan", it must pay a disguise cost CL ($CL < OL_e$, which is deduced by the individual rationality of enterprise), and if banks examine the enterprise's attempt to "deceive for loan", then it will reject the loan and punish enterprise, in other words, make enterprises suffer a reputation loss RL, by increasing the loan interest rate and mortgage value in the next loan application.

It can be concluded from the above criteria that, if banks choose to approve the loan, then the individual rationality of bank needs to be satisfied.

$$p(1-s)(1+r)B + (1-p)s\cdot C_0 > (1+\rho)B. \quad (1)$$

According the above analysis, the pay-off matrix of the bank-enterprise game is shown in Table 1:

TABLE 1 Pay-off matrix of the bank-enterprise game at the pre-loan Stage

		Enterprise	
		Applying Based on Facts	*Deceiving for Loan*
Bank	Approving the Loan	$p(1-s)(1+r)B+(1-p)s\cdot C_0-(1+\rho)B-C_b$ $p(R-(1-s)(1+r)B)-s(1-p)C_0$	$-(1+\rho)B+C_0-C_b$ $p\cdot R-C_0-CL$
	Rejecting the Loan	$-C_b-OL_b, -OL_e$	$-C_b, -CL-RL$

2.2 BALANCE POINTS IN THE PROCESS OF EVOLUTIONARY GAME

Let X be the ratio of the bank group's adoption of the strategy of "approving the loan", then $1-X$ is the ratio of its adoption of the strategy of "rejecting the loan"; let that Y be the ratio of the enterprise group's adoption of the strategy of "applying based on facts", then $1-Y$ is the ratio of its adoption of the strategy of "deceiving for loan"; and the fitness function is expressed by the expected profit.

When banks adopt the strategies of "approving the loan" or "rejecting the loan", the fitness functions and the average fitness functions $U_{a1}, U_{a2}, \overline{U_a}$ are respectively:

$$\begin{aligned} &U_{a1} = Y[p(1-s)(1+r)B + (1-p)s\cdot C_0 - (1+\rho)B - \\ &C_b] + (1-Y)[-(1+\rho)B + C_0 - C_b] \\ &U_{a2} = Y(-C_b - OL_b) + (1-Y)(-C_b) \\ &\overline{U_a} = XU_{a1} + (1-X)U_{a2} \end{aligned} \quad . \quad (2)$$

Similarly, when enterprises apply based on fact or deceive for loan, the fitness functions and the average fitness functions $U_{b1}, U_{b2}, \overline{U_b}$ are respectively:

$$\begin{aligned} &U_{b1}=X[p(R-(1-s)(1+r)B)-(1-p)s\cdot C_0]+ \\ &(1-X)(-OL_e) \\ &U_{b2}=X(P\cdot R-C_0-CL)+(1-X)(-CL-RL) \\ &\overline{U_b}=YU_{b1}+(1-Y)U_{b2} \end{aligned} . \quad (3)$$

According to the duplicator dynamic equation, the following two-dimensional differentiable dynamic system can be obtained:

$$\begin{cases} \dfrac{dX}{dt}=X(U_{a1}-\overline{U_a})=X(1-X)[Y(p(1-s)(1+r)B-(1-(1-p)s)C_0+OL_b)-(1+\rho)B+C_0] \\ \dfrac{dY}{dt}=Y(U_{b1}-\overline{U_b})=Y(1-Y)[X(-p(1-s)(1+r)B+(1-s(1-p))C_0-RL+OL_e)+RL-OL_e+CL] \end{cases} . \quad (4)$$

Let $\frac{dX}{dt}=\frac{dY}{dt}=0$, five balance points of the equation can be obtained, respectively, A(0,0), B(0,1), C(1,0), D(1,1) and $E(X_0,Y_0)$, among which, $X_0=\dfrac{-RL-CL+OL_e}{-p(1-s)(1+r)B+(1-(1-p)C_0)-RL+OL_e}$, and $Y_0=\dfrac{(1+\rho)B-C_0}{p(1-s)(1+r)B-(1-(1-p)s)C_0+OL_b}$ $X_0,Y_0\in[0,1]$.

2.3 EVOLUTIONARY STABLE STRATEGY

According to the stability theory of nonlinear differential equation [16], the stability of balance points can be determined by the sign of the Jacobian matrix's characteristic root. By calculating the determinant $DetJ$, and trace trJ, of the Jacobian matrix J, of the differential dynamical systems (i.e., equation (4)), we can obtain:

$$J=\begin{bmatrix} (1-2X)[Y(p(1-s)(1+r)B+OL_b & X(1-X)[p(1-s)(1+r)B \\ -(1-(1-p)s)C_0)-(1+\rho)B+C_0] & -(1-(1-p)s)C_0+OL_b] \\ Y(1-Y)[-p(1-s)(1+r)B & (1-2Y)[X(-p(1-s)(1+r)B-RL+OL_e \\ +(1-s(1-p))C_0-RL+OL_e] & +(1-s(1-p))C_0)-OL_e+RL+CL] \end{bmatrix}, \quad (5)$$

$$\begin{aligned} DetJ=&(1-2X)[Y(p(1-s)(1+r)B-(1-(1-p)s)C_0+OL_b)-(1+\rho)B+C_0] \\ &\times(1-2Y)[X(-p(1-s)(1+r)B-RL+OL_e+(1-s(1-p))C_0)-OL_e+RL+CL] \\ &-X(1-X)[p(1-s)(1+r)B+(1-p)s\cdot C_0+OL_b] \\ &\times Y(1-Y)[-p(1-s)(1+r)B+(1-s(1-p))C_0-RL+OL_e] \end{aligned}, \quad (6)$$

$$\begin{aligned} trJ=&(1-2X)[Y(p(1-s)(1+r)B-(1-(1-p)s)C_0+OL_b)-(1+\rho)B+C_0] \\ &+(1-2Y)[X(-p(1-s)(1+r)B-RL+OL_e+(1-s(1-p))C_0)-OL_e+RL+CL] \end{aligned}. \quad (7)$$

By calculating the above-mentioned values and signs of $DetJ$ and trJ, in each balance point, we can judge their stability situation and thus obtain the following bank-enterprise evolutionary stable strategies.

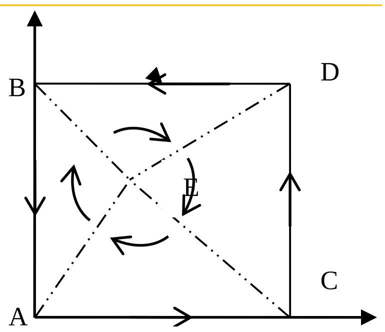
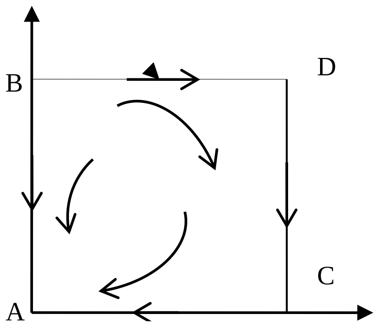
Assumption 1: when $CL<p(1-s)(1+r)B-(1-s(1-p))C_0$, i.e., when the enterprise's disguise cost of gaining a loan is smaller than the difference between the bank's expected profits and mortgage value, the bank will adopt different degrees of punishment, which may lead to the following two results:

Case 1: if $RL>OL_e-CL$, i.e., if the amount of penalty is greater than the difference between the enterprise's opportunity loss and the disguise cost, then, in the long run, it is impossible to achieve a stable and ideal partnership for banks and enterprises, no matter whether the local loan atmosphere is good or not.

Case 2: if $RL<OL_e-CL$, i.e., if the amount of penalty is smaller than the difference between the enterprise's opportunity loss and the disguise cost, then, after development and evolution, enterprises will choose to "deceive for loan" and the bank will choose to reject the loan application.

Proof: in Assumption 1, when the enterprise's disguise cost CL is less than the critical value $p(1-s)(1+r)B-(1-s(1-p))C_0$, makes the enterprise's profits from applying loan based on fact smaller than the profits from deceiving for loan. In the following section, the Jacobian determinant and trace are calculated, in order to obtain the stability of the balance points (see Table 2).

TABLE 2 Bank-enterprise Evolution Path (when the enterprise's disguise cost CL is smaller)

Size of Punishment RL	Balance Point	Sign of $DetJ$	Sign of trJ	Local Stability	Phase Diagram
	A(0,0)	−	±	Saddle point	 FIGURE 1 Phase Diagram in case 1
	B(0,1)	−	±	Saddle point	
	C(1,0)	−	±	Saddle point	
	D(1,1)	−	±	Saddle point	
Case 1: $RL > OL_e - CL$ Note: there are five balance points and $X_0, Y_0 \in [0,1]$	E(X_0, Y_0)	+	0	Centre	
	z	+	−	ESS	 FIGURE 2 Phase Diagram in case 2
	B(0,1)	+	+	Unstable point	
	C(1,0)	−	±	Saddle point	
Case 2: $RL < OL_e - CL$ Note: there are four balance points and $X_0 \notin [0,1]$	D(1,1)	−	±	Saddle point	

From case 1 shown in Table 2 we can see that when $RL > OL_e - CL$, it is impossible to achieve a stable and ideal partnership for banks and enterprises, no matter what the initial ratios of strategies adopted by bank/enterprise groups are. In the process of this evolutionary game, enterprises have a small disguise cost, if banks choose to approve the loan at the very beginning, enterprises tend to choose to "deceive for loan", then, the bank group tends to increasingly reject loan applications. Gradually, as larger sanctions are introduced, the enterprise's rationality tends towards the strategy of applying based on fact. Therefore, the model has no ESS in repeated cycles (see Figure 1 for evolution path).

From case 2 in Table 2, we can deduce that when $RL < OL_e - CL$ (critical value), both banks and enterprises in the game tend towards the stable point $A(0,0)$, i.e., the evolution result of bank-enterprise decision is to choose the strategies of "rejecting the loan" and "deceiving for loan" (see Figure 2 for evolution path).

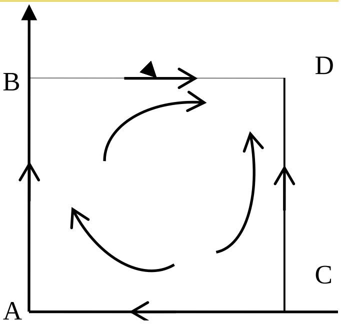
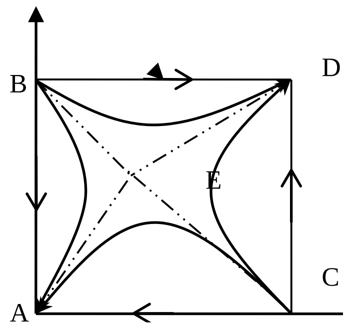
Assumption 2: when $CL > p(1-s)(1+r)B-(1-s(1-p))C_0$, i.e., the enterprise's disguise cost is bigger than the difference between the bank's expected profits and mortgage value, banks will adopt different degrees of punishment, which may lead to the following two different results:

Case 1: if $RL > OL_e - CL$, i.e., when the amount of penalty is bigger than the difference between enterprise's opportunity loss and the disguise cost, then, after development and evolution, banks will choose to approve loan applications and enterprises will choose to apply for loans based on fact.

Case 2: if $RL < OL_e - CL$, i.e., when the amount of penalty is smaller than the difference between the enterprise's opportunity loss and the disguise cost, then, the evolution result depends on the initial loan atmosphere. If the ratio of cheating by enterprises and rejection by banks is large, the bank-enterprise evolution result will choose to reject the loan and "deceive for loan"; if the initial ratio of "honest" enterprise and "approving" bank is high, the evolution result will be that banks approve loan applications and enterprises apply for loans based on fact.

Proof: in Assumption 2, when the enterprise's disguise cost, CL, is less than the critical value $p(1-s)(1+r)B-(1-s(1-p))C_0$, the enterprise's expected profits from applying based on fact are bigger than which from deceiving for loan. Similarly, the aforementioned Jacobian determinant and trace can be calculated, to obtain the stability of the balance point, which is shown in Table 3.

TABLE 3 Bank-enterprise Evolution Path (when the enterprise's disguise cost CL is bigger)

Size of Punishment RL	Balance Point	Sign of $DetJ$	Sign of trJ	Local Stability	Phase Diagram
Case 1: $RL > OL_e - CL$ Note: there are five balance points and $X_0, Y_0 \in [0,1]$	A(0,0)	−	±	Saddle point	 FIGURE 3 Phase Diagram in case 1
	B(0,1)	−	±	Saddle point	
	C(1,0)	+	+	Unstable point	
	D(1,1)	+	−	ESS	
Case 2: $RL < OL_e - CL$ Note: there are four balance points and $X_0 \notin [0,1]$	A(0,0)	+	−	ESS	 FIGURE 4 Phase Diagram in case 2
	B(0,1)	+	+	Unstable point	
	C(1,0)	+	+	Unstable point	
	D(1,1)	+	−	ESS	
	E(X_0, Y_0)	−	0	Saddle point	

From case 1 in Table 3 we can see that when $RL > OL_e - CL$ (critical value) banks and enterprises in the game tend towards the stable point D(1,1) (see Figure 3 for evolution path) i.e., the evolution result of bank-enterprise decision is to choose the strategies of "approving the loan" and "applying based on facts" respectively.

From case 2 in Table 3 we can see that when $RL < OL_e - CL$ (critical value), two players of the game have two local stable points (see Figure 4 for evolution path) and the evolution result depends on the value of the initial ratio of the strategies adopted by bank group and enterprise group. If the initial value is close to A(0,0) i.e., the initial loan atmosphere is enterprises tend to deceive and banks tend to reject the result of decision evolution is to choose strategies of "rejecting the loan" and "deceiving for loan"; if the initial value is close to D(1,1) i.e., the initial atmosphere is that enterprises tend to be honest and banks tend to approve the loan, the result of evolution is to choose the strategies of "approving the loan" and "applying based on facts" respectively.

3 Numerical Simulation of Bank-Enterprise Evolutionary Game Model

To display the bank-enterprise evolutionary game more intuitively, we make a numerical simulation for the previous model for further discussion.

Let $B = 1$ million the mortgage value $C_0 = 0.8$ million the loan interest rate r=7% ; the bank's safe investment interest rate ρ=2.5% the success rate of the enterprise's project p=0.9 the rate of default rate s=0.15.

1) Let parameters CL, RL meet conditions of Assumption 1.

Disguise cost loss $CL = 0.02$ million RL amount of penalty is 0.12 million (in accordance with case 1) and 0.05 million (in accordance with case 2). Figures 5 and 6 show the phase diagrams of the system in both cases. Figure 5 shows five balance points and the solutions around the central point form a closed trajectory without any stable point. Figure 6 shows only four balance points and the trend of solution tends towards point (0, 0), indicating the existence of stable point (0, 0).

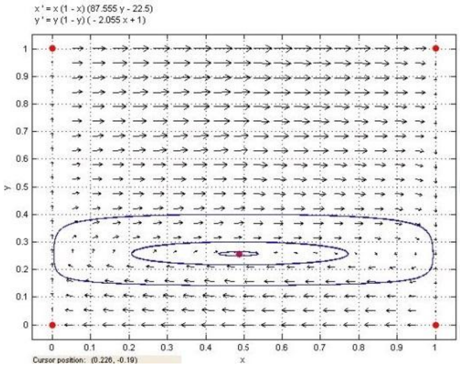


FIGURE 5 Phase Diagram in case 1

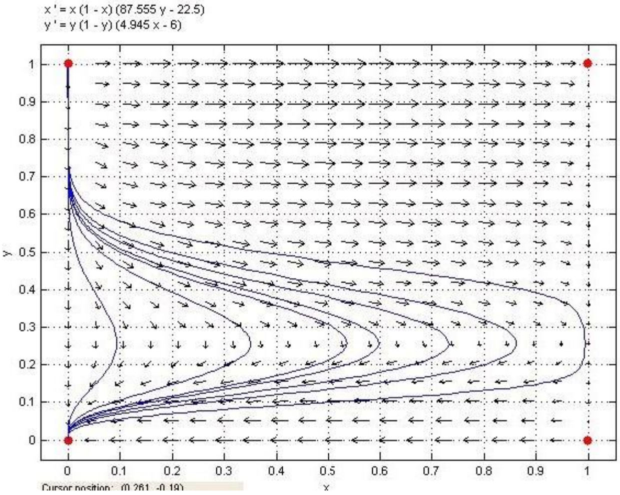


FIGURE 6 Phase Diagram in case 2

Let the initial values of (X, Y) as (0.8, 0.3) and (0.2, 0.1); and (0.1, 0.2) and (0.2, 0.7) respectively and make simulations for case 1 and case 2. Results show that when the disguise cost CL is relatively small and the penalty RL is relatively large, the game players have no stable point and the rate of bank-enterprise decision-making behaviours displays periodic fluctuations (see Figure 7); when both CL and RL are small the decisions tend towards the point (0, 0) (Figure 8) i.e., the evolution result is that the respective players either choose to reject the loan and deceive for loan.

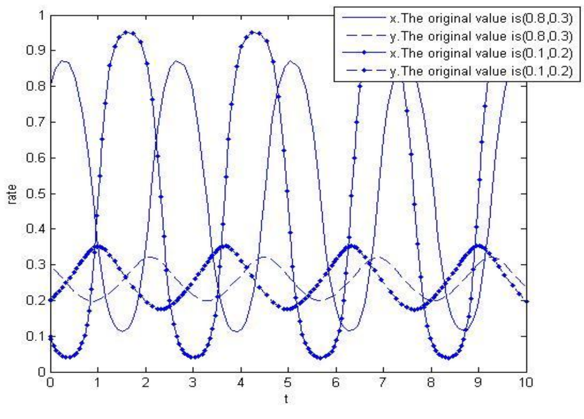


FIGURE 7 Simulation result in case 1

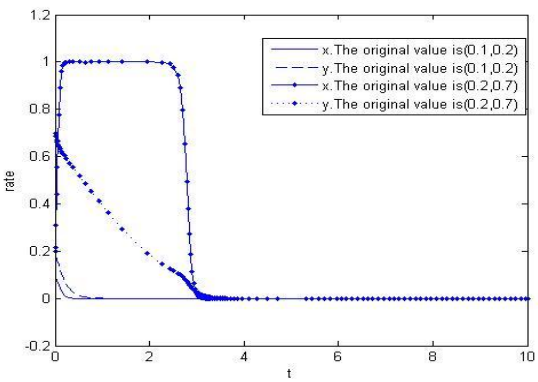


FIGURE 8 Simulation result in case 2

2) Let the parameters CL, RL meet the conditions of Assumption 2.

Let the disguise cost $CL = 0.05$ million and let RL, the bank's penalty for deceiving equal 0.15 million (meet case 1) and 0.05 million (in accordance with case 2). Figures 9 and 10 shows the phase diagrams of the system in both cases. Figure 9 shows four balance points and the direction of solutions points to point (0, 0). Figure 10 shows that the five balance points and solutions tend towards two points, those points being (1, 1) and (0, 0).

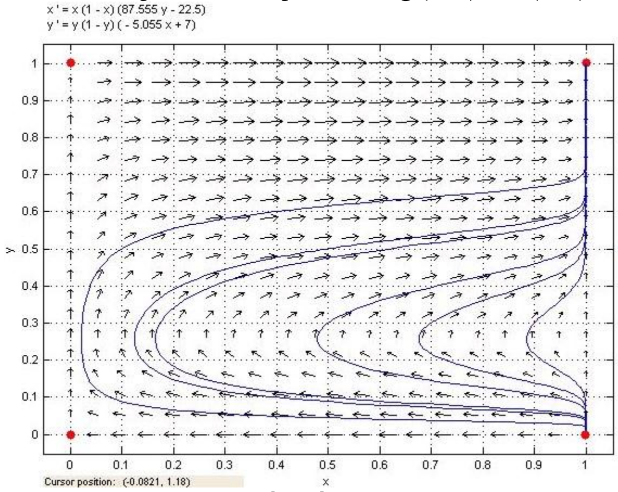


FIGURE 9 Phase diagram in case 1

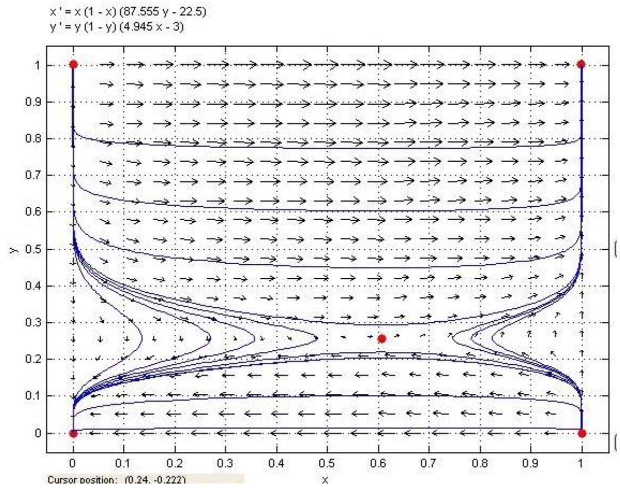


FIGURE 10 Phase diagram in case 2

Let the original values of (X, Y) for each respective case as (0.1, 0.2) and (0.7, 0.1) and (0.1, 0.2) and (0.8, 0.9) and make simulations for cases 1 and 2. The results showed that when the disguise cost CL is increased, the punishment RL increases two players of game tend towards the point (1,1) (Figure 11) and the result of the evolution is that banks and enterprise choose to approve the loan and apply for the loan based on fact; when the amount of penalty RL is small different original values lead to tremendously different evolution results. When the original values of X and Y are (0.1, 0.2) evolution result is that the business and enterprise respectively choose to reject the loan and "deceive for loan"; when the original values of X and Y are (0.8, 0.9) the evolution result is that the business and enterprise respectively choose to approve the loan application and apply for a loan based on fact (Figure 12).

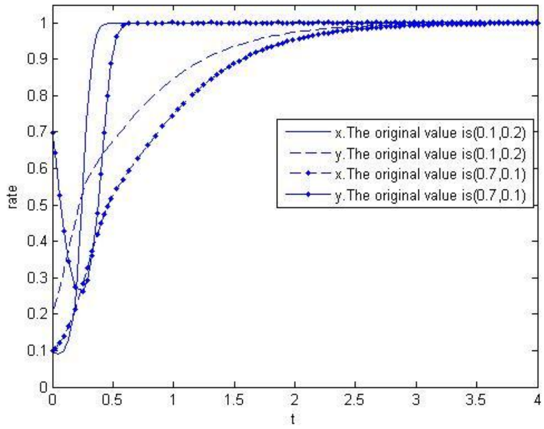


FIGURE 11 Simulation result in case 1

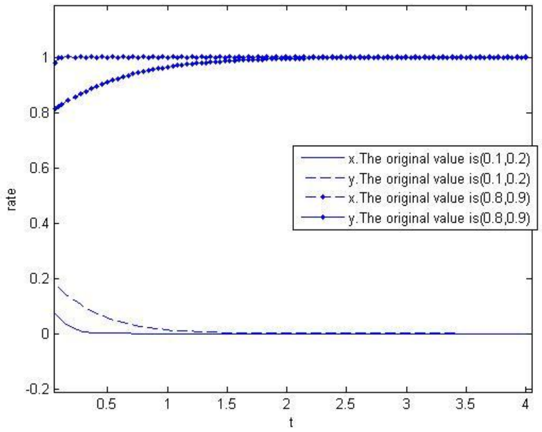


FIGURE 12 Simulation result in case 2

4 Conclusions and Enlightenments

This paper established an evolutionary game model of bank-enterprise at the pre-loan stage and made a numerical simulation. According to the analysis results, the enterprise's disguise cost and the bank's punishments on cheating enterprise play an instrumental role in preventing moral hazard.

Firstly, when the enterprise's disguise cost is so low that the enterprise's profits from deceiving for loan are higher than those from applying based on fact, banks and enterprises will not reach an ideal state in the long-term evolutionary process, even if banks impose large sanctions for enterprises. Furthermore, when the degree of punishments is very low, banks and enterprises may evolve into a state in which cooperation cannot be achieved. Therefore, banks should increase the enterprise's disguised costs using a variety of means, such as examining application materials more rigorously, enhancing the screening ability of commercial banks, improving industrial standards, and enhancing the professional ethics of banking personnel, in order to avoid the opportunities caused by banking personnel's corruptive behaviours.

Secondly, when the enterprise's disguise cost is so large that the enterprise's monetary gains from deceiving for loan are lower than those from applying based on fact, banks and enterprises can reach a stable cooperation state only if banks make appropriate sanction mechanisms according to the local loan atmosphere. If the initial loan atmosphere is favourable, i.e., the proportions of cheating enterprises and banks with stint loans are small, banks only need to focus on increasing the enterprise's disguise cost. If the initial loan atmosphere is unfavourable, i.e., the proportions of cheating enterprises and banks with stint loans are high, a proper punishment amount (at least larger than the difference between the enterprise's opportunity loss and disguise cost) needs to be set, to ensure that evolution can reach a stable state enterprises apply based on fact and banks approve the loan application.

Therefore, while increasing enterprises' disguised costs, banks should design appropriate sanction measures for enterprises according to the local loan atmosphere, enterprise asset appraisals and the profits of the loan investment project. Additionally, banks should add cheating enterprises to a blacklist, and impose restrictions on or make other sanctions such as higher interest for the enterprises' future loans, improvements and upgrades in business credit reference systems and the sharing of blacklists between various commercial banks.

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