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A Tripartite Evolutionary Game Model of Rural Finance: Construction, Simulation, and Policy Analysis

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Abstract: Rural finance is essential to rural revitalization, common prosperity, and high-quality financial development in China. This study constructs a tripartite evolutionary game model involving the government, rural financial institutions, and rural financial service demanders. The demand-side group is defined broadly to include ordinary rural households, smallholder farmers, family farms, members of agricultural cooperatives, and large-scale agricultural producers with credit needs, rather than only poor households. Based on System Dynamics (SD), the paper divides the rural financial system into three interrelated sub-systems and simulates the strategic evolution of the three stakeholders under general punishment, dynamic punishment, and optimized dynamic penalty-incentive scenarios. The results show that a single punishment mechanism can restrain some irregular behavior, but it may also generate repeated fluctuations and excessive regulatory costs. An optimized dynamic penalty-incentive mechanism is more likely to guide rural financial institutions and financial service demanders toward compliance and to form a stable evolutionary equilibrium. The findings provide a basis for designing collaborative rural financial governance mechanisms under China's current goals of rural revitalization and high-quality financial development. Future research may calibrate the model with micro-survey data, administrative credit data, and regional rural financial indicators to improve the empirical validity of parameter settings.

Keywords: Rural Finance; Evolutionary Game; System Dynamics Simulation; Collaborative Governance; High-quality Financial Development

1. Introduction

This study examines rural finance in the context of China's rural revitalization strategy, common prosperity, inclusive finance, and high-quality financial development. High-quality development of inclusive finance has become an important national policy orientation. The 2025 rural policy document further emphasizes deepening rural reform and advancing all-around rural revitalization. International indicators and development reports also show that rural financial inclusion remains closely related to access to credit, payment services, savings, insurance, and risk-management tools for rural households and agricultural operators (Klapper et al., 2025; IFAD, 2025).

In modern economic activity, finance is a central mechanism for resource allocation. Recent macroeconomic data show that agricultural and rural development continues to play a basic role in China's economic stability. Inclusive rural finance research emphasizes that credit, payment, savings, and insurance services should cover diverse rural actors rather than only poor households (World Bank Group, 2018). Empirical studies further indicate that rural finance can promote high-quality agricultural development, while digital inclusive finance has become an important channel for agricultural upgrading (Hu et al., 2023; Zeng et al., 2026).

Earlier rural financial policies were closely connected with targeted poverty alleviation. After the completion of the anti-poverty campaign, however, rural finance has entered a new stage centered on rural revitalization, common prosperity, inclusive finance, and high-quality financial development. Rural financial demand now comes from ordinary rural households, smallholder farmers, family farms, members of agricultural cooperatives, rural entrepreneurs, and agricultural value-chain actors. Studies on family farms and cooperatives show that these groups face real credit constraints and require formal financial support (Chen et al., 2022; Jiang et al., 2024). Rural credit also affects technology adoption and family farm entrepreneurship (Wang et al., 2025; Ni et al., 2026). Agricultural value-chain finance and rural entrepreneurship research further confirms that rural finance should be understood as a multi-actor service system rather than a poverty-alleviation instrument only (Villalba et al., 2023; Liu et al., 2023).

Existing studies have discussed rural financial supply and demand, credit constraints, inclusive finance, rural financial innovation, and digital finance. Digital development has been shown to improve rural financial inclusion and rural revitalization (Wang and Zhang, 2025; Wang, 2023). Digital inclusive finance is also related to common prosperity and rural e-commerce development (Wang et al., 2025; Wei et al., 2024). Recent studies further connect digital finance with rural consumption upgrading and household financial vulnerability (Li et al., 2025; Liu et al., 2024). Nevertheless, relatively few studies examine collaborative rural financial governance from the perspective of incentive and restraint mechanisms. This study therefore introduces an evolutionary game framework to analyze how boundedly rational stakeholders adjust their strategies under changing policy incentives and constraints.

Recent studies further show that digital inclusive finance can improve agricultural total factor productivity and support high-quality agricultural development (Zhai et al., 2023; Zeng et al., 2026). These findings provide a realistic basis for expanding the model's demand-side subject from poor households to broader rural financial service demanders. They also justify shifting the policy background of this paper from targeted poverty alleviation to rural revitalization, common prosperity, inclusive finance, and high-quality financial development.

First, the study clarifies the interaction mechanism among the government, rural financial institutions, and rural financial service demanders in the rural financial system.

Second, the study constructs a tripartite evolutionary game model and uses System Dynamics simulation to analyze the strategic evolution of each stakeholder, thereby identifying the basic conditions for stable and healthy rural financial development in China.Third, the study compares different policy scenarios and discusses feasible ranges of supervision, punishment, and incentive parameters so as to provide more operational policy references for collaborative rural financial governance.

2. Related Theories and Research Methods

2.1 Features of the Tripartite Game of Rural Finance

The rural financial system includes three types of stakeholders: the government, rural financial institutions, and rural financial service demanders. The third stakeholder is not limited to poor households. It includes ordinary rural households, smallholder farmers, family farms, members of agricultural cooperatives, large-scale agricultural producers, rural entrepreneurs, and agricultural value-chain actors. This broader definition is consistent with recent rural finance and inclusive finance research (Klapper et al., 2025). It is also supported by empirical evidence on family farms, cooperatives, and technology adoption in rural China (Chen et al., 2022; Jiang et al., 2024).

2.2 Evolutionary Game Theory and the Tripartite Development of Rural Finance

The economic thought of evolutionary game theory originated from evolutionary biology and was later integrated with classical game theory. It relaxes the assumption of complete rationality and emphasizes bounded rationality, imitation, learning, and dynamic adjustment among heterogeneous agents (Simon, 1986). The concept of evolutionarily stable strategies provides the theoretical basis for analyzing the dynamic adjustment of strategies (Smith, 1982; Taylor and Jonker, 1978). Evolutionary game theory has subsequently been widely used in economics and population-game analysis (Friedman, 1991; Sandholm, 2010).

Under incomplete information, the government, rural financial institutions, and rural financial service demanders each face different strategic choices. Their strategy selection is a long-term dynamic process. The replicator dynamic equation can describe how agents learn from higher-payoff strategies and gradually adjust their behavior over time (Weibull, 1995; Sandholm, 2010). Therefore, evolutionary game theory is suitable for analyzing the stability of collaborative rural financial governance under policy incentives and constraints.

2.3 System Dynamics: Theory, Model and Simulation Method

System Dynamics (SD), founded by J. W. Forrester and later developed into a general modeling approach for complex feedback systems, analyzes causal loops, stock-flow structures, delays, and computer simulation (Forrester, 1997; Sterman, 2000). In this paper, System Dynamics is used as a simulation method rather than as a separate theoretical assumption. It provides a platform for translating the tripartite evolutionary game into a dynamic simulation structure. (1)Identify the problem. Analyzing the problem of the rural financial tripartite game is the initial step of System Dynamics to solve the problem, which mainly includes analyzing the problem and clarifying the research goal.(2)System structure analysis. This step is mainly to form a dynamic hypothesis on the cause of the problem, analyze the influencing factors of the system and the correlation between the factors, divide the subsystems to establish a feedback mechanism, mainly including constructing a causal feedback loop and establishing a system flowchart.(3)Establish a computer simulation model. The influencing factors established through the analysis of the system structure, the correlation between the factors and the feedback mechanism, the use of mathematics to express the relationship between the factors, determine the parameter values, etc., mainly include determining variables and parameters, and establishing equations;(4)Simulation of the model. Simulate the built model, systematically analyze the simulation results, and give countermeasures and suggestions based on the analysis results, mainly including analysis results, conclusions, suggestions and measures;(5)Inspection and evaluation model. That is, the testing and debugging of the model. During the implementation process, if new problems are found, the model should be modified in time to ensure the correctness of the simulation results of the model.

In the rural financial tripartite game, System Dynamics provides a simulation platform for analyzing the stability of evolutionary equilibria (Forrester, 1997; Sterman, 2000). Combining evolutionary game theory with System Dynamics is appropriate when the system contains bounded rationality, feedback loops, repeated interaction, and policy adjustment. Recent agricultural governance studies have also used System Dynamics and evolutionary game analysis to examine multi-agent cooperation under uncertainty (Zhang and Liu, 2024).

3. Tripartite Game Analysis of the Rural Financial System

The rural financial system in this study includes three types of stakeholders: the government, rural financial institutions, and rural financial service demanders. Rural financial service demanders include ordinary rural households, smallholder farmers, family farms, members of agricultural cooperatives, large-scale agricultural producers, rural entrepreneurs, and agricultural value-chain actors. This definition is broader than the category of poor households and better reflects the current rural financial service structure (Klapper et al., 2025). It also corresponds to empirical studies on family farms, cooperatives, and agricultural value-chain finance (Chen et al., 2022; Villalba et al., 2023).

3.1 Analysis of the Interest Subjects of the Tripartite Game of Rural Finance

3.1.1 Basic assumptions of the model

This study assumes that the main costs, expenses, and benefits in the tripartite rural financial game can be quantified. The government's incentive policies for rural financial institutions are assumed to be consistent with the goals of rural revitalization, inclusive finance, and high-quality financial development. All rural financial lending activities are assumed to take place through rural financial institutions or under their participation. Because the three stakeholders are boundedly rational rather than fully rational, their strategies evolve through repeated learning and payoff comparison (Simon, 1986; Weibull, 1995).

3.1.2 Benefit analysis of tripartite stakeholders

In real economic life, incomplete and asymmetric information affects the strategic choices of all stakeholders in rural finance. This section discusses the tripartite game among the government, rural financial institutions, and rural financial service demanders under credit constraints and policy regulation. The strategic choices are defined as follows:

S1={Sg1，Sb1，Sf1}={Supervision, financial institutions abide by the law, farmers abide by the law};

S2={Sg1，Sb1，Sf2}={Supervision, financial institutions abide by the law, farmers violate regulations};

S3={Sg1，Sb2，Sf1}={supervision, financial institutions violate regulations, farmers abide by the law};

S4={Sg1，Sb2，Sf2}={regulation, financial institution violation, farmer violation};

S5={Sg2，Sb1，Sf1}={No supervision, financial institutions abide by the law, farmers abide by the law};

S6={Sg2，Sb1，Sf2}={No supervision, financial institutions abide by the law, farmers violate regulations};

S7={Sg2，Sb2，Sf1}={No supervision, financial institutions violate regulations, farmers abide by the law};

S8={Sg2，Sb2，Sf2}={No supervision, financial institutions violate regulations, farmers violate regulations};

For the above-mentioned strategy choices, each gambling subject makes continuous adjustments according to their own profitability under each strategy choice, as follows:

3.1.3 Government strategy and payoff analysis

The government has two strategic choices in the entire game process: (regulation; no regulation). Which strategy the government chooses depends on whether the government's action benefits are maximized under each strategy state or whether the benefits of this strategy meet or exceed the government's expected benefits. In the tripartite game system of rural finance, the government's social benefits, supervision costs, government subsidies and penalties are involved. Social benefits refer to government credibility and rural economic development. If loans from financial institutions can promptly help agricultural production and promote rural economic development, it can bring a certain increase in government credibility and increase social economic benefits. Supervision costs refer to the costs and expenses incurred by government agencies when they supervise the compliance operation of financial institutions, such as establishing a national credit reporting system. If the farmers' agricultural production funds need to be effectively met, the relevant government departments should do a good job of supervision. In addition, they need to give financial institutions certain preferential policies to increase support, and establish a scientifically designed penalty mechanism to deter rent-seeking and non-compliant behavior by rural financial institutions. The rent-seeking behavior reduces the collusion between financial institutions and farmers, so that the government's own benefits can reach an equilibrium state.

In order to facilitate subsequent research, the introduction of probability distribution $(\alpha, 1-\alpha)$ represents the probability of government supervision and non-regulation. The purpose of introducing supervision probability α is to simulate the actual government supervision situation. The closer α is to 1, the stronger the supervision. , When α=1, it means that the government adopts the strategy of implementing supervision, and when α=0, it means that the government does not supervise at all. In order to facilitate the analysis of the government's income, we assume that the government's regulatory cost is a. If the lack of supervision results in illegal activities between financial institutions and farmers in need of funds, resulting in agricultural production losses and agricultural economic development, then the government Need to bear the expected loss cost in the later period b; if there is a violation between the financial institution and the farmer, the punishment between the financial institution and the farmer is c and d respectively; if the demand for rural financial funds is balanced, the government will give financial institutions and Certain rewards for farmers, such as interest rate cuts, subsidies, etc., are assumed to be e and f, and the social benefits that the government reaps at this time are s.

3.1.4 Rural financial institution strategy and payoff analysis

Financial institution strategy choices are: (compliance; violation), introducing probability distribution $(\beta, 1-\beta)$ to indicate the probability of a financial institution abiding and violating the law, the level of β represents the strength of its law-abiding ability, when β =0, it represents Financial institutions no longer perform their supervisory duties, and even seek rent from farmers who need funds. Financial institutions have the right to supervise the borrowing needs of rural households in pursuit of maximum benefits. When a financial institution chooses to operate in compliance with the law, the income obtained by normal operation is k. When it chooses the strategy of illegal operation, it will save the cost

l in the borrowing process. However, it needs to bear a certain expected loss in taking the illegal operation, including not only the loss of reputation, but also the rent paid by seeking cooperation from farmers. Assume that financial institutions The total expected loss when rent-seeking is successful is m, and the total expected loss when rent-seeking fails is n.

3.1.5 Rural financial service demander strategy and payoff analysis

For farmers who need funds, there are two strategy choices (law-abiding; violation). The probability distribution $(\gamma, 1-\gamma)$ is introduced to indicate the probability of farmers' compliance and violation. When a farmer chooses to abide by the law and fulfill the contract on time and repay the loan on time, the income from normal agricultural production activities is g. When it chooses the strategy of violating regulations, it will save the repayment cost h. However, it needs to bear a certain expected loss when taking illegal operations, including not only the loss of reputation, but also the rent paid by seeking to collude with financial institutions. Assume that farmers are rent-seeking The total expected loss when successful is i, and the total expected loss when rent-seeking fails is j.

Where $0 \leq \alpha, p, \beta, \gamma \leq 1$，The variables used in the evolutionary game model are defined in Table 1.

Table1 Evolutionary game model variables and their meanings

variable	Variable meaning	Remarks
a	Regulatory cost	*a*>0
b	The government ignores the expected cost of supervision	*b*>0
c	Government's punishment of institutions	*c*>0
d	Government's punishment of farmers	*d*>*c*
e	Government rewards for financial institutions	*e*>0
f	Government rewards to farmers	*f*>0
g	Farmers' normal loan production and operation income	*g*>0
h	Farmer's normal repayment cost	h>0
i	The total expected loss cost when the farmers succeed in rent-seeking	*i*<h
j	The total expected loss cost when farmers fail to seek rent	*j*<*i*
k	Income from normal operation of financial institutions	*k*>0
l	Financial institution borrowing costs	*l*>0
m	The total expected loss cost of a financial institution when rent-seeking is successful	*m*<*l*
n	The total expected loss cost of financial institutions when rent-seeking fails	*a*<*m*
s	Social benefits of the government	*s*>0

3.2Construction and Analysis of the Evolutionary Game Model of Tripartite Stakeholders in the Rural Financial System

Evolutionary game theory assumes bounded rationality and repeated strategic adjustment. Stakeholders do not necessarily identify the optimal strategy at the beginning of the game; instead, they learn from payoff differences and gradually adjust their behavior. The replicator dynamic equation is the basic tool for describing the change in the proportion of a strategy within a population. The basic payoff structure of the game is shown in Table 2.

Table2 The income of each game player

	Game subject 2		
		Strategy 1	Strategy 2
Game subject 1	Strategy 1	A1，A2	C1，C2
	Strategy 2	B1，B2	D1，D2

Copying the dynamic differential equation is actually a dynamic differential equation that describes the frequency or frequency of a particular strategy of a participant in the game process and the frequency or frequency selected during the entire process. The general differential equation is expressed as follows:

$$F(y_n) = \frac{\mathrm{d}y_n}{\mathrm{d}_t} = y_n(E(y_n) - \bar{E})$$

Among them, y_n is the proportion of the participants of the n strategy in the evolutionary game process in the entire system, E(y_n) is the expected return value when the n strategy is adopted in the game system, and $\bar{\mathrm{E}}$ represents the average expected return.

3.2.1 Establishment of the payoff matrix

According to the research needs, this paper introduces E_{ij} to represent the income of the i game subject when they choose the j strategy, where $i = g, b, f$，$j = 1,2$. For example, Eg1 represents the income when the government adopts the strategy of supervision, and Eg2 represents the income when the government adopts the strategy of non-regulation.

Table3 Three-party game payment income matrix under government supervision strategy

		Farmer	
		Obey the law	Violation
Financial Institutions	Obey the law	{*s-a-e-f*,*k+e*,*g+f*}	{*s*/2-*a*+*d*-*e*,*k*+*e*,*g*-*d*-*j*+h}
	Violation	{*s*/2-*a*+*c*-*f*,*k*-*c*-*n*+*l*,*g*+*f*}	{-*a*+*c*+*d*,*k*-*c*-*m*+*l*,*g*-*d*-*i*+h}

Table4 Three-party game payment income matrix under the government's non-regulatory strategy

		Farmer	
		Obey the law	Violation
Financial Institutions	Obey the law	{*s*,*k*,*g*}	{*s*/2-*b*,*k*,*g*-*j*+h}
	Violation	{*s*/2-*b*,*k*-*n*+*l*,*g*}	{-*b*,*k*-*m*+*l*,*g*-*i*+h}

In the above table, the first function item in the table set represents government income, the second function item represents the income of financial institutions, and the third function item represents the income of farmers with borrowing needs.

3.2.2 Evolutionary game analysis

The expected benefits Eg1 and Eg2 of the government's regulatory and non-regulatory strategies are:

$$E_{g1} = \beta\gamma(s-a-e-f) + \beta(1-\gamma)(s/2-a+d-e) + (1-\beta)\gamma(s/2-a+c-f) + (1-\beta)(1-\gamma)(-a+c+d) =- a+c+d-\beta(c+e)-\gamma(d+f)$$

$$E_{g2} = \beta\gamma s + \beta(1-\gamma)(s/2-b) + (1-\beta)\gamma(s/2-b) + (1-\beta)(1-\gamma)(-b) =- b(1-\beta\gamma)$$

According to the above calculation, the expected average income of the government $\overline{E_g}$ is

$$\overline{E_g} = \alpha E_{g1} + (1-\alpha)E_{g2}$$

According to evolutionary game theory, the assumption of time in this article is continuous. As a government, it tends to learn to imitate game strategy behaviors with a high rate of return, and which strategy gives higher returns, then the game subject will learn and imitate it more.

Let the probability rate of change when the government adopts a regulatory strategy $\frac{d_\alpha}{d_t}$ is the government's replication dynamic equation $F(\alpha)$, then:

$$\mathrm{F}(\alpha) = \frac{\mathrm{d}\alpha}{\mathrm{dt}} = \alpha\left(\mathrm{E_{g1}} - \overline{\mathrm{E_g}}\right) = \alpha(1-\alpha)\left(\mathrm{E_{g1}} - \mathrm{E_{g2}}\right) = \alpha(1-\alpha)\left(-\mathrm{a}+\mathrm{c}+\mathrm{d}-\beta(\mathrm{c}+\mathrm{e})-\gamma(\mathrm{d}+\mathrm{f}) + \mathrm{b}(1-\beta\gamma)\right)$$

The same can be obtained:

The expected return E_{b1}, E_{b2} and average return $\overline{E_s}$ of financial institutions adopting law-abiding and non-compliance strategies and the probability change rate $F(\beta)$ when adopting law-abiding strategies are:

$$E_{b1} = \alpha\gamma(k+e) + \alpha(1-\gamma)(k+e) + (1-\alpha)\gamma k + (1-\alpha)(1-\gamma)k = \alpha e + k$$

$$E_{b2} = \alpha\gamma(k-c-n+l) + \alpha(1-\gamma)(k-c-m+l) + (1-\alpha)\gamma(k-n+l) + (1-\alpha)(1-\gamma)(k-m+l) = k-m+l-\alpha c+\gamma(m-n)$$

$$\overline{E_b} = \beta E_{b1} + (1-\beta)E_{b2}$$

$$F(\beta) = \frac{d\beta}{dt} = \beta(E_{b1} - \overline{E_b}) = \beta(1-\beta)(E_{b1} - E_{b2}) = \beta(1-\beta)\big(\alpha e + m - l + \alpha c - \gamma(m-n)\big)$$

The expected return E_{f1}, E_{f2} and the average return $\overline{E_f}$ and the probability change rate $F(\gamma)$ when adopting the law-abiding strategy of the farmers with borrowing needs adopting the law-abiding and collusive strategy are:

$$E_{f1} = \alpha\beta(g+f) + \alpha(1-\beta)(g+f) + (1-\alpha)\beta g + (1-\alpha)(1-\beta)g = \alpha f + g$$

$E_{f2} = \alpha\beta(g-d-j+h) + \alpha(1-\beta)(g-d-i+h) + (1-\alpha)\beta(g-j+h) + (1-\alpha)(1-\beta)(g-i+h) = g-i+h-\alpha d+\beta(i-j)$ （3-11）

$\overline{E_f} = \gamma E_{f1} + (1-\gamma)E_{f2}$

$F(\gamma) = \frac{d\gamma}{dt} = \gamma(E_{f1} - \overline{E_f}) = \gamma(1-\gamma)(E_{f1} - E_{f2}) = \gamma(1-\gamma)(\alpha f + i - h + \alpha d - \beta(i-j))$

3.2.3 Game equilibrium analysis

After the above analysis, the various programs described the group dynamics of the evolutionary game of supply and demand between the three parties in the rural financial system. The group dynamics of the game in this system can be expressed by the simultaneous composition $F(x) = \left(F(\alpha), F(\beta), F(\gamma)\right)^T$:

$$F = \begin{cases} F(\alpha) = \dfrac{d\alpha}{dt} = \alpha(1-\alpha)\left(-a+c+d-\beta(c+e)-\gamma(d+f)+b(1-\beta\gamma)\right) \\ F(\beta) = \dfrac{d\beta}{dt} = \beta(1-\beta)\left(\alpha e+m-l+\alpha c-\gamma(m-n)\right) \\ F(\gamma) = \dfrac{d\gamma}{dt} = \gamma(1-\gamma)\left(\alpha f+i-h+\alpha d-\beta(i-j)\right) \end{cases}$$

In evolutionary game theory, copying dynamic equations can reflect the learning speed and evolution direction of the game player in the system. When $F(x) = 0$, it indicates that the game of this evolutionary system has reached a relatively stable equilibrium state, which can be obtained the local equilibrium point of the subject of the system's tripartite game. The local equilibrium point represents the equilibrium solution of the three-party evolutionary game model of the rural financial system.

Therefore, let $F(x) = \left(F(\alpha), F(\beta), F(\gamma)\right)^T = 0$, the equilibrium solution of the tripartite evolutionary game system of the rural financial system can be obtained as:

$$x_1 = \begin{pmatrix}0\\0\\0\end{pmatrix},\ x_2 = \begin{pmatrix}0\\0\\1\end{pmatrix},\ x_3 = \begin{pmatrix}0\\1\\0\end{pmatrix},\ x_4 = \begin{pmatrix}0\\1\\1\end{pmatrix}$$

$$x_5 = \begin{pmatrix}1\\0\\0\end{pmatrix},\ x_6 = \begin{pmatrix}1\\0\\1\end{pmatrix},\ x_7 = \begin{pmatrix}1\\1\\0\end{pmatrix},\ x_8 = \begin{pmatrix}1\\1\\1\end{pmatrix}$$

$$x_9 = \begin{pmatrix}0\\ \frac{i-h}{i-j}\\ \frac{m-l}{m-n}\end{pmatrix},\ x_{10} = \begin{pmatrix}1\\ \frac{f+i+d-h}{i-j}\\ \frac{e+m+c-l}{m-n}\end{pmatrix},\ x_{11} = \begin{pmatrix}\frac{l-m}{e+c}\\ 0\\ \frac{b+c+d-a}{d+f}\end{pmatrix},\ x_{12} = \begin{pmatrix}\frac{h-j}{f+d}\\ 1\\ \frac{b+d-a-e}{d+f+b}\end{pmatrix}$$

$$x_{13} = \begin{pmatrix}\frac{b+c+d-a}{e+c}\\ \frac{l-m}{e+c}\\ 0\end{pmatrix},\ x_{14} = \begin{pmatrix}\frac{l-n}{e+c}\\ \frac{b+c-a-f}{b+c+e}\\ 1\end{pmatrix},\ x_{15} = \begin{pmatrix}\alpha_{15}\\ \beta_{15}\\ \gamma_{15}\end{pmatrix}$$

In the above-mentioned equilibrium solution, which equilibrium point the evolution process tends to,

needs to be judged according to the specific conditions of each equilibrium state. According to Hirshleifer's concept, if the trajectory starting from any small neighborhood of a certain equilibrium point of a dynamic system eventually evolves towards this equilibrium point, then the equilibrium point is said to be locally asymptotically stable. Such a dynamic stable equilibrium point is Evolutionary equilibrium. The local stability of the Jakobian matrix can be used to analyze the stability of the dynamic equilibrium point of this system. Calculate the partial derivatives of α, β, and γ for $F(\alpha)$, $F(\beta)$, and $F(\gamma)$ respectively, we can get:
The local stability of the Jakobian matrix can be used to analyze the stability of the dynamic equilibrium point of this system. Calculate the partial derivatives of α, β, γ for $F(\alpha), F(\beta), F(\gamma)$ respectively, we can get:

$$\frac{\partial F(\alpha)}{\partial \alpha} = (1-2\alpha)\big(-a+c+d-\beta(c+e)-\gamma(d+f)+b(1-\beta\gamma)\big);$$
$$\frac{\partial F(\alpha)}{\partial \beta} = \alpha(1-\alpha)(-c-e-b\gamma);$$
$$\frac{\partial F(\alpha)}{\partial \gamma} = \alpha(1-\alpha)(-d-f-b\beta);$$
$$\frac{\partial F(\beta)}{\partial \alpha} = \beta(1-\beta)(e+c);$$
$$\frac{\partial F(\beta)}{\partial \beta} = (1-2\beta)\big(\alpha e+m-l+\alpha c-\gamma(m-n)\big);$$
$$\frac{\partial F(\beta)}{\partial \gamma} = \beta(1-\beta)(n-m);$$
$$\frac{\partial F(\gamma)}{\partial \alpha} = \gamma(1-\gamma)(f+d);$$
$$\frac{\partial F(\gamma)}{\partial \beta} = \gamma(1-\gamma)(j-i);$$
$$\frac{\partial F(\gamma)}{\partial \gamma} = (1-2\gamma)\big(\alpha f+i-h+\alpha d-\beta(i-j)\big)$$

In summary, the Jacobian matrix can be obtained:

$$= \begin{bmatrix} \frac{\partial F(\alpha)}{\partial \alpha} & \frac{\partial F(\alpha)}{\partial \beta} & \frac{\partial F(\alpha)}{\partial \gamma} \\ \frac{\partial F(\beta)}{\partial \alpha} & \frac{\partial F(\beta)}{\partial \beta} & \frac{\partial F(\beta)}{\partial \gamma} \\ \frac{\partial F(\gamma)}{\partial \alpha} & \frac{\partial F(\gamma)}{\partial \beta} & \frac{\partial F(\gamma)}{\partial \gamma} \end{bmatrix} = \begin{bmatrix} x_{11} & x_{12} & x_{13} \\ x_{21} & x_{22} & x_{23} \\ x_{31} & x_{32} & x_{33} \end{bmatrix} =$$

$$\begin{bmatrix} (1-2\alpha)\begin{pmatrix} -a+c+d-\beta(c+e) \\ -\gamma(d+f)+b(1-\beta\gamma) \end{pmatrix} & \alpha(1-\alpha)(-c-e-b\gamma) & \alpha(1-\alpha)(-d-f-b\beta) \\ \beta(1-\beta)(e+c) & (1-2\beta)\begin{pmatrix} \alpha e+m-l+ \\ \alpha c-\gamma(m-n) \end{pmatrix} & \beta(1-\beta)(n-m) \\ \gamma(1-\gamma)(f+d) & \gamma(1-\gamma)(j-i) & (1-2\gamma)\begin{pmatrix} \alpha f+i-h \\ +\alpha d-\beta(i-j) \end{pmatrix} \end{bmatrix}$$

According to the determinant of Jacobian det_j and trace tr_j to judge the local stability of the evolutionary game system, according to Friedman's method of discriminating stable equilibrium points,

for a group dynamic described by a differential equation system, The stability of the local equilibrium point is determined by the fact that the determinant of the Jacobian matrix J of the replication system is positive and its trace is negative, that is, when $|H|$>0, tr(J) <0, the equilibrium point is Evolutionary Stability Strategy (ESS).
The determinants of Jacobian det_j and trace tr_j are respectively:

$$det_j = x_{11}x_{22}x_{33} - x_{11}x_{32}x_{23} + x_{21}x_{32}x_{13} - x_{21}x_{12}x_{33} + x_{31}x_{12}x_{23} - x_{31}x_{x22}x_{13};$$
$$tr_j = x_{11}+x_{22}+x_{33}。$$

Although the stability of each equilibrium point can be analyzed theoretically through the Jacobian matrix, the calculation is complex. Therefore, this paper further uses computer simulation to analyze the stability of the evolutionary game. System Dynamics is used because it can combine qualitative mechanism analysis with quantitative simulation under incomplete information.

4. Simulation and Stability Analysis of the Evolutionary Game Model

Given the complexity of the rural financial tripartite system, this section uses System Dynamics to construct the feedback structure of the evolutionary game model and to analyze the stability of different equilibrium points under alternative policy scenarios.

4.1 SD Model of the Tripartite Evolutionary Game System of Rural Finance

Based on the evolutionary game analysis above, this section uses Vensim PLE to build the SD model of the rural financial tripartite evolutionary game. The model consists of three sub-models: the government supervision sub-model, the rural financial institution sub-model, and the rural financial service demander sub-model. The functional relationships among state variables, rate variables, and auxiliary variables are determined by the replicator dynamic equations developed in the previous section.

4.1.1 Government supervision SD sub-model

The government supervision model contains 2 state variables, 1 rate variable, intermediate variables, and 6 external variables. In the main body of the game of government, the supervision ratio is represented by 2 state variables, the supervision change rate is represented by the speed change, and the external change The quantity corresponds to the corresponding six variables . The functional relationship among the state variables, rate variables, and intermediate variables in the model is determined by evolutionary game analysis. The government supervision sub-SD model is shown in the figure1:

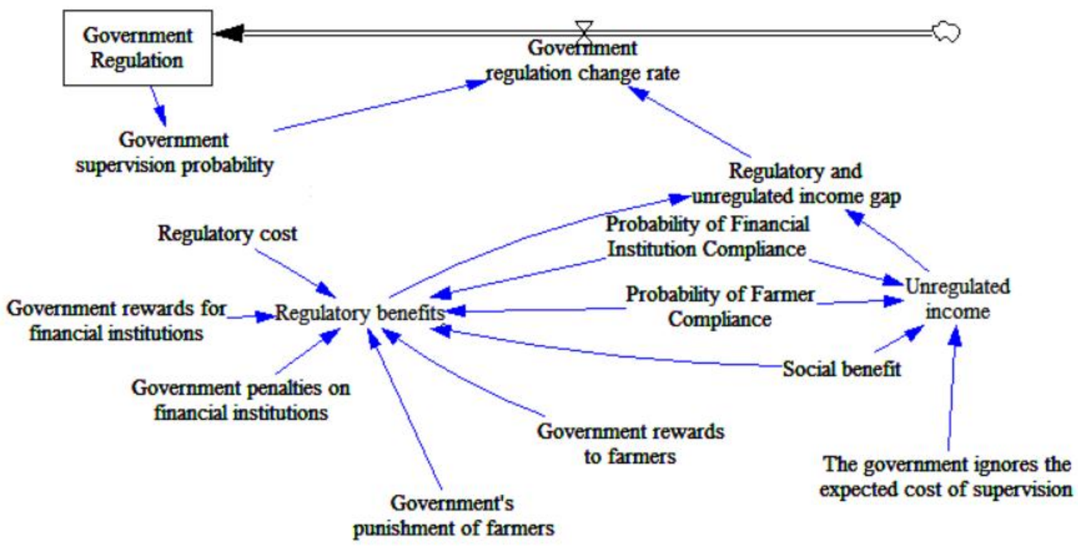

Figure1 Sub-SD model of government supervision

4.1.2 Rural financial institution SD sub-model

The financial institution model contains 1 state variable, 1 rate variable, 7 intermediate variables, and 5 external variables. The state variables, rate variables and intermediate variables in the model are determined by evolutionary game analysis. The SD model of financial institutions is shown in Figure 2:

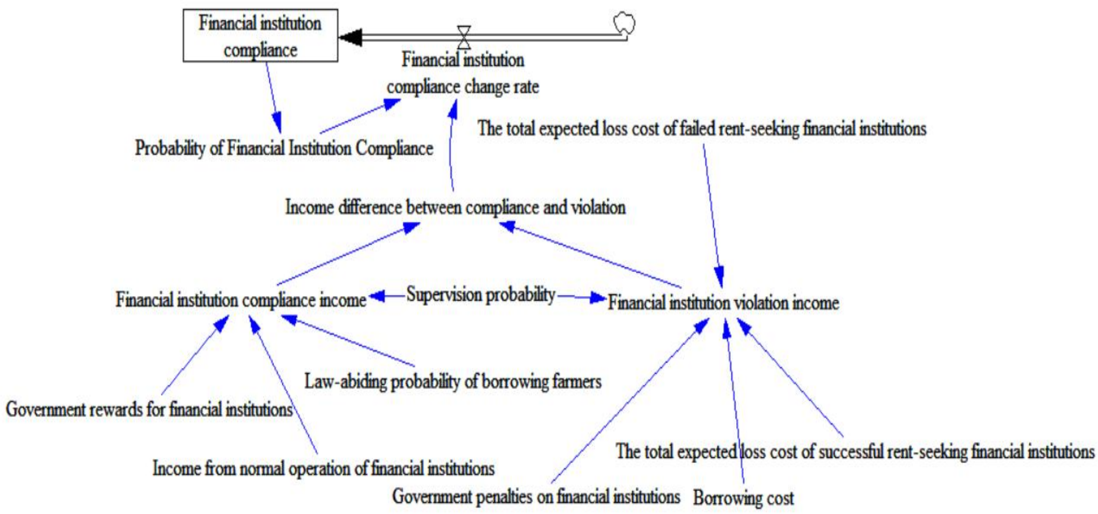

Figure2 Sub-SD model of financial institutions

4.1.3 Rural financial service demander SD sub-model

Through the comprehensive analysis of the sub-SD model system, the SD evolutionary game model of the rural financial tripartite game system can be obtained. The model contains 3 state variables, 3 speed variables, 20 intermediate variables, and 8 external variables as shown in Figure 3.

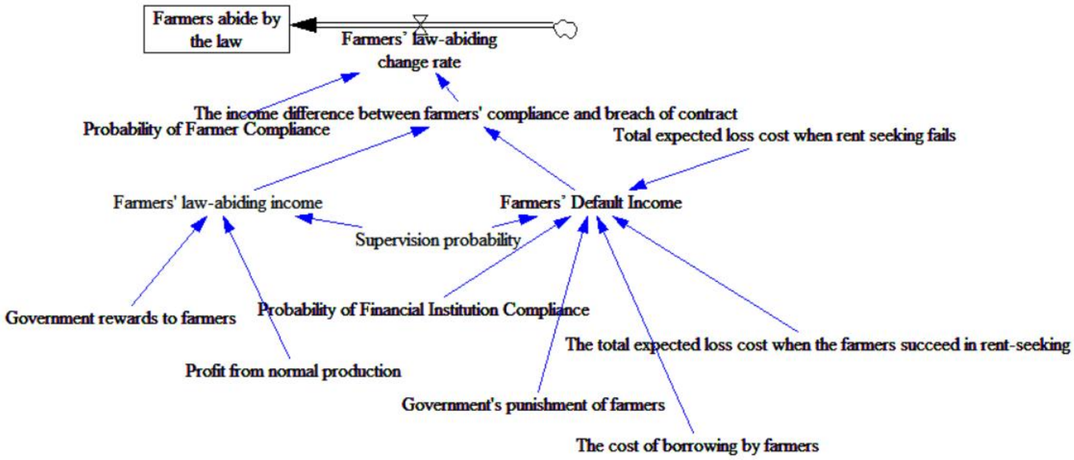

Figure3 SD model of borrowing farm households

4.1.4 SD evolutionary game model of the rural finance tripartite system

After comprehensive analysis of the sub-SD model system, the SD evolutionary game model of the rural financial tripartite game system can be obtained. The model contains 6 state variables, 3 speed variables, 19 intermediate variables, and 8 external variables as shown in Figure4.

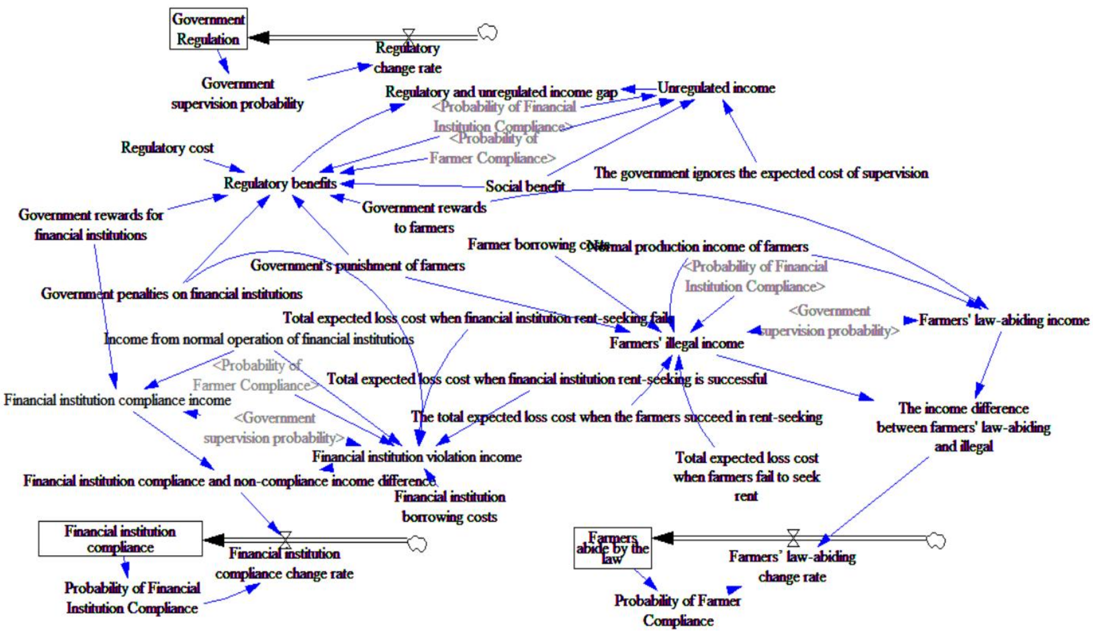

Figure4 SD evolutionary game model of the rural financial tripartite game system

4.2 Simulation and Stability Analysis of the Tripartite Evolutionary Game Model of the Rural Financial System

The model settings are as follows: INITIAL TIME=0, FINAL TIME=100, TIME STEP=0.03125, Units for Time: Year, Integration Type: Euler, according to the definition of the actual meaning of the variables in the previous paragraph, the initial value settings of the external variables in the model are shown in Table 5 ：

Table5 Initial Values of External Variables in the System Dynamics Model

variable	Variable meaning	Remarks
a	Regulatory cost	3
b	The government ignores the expected cost of supervision	7
c	Government's punishment of institutions	4
d	Government's punishment of farmers	2
e	Government rewards for financial institutions	2
f	Government rewards to farmers	1
g	Farmers' normal loan production and operation income	10
h	Farmer's normal repayment cost	2
i	The total expected loss cost when the farmers succeed in rent-seeking	2
j	The total expected loss cost when farmers fail to seek rent	1
k	Income from normal operation of financial institutions	8
l	Financial institution borrowing costs	2
m	The total expected loss cost of a financial institution when rent-seeking is successful	1.5
n	The total expected loss cost of financial institutions when rent-seeking fails	1
s	Social benefits of the government	7

Note: To further improve empirical reliability, future research should calibrate these parameters with micro-survey data, administrative credit records, regional loan default data, and policy subsidy records.

4.2.1 Parameter calibration and data basis

The parameters in Table 5 are dimensionless simulation parameters rather than directly observed monetary values. Their calibration follows three principles. First, the sign restrictions and relative magnitudes are consistent with the theoretical payoff relationships in the model. Second, the parameter setting reflects the practical logic of rural financial governance: supervision and post-loan monitoring involve regulatory costs; violation may produce short-term gains but also causes expected losses, penalties, and reputational costs; and incentives may improve compliance when combined with credible punishment. Third, the benchmark values are calibrated with reference to policy documents, international rural finance reports, and empirical studies on rural credit, family farms, cooperatives, and technology adoption (Klapper et al., 2025; IFAD, 2025). Empirical evidence on family farms and rural credit is used to support the relative importance of credit constraints, repayment incentives, and compliance behavior (Chen et al., 2022; Wang et al., 2025). The simulation does not claim that these parameters are direct statistical estimates. Instead, it uses them to represent relative payoff relationships and then evaluates whether the evolutionary direction is robust under alternative penalty and incentive scenarios. This calibration logic is consistent with System Dynamics modeling, where parameters often combine empirical information, theoretical constraints, and scenario assumptions (Forrester, 1997;

Sterman, 2000). Recent agricultural applications of evolutionary game and System Dynamics models also adopt this scenario-based parameter calibration approach (Zhang and Liu, 2024).

Substituting the initial values in Table 5 into the tripartite payoff matrix yields the following replicator dynamic equations for the rural financial evolutionary game:

$$F = \begin{cases} F(\alpha) = \dfrac{d\alpha}{dt} = \alpha(1-\alpha)\big(-a + c + d - \beta(c+e) - \gamma(d+f) + b(1-\beta\gamma)\big) \\ F(\beta) = \dfrac{d\beta}{dt} = \beta(1-\beta)\big(\alpha e + m - l + \alpha c - \gamma(m-n)\big) \\ F(\gamma) = \dfrac{d\gamma}{dt} = \gamma(1-\gamma)\big(\alpha f + i - h + \alpha d - \beta(i-j)\big) \end{cases}$$

which is

$$F(x) = \begin{cases} F(\alpha) = \dfrac{d\alpha}{dt} = \alpha(1-\alpha)(10 - 6\beta - 3\gamma - 7\beta\gamma) \\ F(\beta) = \dfrac{d\beta}{dt} = \beta(1-\beta)(6\alpha - 0.5\gamma - 0.5) \\ F(\gamma) = \dfrac{d\gamma}{dt} = \gamma(1-\gamma)(3\alpha - \beta) \end{cases}$$

Let $F(x) = \big(F(\alpha), F(\beta), F(\gamma)\big)^T = 0$, we can obtain all the equilibrium solutions of the evolutionary game system of the rural finance tripartite system, as:

$$x_1 = \begin{pmatrix}0\\0\\0\end{pmatrix},\ x_2 = \begin{pmatrix}0\\0\\1\end{pmatrix},\ x_3 = \begin{pmatrix}0\\1\\0\end{pmatrix},\ x_4 = \begin{pmatrix}0\\1\\1\end{pmatrix}$$

$$x_5 = \begin{pmatrix}1\\0\\0\end{pmatrix},\ x_6 = \begin{pmatrix}1\\0\\1\end{pmatrix},\ x_7 = \begin{pmatrix}1\\1\\0\end{pmatrix},\ x_8 = \begin{pmatrix}1\\1\\1\end{pmatrix}$$

$$x_{12} = \left(\frac{1}{3}, 1, \frac{2}{5}\right)^T,\ x_{14} = \left(\frac{1}{6}, \frac{7}{13}, 1\right)^T$$

4.2.2 Stability analysis of pure-strategy equilibrium solutions

According to the analysis of the replication dynamic equation in the evolutionary game model of the rural financial tripartite system, eight pure strategy equilibrium solutions $x_1 \sim x_8$ are obtained. This section mainly analyzes the stability of these eight pure strategy equilibrium solutions. Take x_1 as an example, take x_1 into the evolutionary game system dynamics model of the rural financial tripartite system for simulation, and obtain the evolutionary game state in this situation, as shown in the figure.

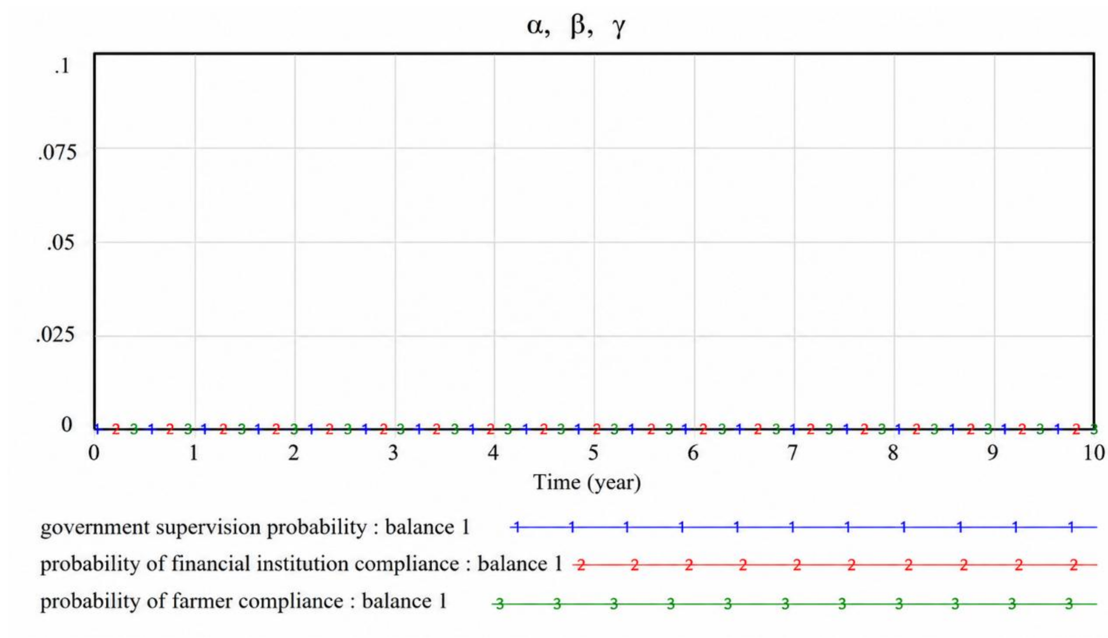

Figure5 The evolutionary game process of the initial pure strategy x_1

Figure 5 shows that when the initial pure strategy is the equilibrium solution x_1, none of the three parties actively change their strategies. At this time, the evolutionary game system is in a state of equilibrium. Similarly, it is found through simulation that when the pure strategy is the other seven equilibrium solutions, the three parties in the game did not actively change their strategies. However, the equilibrium state of this pure strategy is unstable and there is a certain dependence phenomenon. Taking x_1 as an example, if the government has a sudden change in strategy selection due to some reasons, the supervision probability changes from α=0 to α=0.05. Simulation of this situation is performed, and the result is shown in Figure 6.

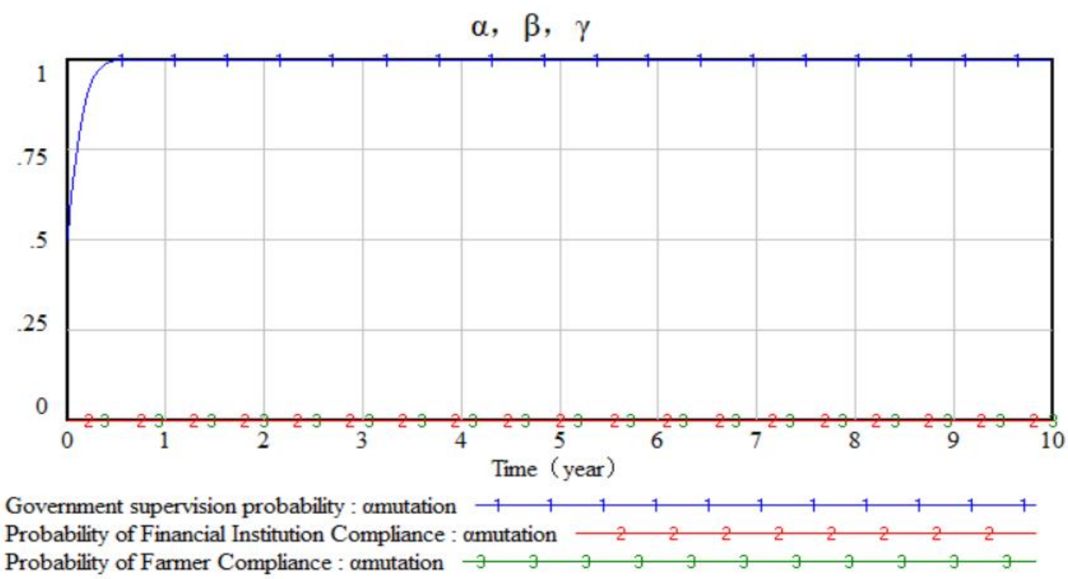

Figure6 The evolutionary game process of the initial pure strategy x_1 (α→0.05)

As shown in the figure above, the equilibrium state of the pure strategy equilibrium solution x_1 is not stable, and it is not an evolutionary stable equilibrium. The government's supervision probability evolves from α=0 to α=1, and the evolutionary equilibrium state changes from $x_1 \rightarrow x_5$ in conclusion. This situation occurs because some reasons lead to a sudden change in the government's strategy and obtain higher benefits compared to the previous strategy choice. Therefore, the government as the main game player will continue to learn and strengthen, and eventually lead to the original non-regulation α= 0 to the supervision α =1, the evolutionary game state of the rural financial tripartite system changes from $x_1 \rightarrow x_5$. Next, we need to study whether x_5 is an evolutionary stable equilibrium. Suppose that in the equilibrium state of x_5, the probability of its compliance is changed from β=0 to β=0.6, and the simulation results are shown in Figure 7.

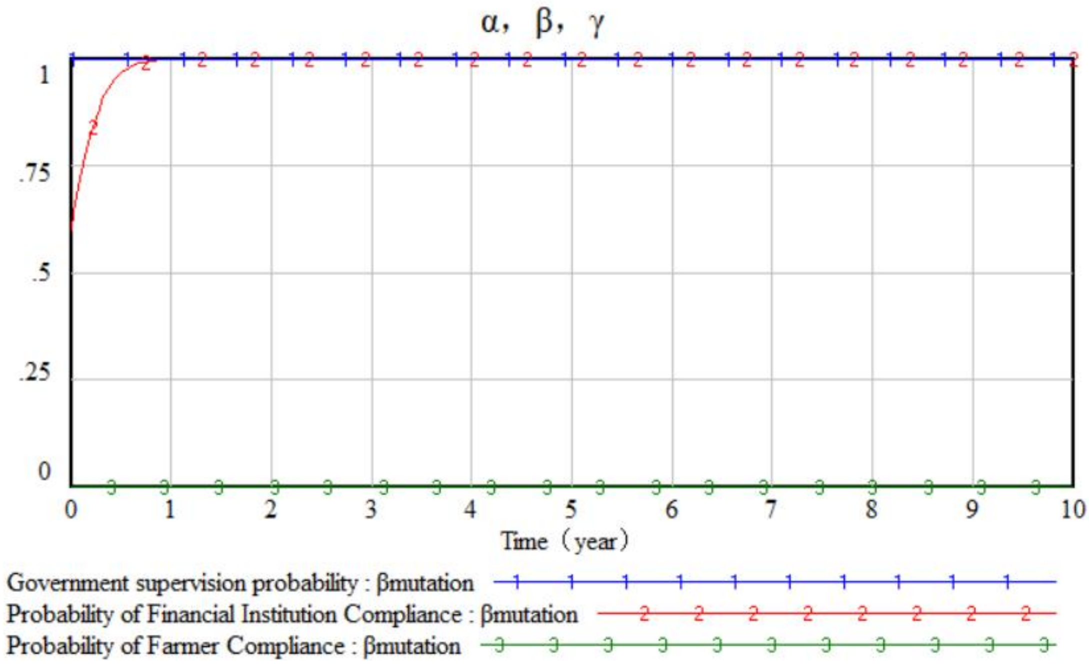

Figure7 The evolutionary game process of the initial pure strategy x_5($\beta \rightarrow$0.6)

It can be shown by 7 that the equilibrium state of the pure strategy equilibrium solution x_5 is not stable. It also shows that x_5 is not an evolutionary stable equilibrium. The main body of the game of financial institutions evolves toward β=1, and the equilibrium state of the evolutionary game system evolves from $x_5 \rightarrow x_7$. Next, we need to study whether x_7 is an evolutionary stable equilibrium. Suppose that under the equilibrium state of x_7, part of the initial strategy of the main game of lending farmers has a sudden change, and the probability of choosing their on-time repayment changes from γ=0 to γ=0.2. This is simulated, and the result is shown in Figure 9. As shown, it can be drawn from the figure that the evolutionary equilibrium state evolves from $x_7 \rightarrow x_8$, which shows that the pure strategy equilibrium solution x_7 is not an evolutionary stable equilibrium state.

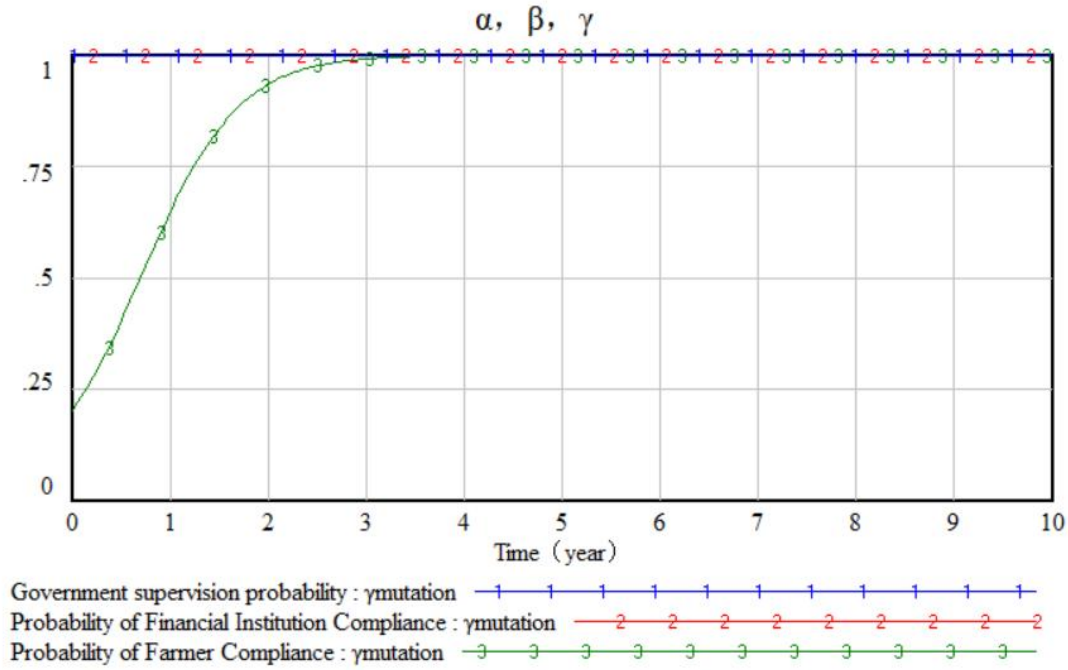

Figure8 The evolutionary game process of the initial pure strategy $x_7(\gamma\rightarrow0.2)$

Is the pure strategy equilibrium solution x_8 an evolutionary stable equilibrium state? Assuming that in this state, since the financial institutions and the host farmers are in a law-abiding state, the government slightly reduces the supervision, α=1 suddenly changes to α =0.9, and the simulation results show that the equilibrium state evolves from $x_8 \rightarrow x_4$, then x_8 is also not an evolutionary stable equilibrium strategy, the evolution process is shown in Figure9.

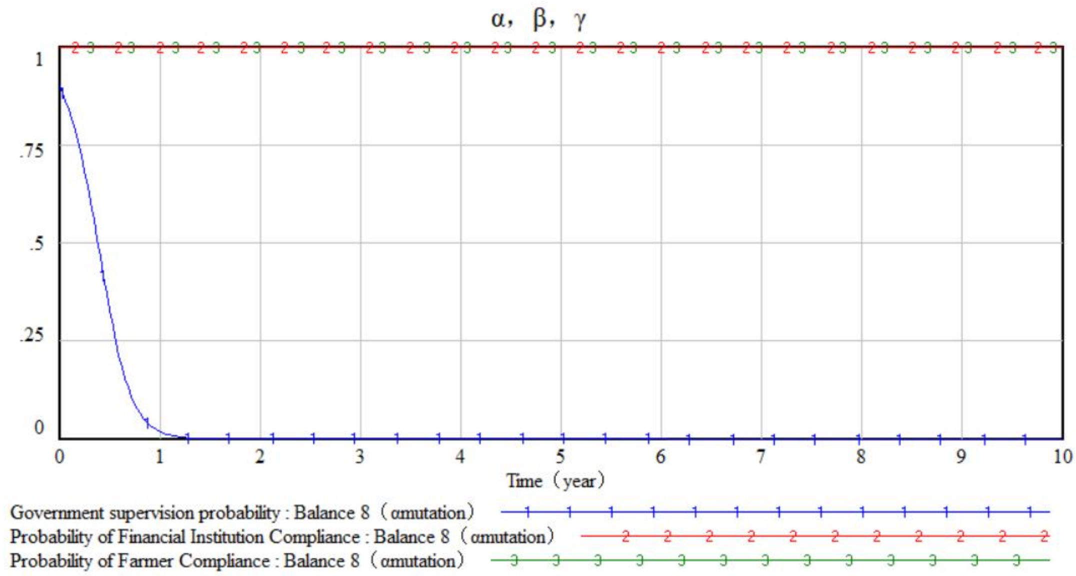

Figure9 The evolutionary game process of the initial pure strategy $x_8(\alpha\rightarrow0.9)$

The simulation analysis of the equilibrium solutions obtained from the remaining evolutionary games found that x_4、x_2、x_3 and x_6 are also unstable. In summary, once a sudden change occurs, the equilibrium will be broken and the existing equilibrium state will evolve to other equilibrium states, that is, all the pure strategy equilibrium solutions of are not evolutionary stable equilibrium solutions.

4.2.3 Analysis of Stability of Mixed Strategy Equilibrium Solution

There are two mixed strategy equilibrium solutions x_{12} and x_{14} in the evolutionary game model of rural finance tripartite system. This section mainly analyzes the stability of x_{12} and x_{14}.

$$x_{12} = \left(\frac{1}{3}, 1, \frac{2}{5}\right)^T, \quad x_{14} = \left(\frac{1}{6}, \frac{7}{13}, 1\right)^T$$

First, take x_{12} as an example, bring it into the model for simulation, and get its evolutionary game process as shown in Figure 10.

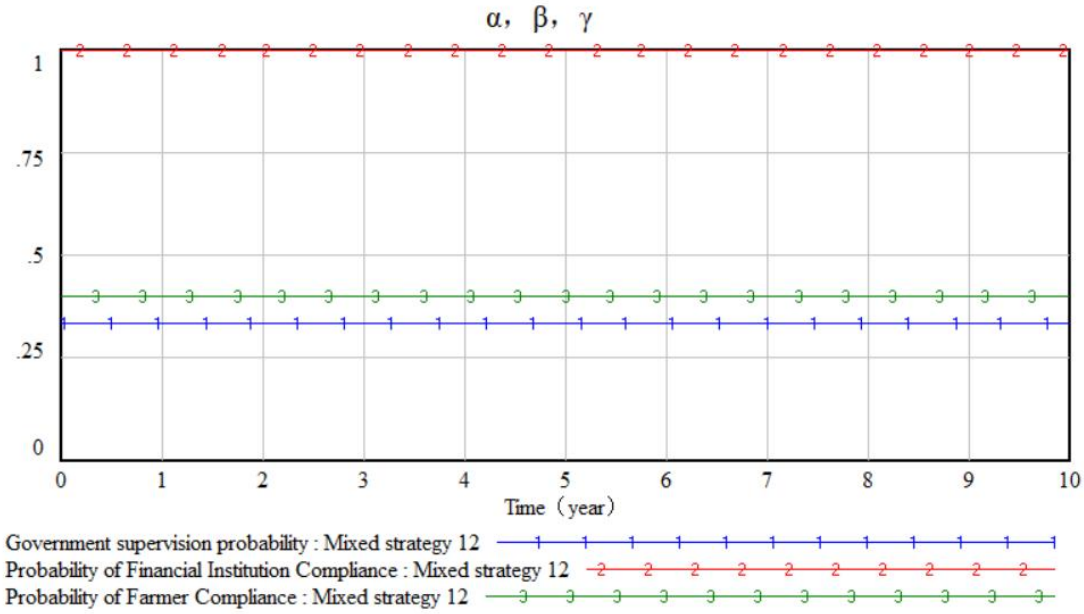

Figure10 The Evolutionary Game Process of the Initial Mixed Strategy x_{12}

Figure shows that in the x_{12} state, the government, financial institutions, and demanding farmers have not actively changed their strategic choices, and the game system at this time maintains an evolutionary equilibrium state. However, this state is not stable. For example, when the government changes its strategy and chooses to reduce its supervision to α=1/5 for some reason, the simulation results of this state are shown in the figure11.

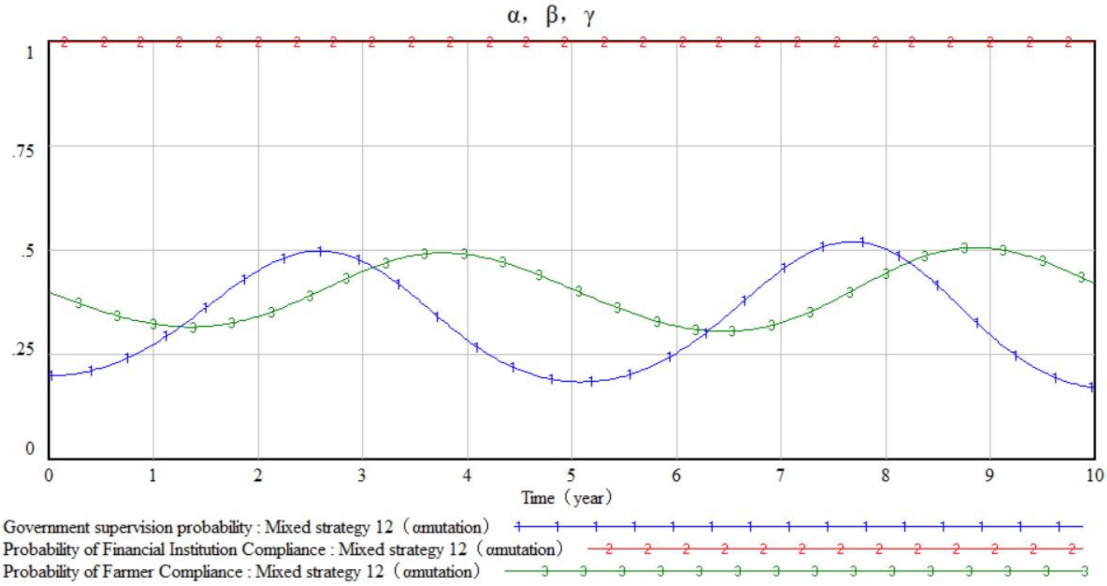

Figure11 The evolutionary game process of the initial mixed strategy x_{12} (α→1/5)

From Figure12, it can be concluded that changes in government supervision will not only cause their own strategic choices, but also lead to changes in the strategies chosen by farmers. Once farmers perceive the decline in government supervision, their probability of violation will increase; at this time, the government will again Will perceive the increase of farmers' irregularities, and will once again increase their own supervision efforts. This change is reflected in the picture in the situation where the government and farmers have evolved game strategy selection around the continuous fluctuations around the original strategy. Similarly, when the strategic choice of farmers or financial institutions changes suddenly, the probability of farmers choosing to comply with the law increases from γ=2/5 to γ=3/5, or the probability of financial institutions choosing to comply with the law decreases from β =1 to β = 0.8, there will be fluctuations in the corresponding evolutionary game process, as shown in Figures 12、13. From this analysis, it can be concluded that the hybrid strategy equilibrium solution x_{12} is not an evolutionary stable equilibrium solution.

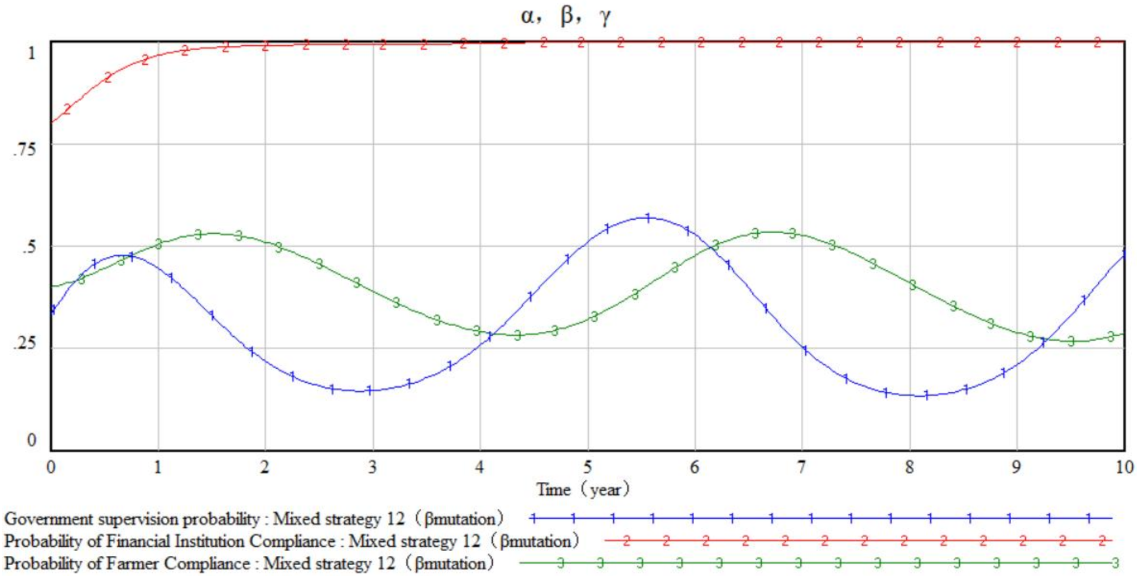

Figure 12 The evolutionary game process of the initial mixed strategy x_{12} ($\gamma \to 3/5$)

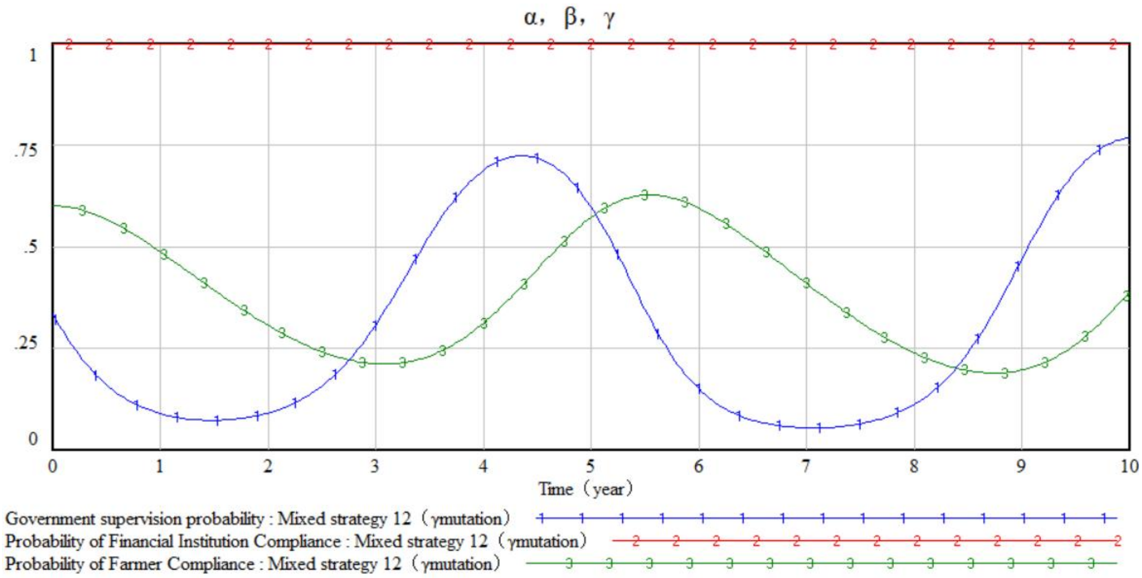

Figure13 The evolutionary game process of the initial mixed strategyx_{12} (β→0.8)

Through simulation analysis, it is not difficult to find that the initial mixed strategy x_{14} is not an evolutionary stable equilibrium strategy. A sudden change in any party will cause the original equilibrium state to be broken, making the evolutionary game a continuous fluctuation process. Therefore, the initial mixed strategy x_{14} is only in a relatively balanced state, the corresponding simulation evolution process is shown in the figure below.

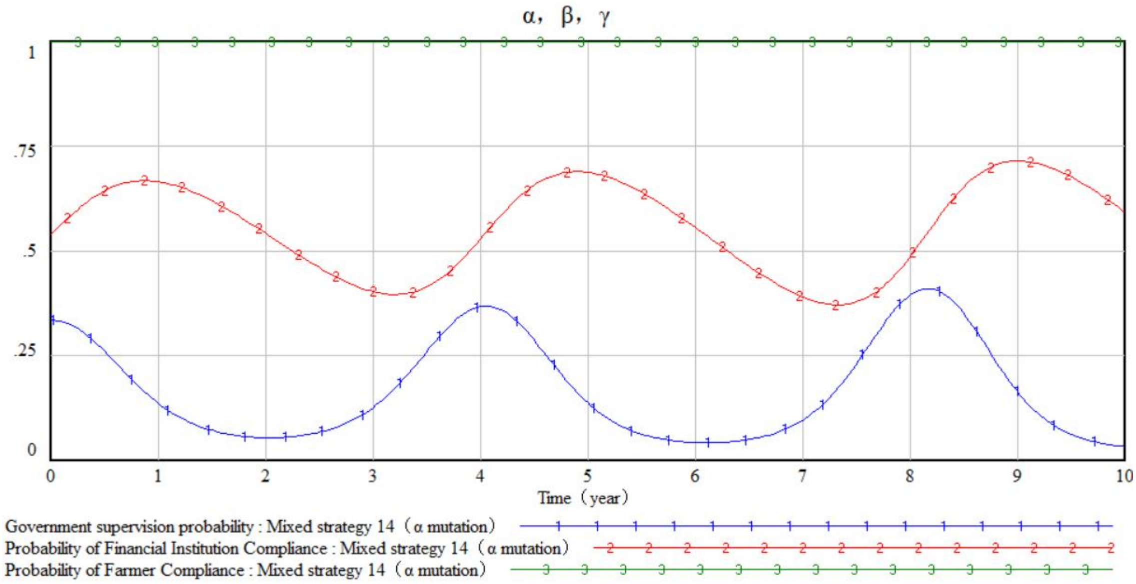

Figure14 The evolutionary game process of the initial mixed strategy x_{14} (α→1/3)

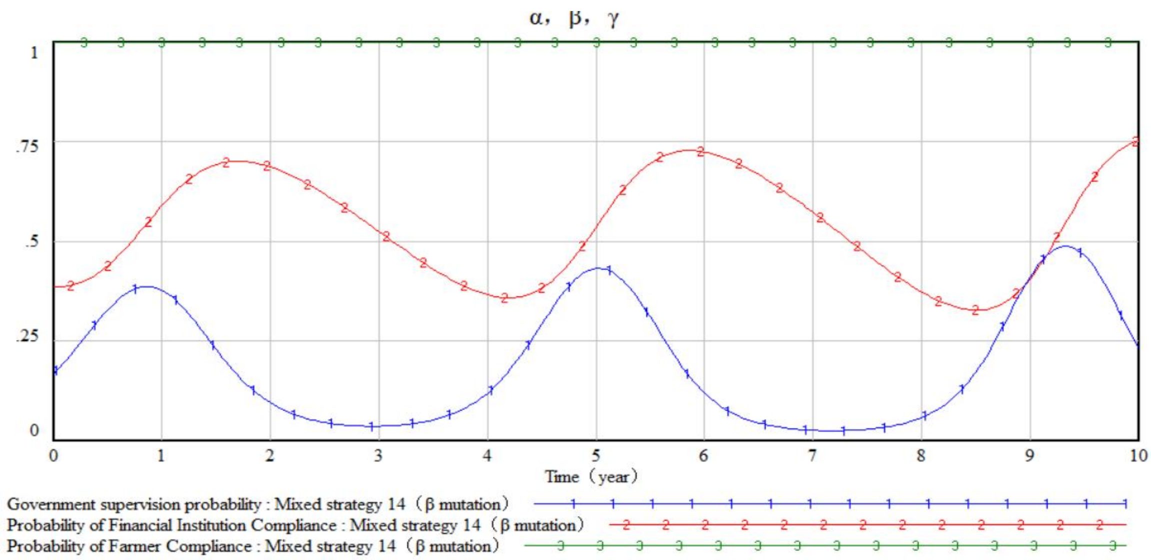

Figure15 The evolutionary game process of the initial mixed strategy x_{14} (*β*→5/13)

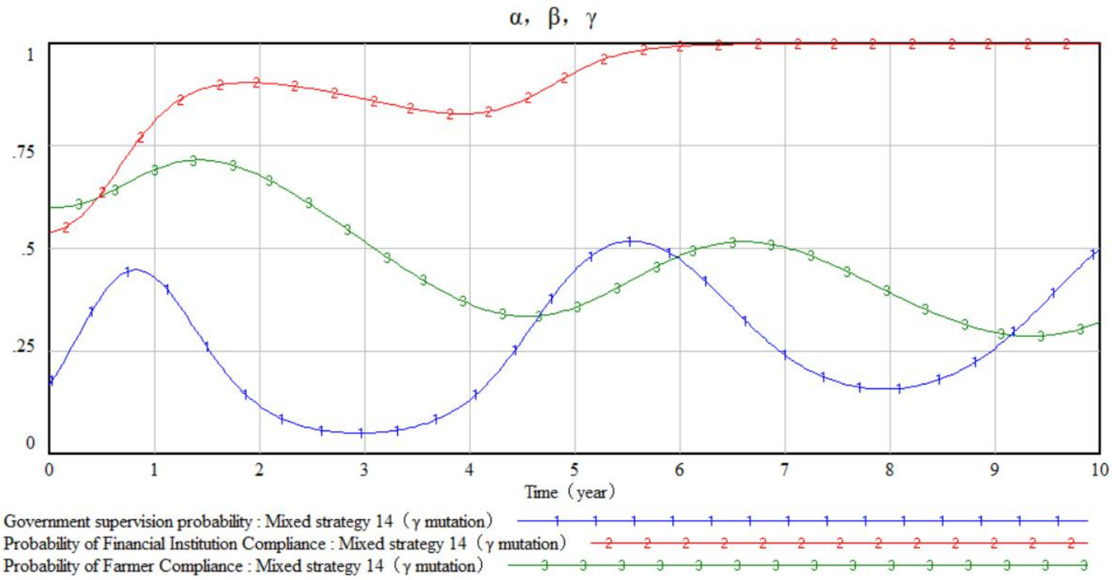

Figure16 The evolutionary game process of the initial mixed strategy$\mathbf{x_{14}}$ (γ→0.6)

Through the simulation results of the equilibrium solutions of the two mixed strategies $x_{12}$and x_{14}, the following conclusions can be drawn: Under the initial mixed strategy, once any game subject in the evolutionary game system undergoes abrupt behavior, the existing equilibrium will be broken, and the evolutionary game will fluctuate up and down. The situation shows that the initial mixed strategies x_{12} and x_{14} are not evolutionary stable equilibrium strategies.

4.2.4 Analysis of stability of general strategy evolution game

In this regard, we will analyze a more general situation, that is, the three-party evolutionary game process of the rural financial system in which the initial strategy is not an equilibrium solution. For example, the initial choices of the government, financial institutions, and farmers are the evolutionary game process when $\alpha = 0.7$、$\beta = 0.8$、$\gamma = 0.4$, and $\alpha = 0.3$、$\beta = 0.1$、$\gamma = 0.4$ The simulation results under the two strategies are shown in Figures 17 and 18.

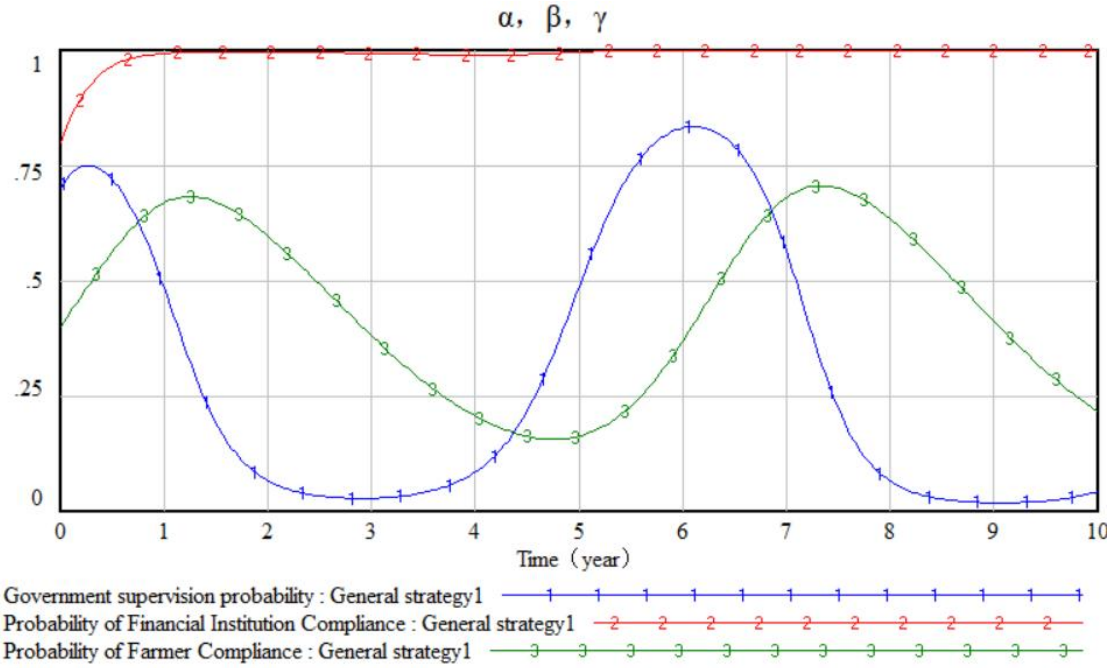

Figure17 Evolutionary game process of general strategy 1 (α =0.7, β =0.8, γ =0.4)

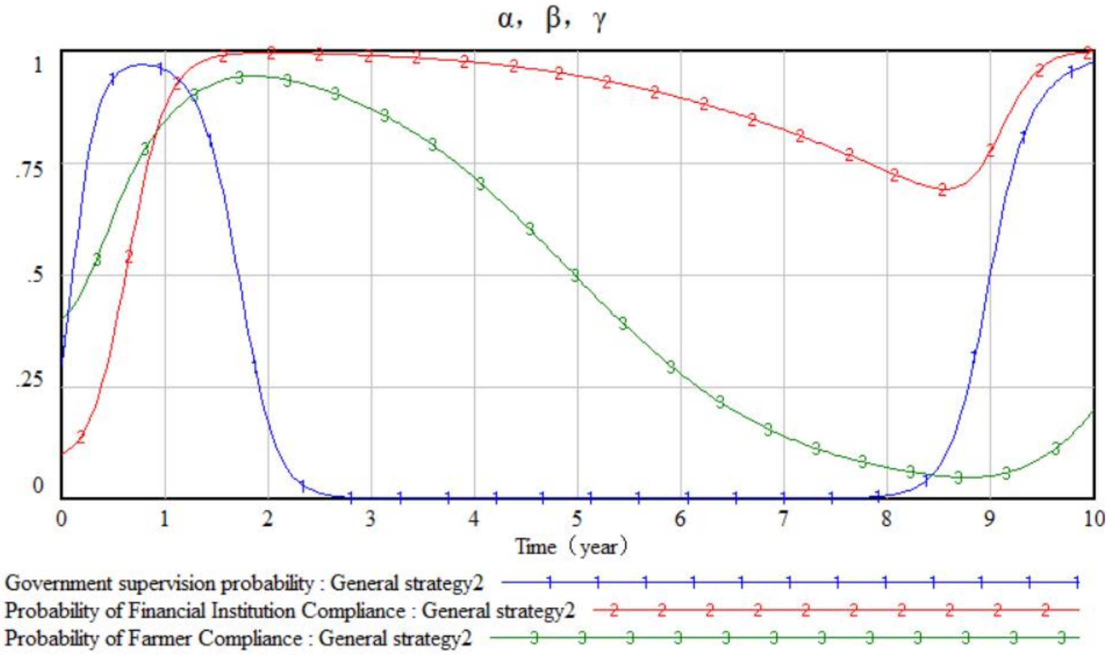

Figure18 Evolutionary game process of general strategy 2 (α =0.3, β =0.1, γ =0.4)

Figure 17 shows that when the government adopts a general initial strategy of stronger supervision, due to the increased risk of being supervised, the punishment on financial institutions after supervision is stronger than that of borrowing farmers. Financial institutions evolve in the direction of β=1, and farmers follow The strength of government supervision is constantly fluctuating.

Figure 18 shows that when the government adopts a general initial strategy of weaker supervision, when the government finds that financial institutions and farmers have more irregularities, the government will strengthen its supervision in a very short time to ensure government credibility and normal rural economy Development. At this time, financial institutions and farmers find that government supervision is constantly strengthening, and their strategic choices will be closer to law-abiding. When the government regulates that the violations of the other two parties are reduced, the supervision will be greatly reduced, and the sharp drop in supervision will give financial institutions and farmers the opportunity to violate regulations and not be supervised, and financial institutions and farmers will respond accordingly. He tilted his strategy towards violations, and so on. By analyzing two general strategies, it is concluded that evolutionary games under general strategies will not have evolutionary stable equilibrium strategies.

This chapter mainly studies the simulation and stability of the evolutionary game model of the rural financial supply and demand tripartite system. The SD model of the evolutionary game is simulated under pure strategy, mixed strategy and general strategy to analyze the stability of the tripartite evolutionary game system. The result found that the evolutionary game system of the rural financial tripartite system does not have an evolutionary stable equilibrium state. In the process of the evolutionary game, there have been development trends such as up and down fluctuations and repeated shocks.

5. Study on effective and stable control scenarios

The evolutionary game analysis of the rural financial tripartite system is to optimize the control scenarios of the rural financial tripartite system model. The key to optimization lies in the analysis of the benefits of the government, financial institutions and farmers in the long-term dynamic game process. This chapter aims at the situation where there is no evolutionary stable equilibrium strategy in the evolutionary game of the rural financial tripartite system, and tries to obtain a certain control scenario to make the evolutionary game system effectively stable. This scenario can effectively control the fluctuation of the evolutionary game process of the rural financial tripartite system. Effectively control violations of financial institutions and farmers, and stabilize the development of agricultural production.

5.1 The impact of general punishment scenarios on the outcome of the system evolution game

In the real situation of government supervision of the rural financial supply and demand system, it is one of the common control scenarios that the government increases the punishment of financial institutions and farmers. Therefore, this section will mainly conduct a simulation analysis of the strategic choices of financial institutions and farmers under different penalties, so as to detect the effect of changing the penalties on financial institutions and farmers' violations.

In the evolutionary game model of the three-party system of rural finance, the government's punishment of financial institutions and farmers is changed, and the value of the punishment c for financial institutions is adjusted from the original 4 to 2, 6, and 8. The initial strategy of the three parties is $(\alpha = 0.5, \beta = 0.5, \gamma = 1)$; the value of the peasant household's penalty d is adjusted from the original 2 to 0, 4, 6, and the initial three-party strategy is $((\alpha = 1, \beta = 0.5, \gamma = 0.5))$; And at the same time, the value of the penalty c for financial institutions was adjusted from the original 4 to 2, 6, and 8, and the value of the penalty d for farmers was adjusted from the original 2 to 0, 4, and 6. The initial strategy of the three parties was $(\alpha = 0.5, \beta = 0.5, \gamma = 0.5)$. The SD model of the rural financial tripartite system evolution game is simulated, compared with the original model, and the game result is obtained. When only changing the punishment of financial institutions, the results of the game between financial institutions and the government are shown in Figure 19 and Figure 20 respectively.

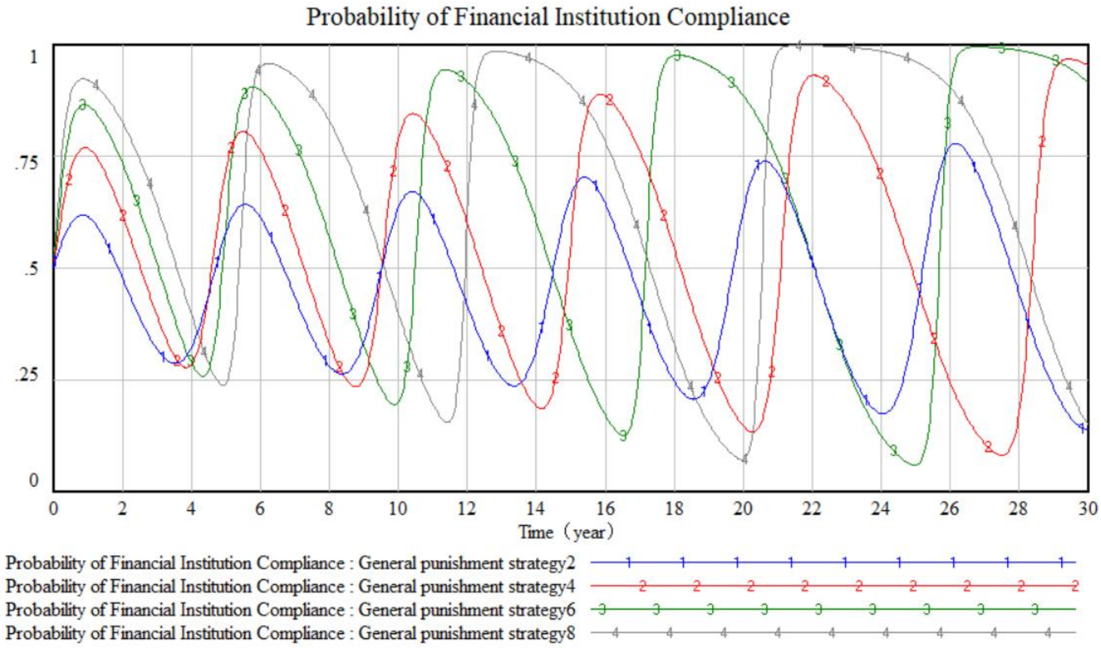

Figure19 The Impact of Changing the Punishment of Financial Institutions on the Strategic Choice of Financial Institutions in the General Punishment Situation

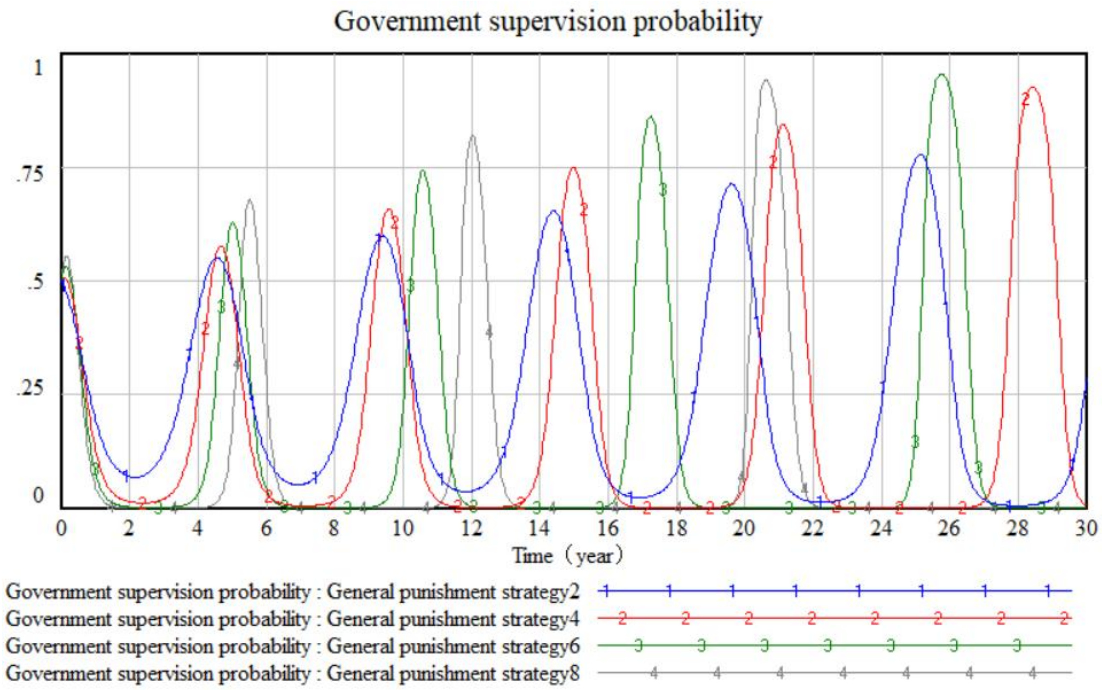

Figure20 The Impact of Changing the Punishment of Financial Institutions on the Government's Strategic Choice in the General Punishment Situation

5.2 Simulation and Theoretical Verification under the Dynamic Penalty Scenario

The repeated turbulence of the evolutionary game process of the rural financial supply and demand tripartite system has made it difficult for the government to formulate a reasonable level of supervision.

By studying the literature and summarizing the research of previous scholars, it is found that the link between the intensity of government punishment and the violation rate of financial institutions and farmers can effectively suppress the repeated shocks in the evolutionary game process. To this end, this article will also introduce dynamic penalty stability control scenarios to suppress the fluctuations in the evolutionary game process of the rural financial tripartite system. The government adopts dynamic penalties for violations of financial institutions and lending farmers, that is, the intensity of the punishment is proportional to the probability of violations of financial institutions and lending farmers. The dynamic punishment is expressed as follows:

$$c_1 = p_1 c(1-\beta),\quad d_1 = q_1 d(1-\gamma)$$

Among them, p_1 and q_1 are the government's penalty coefficients on financial institutions and farmers, respectively.

System evolution game simulation analysis

Adding the penalty stability control scenario to the evolutionary game system dynamics model of the rural financial tripartite system, assuming that the government's penalty coefficients for financial institutions and farmers are both 1, we can get:

$$c_1 = 4(1-\beta),\quad d_1 = 2(1-\gamma)$$

The evolutionary game system dynamics model of the rural financial tripartite system is adjusted to Figure 21.

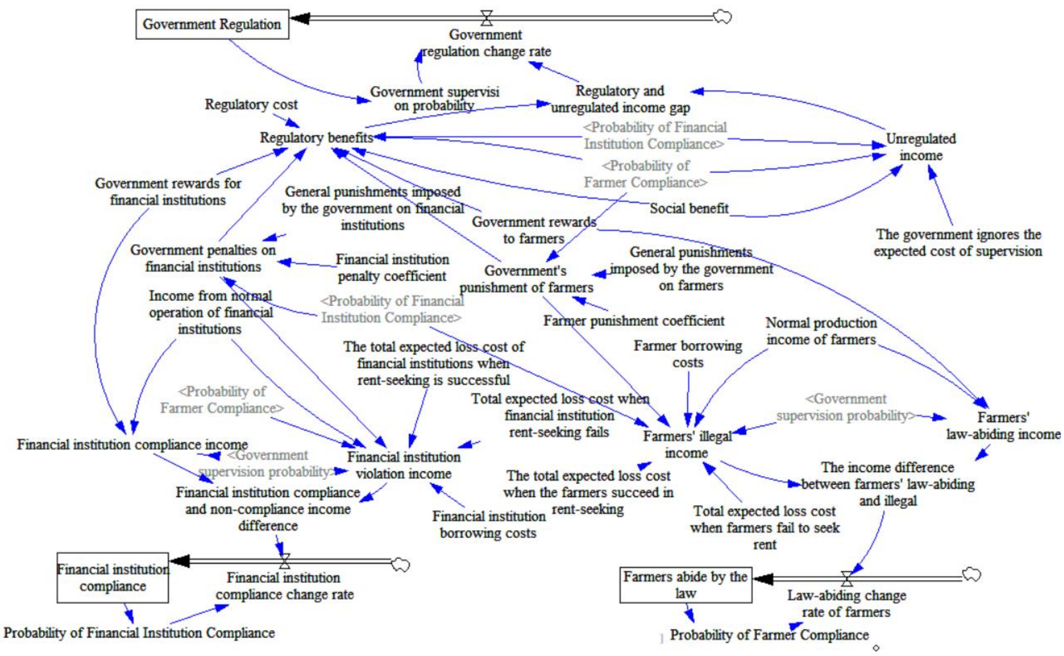

Figure21 The SD model of rural financial tripartite system evolutionary game under dynamic punishment situation

Set the initial strategy of the evolutionary game of the rural financial system to $(\alpha, \beta, \gamma) = (0.5, 0.5, 0.5)$, simulate the evolutionary game of the rural financial tripartite system under the dynamic penalty situation, and obtain the evolutionary game under the dynamic penalty strategy 1. Status, as shown in Figure22.

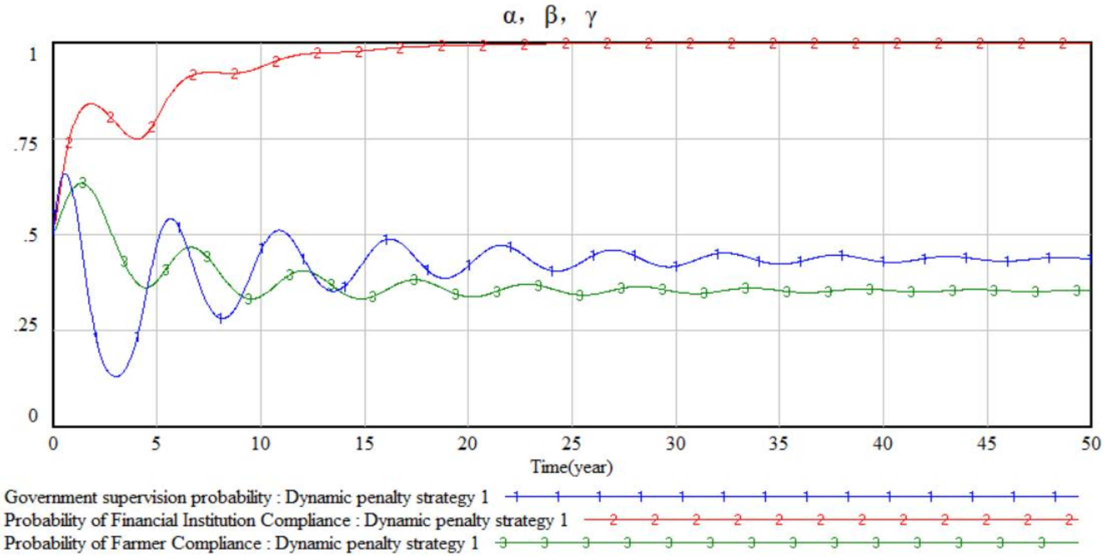

Figure22 Dynamic penalty strategy 1 (α, β, γ) = (0.5, 0.5, 0.5) The evolutionary game process of rural finance tripartite system

It can be seen from Figure that under the dynamic penalty scenario 1, the evolutionary game process of the rural finance tripartite system roughly converges to $x^* = (0.44,1,0.35)$, which shows that under the dynamic penalty scenario 1, the rural finance tripartite system The repeated oscillations of the evolutionary game process of the system are effectively suppressed, and the evolutionary game system tends to a stable state. Next, we will continue to verify whether x^* is an evolutionary stable equilibrium solution. We consider the system evolution process when the initial strategy of the subject of the three-party game is (α, β, γ) = (0.3, 0.1, 0.2), the simulation result of dynamic penalty strategy 2 is shown in Figure 23

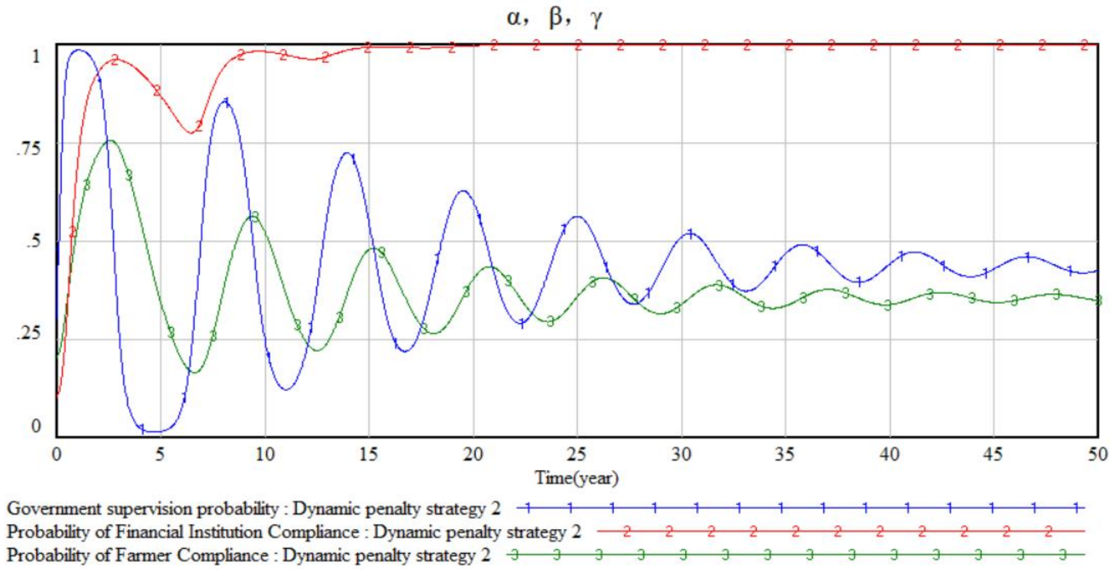

Figure23 Dynamic penalty strategy 2 (α=0.3, β=0.1, γ=0.2) The evolutionary game process of rural finance tripartite system

It can be seen that under dynamic penalty scenario 2, the evolutionary game process of the rural financial tripartite system also roughly converges to $x^* = (0.44,1,0.35)$. Based on this, we guess that x^* is the rural financial tripartite system evolutionary stable equilibrium solution of the evolutionary game. Compare the initial strategy $(\alpha,\beta,\gamma) = (0.9,0.2,0.1)$ the evolution process of the general penalty scenario and the dynamic penalty scenario 3. The simulation comparison chart is shown in the figure below, and it can be seen that the evolution process under the general penalty scenario exists With repeated shocks, the evolution process of dynamic penalty scenario 3 also converges to $x^* = (0.44,1,0.35)$, the system tends to be stable, and there is an evolutionary equilibrium solution x^*.

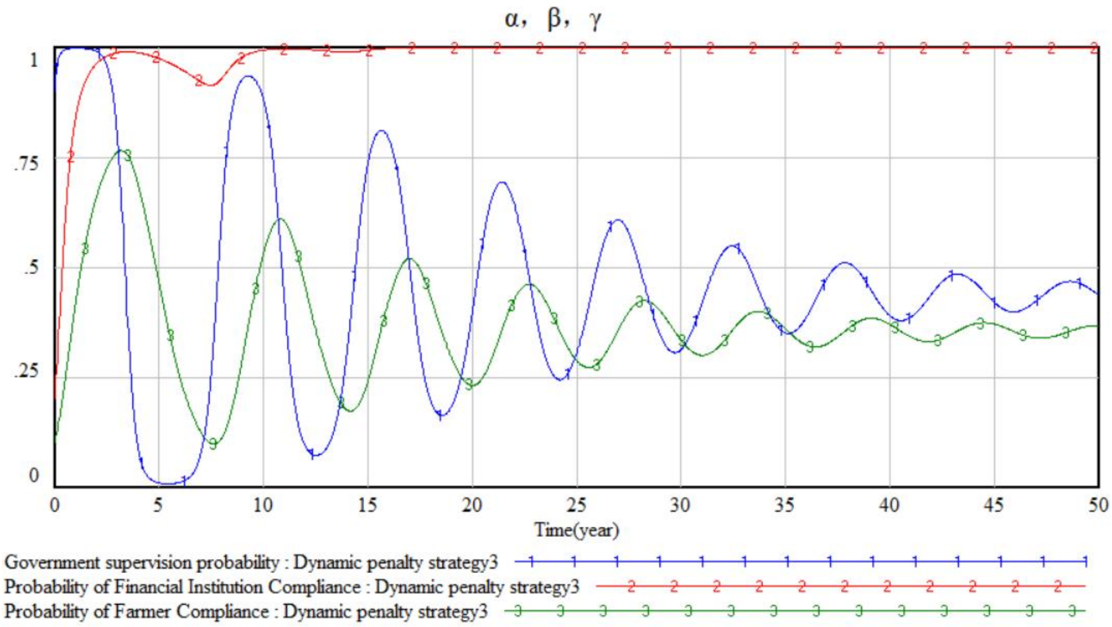

Figure24 Dynamic penalty strategy 3 (α, β, γ) = (0.9, 0.2, 0.1) The evolutionary game process of rural finance tripartite system

Theoretical proof of simulation results of system evolution game stability

Through the simulation analysis of the evolutionary game of the tripartite system of rural finance, it is concluded that the evolutionary game process converges to $x^* = (0.44,1,0.35)$. In order to prove the correctness of the evolutionary equilibrium solution obtained by SD simulation in this state, the equilibrium solution $x^* = (0.44,1,0.35)$ obtained by SD simulation in this section is compared with the equilibrium solution obtained by the evolutionary game model in the dynamic penalty situation , If the equilibrium solution $x^* = (0.44,1,0.35)$ obtained by the simulation is consistent with the equilibrium solution obtained by the evolutionary game model, and the stability of the equilibrium solution can be proved theoretically, the simulation result under the dynamic penalty scenario can be explained It is effective.

First, take $c_1 = p_1 c(1-\beta)$, $d_1 = q_1 d(1-\gamma)$ into Table 5and Table 6 and obtain the payment income matrix of the three-party game subject of the evolutionary game as shown in Table 5 and Table 6.

Table5 Three-party game payment income matrix under the dynamic punishment strategy of government supervision

		Farmer	
		Obey the law	Violation
Financial Institutions	Obey the law	{-a-e-f,k+e,g+f}	{-a+d_1-e,k+e,g-d_1-j+h}
	Violation	{-a+c_1-f,k-c_1-n+l,g+f}	{-a+c_1+d_1,k-c_1-m+l,g-d_1-i+h}

Table6 The Three-Party Game Payment Profit Matrix under the Dynamic Punishment Strategy of the Government Not Regulating

		Farmer	
		Obey the law	Violation
Financial Institutions	Obey the law	$\{0, k, g\}$	$\{-b, k, g-j+h\}$
	Violation	$\{-b, k-n+l, g\}$	$\{-b, k-m+l, g-i+h\}$

The dynamics of the subjects of the evolutionary game of the rural financial system can be represented by the following copy dynamic equations:

$$F(x)=\begin{cases} F(\alpha)=\dfrac{d\alpha}{dt}=\alpha(1-\alpha)\begin{pmatrix}-a+p_1c(1-\beta)+q_1d(1-\gamma)-\beta(p_1c(1-\beta)+e)\\ -\gamma(q_1d(1-\gamma)+f)+b(1-\beta\gamma)\end{pmatrix} \\ F(\beta)=\dfrac{d\beta}{dt}=\beta(1-\beta)\big(\alpha e+m-l+\alpha p_1c(1-\beta)-\gamma(m-n)\big) \\ F(\gamma)=\dfrac{d\gamma}{dt}=\gamma(1-\gamma)\big(\alpha f+i-h+\alpha q_1d(1-\gamma)-\beta(i-j)\big) \end{cases}$$

Incorporating the initial values of external variables into the above formula, the dynamic equation of the evolutionary game replication is obtained as follows:

$$F(x)=\begin{cases} F(\alpha)=\dfrac{d\alpha}{dt}=\alpha(1-\alpha)\big(10-10\beta-5\gamma+4\beta^2+2\gamma^2-7\beta\gamma\big) \\ F(\beta)=\dfrac{d\beta}{dt}=\beta(1-\beta)(6\alpha+0.5-4\alpha\beta-0.5\gamma) \\ F(\gamma)=\dfrac{d\gamma}{dt}=\gamma(1-\gamma)(3\alpha-2\alpha\gamma-\beta) \end{cases}$$

$F(x)=\begin{cases} F(\alpha)=\frac{d\alpha}{dt} \\ F(\beta)=\frac{d\beta}{dt} \\ F(\gamma)=\frac{d\gamma}{dt} \end{cases}$=0，It can be solved that all the equilibrium solutions of the rural finance tripartite system evolution game copy dynamic equation are:

$$x_1=\begin{pmatrix}0\\0\\0\end{pmatrix},\ x_2=\begin{pmatrix}0\\0\\1\end{pmatrix},\ x_3=\begin{pmatrix}0\\1\\0\end{pmatrix},\ x_4=\begin{pmatrix}0\\1\\1\end{pmatrix}$$

$$x_5=\begin{pmatrix}1\\0\\0\end{pmatrix},\ x_6=\begin{pmatrix}1\\0\\1\end{pmatrix},\ x_7=\begin{pmatrix}1\\1\\0\end{pmatrix},\ x_8=\begin{pmatrix}1\\1\\1\end{pmatrix}$$

$$x_{12}=\begin{pmatrix}\frac{2\sqrt{7}+3}{19}\\1\\3-\sqrt{7}\end{pmatrix},\ x_{13}=\begin{pmatrix}\frac{5-\sqrt{15}}{12}\\\frac{5-\sqrt{15}}{4}\\0\end{pmatrix}$$

The determinants of the Jakobian matrix det_j and tr_j can be judged to analyze the stability of the dynamic equilibrium point of the system.

$$\mathrm{J}=\begin{bmatrix}\frac{\partial F(\alpha)}{\partial\alpha} & \frac{\partial F(\alpha)}{\partial\beta} & \frac{\partial F(\alpha)}{\partial\gamma}\\ \frac{\partial F(\beta)}{\partial\alpha} & \frac{\partial F(\beta)}{\partial\beta} & \frac{\partial F(\beta)}{\partial\gamma}\\ \frac{\partial F(\gamma)}{\partial\alpha} & \frac{\partial F(\gamma)}{\partial\beta} & \frac{\partial F(\gamma)}{\partial\gamma}\end{bmatrix}$$

$$=\begin{bmatrix}(1-2\alpha)\begin{pmatrix}10-10\beta-5\gamma\\+4\beta^2+2\gamma^2-7\beta\gamma\end{pmatrix} & \alpha(1-\alpha)(-10+4\beta-7\gamma) & \alpha(1-\alpha)(-5+4\gamma-7\beta)\\ \beta(1-\beta)(6-4\beta) & (1-2\beta)\begin{pmatrix}6\alpha+0.5\\-4\alpha\beta-0.5\gamma\end{pmatrix}-4\alpha\beta(1-\beta) & -\frac{1}{2}\beta(1-\beta)\\ \gamma(1-\gamma)(3-2\gamma) & -\gamma(1-\gamma) & (1-2\gamma)(3\alpha-2\alpha\gamma-\beta)-2\alpha\gamma(1-\end{bmatrix}$$

Bringing the equilibrium solution x_1 into the Jacobian matrix, we can get: $J_{x_1}=\begin{bmatrix}10&0&0\\0&0.5&0\\0&0&0\end{bmatrix}$, Find the characteristic value of J_{x_1}: $\lambda_1=10$, $\lambda_2=0.5$, $\lambda_3=0$.

Among them, all eigenvalues are greater than zero, so the equilibrium solution x_1 is not an evolutionary stable equilibrium solution. It can be solved by calculation that $x_{12}\sim x_8$ also have eigenvalues greater than zero, so they are not evolutionary stable equilibrium solutions.

For $x_{12}=\left(\frac{1}{2\sqrt{7}-3},1,3-\sqrt{7}\right)^T$, $J_{x_{12}}=\begin{bmatrix}0&-2.08562946&-2.60293658\\0&-1.19566540&0\\0.52419624&-0.22875656&-0.19965638\end{bmatrix}$

Its characteristic matrix is:

$$\left|\lambda\mathrm{e}-J_{x_{12}}\right|=\begin{vmatrix}\lambda&-2.08562946&-2.60293658\\0&\lambda+1.19566540&0\\0.52419624&-0.22875656&\lambda+0.19965638\end{vmatrix}$$
$$=(\lambda+1.19566540)(\lambda(\lambda+0.19965638)+2.60293658*0.52419624)$$
$$=(\lambda+1.19566540)\left(\lambda^2+0.19965638\lambda+1.36444958\right)$$

Solving for λ can be obtained: $\lambda_1=-1.19566540$, $\lambda_{2,3}=\frac{-0.19965638\pm\sqrt{-5.41793567}}{2}=\frac{-0.19965638\pm2.32764594\mathrm{i}}{2}$

All eigenvalues of λ are negative real part eigenvalues.

Therefore, the equilibrium solution is: $x_{12} = \left(\frac{1}{2\sqrt{7}-3}, 1, 3-\sqrt{7}\right)^T \approx (0.436, 1, 0.354)^T$

It is the evolutionary stable equilibrium solution of the rural financial tripartite system under the dynamic penalty scenario, which is the same as the result of $x^* = (0.44, 1, 0.35)$ obtained by the system dynamics simulation.

In the same way, when $x_{13} = \left(\frac{5-\sqrt{15}}{12}, \frac{5-\sqrt{15}}{4}, 0\right)^T$, the eigenvalue of matrix $J_{x_{13}}$ is obtained, and there is an eigenvalue greater than zero. Therefore, x_{13} is not an evolutionary stable equilibrium solution. Through theoretical demonstration, the use of system dynamics to simulate the evolutionary game process of the rural financial tripartite system is a scientific and effective method, and through the simulation of dynamic punishment strategies, we find that adopting dynamic punishment strategies can effectively restrain the evolution of the rural financial system repeated shocks of the game process. In this state, the evolutionary game system has a stable equilibrium state.

5.3 Analysis and optimization of the influence variables of system evolution game stability strategy equilibrium under the dynamic penalty stability control scenario

5. 3.1 Analysis of ESS influencing variables under dynamic punishment

Although the above proves that there is an evolutionary stable equilibrium strategy under the dynamic penalty scenario and has passed theoretical demonstrations, it can be seen from the existing evolutionary stable equilibrium solution $x^* = (0.44, 1, 0.35)$ that farmers still have a higher probability of violation , About 65%. Therefore, this section will optimize the dynamic punishment scenario from the three aspects of the government's supervision probability, the government's punishment to farmers, and the benefits of farmers' violations.

The government's supervision. The stronger the government's supervision, the lower the probability of non-compliance by farmers and financial institutions, but similarly, the greater the supervision, the higher the cost of supervision paid by the government, which is likely to cause a waste of government resources. Therefore, there are certain restrictions when the government chooses the intensity of supervision. How to use the limited supervision to restrain the irregularities of financial institutions and farmers and protect the social interests from infringement is the ultimate goal of government supervision.

Considering that the initial strategy choice among the government, financial institutions, and farmers is $(\alpha = 0.3, \beta = 0.1, \gamma = 0.2)$, the government gradually strengthens its supervision, and its supervision probability is adjusted from α=0.3 to α=0.6, α=0.9 After the simulation, the adjusted strategy and the initial strategy are compared and analyzed. The law-abiding probability curves of financial institutions and farmers are shown in Figure 26 and Figure 27.

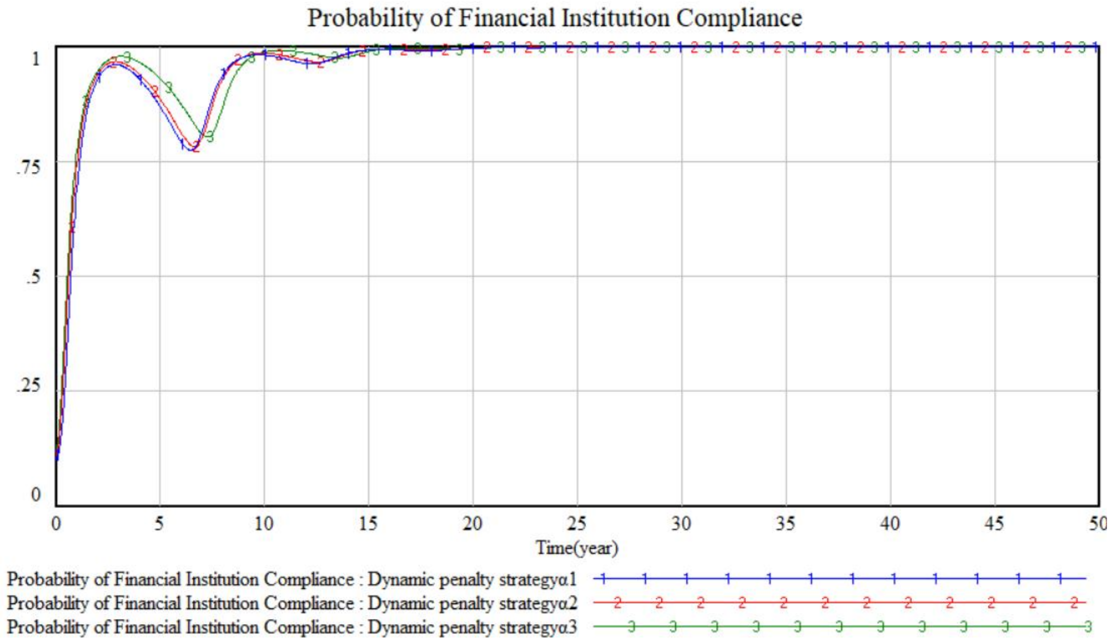

Figure26 The Impact of Changing the Probability of Government Supervision on the Strategic Choice of Financial Institutions in the Dynamic Punishment Scenario

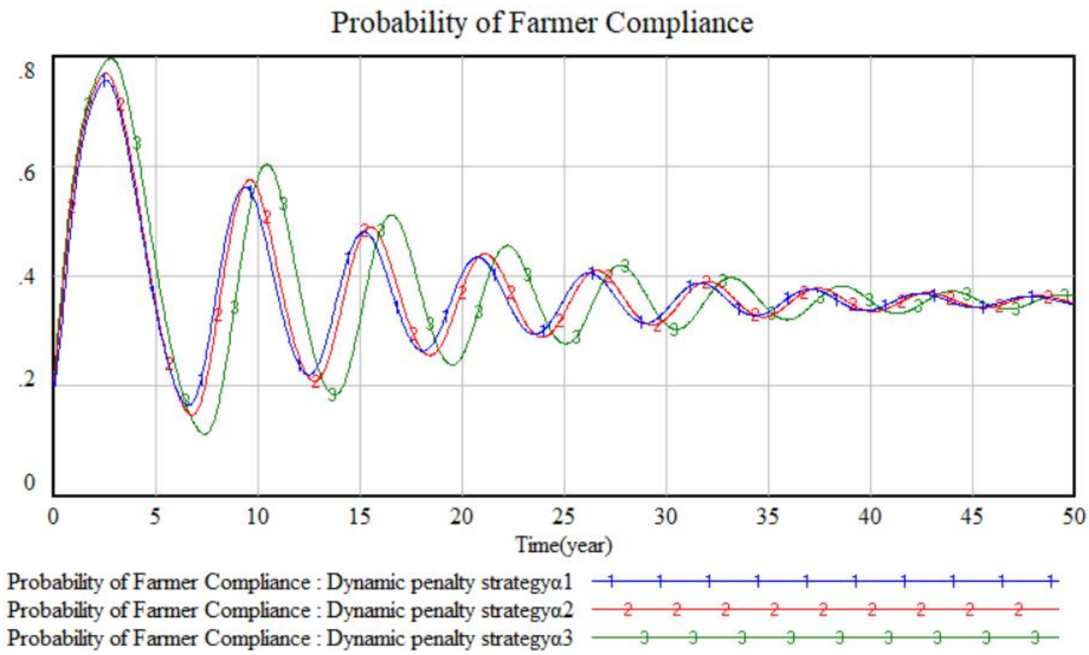

Figure27 The Impact of Changing the Probability of Government Supervision on Farmers' Strategy Choices under Dynamic Punishment Scenarios

It can be seen that the increase in government supervision can prompt financial institutions to increase the probability of compliance, reduce violations, and better fulfill the responsibilities of rural financial institutions in supporting inclusive rural finance and rural revitalization. It can more effectively evolve to the evolutionary stable state of β=1. However, for farmers, the increase in government supervision has not had much effect on curbing the illegal behavior of borrowing farmers. Although the probability of farmers' compliance with the law will increase during the same period, the strategy selection process of farmers has gradually shown fluctuations. Under the supervision, farmers are constantly evolving to an evolutionary stable equilibrium strategy, which means that increasing government supervision has no effect on restraining farmers' irregularities.

5.3.2The government's punishment of farmers

Considering that the initial strategy selection is $(\alpha = 0.3, \beta = 0.1, \gamma = 0.2)$, the government gradually strengthens the punishment of financial institutions and farmers. The punishment coefficient p_1 of financial institutions and the punishment coefficient q_1 of farmers are adjusted from 1 to 2, 3 After the simulation, the adjusted strategy and the initial strategy are compared and analyzed. The law-abiding probabilities of financial institutions and borrowing farmers are shown in Figures 28 and 29.

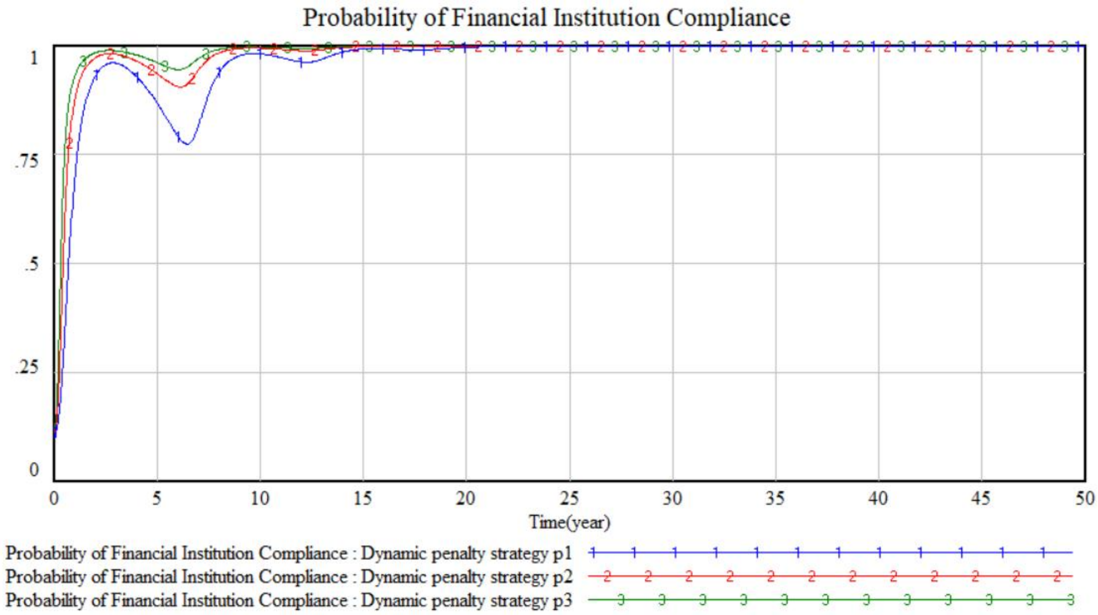

Figure 28 The Impact of Changing Government Punishment Power on the Strategic Choice of Financial Institutions under Dynamic Punishment Scenarios

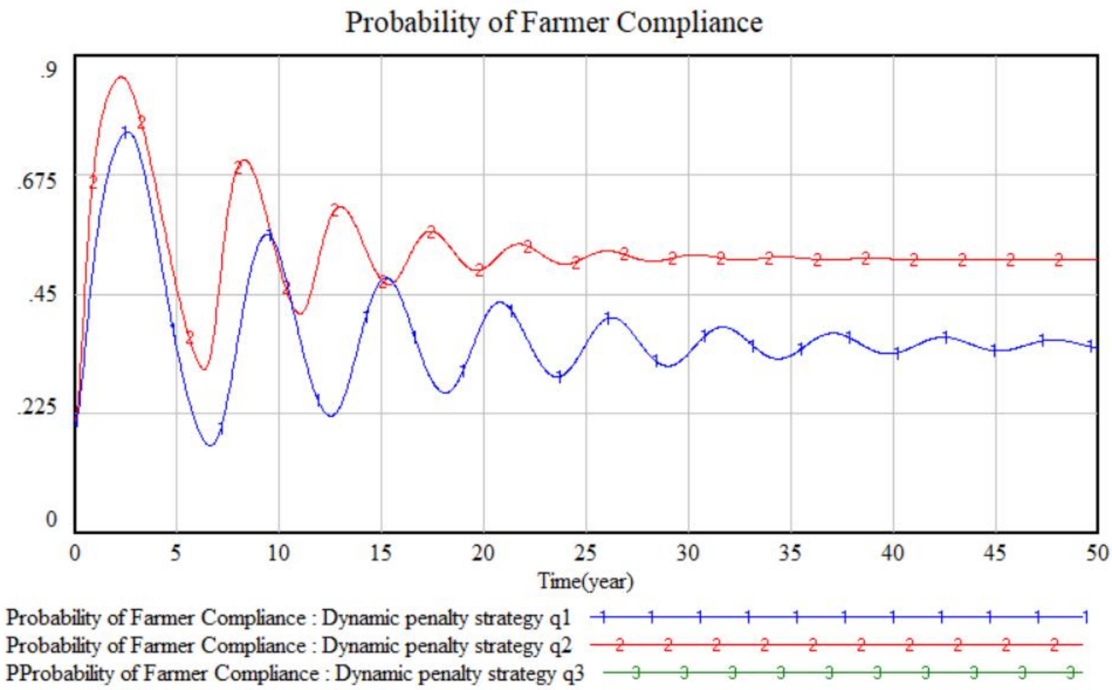

Figure29 The Impact of Changing Government Punishment Intensity on Farmers' Strategic Choices under Dynamic Punishment Situation

It can be seen that as the government's punishment coefficient for financial institutions increases, the probability of compliance of financial institutions during the same period has effectively increased, and it has promoted its faster evolution to β =1. With the increase of the government's punishment coefficient for farmers, the probability of farmers' compliance in the same period has been effectively improved, reducing violations, and with the continuous increase of the punishment coefficient, the evolutionary stable equilibrium solution of farmers γ is also rising. Therefore, we It can be concluded that by changing the government's punishment to farmers, the illegal behavior of farmers can be effectively suppressed, and the effectiveness of government supervision has been well improved.

5.3.3 Actual borrowing cost of borrowing farmers

In the existing financial lending market, because the market mechanism is not yet sound, and the effective lending standards are still being perfected, the measurement of borrowing costs is uncontrollable. When borrowing costs change, what is the evolutionary strategy of farmers? We consider that the initial strategy is selected as $(\alpha = 0.3, \beta = 0.1, \gamma = 0.2)$, changing the cost of borrowing by farmers, adjusting the value of h from 2 to 1.5, 0.5, and comparing the adjusted strategy with the initial strategy after simulation Analysis shows that the law-abiding probability curve of farmers is shown in Figure 30..

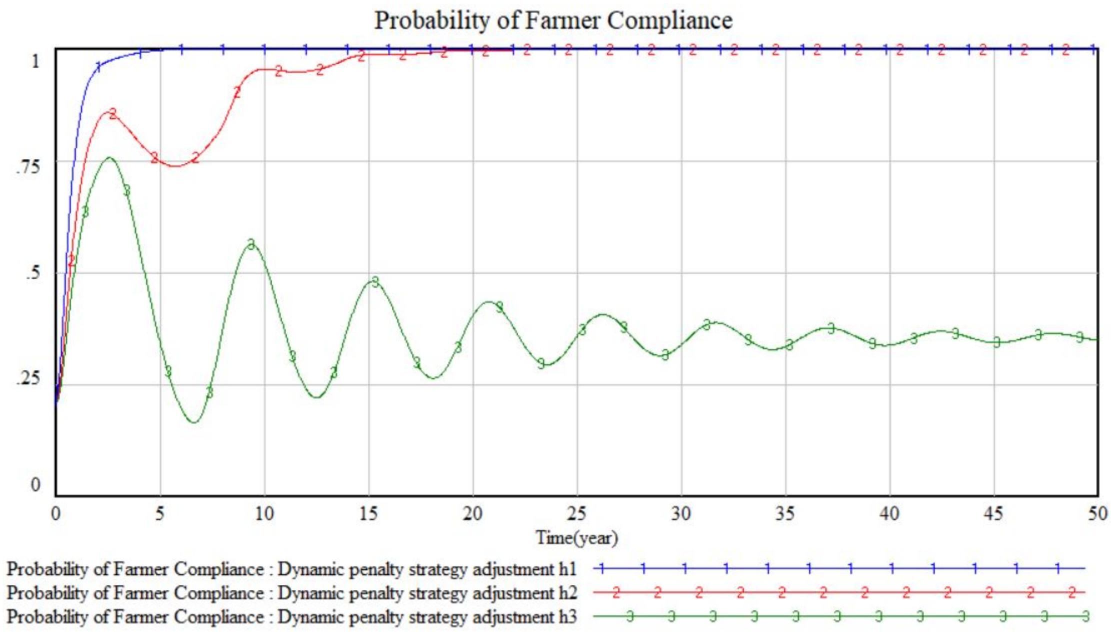

Figure30 The Impact of Changing Farmers' Actual Borrowing Costs on Farmers' Strategic Choices under Dynamic Punishment

It can be seen that if the farmer's borrowing cost is smaller, its motivation to choose to abide by the law will be greater. When the borrowing cost drops to a certain range, the evolutionary stable equilibrium solution of the farmer's strategy γ will continue to evolve towards γ=1, while the actual farmers' When the borrowing cost is high, the farmers' motivation to choose violations will be greatly increased, and the solution γ value of the evolutionary stable equilibrium strategy will be smaller. This conclusion also shows that setting reasonable lending standards and reduction policies, perfecting the market mechanism of the rural financial tripartite system, increasing the probability of farmers complying with laws and policies, is conducive to the increase of government revenue.

5.3.4 Research on control scenario optimization

In the actual government supervision work of the rural financial tripartite system, how to maximize the reduction of irregularities of financial institutions and farmers under the limited supervision probability is the ultimate goal of the evolutionary game of the rural financial tripartite system. Therefore, the penalty-incentive control scenario is introduced on the basis of the previous section to further optimize the control scenario of the evolutionary game. The optimized penalty control scenario introduced is composed of the original dynamic penalty scenario and the dynamic penalty of the newly added item. The newly added item adds penalties to the probability of government supervision and the default costs l and h saved when financial institutions and farmers violate regulations, thereby inhibiting the illegal operations of financial institutions and farmers. The optimized penalties for financial institutions and farmers are expressed as follows:

$$c_2 = p_{21}c(1-\beta) + p_{22}\frac{l}{\alpha},\ \ d_2 = q_{21}d(1-\gamma) + q_{22}\frac{h}{\alpha}$$

Among them, p_{21}、p_{22} and q_{21}、q_{22} are the government's penalty coefficients on financial institutions and farmers, respectively

In order to more effectively curb the illegal behaviors of financial institutions and farmers, such as collusion and mutual rent-seeking behaviors, the government should not only impose dynamic punishments on the two parties' violations, but also impose punishment on financial institutions in accordance with national policies, regulations, and lending policy standards. Dynamic incentives with farmers. The government's optimized incentive scenarios for financial institutions and farmers are expressed as follows:

$$e_2 = s_2 e\beta,\ \ f_2 = t_2 f\gamma$$

Among them, s_2 and $t_2$are the government's incentive coefficients for financial institutions and farmers, respectively. Through the above analysis, in order to maximize the suppression of irregularities of financial institutions and farmers and improve the efficiency of government supervision, the SD model under the dynamic penalty-incentive stability control optimization scenario proposed in this section is shown in 31.

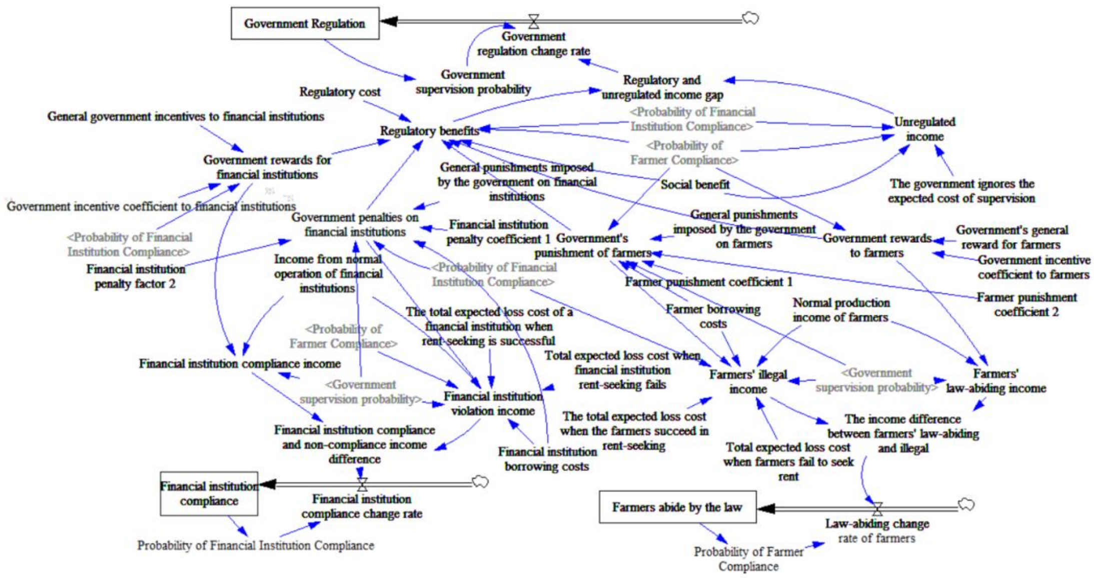

Figure31 Dynamic Penalty-Incentive Stability Control Optimization Scenario Rural Finance Tripartite Game System SD Evolutionary Game Model

5.4 Optimized dynamic penalty-incentive stability control scenario system evolution game stability simulation

This section mainly analyzes the system evolution process of the optimized dynamic penalty-incentive scenario established in the previous section, and explains the simulation results.

5.4.1 System evolution game simulation analysis

Add the optimized penalty-incentive control scenario to the evolutionary game system dynamics model of the rural financial tripartite system. Assuming that the government's optimized dynamic penalty-incentive coefficients for financial institutions and farmers are all 1, bring inc_2、d_2、e_2、f_2 can be obtained:

$$c_2 = 4(1-\beta) + \frac{2}{\alpha},\ d_2 = 2(1-\gamma) + \frac{2}{\alpha},\ e_2 = 2\beta,\ f_2 = \gamma$$

In this situation, set the initial strategy as $(\alpha, \beta, \gamma) = (0.5,0.5,0.5)$, and simulate the evolutionary game model of the rural finance tripartite system. Obtain the evolutionary game state under the optimized dynamic penalty-incentive strategy 1, as shown in the figure.

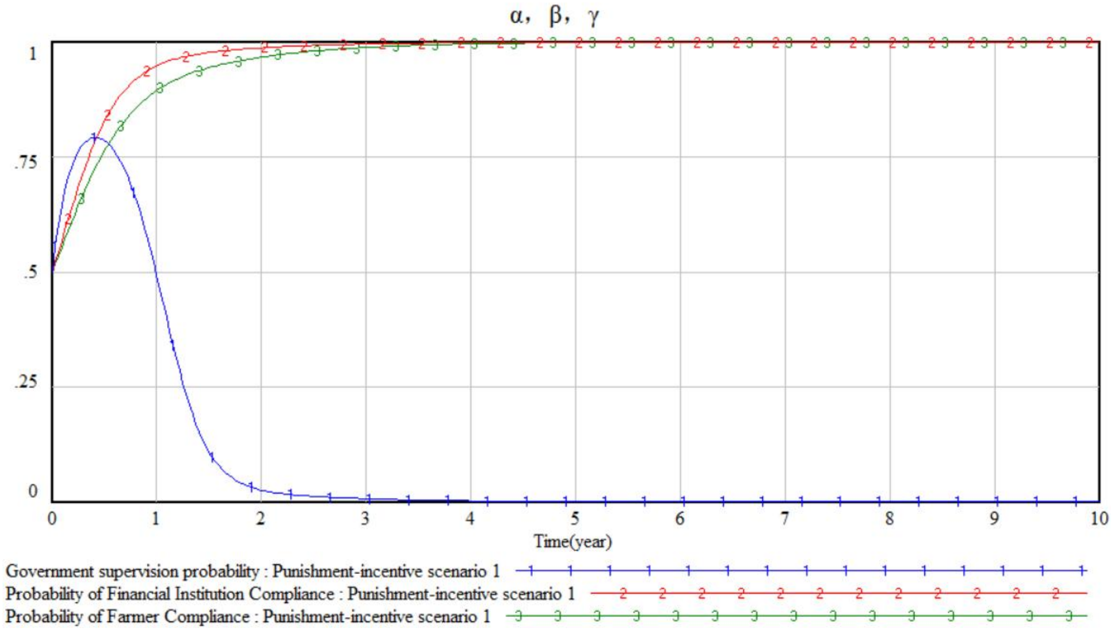

Figure32 Dynamic Penalty-Incentive Stability Control Optimization Scenario Rural Finance Tripartite Game System SD Evolutionary Game Model

Under the optimized dynamic penalty-incentive strategy 1, the evolutionary game process of the rural financial tripartite system roughly converges to $x^* = (0,1,1)$, which shows that the rural financial system evolves under the state of optimizing the dynamic penalty-incentive strategy 1. The repeated oscillations of the game process are effectively suppressed, the evolutionary game system tends to a stable state, and the state of the evolution result is very ideal, reaching our expectations. Next, continue to prove whether x^* is an evolutionary stable equilibrium solution. We consider the system evolution process when the initial strategy of the subject of the three-party game is $(\alpha, \beta, \gamma) = (0.3,0.1,0.2)$ and ((α, β, γ)) = (0.9, 0.2, 0.1), and optimize the dynamic penalty -Incentive strategy 2 and optimized dynamic penalty-The simulation results of incentive strategy 3 are shown in Figures 33 and 34.

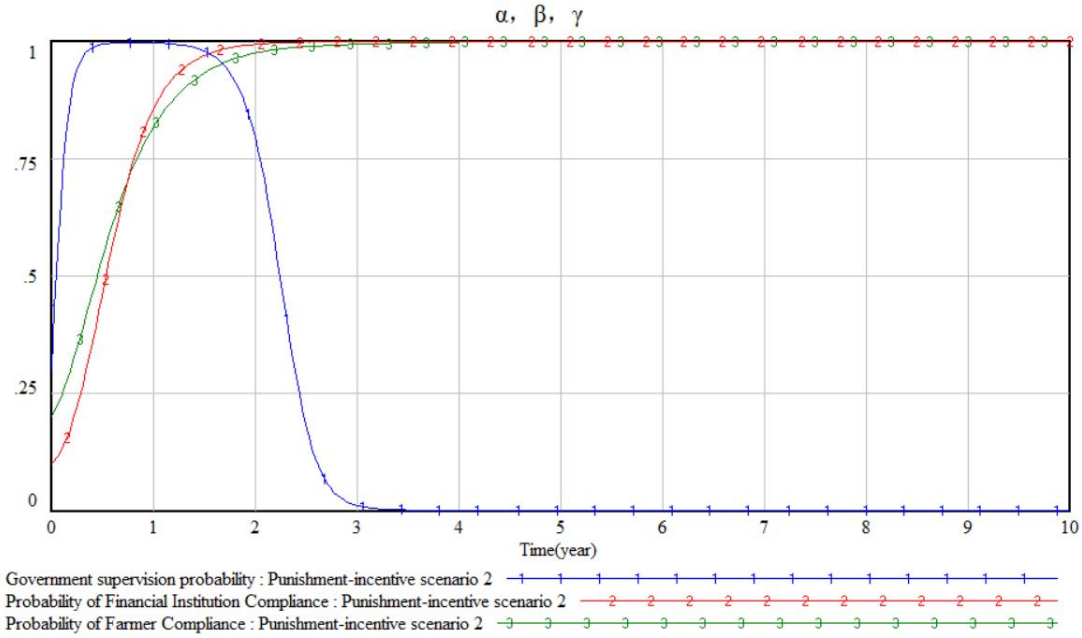

Figure33 Optimize dynamic penalty-incentive strategy 2 $(\boldsymbol{\alpha = 0.3, \beta = 0.1, \gamma = 0.2})$ system evolution game process

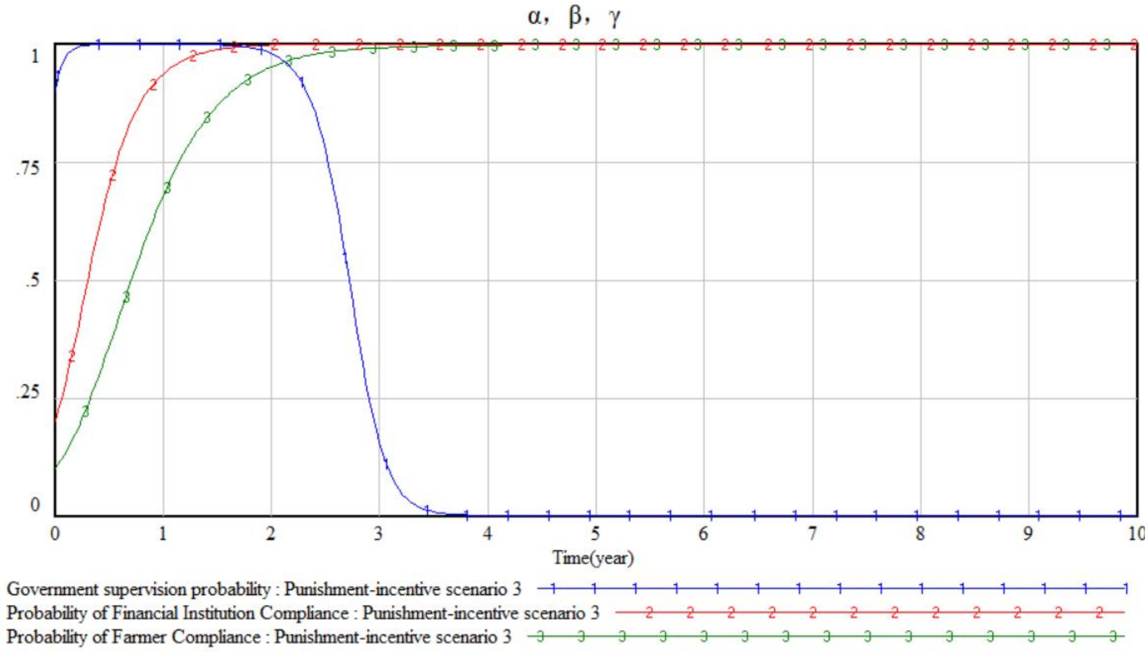

Figure34 Optimize dynamic penalty-incentive strategy 3 $(\boldsymbol{\alpha = 0.9, \beta = 0.2, \gamma = 0.1})$ system evolution game process

It can be seen that under the optimized dynamic penalty-incentive strategy 2 and optimized dynamic penalty-incentive strategy 3, the evolutionary game process of the rural financial tripartite system also roughly converges to $x^* = (0,1,1)$. Based on this, we guess x^* is the evolutionary stable equilibrium solution of the evolutionary game of the tripartite system of rural finance, and this evolutionary stable equilibrium solution can make the state of the subjects of the tripartite game of the tripartite system of rural finance meet the expectations, that is, the government has very weak supervision on financial institutions Supervise with farmers, and at the same time, financial institutions and farmers will strictly abide by the government's various regulations and policies, as well as relevant regulations and financial market lending standards, and the rural financial system can maximize benefits at this time. Based on the above comprehensive analysis, although the system in the dynamic penalty situation can converge to （0.44,1,0.35） , there is a stable equilibrium state, but the result of the stable equilibrium state in this case is not ideal, and farmers still have a high Violations, and the cost of government supervision is also relatively large; in the context of optimizing dynamic punishment-incentives, we found that both the government, financial institutions and farmers have reached a stable equilibrium strategy. The government is not supervising In this state, financial institutions and ex-peasant households can still consciously abide by laws and regulations to make rural production and living loans smoothly, so that the government's credibility and rural economic and social benefits have been effectively guaranteed, and a benign system has been formed.

5.4.2 Theoretical proof of the simulation results of system evolution game stability

Through the simulation analysis of the evolutionary game of the rural financial system, it is concluded that the evolutionary game process under the dynamic optimization penalty-incentive scenario converges to $x^* = (0,1,1)$. This equilibrium point is an evolutionary stable equilibrium solution. And it is very ideal. In order to prove the correctness of the evolutionary equilibrium solution obtained by simulation in this state, in this section, the equilibrium solution $x^* = (0,1,1)$ obtained by SD simulation in 5.4.1 and the evolutionary game model under the dynamic penalty situation Compare the equilibrium solution obtained by simulation. If the equilibrium solution x^* obtained by the simulation is consistent with one of the equilibrium solutions obtained by the evolutionary game model, and the stability of the equilibrium solution can be proved theoretically, the dynamic penalty-incentive scenario can be optimized. The simulation results below are valid

First, bring $c_2 = 4(1-\beta) + \frac{2}{\alpha}$, $d_2 = 2(1-\gamma) + \frac{2}{\alpha}$, $e_2 = 2\beta$, $f_2 = \gamma$ into Table 3 and Table 4 to get the evolution. The payment income matrix of the three-party game player is shown in Table 7and Table8.

Table7 Optimizing Dynamic Punishment-Incentive Strategy under Government Supervision and Tripartite Game Payment Profit Matrix

		Farmer	
		Obey the law	Violation
Financial Institutions	Obey the law	$\{-a-e_2-f_2, k+e_2, g+f_2\}$	$\{-a+d_2-e_2, k+e_2, g-d_2-j+h\}$
	Violation	$\{-a+c_2-f_2, k-c_2-n+l, g+f_2\}$	$\{-a+c_2+d_2, k-c_2-m+l, g-d_2-i+h\}$

Table8 Government does not supervise, optimize dynamic punishment-incentive strategy under the three-party game payment income matrix

		Farmer	
		Obey the law	Violation
Financial	Obey the	$\{0, k, g\}$	$\{-b, k, g-j+h\}$

Institutions	law		
	Violation	$\{-b, k-n+l, g\}$	$\{-b, k-m+l, g-i+h\}$

The dynamics of the subject of the rural financial tripartite game can be represented by the following copy dynamic equations:

$$F(x)=\begin{cases} F(\alpha)=\frac{d\alpha}{dt}=\alpha(1-\alpha)\begin{pmatrix} -a+\left(4(1-\beta)+\frac{2}{\alpha}\right)+\left(2(1-\gamma)+\frac{2}{\alpha}\right)-\beta\left(4(1-\beta)+\frac{2}{\alpha}+2\beta\right) \\ -\gamma\left(2(1-\gamma)+\frac{2}{\alpha}+\gamma\right)+b(1-\beta\gamma) \end{pmatrix} \\ F(\beta)=\frac{d\beta}{dt}=\beta(1-\beta)\left(2\alpha\beta+m-l+\alpha\left(4(1-\beta)+\frac{2}{\alpha}\right)-\gamma(m-n)\right) \\ F(\gamma)=\frac{d\gamma}{dt}=\gamma(1-\gamma)\left(\alpha\gamma+i-h+\alpha\left(2(1-\gamma)+\frac{2}{\alpha}\right)-\beta(i-j)\right) \end{cases}$$

Let $F(x)=\begin{cases} F(\alpha)=\frac{d\alpha}{dt} \\ F(\beta)=\frac{d\beta}{dt} \\ F(\gamma)=\frac{d\gamma}{dt} \end{cases}=0$

The system evolution game can be solved to replicate all the equilibrium solutions of the dynamic equation. The system obtained from the simulation results in the optimized dynamic penalty-incentive scenario in 5.4.1 converges stably to $x^*=(0,1,1)$. For the convenience of analysis, only $x^*=(0,1,1)$ Perform stability analysis. Since there is 2/α in the dynamic equation, α≠0, so the evolution result of the system should be $x^*=(0,1,1)$, where $\lim \alpha \to 0$, the system can be optimized in the dynamic penalty-incentive situation The Jakobian matrix:

$$J=\begin{bmatrix} \frac{\partial F(\alpha)}{\partial \alpha} & \frac{\partial F(\alpha)}{\partial \beta} & \frac{\partial F(\alpha)}{\partial \gamma} \\ \frac{\partial F(\beta)}{\partial \alpha} & \frac{\partial F(\beta)}{\partial \beta} & \frac{\partial F(\beta)}{\partial \gamma} \\ \frac{\partial F(\gamma)}{\partial \alpha} & \frac{\partial F(\gamma)}{\partial \beta} & \frac{\partial F(\gamma)}{\partial \gamma} \end{bmatrix}=\begin{bmatrix} 10\alpha-7 & -2-2\alpha+4\alpha^2 & -2\alpha(1-\alpha) \\ 0 & -2\alpha-1 & 0 \\ 0 & 0 & -\alpha-1 \end{bmatrix}$$

Find the characteristic value of J:

$$\lambda_1=10\alpha-7，\lambda_2=-2\alpha-1，\lambda_3=-\alpha-1。$$

Since $\lim \alpha \to 0$ all the eigenvalues are negative. Therefore, $x^*=(0,1,1)$ is the evolutionary stable equilibrium solution of the rural financial tripartite system under the optimized dynamic penalty-incentive scenario, which is the same as the results of $x^*=(0,1,1)$ obtained by system dynamics simulation are the same. Through the simulation and theoretical demonstration of the optimized dynamic penalty-incentive strategy, we found that adopting the optimized dynamic penalty-incentive strategy can obtain a stable and balanced state of the evolutionary game system, and in this state, the irregularities of financial institutions and farmers have been effectively suppressed .

6. Conclusions and prospects

This paper constructs a tripartite evolutionary game model involving the government, rural financial institutions, and rural financial service demanders, and combines the model with System Dynamics simulation to examine the strategic evolution of rural financial governance. Compared with a narrow poverty-alleviation perspective, the revised framework places rural finance under the policy background of rural revitalization, common prosperity, inclusive finance, and high-quality financial development. The model also broadens the demand-side subject from poor households to ordinary rural households, smallholder farmers, family farms, agricultural cooperatives, rural entrepreneurs, and agricultural value-chain actors. The simulation results show that a single punishment mechanism can restrain some irregular behavior, but it may also generate repeated fluctuations and excessive regulatory costs. An optimized dynamic penalty-incentive mechanism is more likely to guide rural financial institutions and rural financial service demanders toward compliance and to form a stable evolutionary equilibrium.

The policy implications are threefold. First, the government should improve the combination of punishment and incentives. Penalties should be high enough to offset the short-term gains from violation, while incentives should remain targeted and conditional. Second, rural financial institutions should strengthen credit screening, post-loan monitoring, and information sharing, especially for family farms, cooperatives, smallholder farmers, and rural entrepreneurs. Third, the construction of a stable collaborative mechanism should connect government supervision, institutional compliance, and demand-side contract performance, rather than relying only on administrative intervention. Evidence on cooperatives and family farms suggests that differentiated rural financial services are necessary for improving credit access and technology adoption. Evidence on digital inclusive finance also indicates that digital tools can support financial access and reduce household vulnerability, but they still require sound governance and risk-control mechanisms

This study also has limitations. The benchmark parameters are calibrated for simulation purposes and mainly reflect relative payoff relationships. Future research should introduce household-level survey data, financial-institution credit records, and regional rural financial indicators to estimate parameter ranges more accurately. It should also test whether the equilibrium conditions differ across regions, types of rural financial institutions, and categories of rural financial service demanders. In addition, future studies may combine empirical estimation with System Dynamics simulation to improve the external validity of the model.

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