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The Trilateral Game Analysis and Simulation Research of Government, Financial Institutions and Enterprises in the Development of Green Technology Innovation

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Abstract:

In 2020, the outbreak of COVID-19 pandemic caused great shock to domestic economy, left lots of enterprises in business difficulties. During the pandemic, people have come to realize that attention should also be given to ecological environment and public health in the pursuit of economic growth. Currently, faced by the urgent need of recovering economy, countries in the world are required to resolve the pressing problem of giving full play to government's role in motivating financial institutions and enterprises, helping them restore production over time, and invigorating economy. One of the major steps that enterprises should take is to focus on the innovation of green technology, in order to go through the crisis and seek opportunities in economic shock. Exploring the driving force and incentive mechanism of enterprise's green technology innovation is the key to clearing the way for its innovation. The thesis analyzes the dynamics of the trilateral game among government, financial institutions and enterprises in green technology innovation, in order to provide policy proposals for government in stimulating enterprise's development and restoring economy in the context of COVID-19 pandemic. The trilateral evolutionary game model of government, financial institutions and enterprises and its dynamic replication equation were constructed under the premise of bounded rationality assumption. The Matlab software was used to numerically simulate the interaction process of the three parties, the effect of each parameter change on the result of system evolution was analyzed, and the factors affecting final evolution of the system to an ideal state were explored. The research results reveal that strengthening government subsidies for enterprises to adopt green technology innovation and taxation on traditional production, reducing the cost of early-stage green technology innovation of enterprises, and improving the expected benefits and indirect benefits of green technology innovation of enterprises and so on have a positive effect on the development of green technology innovation of enterprises. In addition, reducing the cost of green financial services of financial institutions and improving the direct and indirect benefits of green financial services can promote financial institutions to actively participate in the development of green technology innovation. Government plays a decisive role in promoting the development of green technology innovation. Therefore, it should also play a leading and regulating role in motivating enterprise from the following points. Government should improve its green incentive mechanism driven by the supply side, help financial institutions to provide better green innovation services driven by the demand side, and establish a well-performed system for enterprise's green development based on interaction between supply and demand.

***Keywords**: COVID-19 Pandemic; government; financial institutions; enterprises; evolutionary game*

I. INTRODUCTION

The COVID-19 pandemic swept across the world in 2020, and made countries fall into a global public health crisis that never happened before. To deal with the pandemic, many countries and areas have adopted the prevention measures of lockdown and social isolation, some countries even pinned their hope on herd immunity. Due to the differences in geological cultures and medical conditions, countries also took different measures to prevent and control the pandemic. However, with the wide access of vaccines, in 2021, countries around the world start to walk out of the shadows cast by the pandemic, and restore their regulation production, life and work. After being shocked by the pandemic, countries need to recover economy. Thus it is an urgent problem to play government's role in motivating financial institutions and enterprises, raising capitals, helping enterprises restore production and invigorating economy. Furthermore, the outbreak of pandemic has also prompted people to fully understand the importance of environmental protection, and realize that people should not pursue economic development at the cost of ruining environment and damaging public health. Therefore, the path of sustainable innovation development driven by green technology has attracted the attention of many countries around the world.

With the rapid development of economic globalization in the past, to improve the international competitiveness and maintain the core competitive advantage, industrial enterprises of China continue to invest relatively numerous non-renewable resources, a large number of pollution discharges arising from production process of products lead to increasingly serious environmental pollution problems, and the economic development gradually presents the typical high carbon characteristics [1,2]. According to the prediction of Global Carbon Project report, in 2017, coal and oil consumption of China will increase by 3% and 5% respectively, natural gas consumption will increase by 12% and carbon emissions of China will increase by 3.5% [3]. However, environmental management of China is still dominated by terminal governance model on the whole [4,5]. Although strengthening environmental regulation is an important means to reduce pollution discharges, it may increase the burden of enterprises due to the rise of pollution control cost and secondary energy prices, and seriously frustrate the enthusiasm of enterprises to carry out green technology innovation [6,7]. Under the background of the "new normal" and the "double" constraints of resources and environment, it is urgent to solve the win-win proposition of environmental pollution and the improvement of enterprise competitiveness, and there are many difficulties and problems [8,9]. How to effectively guide enterprises to actively carry out green technology innovation and give play to the role of government and financial institutions in green technology innovation is directly related to the "win-win" of economic development and environmental protection of China [10].

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Scholars at home and abroad have relatively rich research results on green technology innovation [11,12]. In qualitative research, Cleff [13] et al. believed that the market was also an important factor to promote green technology innovation. Based on technology breakthrough and time span perspective, Herrmann [14] et al. believed that green technology innovation mainly experienced four different stages, i.e., green consciousness, green adoption, green transformation and green innovation. Liu Xiaoyin [15] et al. explored the connotation of green technology innovation, and explained that the implementation of green technology innovation was of great significance for enterprises to achieve sustainable development, break through green barriers, take advantage of market opportunities, and create a good social image. Wang Xu [16] et al. believed that green technology innovation of enterprises was the basis of the inevitable choice to promote green development, and put forward the ways and methods of green technology innovation driving green development from the macro and micro levels. Zheng Huizhi [17] discussed the development trend of green technology innovation of Chinese enterprises from three aspects of innovation type, government support strength and international trade barriers, and analyzed the problems in green technology innovation and diffusion of enterprises. Zhang Jiangxue [18] et al. believed that green technology innovation was a new requirement of the concept of green development for traditional technology innovation, and the key to realize green development was to actively explore the institutional obstacles faced by green technology innovation of China and construct policy system.

In quantitative research, Chintrakarn [19] made an empirical research by taking American manufacturing enterprises as the research object, and the results showed that the number of patents of enterprises was reduced through the control of pollution emissions and the environmental regulation inhibited the green technology innovation capability of enterprises. Through the investigation of Japanese industrial enterprises, Cole [20] et al. found that countries with more stringent environmental regulations and policies had higher innovation efficiency than other countries, and environmental regulation had a positive role in promoting technology innovation of enterprises. Based on cost increase perspective, Kemp [21] believed that strict environmental regulation would increase the production cost of enterprises, thus reducing the market competitiveness of enterprises and affecting the development of enterprises. Sun Qunying [22] et al. discussed the connotation and influencing factors of green technology innovation capability of enterprise, constructed the evaluation index system of green technology innovation capability of enterprise from 6 dimensions including green technology innovation input capability of enterprise and so on, and established the multi scheme evaluation model of green technology innovation capability of enterprise based on extension correlation degree. Sun Hongpeng [23] used SFA method to measure the efficiency of green technology innovation in various regions of China, and studied the effect of institutional environment, factor market distortion, resource input proportion, government behavior and other factors on the efficiency of green technology innovation. Hao Zutao [24] et al. constructed the framework of influencing factors of green technology innovation diffusion in mineral resource intensive regions and used entropy-weight multi-index comprehensive evaluation method and Logistic model to explore the effect of green technology innovation diffusion of mineral resource intensive regions. Song Xiaowei [25] used factor analysis to study the effect of environmental regulation factors on green technology innovation capability of regions and used MGWR model to carry out simulated valuation to the spatial relationship between financial resource allocation and green technology innovation capability.

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In the application of game theory method, Yang Guozhong [26] et al. regarded the university as the intermediary of the effect of government input on green technology innovation of enterprises to construct the evolutionary game model of green technology innovation of enterprises and government input. Combining with stakeholder theory, Cao Xia [27] et al. analyzed the interest demands of the stakeholders participating in green innovation of enterprises in the social system, to construct a trilateral evolutionary game model of the government, enterprises and public consumers. Aimed at the unavoidable problem of carbon emission in economic sustainable development of China, Sun Supeng [28] constructed a trilateral evolutionary game model of enterprises, government and environmental NGOs and its dynamic replication equation in the process of carbon emission reduction, and analyzed the local stability of the equilibrium point.

In summary, scholars at home and abroad have conducted relatively comprehensive and solid research on green technology innovation from qualitative and quantitative perspectives, but there are still some shortcomings: (1) Most of the existing literatures focus on the enterprises and the government affecting the green technology innovation, ignoring the role of financial institutions in the development of green technology innovation, and the supporting factors of financial institutions are not considered in the model design[29,30]; (2) No scholars have studied the development of green technology innovation by constructing the trilateral evolutionary game model of enterprises, financial institutions and enterprises, and holistic and in-depth research on the game analysis of stakeholders of green technology innovation is insufficient[31,32]; (3) There are few studies on the effect of government, financial institutions and enterprises on the development of green technology innovation[29], and the degree of its effect strength on choice of the development intensity of green and traditional technology innovation by enterprises[33,34]. In view of this, based on evolutionary game and Matlab simulation analysis method, fully considering the role and effect of financial institutions in the development of green technology innovation, this study constructed a trilateral dynamic evolutionary game model of the government, financial institutions and enterprises from the perspective of bounded rationality, analyzed the interest demands of trilateral game subjects and how to select behavior strategies in the long-term dynamic game process, and discussed the main factors affecting green technology innovation, to provide theoretical basis and relevant reference for the development of green technology innovation in China.

II. THE TRILATERAL EVOLUTIONARY GAME MODEL IN THE DEVELOPMENT OF GREEN TECHNOLOGY INNOVATION

2.1 Basic assumptions of the model

Assumption 1: The game subject in the development of green technology innovation is bounded rationality, and the ultimate goal of the game subjects is to maximize their own interests, i.e., the game participants can choose the strategies conducive to their own development according to their own resources[30,35]. The government has two choices, i.e., incentive strategy or non-incentive strategy; financial institutions have two choices, i.e., support strategy (green finance) or non-support strategy

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(conventional services); enterprises have two choices, i.e., green innovation development strategy (innovation) or traditional production strategy (non-innovation).

Assumption 2: For the government, promoting stable economic growth, improving the level of social welfare and so on are the main aspects of interest expression of the government, i.e., government revenue [36]. The government can encourage enterprises to adopt green technology innovation development mode by means of taxation and subsidies [37]. Green technology innovation development is the key means to improve the quality and efficiency of economic development and improve the environment under the current social development background, which can bring positive external effects for social development [38,39]. However, because green technology innovation activities are characterized by high risk coefficient, large cost investment and slow benefit effect, if the government takes the compulsory implementation of green technology innovation, it will dampen the production enthusiasm of enterprises, and even lead to the closure of enterprises, which will have an impact on economic development and social welfare. On the contrary, if the government does not encourage enterprises to carry out green technology innovation development, it will lead to the deterioration of environmental quality, the decline of residents' life happiness and other problems, thus affecting the government image and social credibility, and causing negative external effects on social development.

Assumption 3: For financial institutions, the conventional financial services of financial institutions are general credit services [40]. Moreover, in green finance, in addition to conventional credit services, financial institutions also provide green IPO, green credit services, green bond services, green insurance services and green fund services related to green technology innovation development. Financial institutions need to invest a certain amount of human, material and financial resources in the implementation of green finance, and there is a certain credit risk in the process of supporting the development of green technology innovation of enterprises. Finally, it is assumed in this study that the government does not provide direct or indirect support, subsidies and other dividend policies to financial institutions.

Assumption 4: For enterprises, they need to invest a lot of human, material and financial resources in the early stage when choosing green technology innovation development, and large investment, high risk coefficient and strong uncertainty of green technology innovation restrict the development process of green technology innovation of enterprises to a certain extent, so they need the incentive and support of the government and financial institutions [41]. In addition, enterprises carrying out green technology innovation development and traditional production can obtain some financial service support including conventional credit from financial institutions.

Assumption 5: Enterprises, financial institutions and the government have two behavior choices [42], i.e., whether enterprises adopt green technology innovation strategy or not, whether financial institutions adopt support strategy or not, and whether the government adopts incentive strategy or not. x, y and z represent choice probability of corresponding strategy, x, y and z $\in[0,1]$, and they are function of time t. In the initial stage, it is assumed that the probability that enterprises choose green technology innovation is x, and the probability that enterprises choose non-innovation is 1-x; the probability that financial

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institutions choose financial support is y, and the probability that financial institutions choose non-support is 1- y; the probability that the government chooses incentive is z and the probability that the government chooses non-incentive is 1- z.

2.2 Related parameters in evolutionary game model and meanings

In combination with the role of government, financial institutions and enterprises in the development of green technology innovation [43], as stakeholders, the effect and role of government, financial institutions and enterprises on green technology innovation are mainly manifested in the role of government in encouraging and guiding green technology innovation behavior of enterprises; enterprises choose technology innovation development strategy according to the market orientation and internal factors; financial institutions carry out green financial innovation services under the guidance of the government, which boosts and catalyzes green technology innovation of enterprises [44]. Driven by interests, the three parties adopt different strategies and systems, and they are closely related, restrict and affect each other. The interest factors and roles of government, financial institutions and enterprises in the development of green technology innovation are shown in Fig.1.

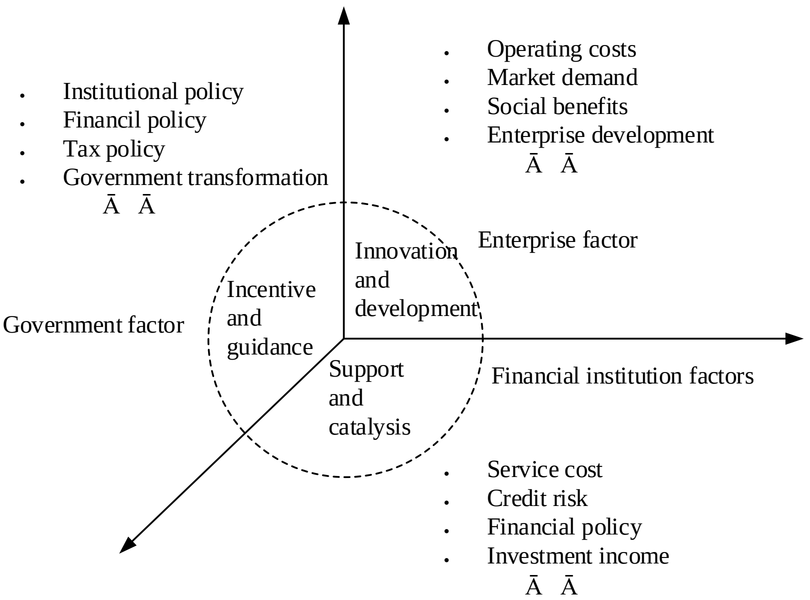

Figure 1 The effect of green technology innovation on stakeholders

According to the analysis chart of the effect of green technology innovation on stakeholders, the interest demands of the government, financial institutions and enterprises can be determined, so as to set the trilateral behavior evolutionary game parameters needing to be studied in this paper, as shown in Table 1.

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TABLE I Main Parameters and Their Meanings

PARAMETERS	MEANINGS
B	Revenue obtained by the government through stable economic growth and improvement of social welfare level
α	Coefficient of positive external effect on the society caused by the incentive of the government to the development of green technology innovation of enterprises ($0 < \alpha \leq 1$)
f	The positive effects of social credibility, government reputation and green economy development of government
c	Negative effects of environmental pollution caused by high energy consumption needing to be paid by the government in the traditional production of enterprises
C_1	Certain subsidies, policy preference and other dividends provided by the government to enterprises engaged in green technology innovation development
C_2	Environmental tax and carbon tax levied by the government to enterprises not engaged in green technology innovation development
S_1	Income obtained by financial institutions through provision of regular credit services
S_2	The ratio of increased credit risk when financial institutions carry out green finance to support green financial innovation of enterprises
m	Various costs and other expenses input when financial institutions carry out green finance to support green financial innovation of enterprises
W	Income obtained when financial institutions carry out green finance to support green financial innovation of enterprises
n	Indirect economic and social benefits obtained when financial institutions carry out green finance (market competitiveness and social honor)
K_1	Profit gained by enterprises when engaged in traditional production mode
K_2	Additional income obtained by enterprises when engaged in green technology innovation production
T	Risk probability of loss caused by failure to meet expectations when enterprises are engaged in green technology innovation
r	The cost of human, material and financial resources paid by the enterprises in the early stage when enterprises are engaged in green technology innovation development
P	The indirect economic and social benefits obtained by enterprises when engaged in green technology innovation (market competitiveness and social honor)
F	The financial service cost paid by enterprises when engaged in green

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	technology innovation
q	The financial service cost paid by enterprises when engaged in traditional production mode ($K_2>K_1$)

2.3 Establishment of the trilateral evolutionary game model

According to the above assumptions and corresponding strategy behaviors of enterprises, financial institutions and government, 8 game strategy sets of enterprises, financial institutions and government are formed, including: (innovation Q_1, support R_1, incentive P_1), (innovation Q_1, support R_1, non-incentive P_2), (innovation Q_1, non-support R_2, incentive P_1),(innovation Q_1, non-support R_2, non-incentive P_2), (Non-innovation Q_2, support R_1, incentive P_1), (Non-innovation Q_2, support R_1, non-incentive P_2), (Non-innovation Q_2, non-support R_2, incentive P_1), and (Non-innovation Q_2, non-support R_2, non-incentive P_2). In combination with assumptions and game combination strategy, evolutionary game income matrix of enterprises, financial institutions and government constructed is shown in Table 2.

TABLE II Behavior Income Matrix of Government, Financial Institutions and Enterprises

STRATEGY COMBINATION	ENTERPRISE INCOME	INCOME OF FINANCIAL INSTITUTIONS	GOVERNMENT REVENUE
(Q_1,R_1,P_1)	$(1-m)(S_1+S_2)-W-K_1+C_1+n$	$(1-r)T+F-P+q$	$\alpha B-C_1+f$
(Q_1,R_1,P_2)	$(1-m)(S_1+S_2)-W-K_1+n$	$(1-r)T+F-P+q$	B
(Q_1,R_2,P_1)	$(1-m)(S_1+S_2)-W-K_1+C_1+n$	$(1-r)T$	$\alpha B-C_1+f$
(Q_1,R_2,P_2)	$(1-m)(S_1+S_2)-W-K_1+n$	$(1-r)T$	B
(Q_2,R_1,P_1)	S_1-C_2	$T-P+q$	$\alpha B+C_2$
(Q_2,R_1,P_2)	S_1	$T-P+q$	$B-c$
(Q_2,R_2,P_1)	S_1-C_2	T	$\alpha B+C_2$
(Q_2,R_2,P_2)	S_1	T	$B-c$

2.4 Solution and analysis of the trilateral evolutionary game model

According to the behavior strategy combination and income matrix of government, financial institutions and enterprises, the dynamic replication equations of behavior strategy of government, financial institutions and enterprises are constructed respectively:

(1) The expected return is V_{11} when enterprises choose "innovation" strategy, expected return is V_{12} when enterprises choose "non-innovation" strategy and average expected return is V_1, then:

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$$
\begin{aligned}
V_{11} = & yz[(1-m)(S_1+S_2)-W-K_1+C_1+n] \\
& +(1-y)z[(1-m)(S_1+S_2)-W-K_2+C_1+n] \\
& +y(1-z)[(1-m)(S_1+S_2)-W-K_1+n] \\
& +(1-y)(1-z)[(1-m)(S_1+S_2)-W-K_2+n] \\
= & y(K_2-K_1)+zC_1+(1-m)(S_1+S_2)-W-K_2+n \\
V_{12} = & yz(S_1-C_2)+(1-y)z(S_1-C_2)+y(1-z)S_1+(1-y)(1-z)S_1 \\
= & S_1-zC_2 \\
V_1 = & xV_{11}+(1-x)V_{12}
\end{aligned}
$$

The following formula can be obtained when V_{11} and V_{12} are substituted into the dynamic replication equation:

$$
\begin{aligned}
F(x)=\frac{dx}{dt} = & x(1-x)[y(K_2-K_1)+z(C_1+C_2)+(1-m) \\
& S_1+S_2)-S_1-W-K_2+n]
\end{aligned}
$$

The following formula can be obtained when first-order derivative related to x is obtained to $F(x)$:

$$
\begin{aligned}
F'(x) = & (1-2x)[y(K_2-K_1)+z(C_1+C_2)+(1-m) \\
& S_1+S_2)-S_1-W-K_2+n]
\end{aligned}
$$

$F(x)$=0 can be made, and then 3 steady state points respectively are: x_1=0, x_2=1 and

$$z^* = \frac{S_1+W+K_2-(1-m)(S_1+S_2)-y(K_2-K_1)-n}{C_1+C_2} \quad (1)$$

(2) The expected return is V_{21} when financial institutions choose "support" strategy, expected return is V_{22} when financial institutions choose "non-support" strategy, and average expected return is V_2, then:

$$
\begin{aligned}
V_{21} = & xz[(1-r)T+F-P+q]+x(1-z) \\
& [(1-r)T+F-P+q]+(1-x)z(T-P \\
& +q)+(1-x)(1-z)(T-P+q) \\
= & x[(1-r)T+F-P+q]+(1-x)(T-P+q) \\
V_{22} = & xz(1-r)T+x(1-z)(1-r)T+z(1-x)T+(1-x)(1-z)T \\
= & x(1-r)T+(1-x)T \\
V_2 = & yV_{21}+(1-y)V_{22}
\end{aligned}
$$

$$F(y)=\frac{dy}{dt}=y(1-y)(xF-P+q)$$

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The following formula can be obtained when first-order derivative related to y is obtained to $F(y)$:

$$F'(y) = (1-2y)(xF - P + q)$$

$F(y)$=0 can be made, and then 3 steady state points respectively are: y_1=0, y_2=1 and

$$y^* = \frac{P-q}{F} \tag{2}$$

(3) It is assumed that the expected return is V_{31} when the government chooses "incentive" strategy, expected return is V_{32} when the government chooses "non-incentive" strategy, and average expected return is V_3, then:

$$\begin{aligned} V_{31} &= xy(\alpha B - C_1 + f) + x(1-y)(\alpha B - C_1 + f) \\ &\quad + y(1-x)(\alpha B + C_2) + (1-x)(1-y)(\alpha B + C_2) \\ &= x(f - C_1 - C_2) + \alpha B + C_2 \end{aligned}$$

$$\begin{aligned} V_{32} &= xyB + x(1-y)B + y(1-x)(B-c) + (1-x)(1-y)(B-c) \\ &= xc + B - c \end{aligned}$$

$$V_3 = zV_{31} + (1-z)V_{32}$$

$$F(z) = \frac{dz}{dt} = z(1-z)[x(f - C_1 - C_2 - c) + \alpha B + R - B + c]$$

The following formula can be obtained when first-order derivative related to z is obtained to $F(z)$:

$$F'(z) = (1-2z)[x(f - C_1 - C_2 - c) + \alpha B + R - B + c]$$

$F(z)$=0 can be made, and then 3 steady state points respectively are: z_1=0, z_2=1 and

$$x^* = \frac{B - \alpha B - C_2 - c}{f - C_1 - C_2 - c} \tag{3}$$

In the evolutionary game process of the government, financial institutions and enterprises, when the three parties reach a stable state, it means that the government, financial institutions and enterprises have found an effective Nash equilibrium through continuous learning, trial error and adjustment. Through the above calculation, it can be seen that there are 8 special equilibrium points in the equation, i.e., (0, 0, 0), (0, 1, 0), (0, 0, 1), (1, 1, 1), (1, 0, 0), (1, 0, 1), (0, 1, 1), (1, 1, 0), ($x^*, y^*, F'(z) < 0$), and the 8 points constitute the boundary of the solution domain of evolutionary game { (x, y, z) | $0 < x < 1$; $0 < y < 1$; $0 < z < 1$}.

III. STABILITY STRATEGY ANALYSIS OF THE TRILATERAL EVOLUTIONARY GAME

According to related properties of evolutionary game [45], when $F'(x) < 0$, $F'(y) < 0$, and $F'(z) < 0$, that

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is the stability strategy that the three parties should adopt. The stability strategies of enterprises, financial institutions and the government will be analyzed below:

(1) Analysis on the evolutionary stability of enterprise strategy

a. When $z^* = \frac{S_1 + W + K_2 - (1-m)(S_1+S_2) - y(K_2-K_1) - n}{C_1+C_2}$, $F(x)$=0, and it indicates a steady state at all levels; that is to say, strategy choice of enterprises does not change with time.

b. When $z > z^* = \frac{S_1 + W + K_2 - (1-m)(S_1+S_2) - y(K_2-K_1) - n}{C_1+C_2}$, $F'(1) < 0$, and $F'(0) > 0$; that is to say, x=1 is globally unique evolutionary stability strategy.

c. When $z < z^* = \frac{S_1 + W + K_2 - (1-m)(S_1+S_2) - y(K_2-K_1) - n}{C_1+C_2}$, $F'(1) > 0$, and $F'(0) < 0$; that is to say, x=0 is globally unique evolutionary stability strategy.

Dynamic evolution path diagram of enterprises is shown as follows (Fig.2).

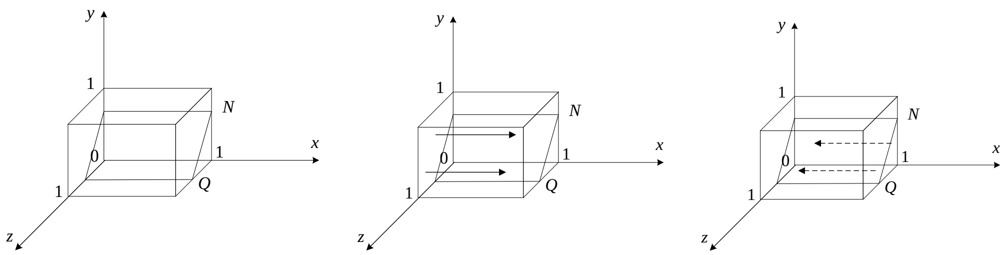

FIGURE 2 Dynamic Evolution Path Diagram of Enterprises

(2) Analysis on the evolutionary stability of financial institution strategy

a. When $x = x^* = \frac{P-q}{F}$, $F(y)$=0, and it indicates a steady state at all levels; that is to say, strategy choice of financial institutions does not change with time.

b. When $x > x^* = \frac{P-q}{F}$, $F'(1) < 0$, and $F'(0) > 0$; that is to say, y=1 is globally unique evolutionary stability strategy.

c. When $x < x^* = \frac{P-q}{F}$, $F'(1) > 0$, and $F'(0) < 0$; that is to say, y=0 is globally unique evolutionary stability strategy.

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Dynamic evolution path diagram of financial institutions is shown as follows (Fig.3).

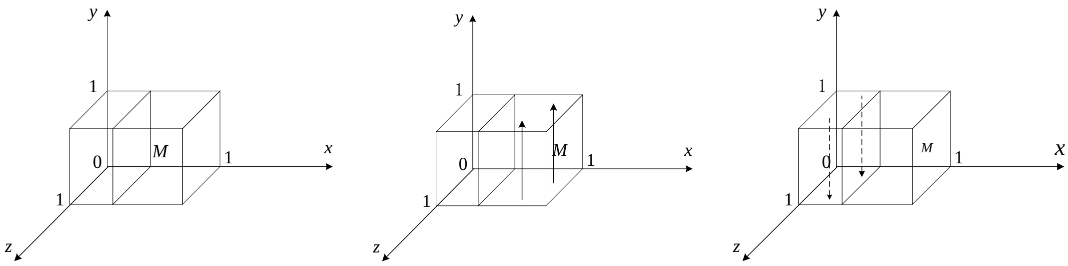

FIGURE 3 Dynamic Evolution Path Diagram of Financial Institutions

(3) Analysis on the evolutionary stability of government strategy

a. When $x = x^* = \dfrac{B-\alpha B-C_2-c}{f-C_1-C_2-c}$, $F(z)$=0, and it indicates a steady state at all levels; that is to say, strategy choice of the government does not change with time.

b. When $x > x^* = \dfrac{B-\alpha B-C_2-c}{f-C_1-C_2-c}$, $F'(1)<0$, and $F'(0)>0$; that is to say, z=0 is globally unique evolutionary stability strategy.

c. When $x < x^* = \dfrac{B-\alpha B-C_2-c}{f-C_1-C_2-c}$, $F'(1)>0$, and $F'(0)<0$; that is to say, z=1 is globally unique evolutionary stability strategy.

Dynamic evolution path diagram of the government is shown as follows (Fig.4).

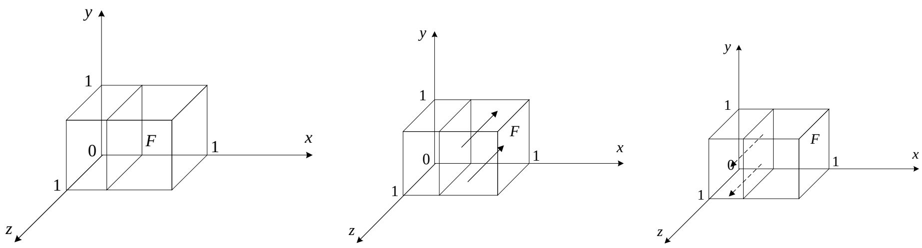

FIGURE 4 Dynamic evolution path diagram of the government

Through the above discussion and analysis on the evolutionary stability of the government, financial institutions and enterprises, it can be seen that the final strategy choice of the government, financial institutions and enterprises will change according to the initial state of the system and learning, adjustment and trial error, so the government, financial institutions and enterprises need to pay attention to the initial

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state of the system when they choose to implement (incentive, support, innovation) strategy set, and they should adopt corresponding strategies according to different initial states. Because the initial state of the government, financial institutions and enterprises is not fixed in the evolution process, we cannot only consider changing the initial conditions to make the system reach a stable state. Therefore, the incentive and guidance role of the government in the development of green technology innovation should be exerted.

IV. ANALYSIS ON STABILITY OF EVOLUTIONARY GAME OF FINANCIAL INSTITUTIONS AND ENTERPRISES UNDER GOVERNMENT INCENTIVE

4.1 Construction of evolutionary game model

To further analyze the behavior of the government in the development of green technology innovation, and study the stability of evolutionary game of enterprises and financial institutions under government incentive, the analysis is carried out under the condition that $x > x^* = \frac{B - \alpha B - C_2 - c}{f - C_1 - C_2 - c}$ and z=1 and others are consistent with the previous assumptions[46,47]. Because of the space, this paper no longer describes the income of financial institutions and enterprises under the government incentive.

(1) It is assumed that the expected return is V_{11} when enterprises choose “innovation” strategy, expected return is V_{12} when enterprises choose “non-innovation” strategy, and average expected return is V_1, then:

$$\begin{aligned} V_{11} &= y[(1-m)(S_1+S_2)-W-K_1+C_1+n] \\ &\quad +(1-y)[(1-m)(S_1+S_2)-W-K_2+C_1+n] \\ V_{12} &= y(S_1-C_2)+(1-y)(S_1-C_2)=S_1-C_2 \\ V_1 &= xV_{11}+(1-x)V_{12} \end{aligned}$$

The following formula can be obtained when V_{11} and V_{12} are substituted into the dynamic replication equation:

$$\begin{aligned} F(x) = \frac{dx}{dt} &= x(1-x)[y(K_2-K_1)+C_1+C_2+(1-m) \\ &\quad (S_1+S_2)-S_1-W-K_2+n] \end{aligned}$$

The following formula can be obtained when first-order derivative related to x is obtained to $F(x)$:

$$\begin{aligned} F'(x) &= (1-2x)[y(K_2-K_1)+C_1+C_2+(1-m) \\ &\quad (S_1+S_2)-S_1-W-K_2+n] \end{aligned}$$

$F(x)$=0 can be made, and then 3 steady state points respectively are: x_1=0, x_2=1

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$$y^* = \frac{S_1 + W + K_2 - (1-m)(S_1 + S_2) - C_1 - C_2 - n}{K_2 - K_1} \tag{4}$$

(2) The expected return is V_{21} when financial institutions choose "support" strategy, expected return is V_{22} when financial institutions choose "non-support" strategy, and average expected return is V_2, then:

$$V_{21} = x[(1-r)T + F - P + q] + (1-x)(T - P + q)$$
$$V_{22} = x(1-r)T + (1-x)T$$
$$V_2 = yV_{21} + (1-y)V_{22}$$
$$F(y) = \frac{dy}{dt} = y(1-y)(xF - P + q)$$

The following formula can be obtained when first-order derivative related to y is obtained to $F(y)$:

$$F'(y) = (1-2y)(xF - P + q)$$

$F(y)$ =0 can be made, and then 3 steady state points respectively are: y_1=0, y_2=1 and

$$x^* = \frac{P - q}{F} \tag{5}$$

Through the above calculation, 5 local equilibrium points of the game matrix can be obtained: F_1 (0, 0), F_2 (0, 1), F_3 (1, 0), F_4 (1, 1) and F_5 (x^*, y^*), where F_1 (0, 0), F_2 (0, 1), F_3 (1, 0) and F_4 (1, 1) are 4 pure strategy equilibrium points; F_5 (x^*, y^*) is mixed strategy equilibrium point.

4.2 Equilibrium point of evolutionary game and its stability analysis

According to verification method of stability strategy of equilibrium point of Friedman (1998), the stability of evolutionary equilibrium of the system can be determined by the local stability of Jacobian matrix (J) of the system, and the sign direction of detJ and trJ can be determined by calculating the determinant of matrix (detJ) and trace of matrix (trJ). The same sign indicates unstable stagnation point, the different sign indicates stable stagnation point, and if the sign cannot be determined accurately, the point is judged as saddle point[48].

$$J = \begin{bmatrix} \frac{\partial\left(\frac{dx}{dt}\right)}{\partial x}, & \frac{\partial\left(\frac{dx}{dt}\right)}{\partial y} \\ \frac{\partial\left(\frac{dy}{dt}\right)}{\partial x}, & \frac{\partial\left(\frac{dy}{dt}\right)}{\partial y} \end{bmatrix} = \begin{vmatrix} (1-2x)[y(K_2 - K_1) + C_1 + C_2 + (1-m)(S_1 + S_2) - S_1 - W - K_2 + n], & x(1-x)(K_2 - K_1) \\ y(1-y)F, & (1-2y)(xF - P + q) \end{vmatrix} \tag{6}$$

Based on the purpose of this study, under the condition that $(1-m)(S_1 + S_2) - C_1 - C_2 + n > S_1$, when the net

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profit (profit - cost) obtained by enterprises in green technology innovation is greater than the profit obtained in traditional production, then enterprises have the power to choose green technology innovation mode; when $C_1+C_2>W$, it shows that the government will be more inclined to encourage enterprises to be engaged in green technology innovation when the input of various costs of the government for engagement in the development of green technology innovation is greater than the input of various costs of enterprises in early stage; because $x^*=\frac{P-q}{F}$, $P-q>0$, and when the cost for implementation of green finance is greater than the indirect benefits, financial institutions will hold a wait-and-see attitude on whether to develop green financial services; when $F+q>P$, it shows that the direct and indirect benefits brought by green finance are greater than various costs invested by financial institutions, and at this time, financial institutions tend to carry out green financial services. In combination with the above assumptions and inferences, the determinant values and trace analysis results of local equilibrium point are shown in Table 3.

Table III. The Determinant Values and Trace of Local Equilibrium Point

LOCAL EQUILIBRIUM POINT	DETJ	SIGN	TRJ	SIGN	STABILITY
F_1 (0, 0)	$[C_1+C_2+(1-m)(S_1+S_2)-S_1-W-K_2+n](q-P)$	-	$[C_1+C_2+(1-m)(S_1+S_2)-S_1-W-K_2+n]+(q-P)$	+	ESS
F_2 (0, 1)	$[C_1+C_2+(1-m)(S_1+S_2)-S_1-W-K_2+n](P-q)$	+	$[C_1+C_2+(1-m)(S_1+S_2)-S_1-W-K_2+n]+(P-q)$	+	Unstable
F_3 (1, 0)	$-[C_1+C_2+(1-m)(S_1+S_2)-S_1-W-K_2+n](q-P+F)$	-	$-[C_1+C_2+(1-m)(S_1+S_2)-S_1-W-K_2+n]+(q-P+F)$	-	Unstable
F_4 (1, 1)	$[C_1+C_2+(1-m)(S_1+S_2)-S_1-W-K_2+n](q-P+F)$	+	$[C_1+C_2+(1-m)(S_1+S_2)-S_1-W-K_2+n]+(q-P+F)$	-	ESS
F_5 (x^*, y^*)	$\{(P-q)(F-P+q)[S_1+W+K_2-(1-m)(S_1+S_2)-C_2-C_1-n][S_1+W+K_1-(1-m)(S_1+S_2)-C_2-C_1-n]\}/[F(K_2-K_1)]$	-	0	?	Saddle point

According to the results in Table 3, F_1 (0, 0), i.e., (non-innovation, non-support) and F_4 (1, 1), i.e., (innovation, support), are steady equilibrium points of the game system, where F_4 (1, 1), i.e., (innovation, support), is the optimal equilibrium point of the evolutionary game system.

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4.3 Analysis of the factors affecting the development of green technology innovation

The evolution path of cooperative development of enterprises and financial institutions in green technology innovation is shown in Fig.5. According to Fig.5, in 5 equilibrium points, F_5 (x^*, y^*) is the starting point of unstable source, F_2 (0, 1) and F_3 (1, 0) are saddle points, and F_1 (0, 0) and F_4 (1, 1) are evolutionary stable states, corresponding to the (non-innovation, non-support) and (innovation, support) strategies adopted by enterprises and financial institutions respectively. That points in area $S_{F2F5F3F4}$ will be eventually converged to the optimal steady-state equilibrium point F_4 (1, 1) through evolution represents that financial institutions carry out green finance to support and promote the development of green technology innovation of enterprises, constituting cooperation area; points in area $S_{F1F2F5F3}$ will be eventually converged to the steady-state equilibrium point F_3 (1, 0) through evolution. F_1 (0, 0), i.e., (non-innovation, non-support) strategy, constitutes the area where enterprises and financial institutions choose not to make cooperation, and although this point is the equilibrium point of evolutionary game system, there is Pareto improvement space of social welfare.

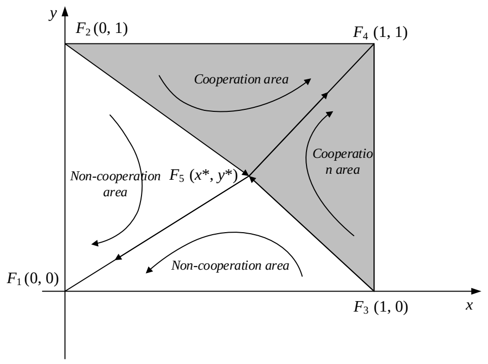

FIGURE 5 Diagram on the evolution path of cooperative development of enterprises and financial institutions in green technology innovation

Because the equilibrium state of evolutionary game cannot be achieved overnight, enterprises and financial institutions need to make the judgment and choice of the next time period through a certain process of learning, adjustment and trial error. In the initial state, if the equilibrium point of evolutionary game is in the area $S_{F2F5F3F4}$, it means that the stable equilibrium strategy of system evolution will continue the state of non-innovation strategy adopted by enterprises in the future. In the initial state, if the stable equilibrium point of the system is in the area $S_{F2F5F3F4}$, equilibrium of the system will change to the direction of the development of green technology innovation chosen by enterprises. Therefore, the transformation of the evolution system of green technology innovation development to the optimal state needs the joint action of the government, enterprises and financial institutions.

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$$S_{F2F5F3F4}=\frac{1}{2}(1-x^*+1-y^*)=1-\frac{1}{2}(x^*+y^*)$$

It can be seen from the above formula that the size of the area $S_{F2F5F3F4}$ changes with the position of saddle point F_5 (x^*, y^*), and the larger the area of $S_{F2F5F3F4}$ is, the more likely the evolutionary stable system will be converged to point F_4 (1, 1). The long-term stability strategy of evolutionary game is restricted and influenced by some factors and their changes before and during the game. Here we set the restricting and influencing factors as fixed parameter σ uniformly, and test the influence of each parameter on the size of area $S_{F2F5F3F4}$ by comparative static analysis. The specific function expression is as follows:

$$\frac{\partial S_{F2F5F3F4}}{\partial \sigma}=1-\frac{1}{2}\left(\frac{\partial x^*}{\partial C_1}+\frac{\partial y^*}{\partial \sigma}\right)$$

Where, $x^*=\frac{P-q}{F}$, $y^*=\frac{S_1+W+K_2-(1-m)(S_1+S_2)-C_1-C_2-n}{K_2-K_1}$, and σ is C1, C2, S2, K1, W, n, F, P and q.

(1) Government level (C1 and C2):

Government subsidies: because $\frac{\partial x^*}{\partial C_1}=0$ and $\frac{\partial y^*}{\partial C_1}=-\frac{1}{K_2-K_1}<0$, then $\frac{\partial S_{F2F5F3F4}}{\partial C_2}>0$. Therefore, the greater the intensity of the government subsidies for green technology innovation development of enterprises is, the more likely the formation of cooperation between financial institutions and enterprises will be promoted.

Taxation intensity: because $\frac{\partial x^*}{\partial C_2}=0$ and $\frac{\partial y^*}{\partial C_2}=-\frac{1}{K_2-K_1}<0$, then $\frac{\partial S_{F2F5F3F4}}{\partial C_2}>0$. Therefore, the greater the amount of taxes and fees levied by the government to enterprises choosing the traditional production mode is, the more likely the formation of cooperation between financial institutions and enterprises will be promoted.

(2) Enterprise level (S2, W, K1 and n):

Additional benefits: because $\frac{\partial x^*}{\partial S_2}=0$ and $\frac{\partial y^*}{\partial S_2}=-\frac{1-m}{K_2-K_1}<0$, then $\frac{\partial S_{F2F5F3F4}}{\partial S_2}>0$. Therefore, the greater the additional benefits obtained by enterprises through green technology innovation development are, the more likely the formation of cooperation between financial institutions and enterprises will be promoted.

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Capital investment in the transformation period: because $\frac{\partial x^*}{\partial W}=0$ and $\frac{\partial y^*}{\partial W}=\frac{1}{K_2-K_1}>0$, then $\frac{\partial S_{F2F5F3F4}}{\partial W}<0$. Therefore, the smaller the human, material and financial resources invested by enterprises in the transformation from traditional production mode to green technology innovation development mode are, the more likely the formation of cooperation between financial institutions and enterprises will be promoted.

Cost of financial services: because $\frac{\partial x^*}{\partial K_1}=0$ nd $\frac{\partial y^*}{\partial K_1}=\frac{S_1+W+K_2-(1-m)(S_1+S_2)-C_1-C_2-n}{(K_2-K_1)^2}>0$, then $\frac{\partial S_{F2F5F3F4}}{\partial K_1}<0$. Therefore, the lower the cost of financial services spent by enterprises in negotiating with financial institutions is, the more likely the formation of cooperation between financial institutions and enterprises will be promoted.

Social benefits: because $\frac{\partial x^*}{\partial n}=0$ and $\frac{\partial y^*}{\partial n}=-\frac{1}{K_2-K_1}<0$, then $\frac{\partial S_{F2F5F3F4}}{\partial n}>0$. Therefore, the higher the social benefits obtained by enterprises (social reputation, social image and brand benefit) are, the more likely the formation of cooperation between financial institutions and enterprises will be promoted.

(3) Financial institution level (F, P and q):

Financial income: because $\frac{\partial x^*}{\partial F}=\frac{q-P}{F^2}<0$ and $\frac{\partial y^*}{\partial F}=0$, then $\frac{\partial S_{F2F5F3F4}}{\partial F}>0$. Therefore, the higher the financial income obtained by financial institutions is, the more likely the formation of cooperation between financial institutions and enterprises will be promoted.

Financial cost: because $\frac{\partial x^*}{\partial P}=\frac{1}{F}>0$ and $\frac{\partial y^*}{\partial P}=0$, then $\frac{\partial S_{F2F5F3F4}}{\partial P}<0$. Therefore, the lower the cost invested by financial institutions to green technology innovation development of enterprises is, the more likely the formation of cooperation between financial institutions and enterprises will be promoted.

Indirect financial income: because $\frac{\partial x^*}{\partial q}=-\frac{1}{F}<0$ and $\frac{\partial y^*}{\partial q}=0$, then $\frac{\partial S_{F2F5F3F4}}{\partial q}>0$. Therefore, the higher the indirect income obtained by financial institutions in investment process of green technology innovation development of enterprises is, the more likely the formation of cooperation between financial institutions and enterprises will be promoted [41,49].

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4.4 Numerical simulation

Through discussion on the evolutionary equilibrium strategy of the government, financial institutions and enterprises, it can be seen that there must be an evolutionary stable equilibrium point in the game among the government, financial institutions and enterprises in the development of green technology innovation [46,50]. However, through the analysis of the evolutionary game model, the reason why the system finally achieves equilibrium cannot be determined. Therefore, to more vividly describe the effect of the income difference among the government, financial institutions and enterprises on the stability of strategy choice and explore the reasons affecting the equilibrium of evolutionary game system, Matlab software is used in this paper to simulate and demonstrate evolution process and trend of the model under the variation of different parameters, and analyze the effect of each parameter change on the evolution result. Main factors of 3 game subjects that affect the game equilibrium are chosen in this paper for comparative analysis: government subsidies C1 and taxation C2; cost P of green financial services and income F of green financial services; financial cost invested by enterprises (K1) and indirect benefits from green technology innovation (n). It is assumed that the initial value of strategy ratio of enterprises and financial institutions is 0.5; that is to say, x0 = 0.5 and y0 =0. 5, and then corresponding initial values of each parameter are set as: K2=50, K1=15, W=10, S1=80, S2=30, m=0.5, n=50, C1=20, C2=30, P=40, q=20, F=45.

(1) The effect of government subsidies C1 and taxation C2 on enterprise strategy

With other parameters unchanged, when the intensity of subsidies is assigned as follows: C1 =15, C1=25, C1 =40 and C1=60, the effect of subsidies on the evolution of enterprise strategy is simulated. The results show that the intensity of government subsidy is positively related to the choice of green technology innovation development strategy by enterprises; that is to say, the greater the intensity of government subsidy to enterprises is, the more enterprises will be stimulated to be engaged in green technology innovation, and the more conducive it will be to the evolution of enterprises to “green innovation” strategy. In the same way, when taxation is assigned as follows: C2 =0, C2=50, C2 =65 and C2=80, the results show that the more tax levied by the government to the enterprises adopting the traditional production mode is, the more conducive it will be to the evolution of enterprises to “green innovation” strategy. The simulation results of dynamic evolution are shown in Fig.6.

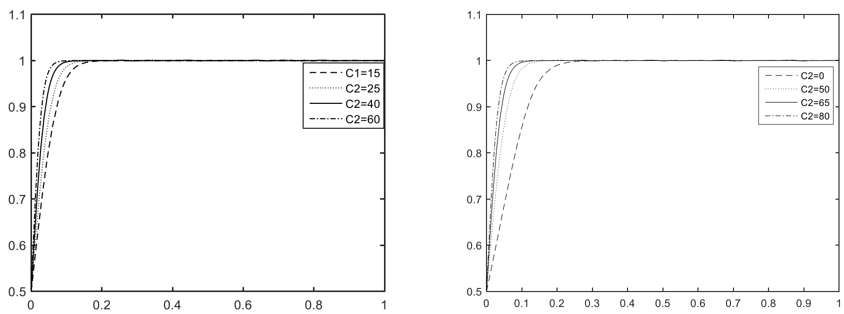

FIGURE 6 Simulation results of dynamic evolution

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(2) The effect of income F of green financial services and cost P of green financial services on enterprise strategy

With other parameters unchanged, when income of green financial services is assigned as follows: F =10, F=30, F=50 and F=80, the effect of green financial services on the evolution of enterprise strategy is simulated. The results show that the income of green financial services is positively related to the choice of green technology innovation development strategy by enterprises; that is to say, the higher the income of green financial services is, the more financial institutions will be stimulated to carry out green financial services, thus promoting cooperation between financial institutions and enterprises in green technology innovation, and being more conducive to the evolution of enterprises to "green innovation" strategy. In the same way, when cost of green financial services is assigned as follows: P =20, P=30, P=40 and P=50, the results show that the cost of green financial services is negatively related to the choice of green technology innovation development strategy by enterprises; that is to say, the lower the cost of green financial services is, the more conducive it will be to promoting the evolution of enterprises to "green innovation" strategy. The simulation results of dynamic evolution are shown in Fig.7.

(3) The effect of financial cost invested by enterprises (K1) and indirect benefits from green technology innovation (n) on enterprise strategy

With other parameters unchanged, when financial cost is assigned as follows: K1 =10, K1=20, K1 =30 and K1=60, the effect of financial cost on the evolution of enterprise strategy is simulated. The results show that financial cost invested by enterprises is negatively related to the choice of green technology innovation development strategy by enterprises; that is to say, the lower the financial cost invested by enterprises is, the more enterprises will be stimulated to be engaged in green technology innovation, and the more conducive it will be to the evolution of enterprises to "green innovation" strategy. In the same way, when indirect benefits are assigned as follows: n=10, n=50, n=35 and n=80, the results show that the greater the indirect benefits obtained by enterprises for engagement in green technology innovation are, the more conducive it will be to promoting the evolution of enterprises to "green innovation" strategy. The simulation results of dynamic evolution are shown in Fig.8.

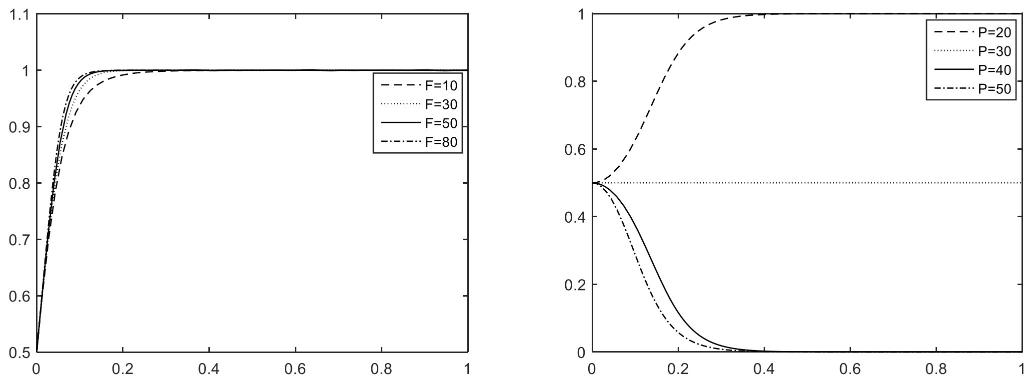

FIGURE 7 Simulation results of dynamic evolution

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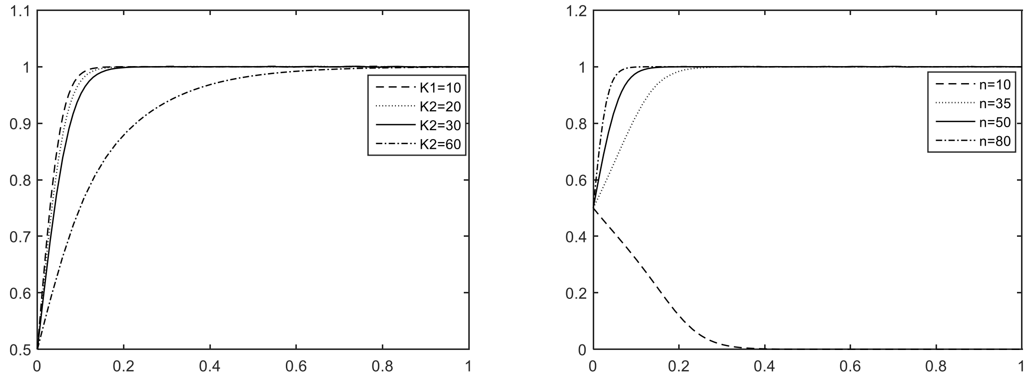

Figure 8 Simulation results of dynamic evolution

V. CONCLUSIONS AND SUGGESTIONS

In this paper, the trilateral evolutionary game model of government, financial institutions and enterprises and its dynamic replication equation were constructed under the premise of bounded rationality assumption. The Matlab software was used to numerically simulate the interaction evolution process of the three parties, the effect of each parameter change on the result of system evolution was analyzed and factors affecting final evolution of the system to an ideal state and the influencing mechanism have been explored. The research results reveal that choice of government, financial institutions and enterprises to (incentive, support, innovation) strategy set is the optimal state of green technology innovation development. Government subsidies for enterprises to adopt green technology innovation and taxation on traditional production, costs and benefits of financial institutions for implementation of green financial services, expected benefits of enterprises for engagement in green technology innovation, indirect income of enterprises and financial institutions and so on will affect the formation of the optimal equilibrium point of green technology innovation development. To further promote the development of green technology innovation in China, the government plays an extremely important role and it should play a guiding and regulating role, and mobilize the enthusiasm of enterprises and financial institutions. The following suggestions are proposed in this paper:

Green incentive mechanism of the government promoted by the supply side should be improved. The first one is subsidy incentive. On the basis of the existing subsidy policy, the intensity of the subsidy for green technology innovation should be enhanced, the scope of beneficiaries should be expanded, and the power of capital market should be introduced to the large green industry projects, such as emerging and strategic industries needing investment of a lot of money, so as to give play to the role of green finance for indirect subsidy. The second one is financial and tax incentive. The ability of correct implementation of tax policy should be improved, the leverage role of tax in regulating economy should be actively exerted, various costs of enterprises for engagement in green technology innovation should be reduced, and the expected and indirect benefits of enterprises for engagement in green technology innovation should be increased, so as to activate the power of enterprises for engagement in green technology innovation. The

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third one is policy and regulation incentive. The legal protection of green technology innovation should be strengthened, relevant policy system and law and regulation system adapting to the operation of market mechanism should be established, and the extensive behavior of traditional production of enterprises should be restricted; governments at all levels should consider incorporating the content of green technology innovation into local economic and social development plans, and improve the formulation of relevant local laws and regulations; enterprises should be guided and stimulated to carry out green technology innovation and diffusion, and green technology innovation behavior of enterprises should be standardized.

The green innovation services of financial institutions assisted by the demand side should be improved. Special green funds should be set, including special funds for loan guarantee, special funds for risk compensation, special funds for financing fee subsidies and special funds for patent pledge financing for green technology innovation and achievement transformation of enterprises. The investment and financing mechanism should be innovated, the venture capital coefficient of green technology innovation should be reduced, and the access scope of social capital should be relaxed, more social capital should be guided and encouraged to flow to green industry, angel investment, venture capital and equity investment should be attracted to invest in green economy, and the exit channel of venture capital should be broadened, and the risk of green technology innovation of enterprises should be shared. Under the same conditions, priority should be given to the listing financing, refinancing or mergers and acquisition of green technology innovation enterprises. Direct investment or loan supply of financial institutions to venture capital institutions should be explored, conversion of credit claim into equity should be explored and financial institutions should be allowed to obtain part of the equity or stock options while providing loan financing to green technology innovation enterprises.

The green development system of enterprises with supply and demand interaction should be improved. First, the connection between supply and demand should be strengthened. With the market as the orientation and enterprises as main bodies, the supply side of enterprises should be promoted to active connection with and aim at the demand side of the green market, enterprises should be promoted to increase investment in basic research and application research of green technology innovation, and suitable green technology innovation development strategy of enterprises can be formulated and implemented according to the situation of ecological environment and market demand. Second, the construction of service system should be strengthened. Professional platforms for green technology innovation, including technology R & D service platform, information service platform, technology trading platform, intellectual property and science and technology achievement transformation platform, should be built within enterprises, green technology consultation and training should be carried out, and connection, cooperation and sharing of industry science and technology resources should be realized, so as to promote the spiral upward development of green technology innovation and diffusion capability of enterprises. Third, the incentive of talent policy should be strengthened. The use, assessment, reward and training should be combined, and through the system innovation within the enterprise, such as technology invested as capital stock, scientific researchers who have made significant contributions to green technology innovation should be rewarded, to form a powerful force promoting the development of green technology innovation within enterprises.

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