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Research Article

Behavioral Analysis of Subjects for Green Technology Innovation: A Tripartite Evolutionary Game Model

Yongquan Guo,[1] **Hua Zou**,[1] **and Zhu Liu**[2]

[1]*School of Management, Shenyang University of Technology, Shenyang 110870, China*
[2]*Shenyang Normal University, Shenyang 110034, China*

Correspondence should be addressed to Yongquan Guo; gyqdyxiang@163.com and Hua Zou; suo-2001@163.com

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The application of green technologies can reduce environmental hazards and promote sustainability. The connotation of green technology innovation has two main aspects: the first aspect is the generation of green technology from nothing to something, and the other aspect is the improvement and upgrading of existing green technology; these two aspects are related. However, from the existing research, there are relatively few studies on the process of green technology innovation from these two aspects at the same time. If green technology is not studied from this perspective, the evolutionary process and influencing factors of green technology from generation to development cannot be clarified, which is not conducive to the development of green technology and the realization of the goal of environmental friendliness. Research considers the green innovation process from R&D to upgrading linkages and analyses the roles of government departments, green technology R&D institutions, and green technology application enterprises in green technology innovation. In addition, the green technology application enterprises are considered to promote technology enhancement through technology application feedback with green technology R&D institutions. The evolutionary game model of three subjects was established, the strategic evolution process of different subjects was analyzed, the influence of each element on the strategic choice of different subjects was explored, and the stability analysis of strategic choice was conducted using simulation software. The study shows the following: (1) The greater the government's punishment and support to green technology R&D institutions, the more favorable it is for green technology R&D institutions to carry out green technology R&D. (2) In green technology applications, if the government has no direct interest relationship with green technology application enterprises, the enterprises will choose negative response behavior. (3) The greater the technology enhancement gains of green technology R&D institutions and the greater the feedback gains of technology applications actively carried out by enterprises in response to the government's call, the more the government departments tend to support green technology R&D.

1. Introduction

Green technology is the basis of "green development", which is a general term for technologies that aim at maximizing energy saving and environmental friendliness. With the increasing global attention towards environmental protection, green production, and green consumption, green technology has become one of the most important technologies for companies to occupy the market and maintain their competitiveness [1]. In addition, green technology is a historically inevitable choice to maintain the sustainability of production and resources. With the emergence of environmental values, the problem of maximizing economic efficiency and low environmental efficiency of natural resource output by previous technologies has gradually emerged, and the ideas of "conquering nature" and "man is better than God" have not been followed by the laws of ecological evolution. In the long run, the value generated by green technology will be conducive to the long-term stable development of eco-friendly production and the balanced interaction between human and nature. Green technology requires adherence to a "green" philosophy from the beginning of technology development to the entire technology application cycle.

Narrowly speaking, green technology refers to a specific technology related to energy and environmental protection, such as magnetic levitation technology. Broadly speaking, it refers to a dynamic system composed of a variety of technologies and material means. [2, 3] with a long history of development or the newly researched hot technologies, such as energy technology, material technology, catalyst technology, separation technology, biotechnology, and resource recovery and utilization. Although green technologies are classified into various categories and involve a wide range of industries, the role played by multiple subjects in the process of green technology innovation needs to be described in a popular context to describe its common laws. This requires a more macroscopic view of the multiple subjects involved in green technology R&D and clarifies the roles played by different subjects in green technology innovation and the interactive game process of subjects in the process of green technology R&D. In what benefit situation, how the decision behavior of each subject is also an important proposition of this paper.

Most of the current research on green technology focuses on green technology innovations [4–7] such as the importance of a certain policy or government subsidy to induce green technology innovation in enterprises [8], the choice of innovation model, and the different effects on different types of subject enterprises [9–11]. The distribution pattern of industrial technology innovation efficiency and the influencing factors of industrial green innovation efficiency, such as industry scale, structure, and government, are studied, and the measures of how to promote industrial green innovation efficiency are clarified [12–14]. In addition, relevant studies are distributed to study the role of intermediaries [15] in green technology innovation in terms of methods, and existing studies mostly use empirical data studies [16–18].

For the study green technologies, Chu et al. [19] have introduced green products as a consideration to explore how to incentivise supply chain agents. In addition, to explore the influence of R&D investment and government regulation on industrial green technology R&D, the guided R&D investment has a stage-positive effect on green technology progress, show the reason why environmental regulation is not obvious to guide, propose that the main influencing factors of industrial green technology improvement are state property rights and enterprise scale, and put forward policy suggestions to promote industrial green technology progress. Research on green technology research and development mainly considers the role of enterprises as the main producers of technological products [20].

The rationality of choosing evolutionary games [21–23] lies in their ability to perform subject behavior analysis, which is consistent with the exploration of the choice of subject strategies in the development and application of green technologies, for example, scholars have used an evolutionary game approach to explore the dynamics of the behavior of parties involved in green buildings [24], other scholars have developed an evolutionary game model of real estate developers and consumers under different carbon tax policies to explore the impact of carbon tax policies on the choice of stakeholders in the construction industry [25]. Chen et al. [26] developed two game models to explore the dynamic process of firms' choice of green innovation and the factors influencing that choice. In addition, the evolutionary game is fully applied to the study of dynamic process change. The choice of participant strategies in the green technology R&D process changes dynamically with the change of interests and influencing factors of each subject, which reflects the applicability of evolutionary game to this problem. For example, evolutionary game is used to analyze the evolutionary process of firms and network structures in innovation networks, [27] and based on the evolutionary game, the dynamic role process among the government, port enterprises, and liner companies and the choice strategies of the three players are discussed [28]. Multiparty evolutionary games are more likely to reveal the intrinsic mechanisms of complex problems and are effective in studying the strategy problems of subjects with limited rationality. Evolutionary games are also applicable in the study of technologies, for example, it is used to study the problem of technology strategy of enterprises, to simulate the factors affecting the choice of technology strategy of enterprises, and to determine the primary and secondary factors of technology strategy through analysis [29]. In addition, this method is used to study technological innovation problems, analyze the roles played by different players in technological innovation, and clarify that technological innovation can only be achieved through the healthy interaction of different players [30]. Therefore, the evolutionary game approach can be applied to the development and application of green technologies.

The analysis of the existing research literature and the applicability of the evolutionary game approach reveals: First, most of the existing literature focuses on the efficiency of green technology innovation. Second, the process of green technology innovation is studied as a whole without considering the intrinsic process of green technology innovation. Third, most of the existing research on green technology R&D only considers the impact of different policies of the same subject on green technology R&D. At the same time, there is a lack of research that studies the green technology innovation process and the interactive behavior of multiple subjects in the whole process from both green technology R&D and green technology upgrading. In this paper, a tripartite evolutionary game model of government departments, green technology R&D institutions, and green technology application enterprises is established from two perspectives of green technology R&D and green technology upgrading, and the equilibrium and stability of the interests of different subjects in the green technology innovation process and the influence of different factors on the subjects' decisions are explored, and the model is verified using simulation software and the different subjects' strategies.

2. Model Construction

The leading and incentive role of the government is introduced. China's emphasis on green technologies is fully reflected in the newly released "*Guiding Opinions on Accelerating the Establishment of a Sound Economic System for Green, Low-Carbon and Circular Development*". The development of green technology can be started from two aspects: improving the economic development system—"forming a green, low-carbon, and circular development system" and transforming the economic development mode—“turning the economic development mode into a green, low-carbon, and circular development track”. If enterprises adopt green technologies, they may be less willing to do so due to the high cost of experimentation at the primary stage and the lack of government guidance and strong support. Government policies and regulations emphasize “green” and provide fertile “soil” for the development of green technologies.

The government plays a leading role in the research and development of green technologies and provides an external environment for the research and development of green technologies.

The feedback process of enterprises is described. The main body of green technology application is enterprises. The embedding of green technology and its integration with enterprise technology innovation are the basic characteristics of enterprise green technology application. As the green technology is still in the development stage, the riskiness of the enterprise determines the uncertainty of the benefit of the application of green technology. For enterprises, it is time-consuming and risky to independently complete the research and development of a green technology and put it into the market, so they will seek cooperation with green technology research and development institutions under the support of government policies and finance to spread the risk and share the benefits. Since enterprises and R&D institutes have different goals, that is, enterprises pursue economic benefits and industrial reality, while green technology R&D institutes focus on the enhancement of technology itself, often ignoring application costs; such goal differences will cause a huge waste of funds and energy and financial resources in the process of green technology R&D if timely correction is not made. Therefore, enterprises and research institutes should communicate in a timely manner to conduct efficient and targeted R&D. If green technology is described as fruit, then a green technology R&D institution can be described as a farmer carrying out the process of cultivation.

The main bearers of green technology R&D are generally universities, research institutes, and other such green technology R&D institutions. The demand of a certain green technology usually comes from the industrial reality and enterprise application, and the technology R&D institutions such as universities and research institutes carry out green technology R&D as the main force of R&D. Through the enterprises’ continuous feedback on technology application and product-market response, the green technologies of universities, research institutes, and other technology R&D institutions become more mature. In summary, whether it is a disruptive green technology or an improved green technology, the government’s policy leadership and incentive, technology application enterprises, and R&D institutions to green technology research and development, make the green technology application cost lower and more and more for the actual use of industry; therefore, in the green technology research and development, government departments, green technology research, and development institutions, green technology application enterprises play an important role. The green technology application companies are described as the pickers and buyers of the fruit, not only picking and buying the fruit but also communicating with the farmer about the quality of the fruit to ensure that it meets the requirements of the purchaser.

Then, the relationship among government departments, R&D institutions of green technologies, and enterprises applying green technologies can be represented in Figure 1, and logic diagram of system interactions is shown in Figure 2.

Assumption 1. All three parties, including universities, research institutes, and other technology R&D institutions, technology application enterprises, and the government, are finite rational. There are two kinds of strategies for green technology R&D institutions, such as universities and research institutes, which are R&D strategies and non-R&D strategies. The strategies of green technology application enterprises are feedback strategies and nonfeedback strategies. Government department will choose to support the R&D of green technology or not to support the R&D of green technology.

Assumption 2. The probability that green technology R&D institutions, such as universities and research institutes, choose R&D is x $(0 < x < 1)$, the probability that green technology application enterprises give feedback on application opinions is y $(0 < x < 1)$, and the probability that government departments support green technology R&D is z $(0 < x < 1)$. Therefore, the probability that green technology R&D institutions do not carry out green technology R&D is $1 - x$, the probability that green technology application enterprises do not provide technology feedback is $1 - y$, and the probability that government departments do not support green technology R&D is $1 - z$.

Assumption 3. Overall revenue of government departments is R_G, the cost of supporting green technology R&D by government departments is S_G, the loss of not supporting green technology R&D by government departments is S_S, and reputation gained by government departments for supporting technology R&D is E $(E > S_G)$.

Assumption 4. The benefits of green technology R&D institutions are R_D, the input cost when carrying out green technology R&D activities is I_D, the input cost when not carrying out green technology R&D is I_{D1}, and $I_D > I_{D1}$. Due to the feedback behavior of the enterprise, the benefits of technology enhancement of green technology R&D institution are R_R, and the penalty amount of government department when green technology R&D institution does not carry out green technology R&D is F.

Assumption 5. The benefits of technology application enterprise is R_T; when the enterprise gives a feedback, its feedback cost is I_T; when the research institute conducts technology research and development, the enterprise’s benefits is R_T; and when the research institute does not conduct research and development, the enterprise’s benefits is R_{T1}. Responding to the call of government departments

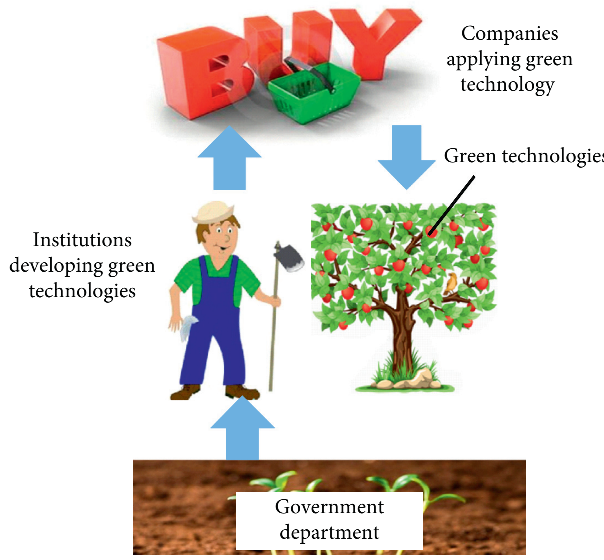

Figure 1: The "fruitful" structure of subject interaction.

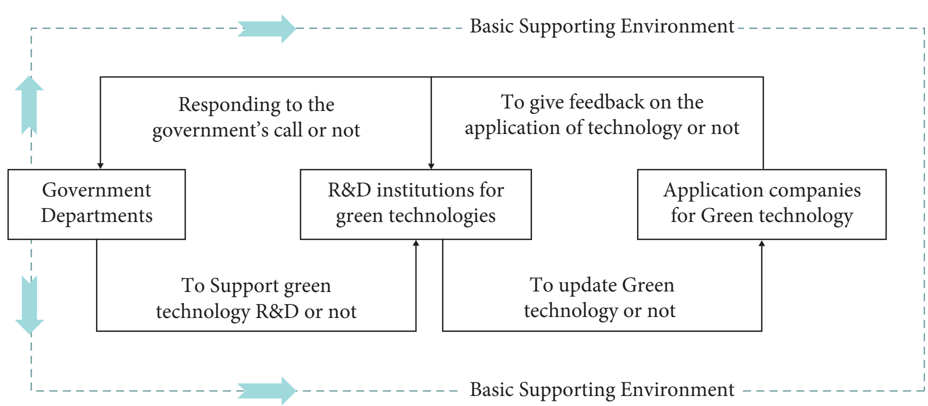

Figure 2: Logic diagram of system interactions.

and actively implementing green technology application activities, the benefits generated by the company is P.

Based on the above assumptions, the Payoff matrix for R&D institutions of green technologies is shown in Tables 1 and 2.

3. Model Analysis

3.1. Strategy Stability Analysis of Green Technology R&D Institutions. The expected payoff of a technology R&D institution conducting green technology R&D is U_{11}, the expected payoff of not conducting green technology R&D is U_{12}, and the average payoff is $\overline{U_1}$; then,

$$\begin{aligned}
U_{11} &= yz(R_D - I_D + R_R) + y(1-z)(R_D - I_D + R_R) + (1-y)z(R_D - I_D) + (1-y)(1-z)(R_D - I_D),\\
U_{12} &= yz(R_D - I_{D1} - F) + y(1-z)(R_D - I_{D1}) + (1-y)z(R_D - I_{D1} - F) + (1-y)(1-z)(R_D - I_D),\\
\overline{U_1} &= xU_{11} + (1-x)U_{12}.
\end{aligned} \quad (1)$$

Replication dynamic equations of the strategic choice of green technology R&D institutions are as follows:

$$F(X) = \frac{\mathrm{d}x}{\mathrm{d}t} = x(U_{11} - \overline{U_1}) = x(x-1)(I_D - I_{D1} - yR_R - zF). \quad (2)$$

Derive $F(X)$ relative to x, and the outcome is as follows:

$$F'(X) = (2x-1)(I_D - I_{D1} - yR_R - zF). \quad (3)$$

From the stability theorem, it is known that the strategy choice of technology R&D institution is in a stable state.

Table 1: Payoff matrix for R&D institutions of green technologies when it is working on green technology.

R&D institutions	Companies that apply green technology	Government departments: Support	Government departments: Do not support
Working on green technology	Feedback	$R_D - I_D + R_R$ $R_T - I_T + P$ $R_G - S_G + E$	$R_D - I_D + R_R$ $R_T - I_T$ R_G
	Do not feedback	$R_D - I_D$ R_T $R_G - S_G + E$	$R_D - I_D$ R_T R_G

Table 2: Payoff matrix for R&D institutions of green technologies when it is not working on green technology.

R&D institutions	Companies that apply green technology	Government departments: Support	Government departments: Do not support
Not working on green technology	Feedback	$R_D - I_{D1} - F$ $R_{T1} - I_T + P$ $R_G - S_G + E + F$	$R_D - I_{D1}$ $R_{T1} - I_T$ $R_G - S_S$
	Do not feedback	$R_D - I_{D1} - F$ R_{T1} $R_G - S_G + F + E$	$R_D - I_{D1}$ R_{T1} $R_G - S_s$

When $F(X) = 0$ and $F(X) < 0$, $y^* = (I_D - I_{D1} - zF/R_R)$ and all x are in an evolutionary stable state. When $y < y^*$, $x = 0$ is the evolutionary stability point. When $y > y^*$, $x = 1$ is the evolutionary stability point.

The probability that green technology R&D institutions do not carry out green technology R&D is C_{11}, and the probability that green technology R&D institutions choose R&D is C_{12}.

$$C_{11} = \int\int \frac{I_D - I_{D1} - zF}{R_R} \mathrm{d}z\mathrm{d}x = \frac{2(I_D - I_{D1}) - F}{2R_R}, \quad C_{12} = 1 - C_{11}. \tag{4}$$

Proposition 1. *The probability of green technology R&D by green technology R&D institutions increases with the intensity of government incentives and increases with the probability of technology application feedback from firms.*

Proof of Proposition 1. From the above analysis of the stability of the strategy choice of green technology R&D institutions, when $z < (I_D - I_{D1} - yR_R/F)$, $y < y^*$ $F'(X)|_{x=0} < 0$ and $x = 0$ is the evolutionary stability point; when $z > I_D - I_{D1} - yR_R/F$, $y > y^*$, $F'(X)|_{x=0} > 0$ and $x = 1$ is the evolutionary stability point. Therefore, as y and z increase, the green technology R&D institution stabilization strategy gradually tends to be 1 from 0. The proposition is proved.

Proposition 1 suggests that increasing the probability of feedback from green technology application companies is conducive to the generation of R&D behaviors by green technology R&D institutions and that government departments can induce green technology R&D institutions to be more biased in conducting R&D activities by increasing their support for feedback behaviors from green technology application companies and by creating a positive green technology R&D climate. □

Proposition 2. *The behavior of a green technology R&D institution in conducting R&D activities is positively related to the technology enhancement benefit it receives from conducting green technology R&D and the penalty it receives from government departments for not conducting R&D, and negatively related to the cost difference between conducting R&D or not.*

Proof of Proposition 2. As $(\partial C_{12}/\partial R_R) > 0$, $(\partial C_{12}/\partial F) > 0$, and $(\partial C_{12}/\partial (I_D - I_{D1})) < 0$, a rise in R_R and F and a fall in $I_D–I_{D1}$ can lead to an increase in the probability of green technology R&D by green technology R&D institutions.

Proposition 2 suggests that green technology R&D institutions are more inclined to conduct green technology R&D when they have a better level of revenue. Government departments can curb the non-R&D behavior of technology R&D institutions by increasing the penalties for their inaction. □

3.2. Strategic Stability Analysis of Green Technology Application Companies. The expected payoff for green technology application companies to carry out technical problem feedback is U_{21}, the expected payoff for technology application companies not to carry out technical problem feedback is U_{22}, and the average payoff is $\overline{U_2}$; then,

$$\begin{aligned} U_{21} &= xz(R_T - I_T + P) + x(1-z)(R_T - I_T) + (1-x)z(R_{T1} + P - I_T) + (1-x)(1-z)(R_{T1} - I_T),\\ U_{22} &= xzR_T + x(1-z)R_T + (1-x)zR_{T1} + (1-x)(1-z)(R_{T1} - I_T),\\ \overline{U_2} &= yU_{21} + (1-y)U_{22}. \end{aligned} \tag{5}$$

Replication dynamic equations for the strategic choice of green technology application firms are as follows:

$$F(Y) = \frac{\mathrm{d}y}{\mathrm{d}t} = y(U_{21} - \overline{U_2}) = y(y-1)[I_T - zP + x(R_T - R_{T1})]. \tag{6}$$

Derive $F(Y)$ relative to y, and the outcome is as follows:

$$F'(Y) = (2y-1)[I_T - zP + x(R_T - R_{T1})]. \tag{7}$$

The strategy choice of green technology application companies is in a stable state when $F(Y) = 0$ and $F'(Y) < 0$.

When $z^* = (x(R_T - R_{T1}) - I_T/P)$, all y are in evolutionary stable state. When $z < z^*$, $y = 0$ is the evolutionary stable point and when $z > z^*$, $y = 1$ is the evolutionary stable point.

The probability of nonfeedback from green technology application companies is $C_{21,}$ and the probability of feedback is C_{22}.

$$C_{21} = \iint \frac{x\left(R_{T-R_{T1}}\right) - I_T}{P} \mathrm{d}x\mathrm{d}y = \frac{\left(R_{T-R_{T1}}\right) - 2I_T}{2P}, \qquad (8)$$
$$C_{22} = 1 - C_{21}.$$

Proposition 3. *The probability of green technology application enterprises conducting green technology application feedback increases with the probability of green technology R&D institutions conducting green technology R&D and the probability of government departments supporting green technology R&D policy environment.*

Proof of Proposition 3. From the aforementioned analysis of the stability of strategy choice of green technology application firms, it is clear that $z < z^*$, $x < (zP - I_T/R_T - R_{T1})$ and the $y = 0$ is an evolutionary stabilization strategy. $z > z^*$, $x > (zP - I_T/R_T - R_{T1})$ and the $y = 1$ is an evolutionary stabilization strategy. As x and z increase, the feedback probability of green technology application firms increases from 0 to 1.

Proposition 3 shows that whether green technology application enterprises choose to give feedback on technology application is influenced by the incentive policies of green technology R&D institutions and government departments. Green technology R&D institutions conduct technology R&D, and government departments strengthen incentives to form a positive R&D environment and strengthen the role of guidance, which can make green technology application enterprises provide feedback on technology application, thus promoting a virtuous cycle of green technology development. □

Proposition 4. *The probability that a green technology application enterprises will provide feedback on its technology application is positively related to its benefit, positively related to the difference in its cost of whether or not to provide feedback, and negatively related to its cost at the time of feedback.*

Proof of Proposition 4. As $(\partial C_{22}/\partial P) > 0$, $(\partial C_{22}/\partial (R_T - R_{T1})) > 0$, and $(\partial C_{22}/\partial I_T) < 0$, so is the increase of P, $(R_T–R_{T1})$ and decrease of I_T, and more green technology application companies tend to feedback on the technology application.

Proposition 4 suggests that when green technology application enterprises provide feedback on technology application, government departments should increase incentives to fully support their feedback behavior. The formation of a positive technology improvement environment is conducive to the good development of green technologies. □

3.3. Evolutionary Stabilization Strategies Supported by Government Departments. The expected payoff for government sector support is U_{31}, the expected payoff for government sector nonsupport is U_{32}, and an average payoff is $\overline{U_3}$; then,

$$\begin{aligned} U_{31} &= xy(R_G – S_G + E) + x(1 - y)(R_G – S_G + E) + (1 - x)y(R_G – S_G + E + F) + (1 - x)(1 - y)(R_G – S_G + E + F),\\ U_{32} &= xy(R_G – S_G + E) + x(1 - y)(R_G – S_G + E) + (1 - x)y(R_G – S_G + E + F) + (1 - x)(1 - y)(R_G – S_G + E + F),\\ \overline{U_3} &= zU_{31} + (1 - z)U_{32}. \end{aligned} \qquad (9)$$

The replication dynamic equation for the selection strategy of the government sector is as follows:

$$F(Z) = \frac{\mathrm{d}z}{\mathrm{d}t} = z(z - 1)\left[x(F + S_S) - (E + F + S_S - S_G)\right]. \qquad (10)$$

Derive $F(Z)$ relative to z, and the outcome is as follows:

$$F'(Z) = (2z - 1)\left[x(F + S_S) - (E + F + S_S - S_G)\right). \qquad (11)$$

From the stability theorem, when $F(Z) = 0$, $F'(Z) < 0$. The government sector's strategic choices are in a steady state. When $x^* = (F + E + S_S - S_G/F + S_S)$, all Z values are in an evolutionary steady state, when $x < x^*$, $z = 1$ is the evolutionary stability point, and when x, $z = 0$ is the evolutionary stability point.

C_{31} represents the probability that government departments do not support green technology R&D, and C_{32} represents the probability that government departments support green R&D.

$$C_{31} = \iint \frac{F + E + S_S - S_G}{F + S_S} \mathrm{d}x\mathrm{d}z = 1 + \frac{E - S_G}{F + S_S}, \qquad (12)$$
$$C_{32} = 1 - C_{31}.$$

Proposition 5. *The probability of government departments supporting green technology R&D increases as the probability of R&D by technology R&D institutions decreases.*

Proof of Proposition 5. From the analysis of the stability of strategy selection in the government sector, it is clear that when $x < x^*$, $z = 1$ is evolutionary stability point and when $x > x^*$, $z = 0$ is evolutionary stability point. As x increases, the z value becomes smaller and smaller.

Proposition 5 suggests that whether government departments support green technology R&D is influenced by the behavior of green technology R&D institutions. When technology R&D institutions tend not to conduct green technology R&D, government departments will stimulate their willingness to conduct green technology R&D by increasing the intensity of incentives. □

Proposition 6. *The probability of government department support is positively correlated with the fines imposed by government departments on research institutes for not conducting R&D, the reputation received for supporting green technology R&D, and the losses caused by nonsupport, and negatively correlated with the cost expenditures incurred for supporting green technology R&D.*

Proof of Proposition 6. As $(\partial C_{32}/\partial F) > 0$, $(\partial C_{32}/\partial E) > 0$, $(\partial C_{32}/\partial S_S) > 0$, and $(\partial C_{32}/\partial S_G) < 0$, so is the increase of F, E, and S_S and this can lead to an increase in the support of the government.

Proposition 6 suggests that the higher the reputation gained by government departments for supporting technology R&D, the more it will promote government departments to support green technology R&D. The higher the loss incurred by not supporting green technology R&D, the more it stimulates the active policy of government departments to support green technology R&D. The willingness of government departments to support green technology R&D activities is seriously lacking when the expenses incurred by government departments to support green technology R&D are very high. The higher the amount of fines charged by government departments, the more it motivates government departments to support green technology R&D. □

4. Analysis of Evolutionary Stability Points

The evolutionary stabilization strategy of the evolutionary game can be derived from the local stability analysis of the Jacobi matrix of the corresponding replicated dynamical system, the analysis of local equilibrium points is as shown in Table 3, the Jacobi matrix is

$$J = \begin{pmatrix} (2x-1)\left(I_D - I_{D1} - yR_R - zF\right), & x(x-1)\left(-R_R\right) & x(x-1)(-F) \\ y(y-1)\left(R_{T\_}R_{T1}\right), & (2y-1)\left[I_T - zP + x\left(R_{T\_}R_{T1}\right)\right] & y(y-1)(-P) \\ z(z-1)\left(F + S_S\right), & 0 & (2z-1)\left[xF + S_S = -\left(E + F + S_S - S_G\right)\right] \end{pmatrix}. \quad (13)$$

Scenario 1. When $I_{D1} + F < I_D$, $P < I_T$, and $S_S > S_G$, the overall loss of the technology R&D institution for not conducting green technology R&D is less than the overall loss of conducting green technology R&D, and the gain that the enterprise gets from conducting green technology application is less than its input of conducting technology satisfaction feedback, and the loss of the government department for not supporting conducting green technology R&D is higher than its input of supporting R&D, so the evolutionary stability point is the point (0, 0, 1), the point means that green technology R&D institutions choose a strategy of no R&D, companies choose a strategy of no feedback, and governments choose a strategy of supporting green technology R&D.

Scenario 2. When $I_{D1} + F < I_D - R_R$, $I_T < P$, and $S_S > S_G$, the expenditure of green technology R&D institutions not conducting technology R&D is smaller than the income obtained from conducting R&D, and the cost of feedback from enterprises is smaller than the benefit obtained from feedback from enterprises, and the loss of government departments not supporting conducting green technology R&D is higher than their input of supporting R&D. The evolutionary stability strategy is (0, 1, 1), the point means that green technology R&D institutions choose the strategy of not conducting technology R&D, companies choose the strategy of providing feedback on technology application, and the government chooses the strategy of supporting green technology R&D.

Scenario 3. When $I_D < F + I_{D1}$, $R_{T1} < R_T - P + I_T$, and $S_G < E$, the R&D cost of green technology R&D institutions is smaller than the loss of not conducting R&D, the benefit of enterprises to conduct technology application feedback is smaller than the benefit of enterprises not to give feedback, and the government sector's inputs are smaller than its benefits. Evolutionary stability strategy is (1, 0, 1), the point means that green technology R&D institutions choose the strategy of conducting technology R&D, companies choose the strategy of not providing feedback on technology application, and the government chooses the strategy of supporting green technology R&D.

Scenario 4. When $I_D - R_R < I_{D1} + F$, $R_T + I_T - P < R_{T1}$, and $S_G < E$, the expenditure of green technology R&D institutions not conducting technology R&D is larger than the income from conducting R&D, the benefit of enterprises' feedback on technology application is larger than the benefit of not feedback, and the government department's investment is smaller than the government department's benefit. The stable strategy is (1, 1, 1), the point means that green

Table 3: Analysis of local equilibrium points.

Equilibrium point	Eigenvalue λ_1	Eigenvalue λ_2	Eigenvalue λ_3
(0, 0, 0)	$-I_D + I_{D1}$	$-I_T$	$E + F + S_S - S_G$
(0, 0, 1)	$I_{D1} - I_D + F$	$P - I_T$	$-(E + F + S_S - S_G)$
(0, 1, 0)	$I_{D1} - I_D + R_R$	I_T	$E + F + S_S - S_G$
(0, 1, 1)	$I_{D1} - I_D + R_R + F$	$I_T - P$	$-(E + F + S_S - S_G)$
(1, 0, 0)	$I_D - I_{D1}$	$R_{T1} - R_T - I_T$	$E - S_G$
(1, 0, 1)	$I_D - I_{D1} - F$	$R_{T1} - R_T + P - I_T$	$S_G - E$
(1, 1, 1)	$I_D - I_{D1} - R_R$	$R_T - R_{T1} + I_T$	$E - S_G$

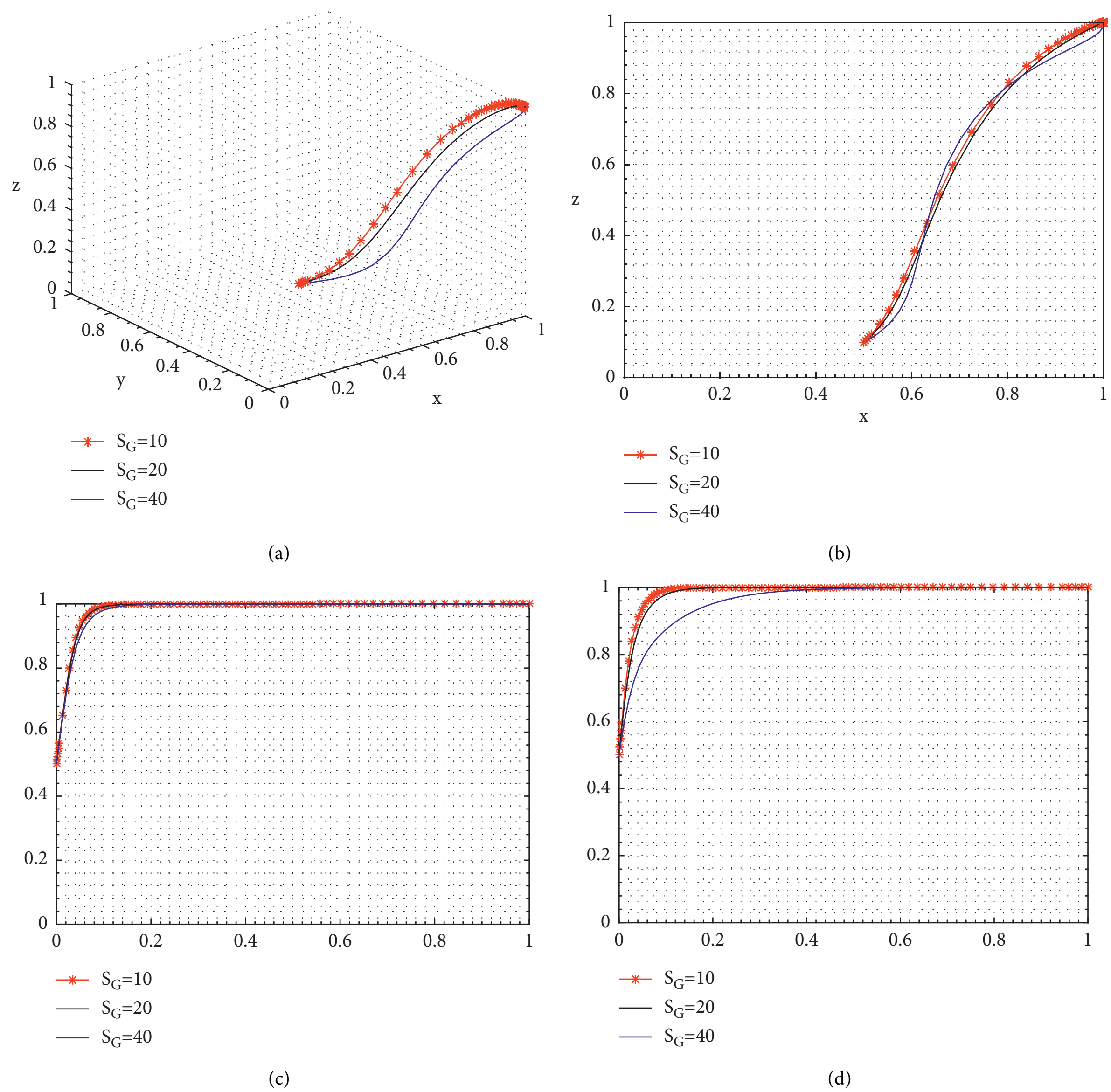

Figure 3: The influence of cost expenditures. The influence on (a) x, y, and z; (b) x and z; (c) x (with the change of time); and (d) z (with the change of time).

technology R&D institutions choose the strategy of conducting technology R&D, companies choose the strategy of providing feedback on technology application, and the government chooses the strategy of supporting green technology R&D.

5. Simulation Analysis

According to the aforementioned replicated dynamic equations of the system, the stability of the system is verified using simulation software to analyze the influence of

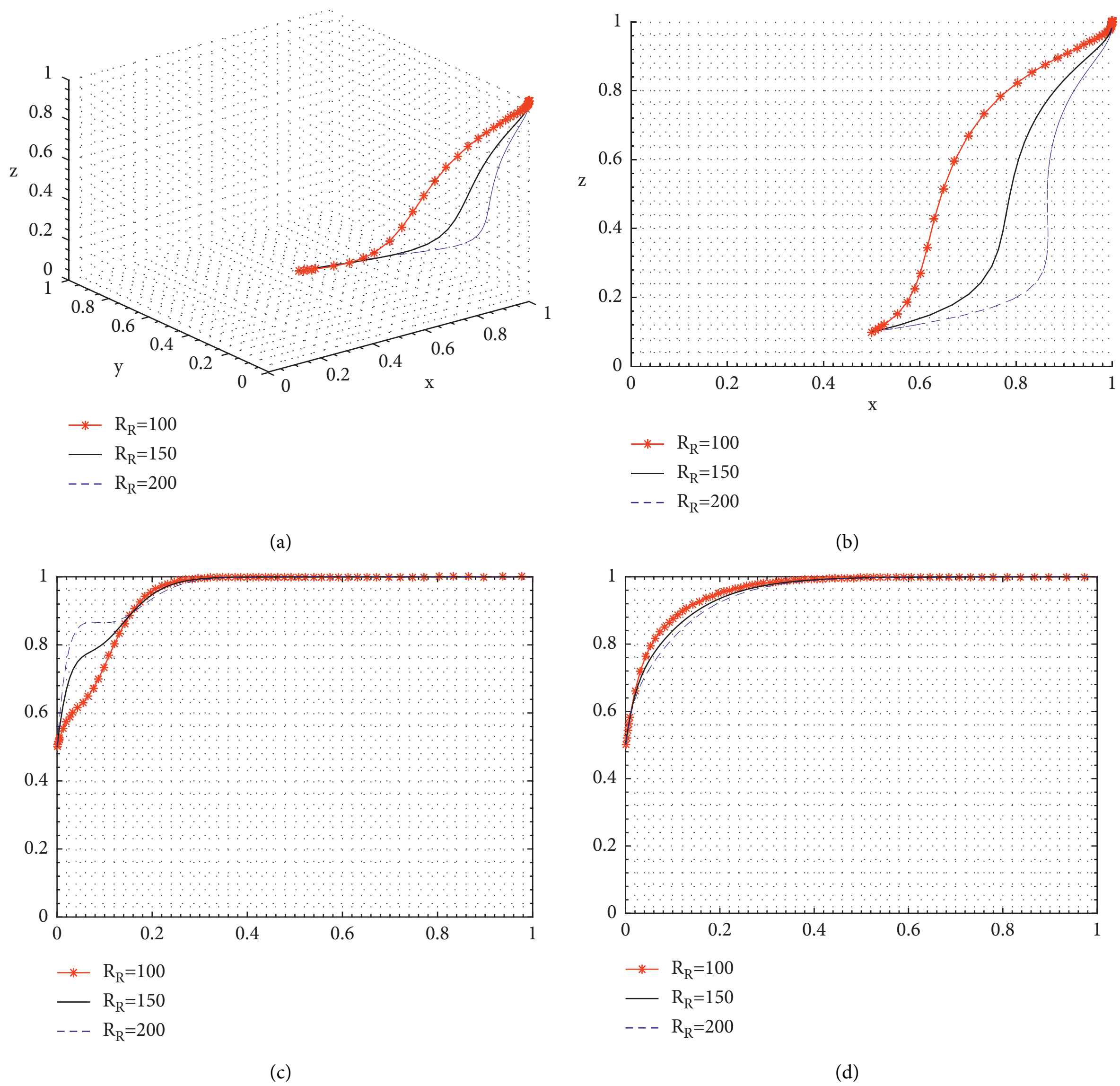

FIGURE 4: The influence of R&D institutional earnings. The influence on (a) x, y, and z; (b) x and z; (c) x (with the change of time); and (d) z (with the change of time).

different parameter changes on the evolutionary stability of the system and to synthesize the experience of existing literature on the value of the parameters, the parameters are assigned as follows: $R_R = 100$, $F = 60$, $I_T = 25$, $P = 35$, $R_T – R_{T1} = 25$, $F + S_S = 60$, $E = 50$, and $S_G = 40$.

5.1. Impact of S_G Changes on the System. The effect of S_G changes on the system is analyzed so that S_G takes the values of 10, 20, and 40, and the system evolution results are shown in Figure 3.

When $S_G < E$, government departments tend to choose to support green technology R&D as the value of S_G increases, but the evolution to 1 becomes slower as S_G increases, indicating that the willingness of government departments to support green technology R&D decreases as spending increases. The probability of technology R&D by green technology R&D institutions increases with the increase of government departmental input.

5.2. Impact of R_R Changes on the System. The effect of R_R changes on the system is analyzed so that R_R takes the values of 100, 150, and 200, and the system evolution results are shown in Figure 4.

With the increase of R_R, the benefits of technology R&D institutions for technology enhancement increases, and technology R&D institutions are more inclined to choose to conduct technology R&D activities, and government policies are biased to support green technology R&D at this time.

5.3. Impact of F Changes on the System. The effect of F changes on the system is analyzed so that F takes the values

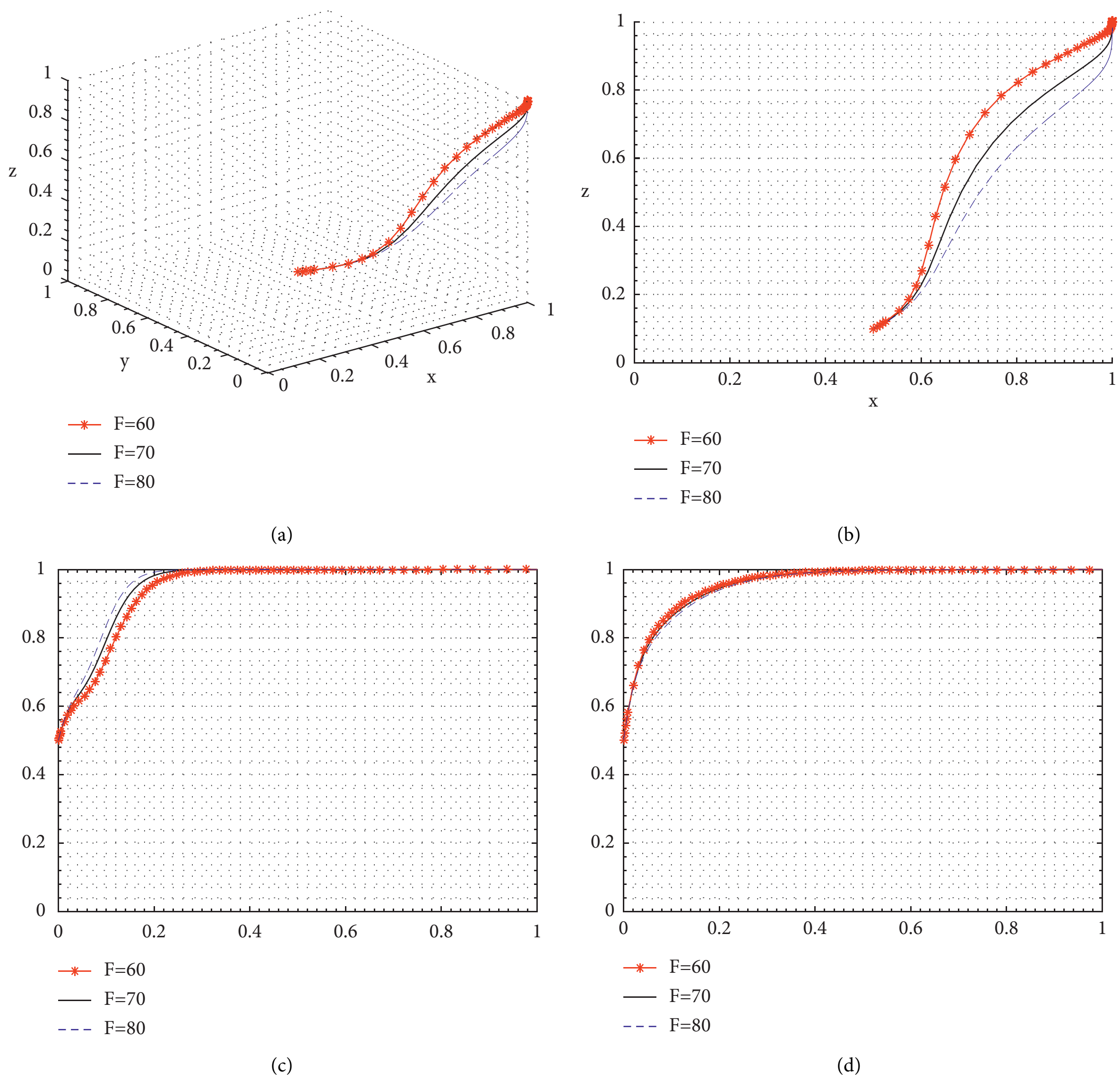

FIGURE 5: The influence of government fines. The influence on (a) x, y, and z; (b) x and z; (c) x (with the change of time); and (d) z (with the change of time).

of 60, 70, and 80, and the system evolution results are shown in Figure 5.

When a technology R&D institution does not conduct green technology R&D, the higher the amount of penalty imposed by the government department, the probability that the green technology R&D institution will choose to conduct green technology R&D increases, and the government department will tend to support the R&D activities of the technology R&D institution.

As can be seen from Figures 3 to 5, enterprises will not take feedback on the application of green technology when it does not directly involve their own benefits, and once they do, they will incur corresponding costs, such as facing inaction of research institutes in the feedback process, reduced short-term benefits, and facing technological innovation risks after feedback.

5.4. Impact of P Changes on the System. The effect of P changes on the system is analyzed so that P takes the values of 35, 70, and 150, and the system evolution results are shown in Figure 6.

The probability of feedback from enterprises on the application of green technology gradually increases to 1 as the benefits received by enterprises increase. The feedback from enterprises is a reflection of their positive attitude towards green technology and the policy preference of government departments, which coincides with the analysis of enterprises' wait-and-see attitude towards green technology. When enterprises have a positive attitude towards green technology research and development, which is reflected in a high level of initiative towards green technology research and development and application, both government departments and green technology research and

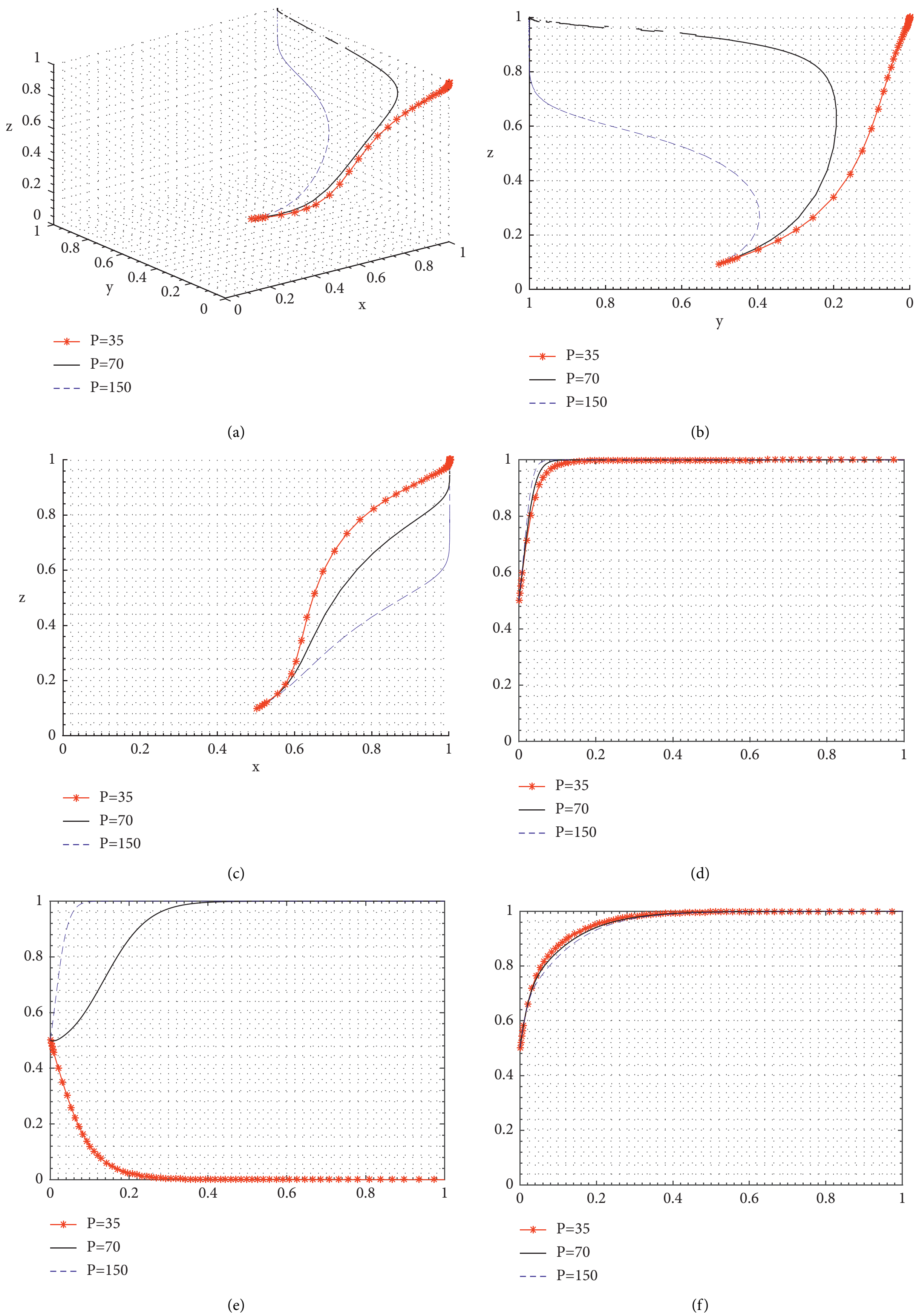

Figure 6: The influence of additional benefits to the business. The influence on (a) x, y, and z; (b) y and z; (c) x and z; (d) x (with the change of time); (e) y (with the change of time); and (f) z (with the change of time).

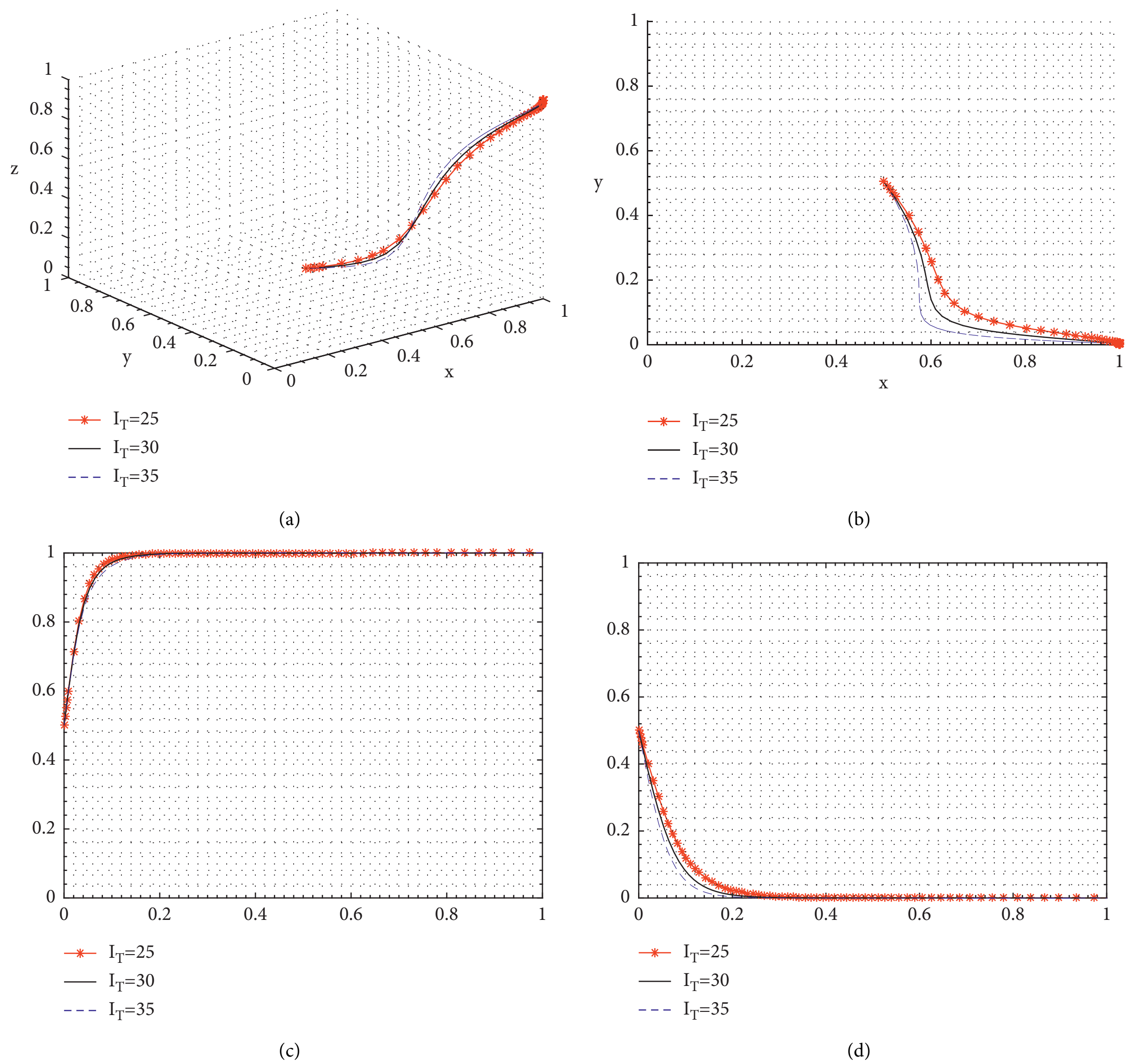

FIGURE 7: The influence of cost of feedback. The influence on (a) x, y, and z; (b) x and y; (c) x (with the change of time); and (d) y (with the change of time).

development institutions will move in the direction of supporting technology research and development.

5.5. Impact of I_T Changes on the System. The effect of I_T changes on the system is analyzed so that I_T takes the values of 25, 30, and 35, and the system evolution results are shown in Figure 7.

As the cost of feedback increases, enterprises tend to choose not to give feedback on technology application, and the higher the cost of feedback, the faster convergence to no feedback. The increase in feedback cost of enterprises, such as the increase in the number of researchers or investment energy as well as the longer duration period, laterally reflects that the more enterprises attach importance to green technology and their positive attitude towards green technology, at this time, green technology research and development institutions will carry out technology research and development, and government departments will choose to support green technology research and development.

6. Conclusion

At present, most of the academics start from the perspective of green technology innovation, emphasizing on the issues of green technology innovation influencing factors and innovation efficiency, while ignoring the innovation process of green technology from R&D to upgrading. Based on this, explores the process of green technology innovation from the perspective of R&D to upgrading, and uses the evolutionary game method to establish a three-party game model between government departments, green technology R&D institutions, and green technology application enterprises, and explores the interaction process and strategy selection process of the three parties in the process of green technology R&D and application.

First, the impact of each subject in green technology innovation is studied. By establishing an evolutionary game model among three subjects, namely, government departments, green technology R&D institutions, and green technology application enterprises, the strategic choices of the subjects and the influence of different elements on the strategic choices are analyzed.

The second is to consider the feedback process of green technology application enterprises to green technology R&D institutions, rather than the one-way circulation problem in most studies.

Third, the role played by different agents in green technology R&D is analyzed. The government is the first to realize the importance of green technology R&D in the R&D to application process and has a certain tendency to implement it, playing a leading and motivating role. Green technology R&D institutions are directly responsible for the development of green technologies, so the relationship between the government and its direct interests is considered. Green technology application enterprises and green technology R&D institutions communicate on green technology R&D and application to eliminate the impact of target differences. With the supplement of numerical analyses, the results show that:

The analysis shows that the greater the government's punishment and support to green technology R&D institutions, the more beneficial it is for green technology R&D institutions to conduct green technology R&D. There are three main policies adopted by the government. One is that the government uses a number of economic approaches to monitor and regulate green technology innovation. For example, it charges companies that emit emissions and raises the standard of emission charges, thus strengthening the constraints on companies. The second is to develop and improve regulations. For example, clarify the judicial procedures and strengthen the enforcement of environmental issues, so as to give full play to the mandatory nature of the regulations. The third is to adjust the green technology policy and eliminate backward production capacity.

In the application of green technology, the internal efficiency goal of enterprises is the internal motivation mechanism of enterprise development, and the innovation revenue of green technology carrier-green products is an important driving force for enterprises to carry out green technology innovation. In addition, if the government has no direct benefit relationship with the green technology application enterprises, the enterprises will choose the negative response behavior. In order to encourage enterprises to actively carry out green technology application and innovation, the government will adopt a series of incentive measures. For example, enterprises that carry out green technology innovation are given environmental protection subsidy funds, and enterprises that transform and upgrade old equipment are given financial subsidies and other measures, which also reflect the leading and motivating role played by government departments in green technology research and development.

With the proposal of "carbon neutral and carbon peak" in China, more and more attention is paid to the R&D of green technology, but the competition in the industry is getting fierce and requires the technology R&D cycle to be shortened as much as possible, while the R&D cycle of green technology is long, risky, and high investment, some enterprises have limited resources and capacity, so they will cooperate with R&D institutions to share the technology, some enterprises have limited resources and capacity, so they will cooperate with R&D institutions. Multisubjects to cooperate and form alliances to share the cost and risk of R&D to ensure their competitive advantages in the market. Green technology research and development institutions and enterprises communicate to achieve the level of scientific research to improve, to get more in line with their own requirements of green technology, and to achieve a win-win situation.

In addition, it is clear from the numerical simulation that the greater the gains from the technology enhancement of green technology R&D institutions and the greater the gains from the feedback of enterprises responding to the government's call to actively carry out technology application, the more the government departments tend to support green technology R&D. Therefore, the positive attitudes of green technology R&D institutions and green technology application enterprises will inversely affect the decision of government support behavior.

In this study, only the role of feedback behavior in the process of green technology R&D is considered, and the influence of green technology application efficiency on feedback behavior is not considered. Only the specificity of green technology was focused on, and the evolution of the behavior strategy of the subject in the R&D process of different types of technology was not considered; such direction will be a possible work for future research.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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