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# Evolutionary game of green manufacturing mode of enterprises under the influence of government reward and punishment

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**ABSTRACT**

Green production mode is an advanced manufacturing mode. However, due to the environmental externality of green production, it is different for a pure market mechanism to promote the evolution of green operation mode of manufacturing enterprises. Government regulation is very important. This paper establishes an evolutionary game model of whether manufacturing enterprises choose to implement green production mode when the government implements two different mechanisms of reward and punishment. Considering the complexity of strategy selection of enterprises' green production behaviour under market competition, the method constructs the simulation analysis model of enterprises' green product production behaviour with multi-subject participation. We can simulate the influence of these factors on the strategic choice of both parties (enterprises and governments) by changing the different influence factors, and studying the evolutionary law of different government guidance and regulation strategies on the production behaviour of green products. These factors include government incentives, penalties, reputations, costs, differences in the cost of implementing green production on the corporate side, corporate reputation, and false rewards or penalties. By the computer implementation of multi-subject modelling, the results show that enterprises' green product production behaviour needs the government's guidance and regulation. When formulating relevant policies, the government should combine various guidance and regulation strategies and fully consider the influence of market competition.



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## 1. Introduction

The green operation of enterprises is an important way to realize social sustainable development. Green operation mode refers to the operation mode in which the production and operation activities of an enterprise can be harmonious with the environment. In the process of green manufacturing, manufacturing enterprises not only pursue profit but also bear social and environmental responsibility [1]. The government should not only supervise and manage enterprises to implement green manufacturing, but also promote the development and popularization of green manufacturing mode and application. Green manufacturing involves complex game subjects with different goals, dynamic complex environments, and many uncertain factors, therefore the stability of the economic and political environment in the game process can't be guaranteed. Manufacturing enterprises have insufficient power and the ability to carry out green manufacturing. Only through the guidance of penalty policy or direct subsidy and reward can this advanced manufacturing mode be gradually promoted among manufacturing enterprises [2]. Evolutionary Game Theory will no longer be modelled into a completely rational game party, but humans usually achieve the game equilibrium by trial and error method. The choice of equilibrium is the function whose balanced process has been achieved, thus historical, institutional factors and balanced process details will have an influence on the multiple equilibrium choices in a game.

Zhu and He [3] analysed the influence of government subsidy on the choice of enterprise innovation mode. They point out that increasing innovation subsidy and establishing a long-term subsidy mechanism can make innovation subsidy become an effective incentive measure. Govindan *et al*. established the reward and punishment mechanism supply chain, and point out that the reward and punishment mechanism can not only improve the recovery rate, reduce the price of new products, but also benefit the whole social welfare [4-5]. Tseng *et al*. constructed a game model which considers green consumption subsidy and non-green consumption tax, analyses and discusses the influence of government financial strategy on the optimal decision of supply chain members under decentralized decision and centralized decision [6]. A game model of a green supply chain is built under a single channel, and different subsidy strategies are compared under the same government subsidy expenditure [7]. Micheli *et al*. established a green supply chain model with reward and punishment mechanism under different government target decisions. They discuss the influence of product market size, sensitivity coefficient of energy-saving level, and cost coefficient of energy-saving input on the reward and punishment intensity [8]. This paper constructs a green supply chain model considering government subsidies and risk aversion of supply chain members, and studies the risk aversion behaviours of manufacturers and retailers under centralized and decentralized decisions.

## 2. Model building

### 2.1 Evolutionary game analysis of green manufacturing

The formation mechanism of green manufacturing is due to the different social division of labour. Hence, the government supervision decision and the enterprise production decision have different responsibilities in the final production mode selection, and the relationship between the two is an evolutionary game, jointly promoting the sustainable development of green manufacturing [9-10]. However, in reality, due to the different divisions of functions between government and enterprises, their decision focus is different. Governments mainly focus on social and environmental benefits, while enterprises pay more attention to their economic benefits [11]. There is somehow a competitive relationship in profit distribution between them. Therefore, the government and enterprises are in a game state of cooperation and competition as to whether to carry out green manufacturing or not. The main manifestations are as follows: First, there is an asymmetric partnership between the government and enterprises. From the perspective of environmental and social sustainable development, both the government and enterprises need green manufacturing mode. Green manufacturing can improve government performance and regional social reputation, which includes both government reputation and corporate reputation [12]. The green production of enterprises in the region is conducive to the formation of a green industrial chain and a green manufacturing industrial cluster in the region. This forms an agglomeration effect and attracts more enterprises to adopt the green manufacturing production mode. Thus, the virtuous circles of the government tax increase and enterprise green manufacturing cost reduction are realized.

For any specific green manufacturing mode, the reason it can gain market share in the market is that the manufacturing mode satisfies the supervision and management of government market access departments, safety supervision departments, environmental supervision departments, industrial and commercial administration departments, and taxation departments outside the enterprise [13]. At the same time, it is also the result of internal and external cooperation between product design departments, the processing industrial arts department, the marketing department, the comprehensive management department, and the internal planning department which is needed for production [14].

The manufacturing industry chain is reflected in the cooperation between raw material suppliers, parts suppliers, manufacturers, service providers, capital operators, terminal equipment suppliers, and relevant government departments.

The formation mechanism of the region where the industrial cluster is located is based on the existence of the social division of labour [15]. The main approach adopted is the construction of the assistance of the upstream and downstream of the manufacturing, with the support of government policies to form a close relationship between them.

As a public policy service provider, the government carries out policy planning on environmental rewards and punishment and provides manufacturing enterprises with the environment for the development of the guaranteed green manufacturing mode. As the provider of specific green manufacturing mode, manufacturing enterprises put the environmentally friendly production mode into practice through advanced technological innovation to produce green industrial products, which can be directly used by consumers. Therefore, they are interdependent and have a cooperative relationship [16].

### 2.2 Model assumption

The basic assumptions of the evolutionary game model between the government and manufacturers in the green manufacturing industry chain are:

- $A$ is the government's reward for enterprises to implement green production. $-A$ is the government's reward for the implementation of green production enterprises. $B$ is the government's punishment for not implementing green production enterprises. $-B$ is the fine submitted by the enterprises for not implementing green production.
- $R_1$ symbolises that the government gives incentives to the green production enterprises to gain social reputation; $R_2$ symbolises that the government wrongly penalizes the enterprises that implement green production resulting in the loss of social reputation; $R_3$ is the social reputation loss caused by the government's false reward to enterprises that fail to implement green production; $R_4$ is the social reputation gained by the government for punishing enterprises that fail to implement green production.
- $\pi_0$ is the income obtained by the enterprises; $G_0$ is the office income obtained by the government.
- $r_1$ and $r_2$ are the enterprises gains of the social reputation by implementing green production; $r_3$ and $r_4$ are the losses of the social reputation of the enterprises for not implementing green production; The social reputation that enterprises gain or lose only depends on whether they have implemented green production or not, and has nothing to do with whether the government has carried out the right incentives and penalties or not.
- $\theta$ is the probability that the enterprise is rewarded for not implementing green production; $\phi$ is the probability that the enterprise is punished for green production, $0 \leq \theta \leq 1$, $0 \leq \phi \leq 1$.
- Suppose that the proportion of the government choosing incentive strategy is $x$, the proportion of the punishment strategy is $1-x$, the proportion of the enterprise choosing to implement green production is $y$, the proportion of choosing not to implementing green production is $1-y$, where $0 \leq x \leq 1, 0 \leq y \leq 1$.
- Based on the above assumptions, their payment matrix can be obtained, as shown in Table 1.

**Table 1** Payment matrix of government and enterprises

| Government \ Enterprise | Green manufacturing | Non-green manufacturing |
|---|---|---|
| Reward | $G_0 - C_1 - A + R_1$, $\pi_0 - c_1 + A + r_1$ | $G_0 - C_1 - \theta A - R_3$, $\pi_0 - c_2 + \theta A - r_3$ |
| Punishment | $G_0 - C_2 + \varphi B - R_2$, $\pi_0 - c_1 - \varphi B + \mathrm{r}_2$ | $G_0 - C_2 + B + R_4$, $\pi_0 - c_2 - B - r_4$ |

## 3. Game analysis of government rewards, punishments, and green production evolution of manufacturing enterprises

### 3.1 Game pay-off matrix

Based on the above assumptions, the evolutionary game analysis of the government presented is as follows:

**(1)** ***The payment when the government chooses the reward strategy***

$$W_1 = y(G_0 - C_1 - A + R_1) + (1 - y)(G_0 - C_1 - \theta A - R_3) \quad (1)$$

The payment when the government carries out the penalty policy:

$$W_2 = y(G_0 - C_2 + \varphi B - R_2) + (1 - y)(G_0 - C_2 - B + R_4) \quad (2)$$

The average payment from the government:

$$\overline{W} = xW_1 + (1 - x)W_2 \quad (3)$$

Therefore, the dynamic differential equation for the government is shown as follows:

$$\frac{dx(t)}{dt} = x(W_1 - \overline{W}) \quad (4)$$

$$= x(1 - x)\ \{[(1 - \varphi)B + (\theta - 1)A + R_1 + R_2 + R_3 + R_4]y + C_2 - C_1 - A\theta - B - R - R_4\}$$

$$F(x) = x(1 - x)\{[(1 - \varphi)B + (\theta - 1)A + R_1 + R_2 + R_3 + R_4]y + C_2 - C_1 - A\theta - B - R_3 - R_4\} \quad (5)$$

and so,

$$F'(x) = (1 - 2x)\{[(1 - \varphi)B + (\theta - 1)A + R_1 + R_2 + R_3 + R_4]y + C_2 - C_1 - A\theta - B - R_3 - R_4\} \quad (6)$$

According to the stability principle: If $F'(x^*) < 0$, $x^*$ will be in a stable state.

$\frac{dx(t)}{dt} = 0 \Rightarrow x_1 = 0\ ,\ x_2 = 1\ ,\ y = \frac{\theta A + B + R_3 + R_4 + C_1 - C_2}{(1-\phi)B + (\theta-1)A + R_1 + R_2 + R_3 + R_4}$

Next, the evolutionary stable state analysis is carried out for the three points:

**a)** When $y = \frac{\theta A + B + R_3 + R_4 + C_1 - C_2}{(1-\varphi)B + (\theta-1)A + R_1 + R_2 + R_3 + R_4}$, $\frac{dx(t)}{dt}$ is always zero (0), this means that $x$ does not change over time;

**b)** When $y > \frac{\theta A + B + R_3 + R_4 + C_1 - C_2}{(1-\varphi)B + (\theta-1)A + R_1 + R_2 + R_3 + R_4}$, $F'(x) < 0\ ,\ x = 1$. This is an evolutionary stable state. It means that through continuous imitation and learning, the proportion of reward chosen by the government tends to be 100 %.

**c)** When $y < \frac{\theta A + B + R_3 + R_4 + C_1 - C_2}{(1-\varphi)B + (\theta-1)A + R_1 + R_2 + R_3 + R_4}$, $F'(x) < 0\ ,\ x = 0$. This is an evolutionary stable state. It means that through continuous imitation and learning, the proportion of punishment chosen by the government tends to be 100 %.

**(2)** ***The payment when the manufacturer chooses to implement the green production strategy***

$$U_1 = x[\pi_0 - c_1 + A + r_1] + (1 - x)(\pi_0 - c_1 - \varphi B + r_2) \quad (7)$$

The payment when the manufacturer chooses not to implement the green production strategy:

$$U_2 = x[\pi_0 - c_2 + \theta A - r_3] + (1 - x)(\pi_0 - c_2 - B - r_4) \quad (8)$$

The average payment of the manufacturer:

$$\overline{U} = yU_1 + (1 - y)U_2 \quad (9)$$

$$\frac{dx(t)}{dt} = y(U_1 - \overline{U}) \quad (10)$$

$$= y(1 - y)\{[(1 - \theta)A + (\varphi - 1)B + r1 - r_2 + r_3 - r_4]x + (1 - \varphi)B - c_1 + c_2 + r_2 + r_4\}$$

Therefore, the dynamic differential equation of the production enterprise is shown as follows:

$$F(y) = y(1-y)\{[(1-\theta)A + (\varphi-1)B + r_1 - r_2 + r_3 - r_4]x + (1-\varphi)B - c_1 + c_2 + r_2 + r_4\} \quad (11)$$

and so,

$$F'(y) = (1-2y)\{[(1-\theta)A + (\varphi-1)B + r_1 - r_2 + r_3 - r_4]x + (1-\varphi)B - c_1 + c_2 + r_2 + r_4\} \quad (12)$$

According to the stability principle: If $F'(y^*) < 0$, $y^*$ is a stable state.

$\frac{dy(t)}{dt} = 0 \Rightarrow y_1 = 0$ , $y_2 = 1$ , $x = \frac{(\varphi-1)B + c_1 - c_2 - r_2 - r_4}{(1-\theta)A + (\varphi-1)B + r_1 - r_2 + r_3 - r_4}$

Next, the evolutionary stable state analysis is carried out for the three points:

**a)** When $x = \frac{(\varphi-1)B + c_1 - c_2 - r_2 - r_4}{(1-\theta)A + (\varphi-1)B + r_1 - r_2 + r_3 - r_4}$, $\frac{dx(t)}{dt}$ always is 0. This means that $y$ doesn't change over time.

**b)** When $x > \frac{(\varphi-1)B + c_1 - c_2 - r_2 - r_4}{(1-\theta)A + (\varphi-1)B + r_1 - r_2 + r_3 - r_4}$, $F'(x) < 0$ , $y = 1$. This is a revolutionary stable state. It means that through continuous imitation and learning, the proportion of production enterprises choosing to implement green production tends to be 100 %.

**c)** When $x < \frac{(\varphi-1)B + c_1 - c_2 - r_2 - r_4}{(1-\theta)A + (\varphi-1)B + r_1 - r_2 + r_3 - r_4}$, $F'(x) < 0$ , $y = 0$. This is a revolutionary stable state. It means that through continuous imitation and learning, the proportion of production enterprises choosing not to implement green production tends to be 100 %.

**(3)** ***System evolution game stability strategy***

Eq. 4 and Eq. 10 can be combined to obtain a system of differential Eq. 13, which can represent the game evolution process of the whole system:

$$\begin{cases} \frac{dx(t)}{dt} = x(1-x)\begin{Bmatrix} [(1-\varphi)B + (\theta-1)A + R_1 + R_2 + R_3 + R_4]y \\ +C_2 - C_1 - A\theta - B - R_3 - R_4 \end{Bmatrix} \\ \frac{dy(t)}{dt} = y(1-y)\begin{Bmatrix} [(1-\theta)A + (\varphi-1)B + r_1 - r_2 + r_3 - r_4]x \\ +(1-\varphi)B - c_1 + c_2 + r_2 + r_4 \end{Bmatrix} \end{cases} \quad (13)$$

Make $\begin{cases} \frac{dx(t)}{dt} = 0 \\ \frac{dy(t)}{dt} = 0 \end{cases}$ to get the possible equilibrium point of the system A $(0,0)$, B $(0,1)$, C $(1,0)$, D $(1,1)$, E $\left(\frac{(\varphi-1)B + c_1 - c_2 - r_2 - r_4}{(1-\theta)A + (\varphi-1)B + r_1 - r_2 + r_3 - r_4}, \frac{\theta A + B + R_3 + R_4 + C_1 - C_2}{(1-\varphi)B + (\theta-1)A + R_1 + R_2 + R_3 + R_4}\right)$, which is the point of the Evolutionary Stable Strategy (ESS). In this paper, according to the method of calculating the local stability of the system created by Friedman in 1991, the Jacobi matrix of the equations of evolutionary systems can be analysed [17].

From Eq. 13, partial derivatives of the two equations can be obtained as shown in Eq. 14.

$$J = \begin{vmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{vmatrix} \quad (14)$$

$$\frac{\partial \mathrm{F}(x)}{\partial x} = (1-2x)\{[(1-\varphi)\mathrm{B} + (\theta-1)A + R_1 + R_2 + R_3 + R_4]y + C_2 - C_1 - A\theta - B - R_3 - R_4\} \quad (15)$$

$$\frac{\partial \mathrm{F}(x)}{\partial y} = x(1-x)[(1-\varphi)\mathrm{B} + (\theta-1)A + R_1 + R_2 + R_3 + R_4] \quad (16)$$

$$\frac{\partial \mathrm{F}(y)}{\partial x} = y(1-y)[(1-\theta)\mathrm{A} + (\varphi-1)B + r_1 - r_2 + r_3 - r_4] \quad (17)$$

$$\frac{\partial \mathrm{F}(y)}{\partial y} = (1-2y)\{[(1-\theta)\mathrm{A} + (\varphi-1)B + r_1 - r_2 + r_3 - r_4]x + (1-\varphi)B - c_1 + c_2 + r_2 + r_4\} \quad (18)$$

The local equilibrium points A, B, C, D, and E are put into the Jacobi matrix and $\det J$ and $\operatorname{tr} J$ can be obtained to find the Evolutionary Stable Strategy (ESS) of the system. The determinant of the matrix is:

$$\det J = \left(\frac{\partial F(x)}{\partial x} \times \frac{\partial F(y)}{\partial y} - \frac{\partial F(y)}{\partial x} \times \frac{\partial F(x)}{\partial y}\right) > 0 \tag{19}$$

The trace of the matrix is:

$$\operatorname{tr} J = \left(\frac{\partial F(x)}{\partial x} + \frac{\partial F(y)}{\partial y}\right) < 0 \tag{20}$$

### 3.2 Phase diagram of evolutionary game

Put the above five points (A, B, C, D, and E) into the trace and determinant of the matrix respectively, and further analyse the strategy behaviour trend and system stability state of the evolutionary game system according to the symbol of sum:

1. When $x = 0, y = 0$, as shown in Fig. 1, the determinant and trace of matrix $J$ is:

$$\begin{cases} \det J = (C_2 - C_1 - A - \varphi B + R_1 + R_2)(-1)[(1-\varphi)B - c_1 + c_2 + r_2 + r_4] \\ \operatorname{tr} J = (C_2 - C_1 - A - \varphi B + R_1 + R_2) - [(1-\varphi)B - c_1 + c_2 + r_2 + r_4] \end{cases} \tag{21}$$

and the result is as shown in Table 2.

When the model parameters take the following values respectively: $C_1 = 10$, $C_2 = 1$, $c_1 = 10$, $c_2 = 1$, $s = 0.5$, $f = 0.3$, $B = 1$, $A = 1$, $r_1 = 1$, $r_2 = 1.5$, $r_3 = 1.7$, $r_4 = 2$, $R_1 = 2$, $R_2 = 1.5$, $R_3 = 3$, $R_4 = 1$, the cost of government supervision and management is high, and this tends to impose penalties on enterprises to reduce operating costs. Enterprises with high cost of green manufacturing tend to choose non-green manufacturing to reduce costs. The ESS point is at this time (penalty, non-green manufacturing).

**Table 2** The result of (0, 0)

| | | |
|---|---|---|
| $(C_2 - C_1 - A\theta - B - R_3 - R_4) > 0$, $[(1-\varphi)B - c_1 + c_2 + r_2 + r_4] > 0$ | $\det J > 0$, $\operatorname{tr} J > 0$ | Instability |
| $(C_2 - C_1 - A\theta - B - R_3 - R_4) > 0$, $[(1-\varphi)B - c_1 + c_2 + r_2 + r_4] < 0$ | $\det J < 0$, $\operatorname{tr} J$ Not sure | Saddle point |
| $(C_2 - C_1 - A\theta - B - R_3 - R_4) < 0$, $[(1-\varphi)B - c_1 + c_2 + r_2 + r_4] > 0$ | $\det J < 0$, $\operatorname{tr} J$ Not sure | Saddle point |
| $(C_2 - C_1 - A\theta - B - R_3 - R_4) < 0$, $[(1-\varphi)B - c_1 + c_2 + r_2 + r_4] < 0$ | $\det J > 0$, $\operatorname{tr} J < 0$ | Stability |

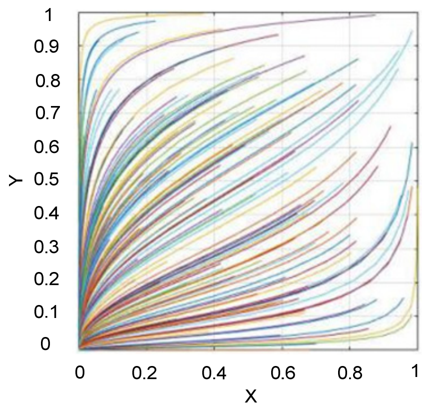


**Fig. 1** (0, 0) evolutionary equilibrium

2. When $x = 0, y = 1$, as shown in Fig. 2, the determinant and trace of matrix $J$ is:

$$\begin{cases} \det J = (-1)(C_2 - C_1 - A - \varphi B + R_1 + R_2)[(1-\varphi)B - c_1 + c_2 + r_2 + r_4] \\ \operatorname{tr} J = [(1-\varphi)B - c_1 + c_2 + r_2 + r_4] - (C_2 - C_1 - A - \varphi B + R_1 + R_2) \end{cases} \tag{22}$$

and the result is as shown in Table 3.

When the model parameters take the following values, respectively: $C_1 = 10$, $C_2 = 1$, $c_1 = 1$, $c_2 = 8$, $s = 0.5$, $f = 0.3$, $B = 2$, $A = 1$, $r_1 = 1$, $r_2 = 3.5$, $r_3 = 1.7$, $r_4 = 4$, $R_1 = 2$, $R_2 = 1$, $R_3 = 3$, $R_4 = 1$, the cost of government supervision and management is high, which tends to impose penalties on enterprises to reduce operating costs. Enterprises with high cost of green manufacturing tend to choose non-green manufacturing to reduce costs. The ESS point is at this time (i.e. penalty and non-green manufacturing).

**Table 3** The result of (0, 1)

| | | |
|---|---|---|
| $(C_2 - C_1 - A - \varphi B + R_1 + R_2) > 0$, $[(1-\varphi)B - c_1 + c_2 + r_2 + r_4] > 0$ | tr $J$ Instability | Saddle point |
| $(C_2 - C_1 - A - \varphi B + R_1 + R_2) > 0$, $[(1-\varphi)B - c_1 + c_2 + r_2 + r_4] < 0$ | det $J$ > 0, tr $J$ > 0 | Instability |
| $(C_2 - C_1 - A - \varphi B + R_1 + R_2) < 0$, $[(1-\varphi)B - c_1 + c_2 + r_2 + r_4] > 0$ | det $J$ < 0, tr $J$ < 0 Not sure | Stability |
| $(C_2 - C_1 - A - \varphi B + R_1 + R_2) < 0$, $[(1-\varphi)B - c_1 + c_2 + r_2 + r_4] < 0$ | det $J$ > 0, tr $J$ Instability | Saddle point |

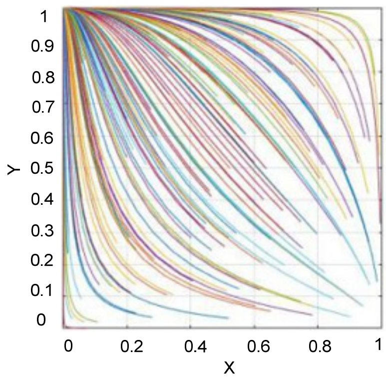


**Fig. 2** (0, 1) evolutionary equilibrium

3. When $x = 1$, $y = 0$, as shown in Fig. 3, the determinant and trace of matrix $J$ is:

$$\begin{cases} \det J = (-1)(C_2 - C_1 - A\theta - B - R_3 - R_4)[(1-\theta)A + r_1 + r_3 - c_1 + c_2] \\ \operatorname{tr} J = [(1-\theta)A + r_1 + r_3 - c_1 + c_2] - (C_2 - C_1 - A\theta - B - R_3 - R_4) \end{cases} \tag{23}$$

and the result is as shown in Table 4.

When the model parameters take the following values, respectively: $C_1 = 2$, $C_2 = 10$, $c_1 = 15$, $c_2 = 1$, $s = 0.5$, $f = 0.3$, $B = 2$, $A = 1$, $r_1 = 6.5$, $r_2 = 5$, $r_3 = 1.7$, $r_4 = 4$, $R_1 = 2$, $R_2 = 1$, $R_3 = 3$, $R_4 = 1$, the government rewards management cost is low, and tends to implement rewards to enterprises to reduce the operation cost. Enterprises with high cost of green manufacturing tend to choose non-green manufacturing to reduce costs. This time (reward, non-green production) has the ESS point.

**Table 4** The result of (1, 0)

| | | |
|---|---|---|
| $(C_2 - C_1 - A\theta - B - R_3 - R_4) > 0$, $[(1-\theta)A + r_1 + r_3 - c_1 + c_2] > 0$ | det $J$ < 0, tr $J$ Not sure | Saddle point |
| $(C_2 - C_1 - A\theta - B - R_3 - R_4) > 0$, $[(1-\theta)A + r_1 + r_3 - c_1 + c_2] < 0$ | det $J$ > 0, tr $J$ < 0 | Stability |
| $(C_2 - C_1 - A\theta - B - R_3 - R_4) < 0$, $[(1-\theta)A + r_1 + r_3 - c_1 + c_2] > 0$ | det $J$ > 0, tr $J$ > 0 | Instability |
| $(C_2 - C_1 - A\theta - B - R_3 - R_4) < 0$, $[(1-\theta)A + r_1 + r_3 - c_1 + c_2] < 0$ | det $J$ < 0, tr $J$ Not sure | Saddle point |

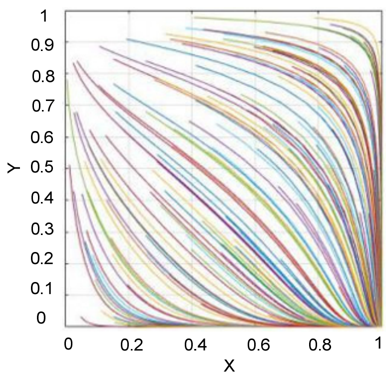


**Fig. 3** (1, 0) evolutionary equilibrium

4. When $x = 1, y = 1$, as shown in Fig. 4, the determinant and trace of matrix $J$ is:

$$\begin{cases} \det J = (C_2 - C_1 - A - \varphi B + R_1 + R_2)[(1-\theta)A + r_1 + r_3 - c_1 + c_2] \\ \operatorname{tr} J = (-1)(C_2 - C_1 - A - \varphi B + R_1 + R_2) + (-1)[(1-\theta)A + r_1 + r_3 - c_1 + c_2] \end{cases} \tag{24}$$

and the result is as shown in Table 5.

When the model parameters take the following values, respectively: $C_1$ = 2, $C_2$ = 10, $c_1$ = 1, $c_2$ = 5, $s$ = 0.5, $f$ = 0.3, $B$ = 2, $A$ = 1, $r_1$ = 6.5, $r_2$ = 5, $r_3$ = 1.7, $r_4$ = 4, $R_1$ = 5, $R_2$ = 6, $R_3$ = 3, $R_4$ = 1; the government rewards management cost is low, and tends to implement rewards to enterprises to reduce the operation cost. The cost of green manufacturing is not significantly higher than that of non-green manufacturing, so enterprises tend to choose green manufacturing to improve their social image and win government awards. The ESS point is recorded at this time (reward, non-green production).

**Table 5** The result of (1, 1)

| | | |
|---|---|---|
| $(C_2 - C_1 - A - \varphi B + R_1 + R_2) > 0$, $[(1-\theta)A + r_1 + r_3 - c_1 + c_2] > 0$ | $\det J > 0$, $\operatorname{tr} J < 0$ | Stability |
| $(C_2 - C_1 - A - \varphi B + R_1 + R_2) > 0$, $[(1-\theta)A + r_1 + r_3 - c_1 + c_2] < 0$ | $\det J < 0$, $\operatorname{tr} J$ Not sure | Saddle point |
| $(C_2 - C_1 - A - \varphi B + R_1 + R_2) < 0$, $[(1-\theta)A + r_1 + r_3 - c_1 + c_2] > 0$ | $\det J < 0$, $\operatorname{tr} J$ Not sure | Saddle point |
| $(C_2 - C_1 - A - \varphi B + R_1 + R_2) < 0$, $[(1-\theta)A + r_1 + r_3 - c_1 + c_2] < 0$ | $\det J > 0$, $\operatorname{tr} J > 0$ | Instability |

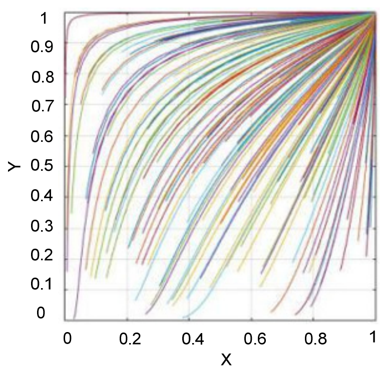


**Fig. 4** (1, 1) evolutionary equilibrium

5. Then, at E, because $\operatorname{tr} J = 0$, there is no stable point.

## 4. Simulation analysis of the evolutionary game

**(1)** The influence of government reward on the evolutionary game between the two sides is as shown in Fig. 5.

The graph in Fig. 5 shows that compared with enterprises, the incentive value has a greater impact on the government. With the increase of the incentive value, the government's governance cost increases, and the incentive value can stimulate enterprises to maintain the status quo. However, due to the existence of a speculative effect, the government tends to reduce the incentive value, enterprises are stimulated by the incentive value, and non-green manufacturing tends to slow down.

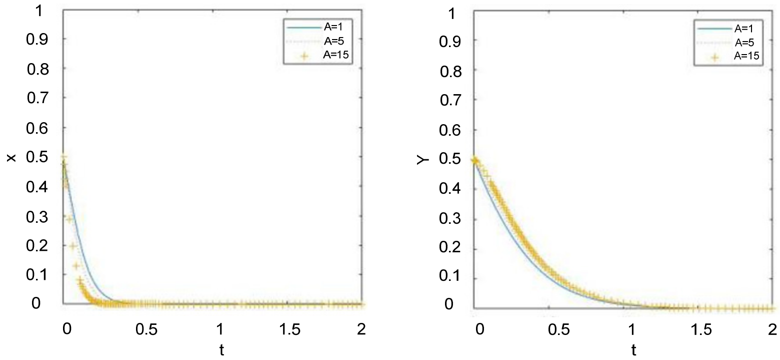


**Fig. 5** Different government incentive intensities

**(2)** The influence of government punishment on the evolutionary game between the two sides is as shown in Fig. 6.

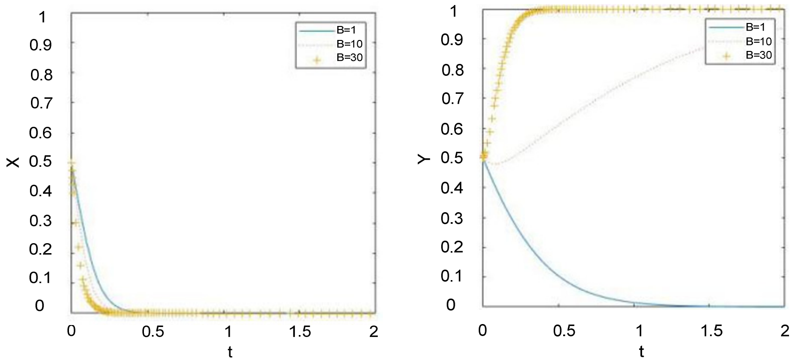


**Fig. 6** Different government penalty intensities

The graph in Fig. 6 shows that with the increase of the punishment intensity, the government will quickly implement green manufacturing with the increase of the punishment, reducing the chances of being punished.

**(3)** The influence of government operating costs on the evolutionary game between the two sides is as shown in Fig. 7.

It can be seen from Fig. 7 that the government is more inclined to adopt a penalty strategy with the increase of operating cost of incentive strategy. Since the increase in government operating costs cannot directly affect enterprises, it has little impact on their green manufacturing strategies. With the increase of operating cost of punishment strategy, the government is more inclined to adopt an incentive strategy.

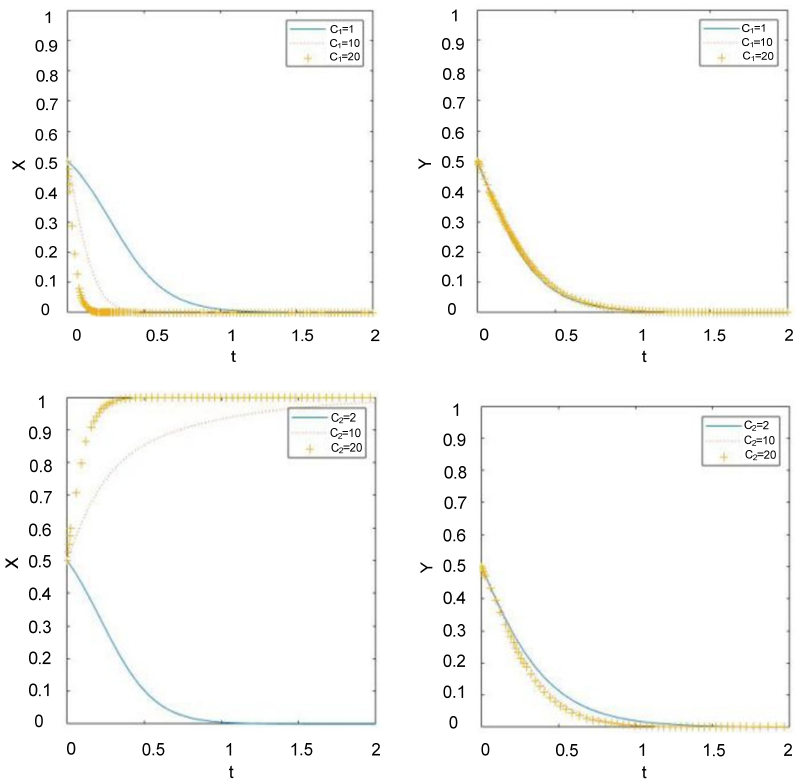


**Fig. 7** Different government operating costs

**(4)** The influence of the change in government social reputation on the evolution game between the two sides is as shown in Fig. 8.

It can be seen from Fig. 8 that the increase of $R_1$ and $R_2$ in the social credibility of the government will slow down the government's punishment strategy, while the increase of $R_3$ and $R_4$ will lead to the government's tendency to adopt punishment strategy.

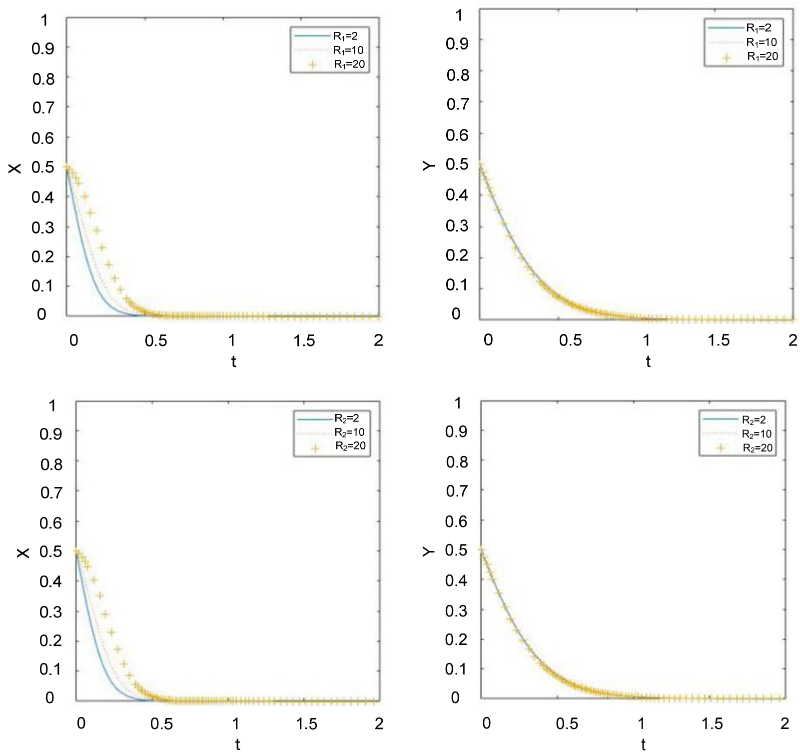


**Fig. 8** Different social credibility of the government

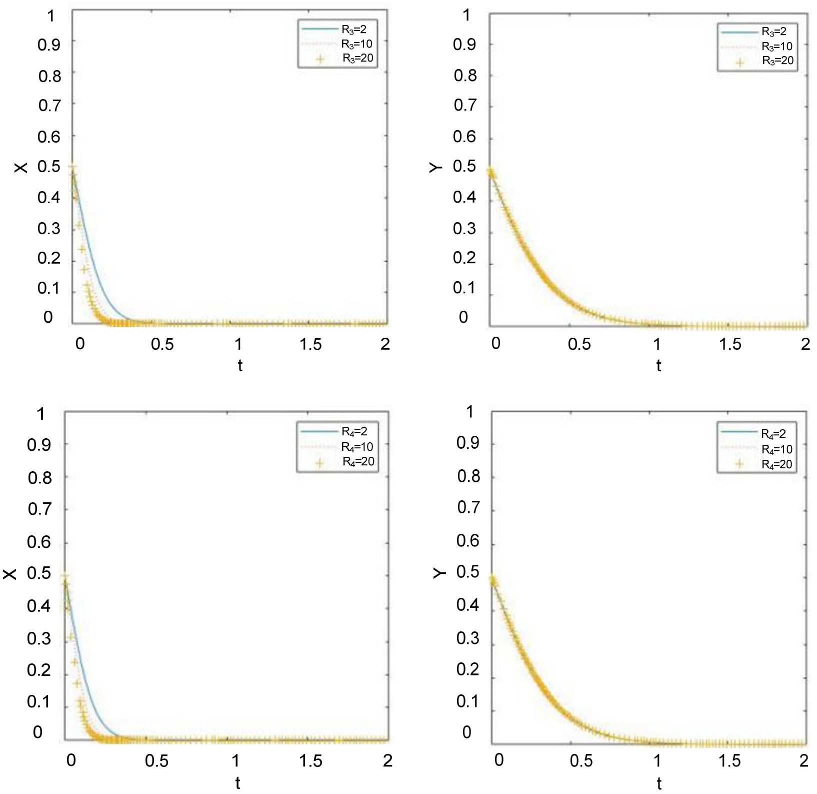


**Fig. 8** Different social credibility of the government (continuation)

**(5)** The influence of the change in corporate social reputation on the evolutionary game between the two sides is as shown in Fig. 9.

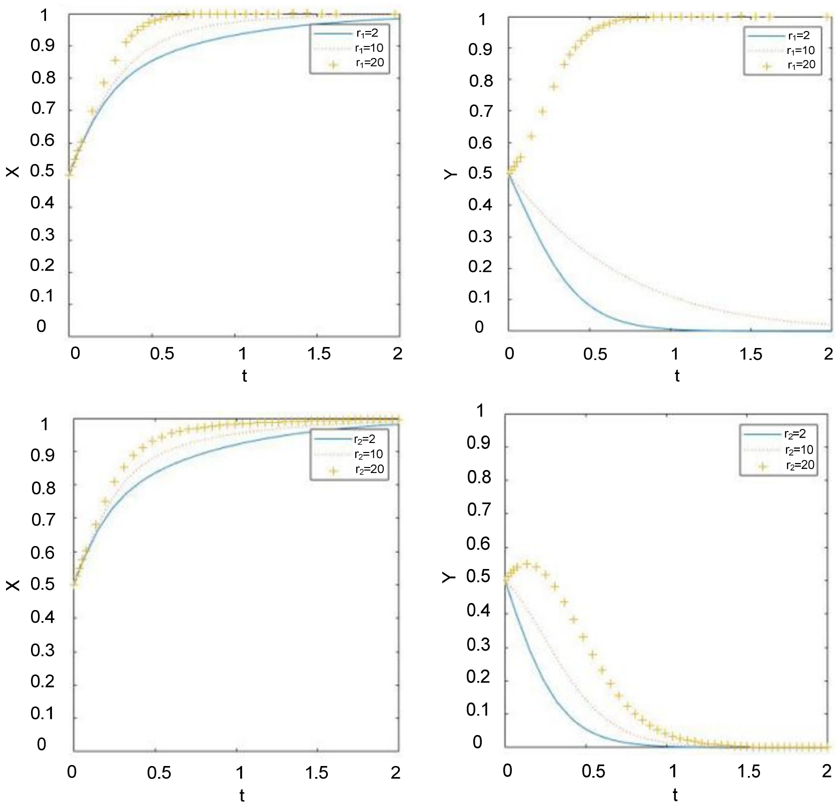


**Fig. 9** Different social credibility of enterprises

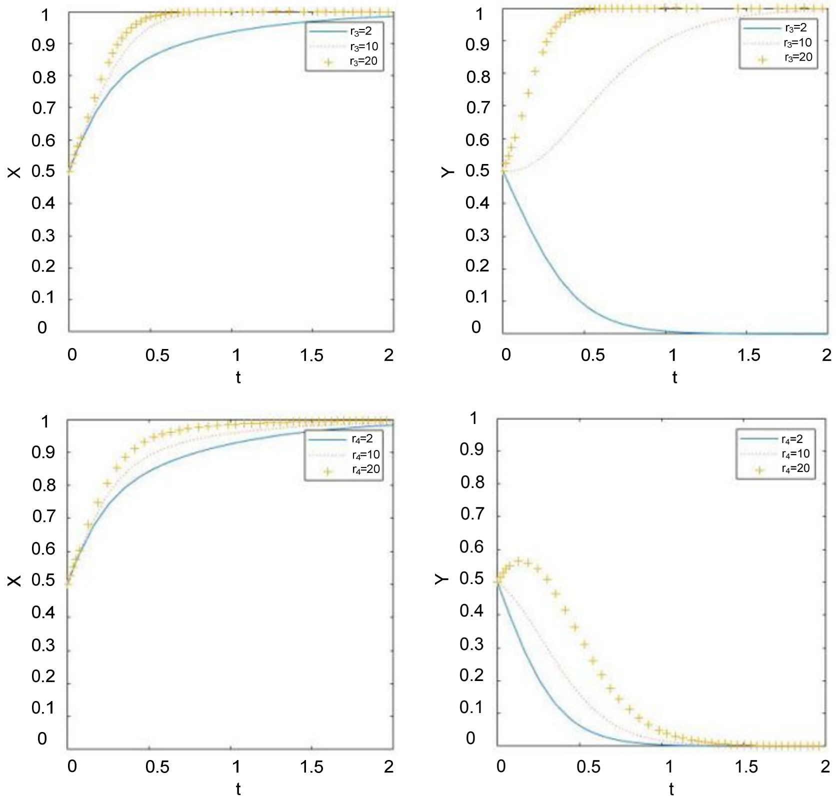


**Fig. 9** Different social credibility of enterprises (continuation)

From Fig. 9, it shows that the increase of $r_1$, $r_2$, $r_{3,}$ and $r_4$ in the social reputation of enterprises will stimulate the government to adopt incentive strategies for enterprises. $r_3$ is the fastest way to stimulate enterprises to adopt green manufacturing mode. Although $r_1$ is slower than $r_3$, it can still stimulate enterprises to adopt green manufacturing mode. The increase of $r_2$ and $r_4$ will lead enterprises to adopt green manufacturing mode, but after a long time, they will revert to non-green manufacturing mode.

**(6)** The influence of the cost of enterprises' green production cost on the evolutionary game between the two sides is as shown in Fig. 10.

As can be seen from the figure, with the increase of $c_1$ in green manufacturing operation cost, the government is inclined to take punitive measures to strengthen green production, but the change in the intensity of this measure is not obvious. With the improvement of $c_1$, enterprises will largely choose non-green manufacturing mode for production. With the increase of $c_2$ of non-green operating cost of enterprises, the government tends to choose incentive measures, but the change of the intensity of this measure is not obvious. With the improvement of $c_2$, enterprises will largely choose green manufacturing mode for production.

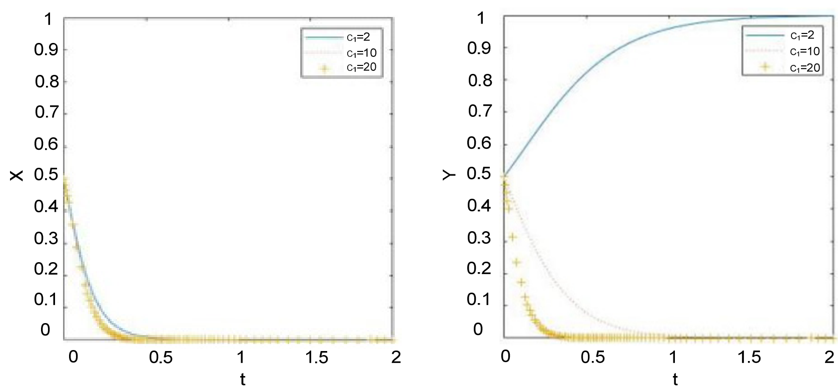


**Fig. 10** Different manufacturing costs of enterprises

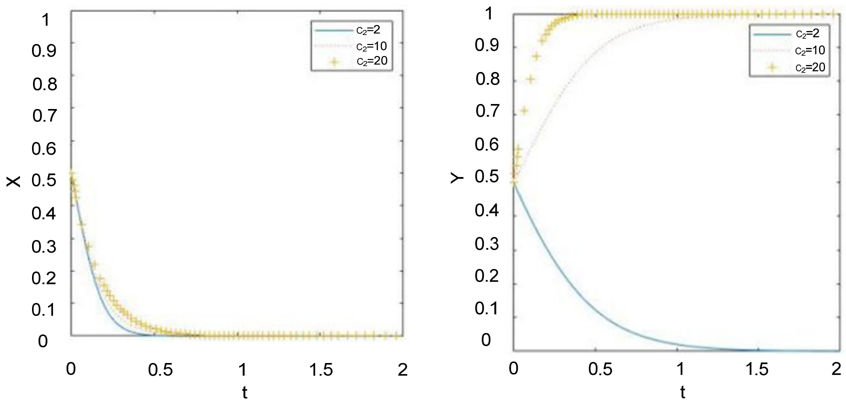


**Fig. 10** Different manufacturing costs of enterprises (continuation)

**(7)** The influence of the false reward on the evolutionary game between the two sides is as shown in Fig. 11.

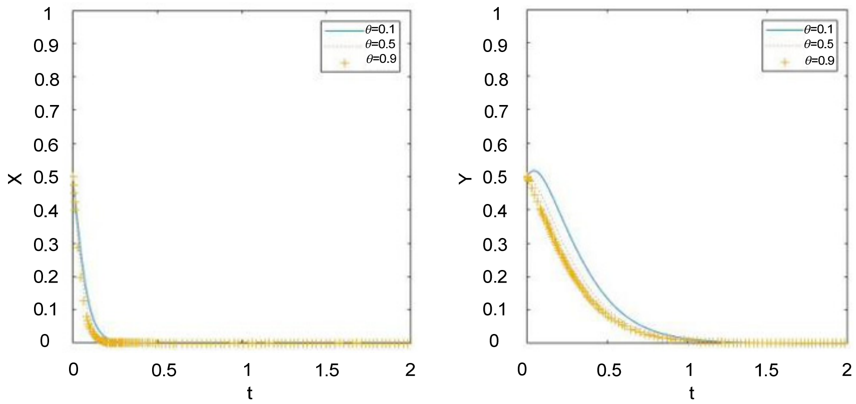


**Fig. 11** Different error reward probabilities

From Fig. 11, it shows that, with the increase of possibility $\theta$ of the government's false reward, the government tends to choose punishment measures to avoid the waste of rewards, but the change of the intensity of this measure is not obvious. With the improvement of $\theta$, enterprises will choose non-green manufacturing mode for production more quickly, so that they may get more government error rewards.

**(8)** The influence of the wrong punishment on the evolutionary game between the two sides is as shown in Fig. 12.

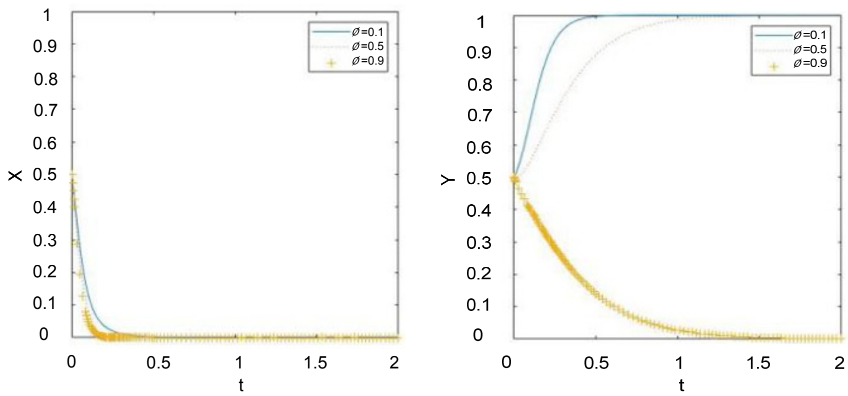


**Fig. 12** Different error punishment probabilities

It can be seen from Fig. 12 that with the increase of possibility $\phi$ of government error punishment, the intensity of government punishment measures will increase, but the intensity of this measure also does not change significantly. With the improvement of $\phi$, enterprises will choose non-green manufacturing mode for production more quickly, so as to reduce the possible government error penalty.

## 5. Conclusion

Through the simulation solution, it can be seen that the two evolutionary equilibrium points (0, 0) and (1, 1) passed through the parameter adjustment. It can be concluded that: the expansion of government incentives or penalties indicates the government's determination to recommend the development of green manufacturing mode. For enterprises, the increase of incentive value would increase the willingness to implement green manufacturing to a certain extent, but the increase of government penalty value would significantly increase their decision willingness to choose the green manufacturing mode. The change in government operating cost would seriously affect the decision of reward and punishment, however, it has little influence on the decision of enterprises. The change in social reputation plays a certain role in accelerating or decelerating the government's decision, however, it has a great influence on the decision of whether enterprises implement green manufacturing or not. Enterprises are most sensitive to the cost difference between green manufacturing mode and non-green manufacturing mode. The government's false reward has little influence on itself and enterprises, but the wrong punishment has a great influence on the enterprise and limited influence on the government. Therefore, from the perspective of the government, it is the best decision plan to strengthen the government that increase the punishment intensity of enterprises that violate the rules, increase the frequency of enterprise supervision, explore various forms of social reputation evaluation value of enterprises, and reduce the wrong punishment of enterprises by the government. From the perspective of enterprises, it is the best decision plan for enterprises that reduce the operating costs of green manufacturing mode by science and technology innovation, expand the popularity of green manufacturing mode, to improve the social reputation of enterprises.

The main contributions of this paper are as follows:

- Combination of reward and punishment into a model, which expands the previous model to measure the evolutionary game between government departments and enterprises only from one aspect of reward or punishment;
- Introduction of the error judging factor $\theta$ and $\phi$ of reward and punishment, making the model assumption closer to the actual situation;
- Through the simulation analysis of different parameters, this paper gives the government reward and punishment strategy, changes the value of influencing factors of enterprises' green manufacturing selection strategy, and influences the result of evolutionary game.

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