Influence of heterogeneous environmental regulation policies on the strategy of pollutant discharge for enterprise: an evolutionary game approach

Zhiqiang Zhou, Huanhuan Feng, Huilin Wang and Kexi Wang

School of Business, Hunan University of Science and Technology, Xiangtan 411201, People’s Republic of China

* Author to whom any correspondence should be addressed.

E-mail: huilin.wangx@outlook.com

Keywords: administrative environmental regulation, market-oriented environment regulation, socialized environment regulation, pollutant discharge volumes, evolutionary game

Supplementary material for this article is available online

Abstract

To improve the effectiveness of the government’s environmental regulation policy, this study aims to solve the problem of the low willingness of enterprises to cooperate. This study redefined and defined the types of environmental regulations based on the policy realization path, and gradually added them into the game system between the government and enterprises, using the evolutionary game to analyze the impact of different regulatory means on the enterprises’ choice of whether or not to cooperate with the regulatory policy, and using MATLAB to perform a numerical simulation to compare the degree of impact. In this way, the best regulatory objects of different regulatory means were determined, and the theoretical basis and practical reference for the government to implement classified governance policies were provided. In addition, this study for the first-time classified enterprises based on the relationship between the number of pollutants discharged by enterprises and the government’s pollutant discharge quota, and incorporated them into the model for further research. The results showed that the government should implement administrative regulations for enterprises discharging a small number of pollutants; implement a combination of administrative and market-oriented regulations for enterprises discharging a medium number of pollutants; implement administrative, market-oriented, and socialized regulations at the same time for enterprises discharging a large number of pollutants. Moreover, these should be based on the premise of reasonably arranging the performance appraisal of local governments.

1. Introduction

Since the reform and opening up, China’s economy has developed rapidly and has become the second largest economy in the world. However, while making such achievements, China also has serious environmental pollution problems. In the new era, China is implementing a new development pattern of ‘domestic circulation as the main body, domestic and international dual circulations promoting each other. Therefore, it is an important task and guiding concept for China’s economic and social development to promote the government’s environmental regulation and alleviate the current contradiction between domestic economic growth and environmental degradation.

However, the current Chinese government’s environmental regulation policies are less effective. Fundamentally, the main reason lies in the low willingness of enterprises to cooperate with the implementation of policies. The main guiding ideology of environmental regulation is the ‘internalization of external diseconomies’, which will inevitably change the original pattern of interests. Therefore, the coordination of interests between subjects is the key to the smooth development of environmental regulation. However, the richness of policies and the diversification of enterprises has led to an increasingly complex distribution of interests. As the main target of regulation, it is difficult for enterprises to clearly define whether the impact of
regulation is positive or negative, their interests cannot be guaranteed, and their willingness to cooperate gradually decreases, which affects the effectiveness of environmental regulation. Therefore, it is of great theoretical and practical significance to construct a dynamic evolutionary game model between the government and enterprises, to clarify the advantages and disadvantages of government environmental regulation on enterprises, and to effectively improve the willingness of enterprises to cooperate.

The research on the effect of environmental regulation in academic circles has not reached a consistent conclusion. Scholars of the traditional neoclassical school of economics emphasized the negative impact of environmental regulation on enterprises [1, 2], arguing that environmental regulation causes costs for enterprises such as purchasing pollution control equipment and training operators [3, 4]. The famous ‘Porter Hypothesis’ believed that environmental regulation will have an ‘innovation compensation effect’ on enterprises, which will help enterprises to innovate technology and improve production efficiency [5–7]. Some scholars believed that the impact of environmental regulation on enterprises is not clear or nonlinear [8–11].

Scholars have also carried out a lot of discussions on the continuous and complicated game of interests between the government and enterprises in the process of environmental regulation and obtained many valuable conclusions. Game theory is a theory that studies the logic of behavioral interaction and strategy selection between subjects with interests. Each subject analyzes the benefits and costs of both parties according to the existing information, so as to take optimal behavioral measures [12]. The traditional game theory requires the subject to be in an ideal state of being completely rational and having access to all information, which is almost impossible in reality [13]. In the practice of environmental regulation, both the government and enterprises are the subject of bounded rationality. They make their own decisions by observing, imitating, and learning. Moreover, decisions are constantly changing in the course of interaction. Therefore, the evolutionary game is more in line with the actual situation of the interaction between subjects in the process of environmental regulation practice [14]. And evolutionary game theory provides a powerful framework to study this cooperative behavior between government and business [15]. Taxes, penalties, subsidies, etc. are currently the most important environmental regulation tools. Mahmoudi and RastiBarzoki, Zhou and Dou, Zhu et al., Wu B et al., and Chen and Hu all established evolutionary game models from different perspectives to study the interaction between the government and enterprises under regulatory tools such as taxation, punishment, and subsidies [16–20]. Fan et al. established a small-world network model to study the behavioral measures of enterprises under the government’s low-carbon subsidies and obtained the government’s optimal supervision strategy and supervision probability [21]. Pricing policy is a new tool developed gradually. Zhang et al. found that under the government’s dynamic carbon trading pricing policy, enterprises have a stable equilibrium strategy [22]. Kang et al. conducted an evolutionary game analysis on the low-carbon strategies of enterprises in the supply chain and believed that the government can encourage enterprises to reduce carbon emissions by controlling carbon prices rather than setting carbon caps [23]. With the enhancement of public awareness of environmental protection, informal regulatory means have received attention. In a three-party evolutionary game analysis of government-enterprise-public, Zou et al. found that the behavior of the public to purchase carbon label products can promote enterprises to develop low-carbon production technologies [24]. Adding consumers’ environmental awareness to the game between the government and power producers, Zu et al. found that consumer awareness will have an impact on corporate emission reduction strategies [25].

The above research has its rationality and great significance, but there are also one-sided problems. First of all, most scholars have conducted research on the effect of environmental regulation under the larger policy background of environmental regulation, and have not conducted a more detailed analysis of enterprises. At present, the types of regulatory policies are becoming more and more abundant, and the types of enterprises are becoming more and more diverse. These heterogeneities make the impact of government environmental regulations on enterprises may be far more complex than we imagined. Secondly, for the study of the interactive game between the government and enterprises, scholars mainly focus on the environmental regulation tools as the research starting point and seldom discuss it from the perspective of a certain type of regulation. However, from the practical point of view, the classification standards of regulatory policies are gradually diversified and clear, which have a greater impact than a single tool, and the research value is also higher and higher. Therefore, to provide more accurate and effective suggestions to the government, this study comprehensively considered the heterogeneity of regulatory policies and enterprises, and established the evolution game model of the government and different types of enterprises under different environmental regulations, to clarify the interaction law between the government and enterprises, and analyze the effect and the impact of strategic choices of different environmental regulations on different types of enterprises.

To do this, this study mainly needs to solve the following three problems:

(1) How do divide the types of environmental regulation?

(2) How do classify the types of enterprises?
(3) For different types of enterprises, how does the government carry out regulations to encourage enterprises to actively cooperate?

More importantly, the research on this issue has a certain generality. Although this study mainly analyzed environmental regulation issues, other regulatory systems, such as health care regulation, water resource regulation, etc, also have the same tedious problems as the above-mentioned unclear effects and complicated game relationships caused by the heterogeneity of policies or enterprises. Therefore, it is hoped that this research can bring new ideas for analyzing and solving similar problems for other regulatory systems while bringing new policy recommendations for environmental regulation issues.

2. Methods

2.1. Classification of environmental regulatory policies

This research divided environmental regulation into administrative regulation, market-oriented regulation, and socialized regulation. Traditional government regulation mainly refers to command and control. The new regulatory concepts such as competition, interaction and cooperation, and randomness have brought new regulatory methods on the basis of overcoming the shortcomings of the command and control mechanism [26, 27]. Based on this, Hood proposed four control mechanisms ‘Oversight, Competition, Mutuality, and Randomness’, as well as three major elements of the control process ‘standard setting, information gathering, and behavior regulation’ [28]. It is with the help of these specific implementation mechanisms that the government supervises and promotes the subject’s compliance with the rules [29]. It can be seen that the theory of government regulation by Hood et al is highly applicable and inclusive, and can cover almost all regulatory tools. On the basis of Hood’s supervision theory (mainly based on the three major mechanisms of oversight, competition, and mutuality), this study combined the realization path and mechanism of policies to divide regulatory policies into three categories. The first is administrative regulation, which relies on government coercive constraints and emphasizes end-of-line management [30]. It includes direct regulation as well as economic guidance. Direct regulation is the traditional mandatory command-and-control regulation, including establishing laws, setting standards, etc [31]. Economic guidance includes pollution taxes, fines, and subsidies for innovative pollution control technologies that originally belonged to market-incentive regulation. The second is market-oriented regulation, which plays a role through the innovative compensation effect and encourages enterprises to take the initiative to reduce pollution from the source. Its main tool is the trading of pollution rights. The third is socialized regulation, which plays a role through public opinion, mainly through education, publicity, and other means to improve local environmental protection preferences, to promote industry associations, ENGO, media, the public, and enterprises themselves to actively participate in environmental protection supervision.

2.2. Classification of enterprises

In this study, the enterprises were divided into three categories: enterprises with small discharge volume, enterprises with medium discharge volume, and enterprises with large discharge volume according to the standard of pollutant discharge volume and pollutant discharge limit. At present, the research on environmental regulation lacks attention to the heterogeneity of enterprises, but its impact cannot be ignored. For example, the difference in the industry and scale of enterprises makes the effect of environmental regulation policies different [33, 34]. The first is an enterprise with a small amount of pollutant discharge, and its original pollutant discharge amount is less than the government limit. The second is an enterprise with a medium discharge volume, whose original discharge volume is greater than the limit and is less than the limit after emission reduction. The third type is an enterprise with a large number of pollutants, whose pollutant emission is still greater than the limit after the emission reduction.

2.3. Basic assumptions

The government and enterprises are both bounded rational subjects with subjective initiative. Therefore, the essence of failure to achieve ideal cooperation lies in the difference in interest goals. Governments repeatedly coordinate between economic performance and environmental performance, while companies swing back and forth between costs and benefits. So, the game process must be a continuous and repeated dynamic evolution process, which is difficult to consider comprehensively. For the convenience of research, the following assumptions were put forward:
Assumption 1: Participating subjects include government and enterprises. The government’s behavior strategy includes strict regulation and lax regulation. The probability that the government chooses strict regulation is \( p \), and the probability that it chooses lax regulation is \( 1-p \). The firm’s behavioral strategies include positive cooperation and negative cooperation. The probability of an enterprise choosing positive cooperation is \( q \), and the probability of choosing negative cooperation is \( 1-q \).

Assumption 2: The government regulates as follows. The first is administrative regulation. The amount of pollutants discharged by the enterprise is \( M \), and the government limit is \( X \). Charge the tax and fee of discharging pollutants. when \( M \leq X \), the pollutant discharge tax is per unit \( T_1 \); and when \( M > X \), the pollutant discharge fee is charged per unit \( T_2 \) (\( T_2 > T_1 \)). When the enterprise fails to pay the fees as required and is found, the fine for pollutant discharge shall be charged per unit \( T_3 \) (\( T_3 > T_2 > T_1 \)). Set up innovative pollution control technology subsidy \( I \) to encourage enterprises to innovate pollution control technology. The second is market-oriented regulation. The government establishes a pollution trading platform. The unit price of pollutant discharge volumes on the platform is \( V \) (\( T_1 < V < T_2 \)). Third, Socialized regulation. Improve local environmental protection preferences and improve the impact of environmental protection image on corporate earnings.

Assumption 3: Under administrative regulation, enterprises innovate pollution control technology, reducing pollutant discharge volumes \( N_1 \). Under market-oriented regulation, enterprises improve production technology, reducing pollutant discharge volumes \( N_2 \), increasing business profits \( L_1 \), and increasing government tax \( W_1 \). Under Socialized environmental regulation, corporate image affects operating income \( L_2 \), affecting government tax \( W_2 \).

Assumption 4: The classification of enterprises is described as follows. First, A-class enterprises, \( M \leq X \). Second, B-class enterprises, \( M > X \) and \( M-N_1 \leq X \). Third, C-class enterprises, \( M-N_1-N_2 > X \).

The specific variable settings are shown in table 1 below.

### Table 1. Variables and their meanings.

| Variables | Meanings |
|-----------|----------|
| \( p \)   | The probability that the government chooses strict regulation |
| \( 1-p \) | The probability that the government chooses lax regulation |
| \( q \)   | The probability that a firm chooses positive cooperation |
| \( 1-q \) | The probability that a firm chooses negative cooperation |
| \( L \)   | Enterprise operating income |
| \( M \)   | Original pollutant discharge volumes |
| \( W \)   | Business tax |
| \( C \)   | The cost of the government choosing strict regulation (gradually increasing) |
| \( g \)   | The cost of the enterprises choosing positive cooperation (gradually increasing) |
| \( X \)   | Pollutant discharge limit |
| \( T_1 \) | The unit price of pollutant discharge tax |
| \( T_2 \) | The unit price of pollutant discharge fee |
| \( T_3 \) | The unit price of pollutant discharge fine |
| \( I \)   | Subsidies for innovative pollution control technologies |
| \( N_1 \) | The emission reduction volumes of the enterprise’s innovative pollution control technology |
| \( V \)   | The unit price of the pollution trading platform |
| \( N_2 \) | The emission reduction volumes of the enterprises improving production technology |
| \( L_1 \) | Increased operating income of the enterprises improving production technology |
| \( W_1 \) | Increased business tax of the enterprises improving production technology |
| \( L_2 \) | Operating income affected by corporate environmental protection image |
| \( W_2 \) | The business tax affected by corporate environmental protection image |
| \( H \)   | Social benefits brought by unit emission reduction |

2.4. Game model construction and analysis

2.4.1. Construction and analysis of the game model between the government and A-class enterprises

2.4.1.1. Game model construction

Under different regulatory policies, the benefits and strategic choices of the government and enterprises are different. The specific changes are shown in the following table 2.
2.4.1.2 Equilibrium strategy analysis

After the government adds the socialized regulation:

\[ W + (M-N_2)T_1-C + N_1H \]

After the government adds the market-oriented regulation:

\[ W + (M-N_2)T_1-g+I \]

\[ W + MT_1 \]

\[ W + MT_1 \]

\[ L-MT_1 \]

Table 2. The game matrix between the government and A-class enterprises.

| Game subject | Cooperate positively (q) | Cooperate negatively (1-q) |
|--------------|--------------------------|---------------------------|
| Government  | Regulate | \( W + (M-N_2)T_1-C + N_1H \) | \( W + MT_1 \) |
|             | Strictly (p) | \( L-(M-N_2)T_1-g+I \) | \( L-MT_1 \) |
|             | Regulate | \( W + MT_1 \) | \( W + MT_1 \) |
|             | laxy (1-p) | \( L-MT_1 \) | \( L-MT_1 \) |

After the government adds the market-oriented regulation:

\[ W + (M-N_2)T_1-C + N_1H + W_2 \]

\[ W + MT_1-C-W_2 \]

\[ L-MT_1 \]

\[ W + MT_1 \]

\[ L-MT_1 \]

2.4.1.2 Equilibrium strategy analysis

The replication dynamics equation is calculated using the entity’s expected return, as shown in the following example:

\[ F_t(p) = \frac{dp}{dt} = p(U_i - E_i) = p(U_i) - p(U_i - U_1) \]

Under administrative regulation, the replication dynamic equation of the government and enterprises is as follows:

\[ F_t(p) = p(1 - p)\{qN_1(H - T_1) - C\} \]

\[ F_t(q) = q(1 - q)p(I - g + (N_1 + N_2)T_1) \]

(1)

(2)

Let \( F_t(p)=0 \) and \( F_t(q)=0 \). The four partial equilibrium points of the game system at this time are \( A_1 (0,0), B_1 (0,1), C_1 (1,0), \) and \( D_1 (1,1) \). They represent strategies \( A_1 \) (regulate laxly, cooperate negatively), \( B_1 \) (regulate laxly, cooperate positively), \( C_1 \) (regulate strictly, cooperate negatively), and \( D_1 \) (regulate strictly, cooperate positively).

After adding the market-oriented regulation, the replication dynamic equation of the government and enterprises is as follows:

\[ F_2(p) = p(1 - p)\{q[(N_1 + N_2)(H - T_1) + W_1] - C\} \]

\[ F_2(q) = q(1 - q)p[I - g + (N_1 + N_2)T_1] \]

\[ +(X - M + N_1 + N_2)V + L_1 \]

(3)

(4)

At this time, the four partial equilibrium points of the game system are \( A_2 (0,0), B_2 (0,1), C_2 (1,0), \) and \( D_2 (1,1) \). After adding socialized regulation, the replication dynamic equation is as follows:

\[ F_3(p) = p(1 - p)\{q[(N_1 + N_2)(H - T_1) + W_1 + 2W_2] - (C + W_2)\} \]

\[ F_3(q) = q(1 - q)p[I - g + (N_1 + N_2)T_1] \]

\[ +(X - M + N_1 + N_2)V + L_1 + 2L_1 \]

(5)

(6)

At this time, the four partial equilibrium points of the game system are \( A_3 (0,0), B_3 (0,1), C_3 (1,0), \) and \( D_3 (1,1) \).

2.4.1.3 Analysis of the stability of the equilibrium strategy

Partial equilibrium strategies of game systems are not always stable. This study drew on the strategic stability requirements of game systems proposed by Friedman [35], and analyzed the stability of equilibrium strategies according to the sign of determinant and the trace of the Jacobian matrix.
The Jacobian matrix calculation formula is as follows:
\[
J_1 = \begin{bmatrix}
\frac{F_1(p)}{dp} & \frac{F_1(p)}{dq} \\
\frac{F_2(q)}{dp} & \frac{F_2(q)}{dq}
\end{bmatrix}
\]

When implementing administrative regulations, the determinant \(\text{Det}(J_1)\) and trace \(\text{Tr}(J_1)\) of matrix \(J_1\) can be obtained:
\[
\text{Det}(J_1) = (1 - 2p)q[N_i(H - T_i) - C] \\
\times (1 - q)p(N_iT_i - g + I) \\
- p(1 - p)N_i(H - T_i) \times q(1 - q)(N_iT_i - g + I) \\
\text{Tr}(J_1) = (1 - 2p)q[N_i(H - T_i) - C] \\
+ (1 - 2q)p(N_iT_i - g + I)
\]

After adding market-oriented regulation, the determinant \(\text{Det}(J_2)\) and trace \(\text{Tr}(J_2)\) of matrix \(J_2\) can be obtained:
\[
\text{Det}(J_2) = (1 - 2p)q[N_i + N_j](H - T_i) + W_i - C] \\
\times (1 - 2q)p(N_i + N_j)T_i - g + I + (X - M + N_i + N_j)V + L_1) \\
- p(1 - p)[(N_i + N_j)(H - T_i) + W_i] \\
\times q(1 - q)[(N_i + N_j)T_i - g + I + (X - M + N_i + N_j)V + L_1] \\
\text{Tr}(J_2) = (1 - 2p)q[N_i + N_j](H - T_i) + W_i - C] \\
+ (1 - 2q)p[N_i + N_j]T_i - g + I + (X - M + N_i + N_j)V + L_1)
\]

After adding socialized regulation, the determinant \(\text{Det}(J_3)\) and trace \(\text{Tr}(J_3)\) of matrix \(J_3\) can be obtained:
\[
\text{Det}(J_3) = (1 - 2p)q[N_i + N_j](H - T_i) + W_i + 2W_2] \\
- (C + W_2) \times (1 - 2q)p(N_i + N_j)T_i - g + I \\
+ (X - M + N_i + N_j)V + L_1 + 2L_2) \\
- p(1 - p)[(N_i + N_j)(H - T_i) + W_i + 2W_2] \\
\times q(1 - q)[(N_i + N_j)T_i - g + I + (X - M + N_i + N_j)V \\
+ L_1 + 2L_2] \\
\text{Tr}(J_3) = (1 - 2p)q[N_i + N_j](H - T_i) + W_i + 2W_2] \\
- (C + W_2) + (1 - 2q)p[N_i + N_j]T_i - g + I \\
+ (X - M + N_i + N_j)V + L_1 + 2L_2)
\]

Substitute each local equilibrium point into the determinant and the trace respectively. When the determinant \(\text{Det}(J) > 0\) and the trace \(\text{Tr}(J) < 0\), the partial equilibrium strategy is the stable equilibrium strategy (ESS). The specific situation is shown in table 3.

2.4.2. Construction and analysis of the game model between the government and B-class enterprises

2.4.2.1. Equilibrium strategy analysis

The interest game between the government and B-class enterprises is shown in the table 4 below.

2.4.2.2. Equilibrium strategy analysis

When the government implements administrative regulations, the replication dynamic equation of the government and enterprises is as follows:
\[
F_1(p) = p(1 - p)[q((M - X) (T_i - T_j) - C] \\
+ N_i(H - T_i)] + [(M - X) T_j - C)] \\
F_2(q) = q((1 - q)[p[(M - X)(T_i + T_j - T_j)] + I - g \\
+ N_iT_i + (M - X)(T_j - T_j)] \\
\]

At this point, the local equilibrium point can be obtained: A1 (0,0), B1 (0,1), C1 (1,0), D1 (1,1), E1 (p1,q1). In E1, p1=q1=(M-X)(T_i-T_j)/[(M-X)(T_i-T_j) + C].

After adding market-oriented regulation, the replication dynamic equation is as follows:
\[
F_2(p) = p(1 - p)[q((M - X)(T_i - T_j) - C] \\
+ (N_i + N_j)(H - T_i) + W_i] + [(M - X) T_j - C)] \\
\]

After adding social oriented regulation, the replication dynamic equation is as follows:
\[
F_2(p) = p(1 - p)[q((M - X)(T_i - T_j) - C] \\
+ (N_i + N_j)(H - T_i) + W_i] + [(M - X) T_j - C)] \\
\]
Table 3. The stability analysis results from the equilibrium strategy of the government and A-class enterprises.

| Equilibrium          | Det(f) | Tr(f) | Stability |
|----------------------|--------|-------|-----------|
| When the government only implements administrative regulations: |
| A₁ (0,0)             | 0      | —     | unstable  |
| B₁ (0,1)             | 0      | +     | unstable  |
| C₁ (1,0)             | +      | +     | unstable  |
| D₁ (1,1)             | +      | —     | ESS      |
| After the government adds market-oriented regulation: |
| A₂ (0,0)             | 0      | —     | unstable  |
| B₂ (0,1)             | 0      | +     | unstable  |
| C₂ (1,0)             | +      | +     | unstable  |
| D₂ (1,1)             | +      | —     | ESS      |
| After the government adds socialized regulation: |
| A₃ (0,0)             | 0      | —     | unstable  |
| B₃ (0,1)             | 0      | +     | unstable  |
| C₃ (1,0)             | +      | +     | unstable  |
| D₃ (1,1)             | +      | —     | ESS      |

Table 4. The game matrix between the government and B-class enterprises.

| Game subject | Cooperate positively (q) | B-class enterprises | Cooperate negatively (1-q) |
|--------------|--------------------------|--------------------|---------------------------|
| When the government only implements administrative regulations: |
| Government  | Regulate                  | W + (M-N₁)T₁ - C + N₁H | W + MT₁ C + (M-X)T₂ |
| Strictly (p) | L-(M-N₁)T₁ - g + 1           | L-MT₁ (M-X)T₂     |                          |
| laxly (1-p)  | L-XT₁+(M-X)T₂             | W + MT₁           |                          |
| After the government adds the market-oriented regulation: |
| Government  | Regulate                  | W + (M-N₁-N₂)T₁ + W₁ - C + (N₁ + N₂)H + W₂ | W + MT₁ C + (M-X)T₂ |
| Strictly (p) | L-(M-N₁-N₂)T₁ - g + 1 + 1+(X-M + N₁ + N₂) | L-MT₁ (M-X)T₂     |                          |
| laxly (1-p)  | L-XT₁+(M-X)T₂             | W + MT₁           |                          |
| After the government adds the socialized regulation: |
| Government  | Regulate                  | W + (M-N₁-N₂)T₁ + W₁ - C + (N₁ + N₂)H + W₂ | W + MT₁+(M-X)T₂ - C-W₂ |
| Strictly (p) | L-(M-N₁-N₂)T₁ - g + 1 + 1+(X-M + N₁ + N₂) | L-MT₁ (M-X)T₂-W₂  |                          |
| laxly (1-p)  | L-XT₁+(M-X)T₂             | W + MT₁           |                          |

\[
F₂(q) = q(1 - q)\{p[I - g + (M - X)(T₂ + T₃ - T₁)] + (N₁ + N₂)T₁ + (X - M + N₁ + N₂)V + L₁] + (M - X)(T₁ - T₂)\}
\]

At this time, the five partial equilibrium points of the game system are A₂ (0,0), B₂ (0,1), C₂ (1,0), D₂ (1,1), E₂ (p₂,q₂). In \(E₂, p₂ = \frac{(M - X)T₂ + T₁ - T₃}{(M - X)T₁ + T₂ - T₃ + (N₁ + N₂)T₁ + X - g + 1 + (X - M + N₁ + N₂)V + L₁}\), q₂ = \(\frac{(N₁ + N₂)(M - X)(T₁ - T₂) - (M - X)(T₁ - T₂)}{(M - X)(T₁ - T₂) - (M - X)(T₁ - T₂) + W} \).

After adding socialized regulation, the replication dynamic equation is as follows:

\[
F₃(p) = p(1 - p)\{q[(M - X)(T₁ - T₂ - T₃)] + (N₁ + N₂)(H - T₁) + W₁ + 2W₂] + [(M - X)T₂ - C - W₂]\}
\]

\[
F₃(q) = q(1 - q)\{p[I - g + (M - X)(T₂ + T₃ - T₁)] + (N₁ + N₂)(H - T₁) + W₁ + 2W₂] + [(M - X)T₂ - C - W₂]\}
\]
At this time, the five partial equilibrium points of the game system are $A_3(0,0)$, $B_3(0,1)$, $C_3(1,0)$, $D_3(1,1)$, and $E_3(p_3,q_3)$. In $E_3$, $p_3 = (M - X)T_i T_2 - T_3 + N_i + N_2 T_i T_2 + L_1 + 2L_2$, $q_3 = + (N_1 + N_2)T_i T_2 + (X - M + N_1 + N_2)V + L_1 + 2L_2$.

\begin{equation}
+ (N_1 + N_2)T_i T_2 + (X - M + N_1 + N_2)V + L_1 + 2L_2
\end{equation}

\begin{equation}
(M - X)(T_i - T_3)
\end{equation}

2.4.2.3. Equilibrium strategy analysis

The stability of the equilibrium strategy is analyzed in the same way.

When the government only implements administrative regulation, the determinant $\text{Det}(J_1)$ and trace $\text{Tr}(J_1)$ of matrix $J_1$ can be obtained:

\begin{equation}
\text{Det}(J_1) = (1 - 2p)(q[M - X](T_i - T_2 - T_3) + N_i(H - T_i) + [(M - X)T_3 - C])
\end{equation}

\begin{equation}
\times(1 - 2q)(p[(M - X)(T_2 + T_3 - T_1) + (N_i + N_2)T_i - g + I] + (M - X)(T_2 - T_3))
\end{equation}

\begin{equation}
- p(1 - p)[(M - X)(T_i - T_2 - T_3) + N_i(H - T_i)]
\end{equation}

\begin{equation}
\times q(1 - q)[(M - X)(T_2 + T_3 - T_1) + (N_i + N_2)T_i - g + I]
\end{equation}

\begin{equation}
\text{Tr}(J_1) = (1 - 2p)[q(M - X)(T_i - T_2 - T_3)]
\end{equation}

\begin{equation}
+ (N_i + N_2)(H - T_i) + [(M - X)T_3 - C])
\end{equation}

\begin{equation}
+ (1 - 2q)[p(M - X)(T_2 + T_3 - T_1) + (N_i + N_2)T_i - g + I]
\end{equation}

\begin{equation}
+ (M - X)(T_2 - T_3)
\end{equation}

When adding market-oriented regulation, the determinant $\text{Det}(J_2)$ and trace $\text{Tr}(J_2)$ of matrix $J_2$ can be obtained:

\begin{equation}
\text{Det}(J_2) = (1 - 2p)[q(M - X)(T_i - T_2 - T_3)]
\end{equation}

\begin{equation}
+ (N_i + N_2)(H - T_i) + W_i] + [(M - X)T_3 - C])
\end{equation}

\begin{equation}
\times (1 - 2q)[p[M - X](T_2 + T_3 - T_1) + (N_i + N_2)T_i - g + I]
\end{equation}

\begin{equation}
+ L_1 + (X - M + N_1 + N_2)V]
\end{equation}

\begin{equation}
- p(1 - p)[(M - X)(T_i - T_2 - T_3) + (N_i + N_2)(H - T_i) + W_i]
\end{equation}

\begin{equation}
\times q(1 - q)[(M - X)(T_2 + T_3 - T_1) + (N_i + N_2)T_i - g + I]
\end{equation}

\begin{equation}
+ L_1 + (X - M + N_1 + N_2)V]
\end{equation}

\begin{equation}
\text{Tr}(J_2) = (1 - 2p)[q(M - X)(T_i - T_2 - T_3)]
\end{equation}

\begin{equation}
+ (N_i + N_2)(H - T_i) + W_i] + [(M - X)T_3 - C])
\end{equation}

\begin{equation}
+ (1 - 2q)[p(M - X)(T_2 + T_3 - T_1) + (N_i + N_2)T_i - g + I]
\end{equation}

\begin{equation}
+ (M - X)(T_2 - T_3)
\end{equation}

When adding social regulation, the determinant $\text{Det}(J_3)$ and trace $\text{Tr}(J_3)$ of matrix $J_3$ can be obtained:

\begin{equation}
\text{Det}(J_3) = (1 - 2p)[q(M - X)(T_i - T_2 - T_3)]
\end{equation}

\begin{equation}
+ (N_i + N_2)(H - T_i) + W_i] + [(M - X)T_3 - W_2 - C])
\end{equation}

\begin{equation}
\times (1 - 2q)[p[M - X](T_2 + T_3 - T_1) + (N_i + N_2)T_i - g + I]
\end{equation}

\begin{equation}
+ L_1 + 2L_2 + (X - M + N_1 + N_2)V] + (M - X)(T_i - T_2 - T_3)
\end{equation}

\begin{equation}
- p(1 - p)[(M - X)(T_i - T_2 - T_3) + (N_i + N_2)(H - T_i) + W_i + 2W_2]
\end{equation}

\begin{equation}
\times q(1 - q)[(M - X)(T_2 + T_3 - T_1) + (N_i + N_2)T_i - g + I]
\end{equation}

\begin{equation}
+ 2W_1 + 2W_2 + [(M - X)(T_i - T_2 - T_3) + (N_i + N_2)T_i - g + I] + L_1 + 2L_2 + (X - M + N_1 + N_2)V]
\end{equation}

\begin{equation}
\text{Tr}(J_3) = (1 - 2p)[q(M - X)(T_i - T_2 - T_3)]
\end{equation}

\begin{equation}
+ (N_i + N_2)(H - T_i) + W_i] + [(M - X)T_3 - C])
\end{equation}

\begin{equation}
+ (1 - 2q)[p[M - X](T_2 + T_3 - T_1) + (N_i + N_2)T_i - g + I]
\end{equation}

\begin{equation}
+ (M - X)(T_2 - T_3)
\end{equation}

\begin{equation}
+ I + L_1 + 2L_2 + (X - M + N_1 + N_2)V] + (M - X)(T_i - T_2 - T_3)
\end{equation}

The stability of the strategy is shown in table 5.

2.4.3. Construction and analysis of the game model between the government and C-class enterprises

2.4.3.1. Game model construction

The interest game between the government and C-class enterprises is shown in the table 6 below.
Table 5. The stability analysis results from the equilibrium strategy of the government and B-class enterprises.

| Equilibrium | Det(J) | Tr(J) | Stability |
|-------------|--------|-------|-----------|
| A1 (0,0)    | 0      | -     | ESS       |
| B1 (0,1)    | 0      | 1     | unstable  |
| C1 (1,0)    | 0      | 1     | unstable  |
| D1 (1,1)    | 0      | 0     | saddle point |

When the government only implements administrative regulations:

$E\left\{\begin{aligned}
(M - X)(T_2 - T_3) \\
C - (M - X)T_1 \\
N_1(H - T_1) + (M - X)(T_2 - T_3) + W_1
\end{aligned}\right.$

After the government adds market-oriented regulation:

$E\left\{\begin{aligned}
(M - X)(T_2 - T_3) \\
C + W_2 - (M - X)\bar{T}_3 \\
(N_1 + N_2)(H - T_1) + (M - X)(T_2 - T_3) + W_1 + W_2
\end{aligned}\right.$

After the government adds socialized regulation:

$E\left\{\begin{aligned}
(M - X)(T_2 - T_3) \\
C + (M - X)\bar{T}_3 \\
(N_1 + N_2)(H - T_1) + (M - X)(T_2 - T_3) + W_1 + W_2
\end{aligned}\right.$

Table 6. The game matrix between the government and C-class enterprises.

| Game subject | Cooperate positively \(q\) | C-class enterprises | Cooperate negatively \(1-q\) |
|--------------|-----------------------------|---------------------|-----------------------------|
| Government   | Regulate \( W + XT_1 + (M-N_1)X\bar{T}_2-C + N_1H \) | \( W + MT_1-C+(M-X)\bar{T}_3 \) | \( W + MT_1+C-(M-X)\bar{T}_3 \) |
|              | Strictly \( p \) \( LXT_1-(M-N_1)X\bar{T}_2=g+I \) | \( LMT_1-(M-X)\bar{T}_3 \) | \( LMT_1-(M-X)\bar{T}_3 \) |
|              | Regulate \( W + XT_1+(M-X)\bar{T}_2 \) | \( W + MT_1 \) | \( W + MT_1 \) |
|              | laxly \( 1-p \) \( LXT_1-(M-X)\bar{T}_2 \) | \( LMT_1 \) | \( LMT_1 \) |

When the government only implements administrative regulations:

| Government   | Regulate \( W + XT_2 + W_1-C+(N_1 + N_2)H \) | \( W + MT_1-C+(M-X)\bar{T}_3 \) | \( W + MT_1+C-(M-X)\bar{T}_3 \) |
|              | Strictly \( p \) \( LXT_1-(M-N_1,N_2)XV\bar{g}+L_1+I \) | \( LMT_1-(M-X)\bar{T}_3 \) | \( LMT_1-(M-X)\bar{T}_3 \) |
|              | Regulate \( W + XT_1+(M-X)\bar{T}_2 \) | \( W + MT_1 \) | \( W + MT_1 \) |
|              | laxly \( 1-p \) \( LXT_1-(M-X)\bar{T}_2 \) | \( LMT_1 \) | \( LMT_1 \) |

After the government adds the market-oriented regulation:

| Government   | Regulate \( W + XT_1 + W_1-C+(N_1 + N_2)H + W_2 \) | \( W + MT_1-C+(M-X)\bar{T}_3 \) | \( W + MT_1+C-(M-X)\bar{T}_3 \) |
|              | Strictly \( p \) \( LXT_1-(M-N_1,N_2)XV\bar{g}+L_1+L_2+I \) | \( LMT_1-(M-X)\bar{T}_3 \) | \( LMT_1-(M-X)\bar{T}_3 \) |
|              | Regulate \( W + XT_1+(M-X)\bar{T}_2 \) | \( W + MT_1 \) | \( W + MT_1 \) |
|              | laxly \( 1-p \) \( LXT_1-(M-X)\bar{T}_2 \) | \( LMT_1 \) | \( LMT_1 \) |

After the government adds the socialized regulation:

| Government   | Regulate \( W + XT_1 + W_1-C+(N_1 + N_2)H + W_2 \) | \( W + MT_1-C+(M-X)\bar{T}_3 \) | \( W + MT_1+C-(M-X)\bar{T}_3 \) |
|              | Strictly \( p \) \( LXT_1-(M-N_1,N_2)XV\bar{g}+L_1+L_2+I \) | \( LMT_1-(M-X)\bar{T}_3 \) | \( LMT_1-(M-X)\bar{T}_3 \) |
|              | Regulate \( W + XT_1+(M-X)\bar{T}_2 \) | \( W + MT_1 \) | \( W + MT_1 \) |
|              | laxly \( 1-p \) \( LXT_1-(M-X)\bar{T}_2 \) | \( LMT_1 \) | \( LMT_1 \) |
2.4.3.2. Equilibrium strategy analysis
When the government only implements administrative regulations, the replication dynamic equation of the government and enterprises is as follows:

\[
F_i(p) = p(1 - p)\{q[N_i(H - T_i) - (M - X)(T_i - g)] + [(M - X)T_i - C]\} + [(M - X)T_i - C] \quad (13)
\]

\[
F_i(q) = q(1 - q)\{p[(M - X)T_i + I - g + N_iT_i] + (M - X)(T_i - T_j)\} \quad (14)
\]

At this time, the five partial equilibrium points of the game system are \(A_1(0,0), B_1(0,1), C_1(1,0), D_1(1,1),\) and \(E_1(p_1,q_1). \) In \(E_1, p_1 = \frac{1}{2} \frac{(M - X)(T_i - C)}{C - (M - X)T_i}, q_1 = \frac{1}{2} \frac{N_i(H - T_i) - (M - X)T_i}{N_i(H - T_i) - (M - X)T_i}.

After adding market-oriented regulation, the replication dynamic equation is as follows:

\[
F_3(p) = p(1 - p)\{q(N_i + N_2)(H + W_i) - (M - X)(T_i + T_j) \}
- (M - X)(T_i + T_j) + [(M - X)T_i - C]\} \quad (15)
\]

\[
F_3(q) = q(1 - q)\{p[(M - X)(T_i + T_j) + I - g + L_1]
+ (M - X)(T_i - T_j)\} \quad (16)
\]

At this time, the five partial equilibrium points of the game system are \(A_2(0,0), B_2(0,1), C_2(1,0), D_2(1,1),\) and \(E_2(p_2,q_2). \) In \(E_2, p_2 = \frac{1}{2} \frac{(M - X)(T_i + T_j) - (M - N_i - N_2 - X)V - g + I + L_2}{(N_i + N_2)(H + W_i + 2W_i - (M - X)(T_i + T_j))}, q_2 = \frac{1}{2} \frac{N_i(H - T_i) - (M - X)T_i}{N_i(H - T_i) - (M - X)T_i}.

2.4.3.3. Analysis of the stability of the equilibrium strategy

The following analysis of equilibrium strategy stability. When only implementing administrative regulation, the determinant \(\text{Det}(J_1)\) and trace \(\text{Tr}(J_1)\) of matrix \(J_1\) are shown below:

\[
\text{Det}(J_1) = (1 - 2p)\{q[N_i(H - T_i) - (M - X)(T_i + T_j) + [(M - X)T_i - C]\} \times (1 - 2q)\{p[(M - X)(T_i + T_j) + N_iT_j - g + I] + (M - X)(T_i - T_j) - T_i]\}
- p(1 - p)[N_i(H - T_i) - (M - X)T_i] \times q(1 - q)\{(M - X)T_j + N_iT_j - g + I\}
\]

\[
\text{Tr}(J_1) = (1 - 2p)\{q[N_i(H - T_i) - (M - X)T_i]\} \times (1 - 2q)\{p[(M - X)(T_i + T_j) + N_iT_j - g + I] + (M - X)(T_i - T_j) - T_i]\}
- p(1 - p)[N_i(H - T_i) - (M - X)T_i] \times q(1 - q)\{(M - X)T_j + N_iT_j - g + I\}
\]

After adding market-oriented regulation, the determinant \(\text{Det}(J_2)\) and trace \(\text{Tr}(J_2)\) of matrix \(J_2\) can be obtained:

\[
\text{Det}(J_2) = (1 - 2p)\{q[N_i + N_2](H + W_i - (M - X)(T_i + T_j)]
+ [(M - X)T_i - C]\} \times (1 - 2q)\{p[(M - X)(T_i + T_j) + N_2T_j - g + I] + (M - X)(T_i - T_j) - T_i\}
- p(1 - p)[N_i + N_2]H - W_i - (M - X)(T_i + T_j)] \times q(1 - q)\{(M - X)(T_i + T_j) - N_i - N_2 - X)V - g + I + L_1\}
\]

\[
\text{Tr}(J_2) = (1 - 2p)\{q[N_i + N_2](H + W_i - (M - X)(T_i + T_j)]
+ [(M - X)T_i - C]\} \times (1 - 2q)\{p[(M - X)(T_i + T_j) + N_2T_j - g + I] + (M - X)(T_i - T_j) - T_i\}
- p(1 - p)[N_i + N_2]H - W_i - (M - X)(T_i + T_j)] \times q(1 - q)\{(M - X)(T_i + T_j) - N_i - N_2 - X)V - g + I\}
\]

After adding socialization, the determinant \(\text{Det}(J_3)\) and trace \(\text{Tr}(J_3)\) of matrix \(J_3\) can be obtained:

\[
\text{Det}(J_3) = (1 - 2p)\{q[N_i + N_2](H + W_i - (M - X)(T_i + T_j)]
+ 2W_i\} \times (1 - 2q)\{p[(M - X)(T_i + T_j) + N_2T_j - g + I] + (M - X)(T_i - T_j) - T_i\}
- p(1 - p)[N_i + N_2]H - W_i - (M - X)(T_i + T_j)] + 2W_i\} \times q(1 - q)\{(M - X)(T_i + T_j) - N_i - N_2 - X)V - g + I\}
\]

\[
\text{Tr}(J_3) = (1 - 2p)\{q[N_i + N_2](H + W_i - (M - X)(T_i + T_j)]
+ 2W_i\} \times (1 - 2q)\{p[(M - X)(T_i + T_j) + N_2T_j - g + I] + (M - X)(T_i - T_j) - T_i\}
- p(1 - p)[N_i + N_2]H - W_i - (M - X)(T_i + T_j)] + 2W_i\} \times q(1 - q)\{(M - X)(T_i + T_j) - N_i - N_2 - X)V - g + I\}
\]
The stability situation is shown in table 7.

3. Result

3.1. Phase diagram analysis

3.1.1. Phase diagram analysis of dynamic evolution of strategic choice of government and A-class enterprises

From table 3, the stable equilibrium strategy for the game between the government and A-class enterprises is only D (regulate strictly, cooperate positively), while A (regulate laxly, cooperate negatively) and B (regulate laxly, cooperate positively) and C (regulate strictly, cooperate negatively) are both unstable strategies, and the system has no saddle point. As shown in figure 1, no matter what the initial strategic choices of the government and enterprises are, the game system will eventually tend to a stable equilibrium strategy (regulate strictly, cooperate positively).

3.1.2. Phase diagram analysis of the stable equilibrium strategy of the government and B-class enterprises

From table 5, the stable equilibrium strategies for the game between the government and B-class enterprises are A (regulate laxly, cooperate negatively), D (regulate strictly, cooperate positively), while B (regulate laxly, cooperate positively) and C (regulate strictly, cooperate negatively) are both unstable strategies, and at this time, a saddle point E exists. As shown in figure 2, with the addition of the regulatory policy, the position of the saddle point E moves, and the area of the BCDE area gradually becomes larger, indicating that the possibility of the game system tending to the D strategy increases.

3.1.3. Phase diagram analysis of the stable equilibrium strategy of the government and C-class enterprises

From table 7, the stable equilibrium strategies for the game between the government and C-class enterprises are A (regulate laxly, cooperate negatively) and D (regulate strictly, cooperate positively), while B (regulate laxly, cooperate positively) and C (regulate strictly, cooperate negatively) are both unstable strategies, and there is also a saddle point E that gradually shifting with the addition of regulatory means. The dynamic evolution process of its stable equilibrium strategy is shown in figure 3.

3.2. Numerical simulation

From the above analysis, only A-class enterprises will choose to actively cooperate under the administrative regulation of the government; B-class and C-class enterprises both require the government to adopt combined regulation measures. Therefore, we have not been able to draw specific conclusions about the optimal means. So, this research used MATLAB to implement numerical simulation for verification. First, control the parameter variables $N_1 = 3, N_2 = 2, H = 100, T_1 = 10, W_1 = 80, W_2 = 90, I = 150, X = 15, V = 20, L_1 = 150, L_2 = 180$, And the initial decision-making points of government and enterprise $S_1 (0.1, 0.7), S_2 (0.2, 0.65), S_3 (0.3, 0.9), S_4 (0.4, 0.6), S_5 (0.5, 0.8), S_6 (0.7, 0.6)$; Then, observe the final trend of each decision point under different regulatory means; test the effect of different regulatory means on enterprises with different pollutant discharges and finally obtain the best regulatory means for enterprises.

3.2.1. Numerical simulation of the dynamic evolution of strategic choice of government and A-class enterprises

Figures 4(a)–(c) respectively show the change in the strategic choices of A-class enterprises after the government gradually joins administrative, market-oriented, and socialized environmental regulations. At this time, $M \leq X$, so $M = 12$. Under the administrative regulation of the government, although $S_1 (0.1, 0.7), S_2 (0.2, 0.65), S_3 (0.3, 0.9)$, and $S_6 (0.7, 0.6)$ have inflection points, six different decision points all eventually tend to D. When the government adds market-oriented regulations, the inflection point disappears, which shows that market-oriented regulation has a certain incentive effect on A-class enterprises. But the effect of socialized regulation is not obvious.

3.2.2. Numerical simulation of the dynamic evolution of strategic choice of government and B-class enterprises

Figures 5(a)–(c) respectively show the change in the strategic choices of B-class enterprises after the government gradually joins administrative, market-oriented, and socialized environmental regulations. At this time, $M > X$ and $M-N_1 \leq X$, so $M = 18$. Under the administrative regulation method, there is a saddle point about $E_1 (0.33, 0.81)$. At this time, the decision point below the BEC connection tends to A (regulate laxly, cooperate negatively),
Table 7. The stability analysis results from the equilibrium strategy of the government and C-class enterprises.

| Equilibrium | Det(J) | Tr(J) | Stability |
|-------------|--------|-------|-----------|
| When the government only implements administrative regulations: | | | |
| A₁ (0,0) | + | — | ESS |
| B₁ (0,1) | + | + | unstable |
| C₁ (1,0) | + | + | unstable |
| D₁ (1,1) | + | — | ESS |
| E₁ \( \frac{(M - X)(T₂ - T₁)}{(M - X)T₂ + N₂T₂ - g + l} \) \( \frac{C - (M - X)T₁}{N₁(T₂ - T₁) - (M - X)T₂} \) | — | 0 | saddle point |
| After the government adds market-oriented regulation: | | | |
| A₂ (0,0) | + | — | ESS |
| B₂ (0,1) | + | + | unstable |
| C₂ (1,0) | + | + | unstable |
| D₂ (1,1) | + | — | ESS |
| E₂ \( \frac{(M - X)(T₂ - T₁)}{(M - X)(T₂ + T₁) - (M - N₁ - N₂ - X)V - g + l + l₂} \) \( \frac{C - (M - X)T₁}{(N₁ + N₂)H + W₁ - (M - X)(T₂ + T₁)} \) | — | 0 | saddle point |
| After the government adds socialized regulation: | | | |
| A₃ (0,0) | + | — | ESS |
| B₃ (0,1) | + | + | unstable |
| C₃ (1,0) | + | + | unstable |
| D₃ (1,1) | + | — | ESS |
| E₃ \( \frac{(M - X)(T₂ - T₁)}{(M - X)(T₂ + T₁) - (M - N₁ - N₂ - X)V - g + l + l₂ + 2l₂} \) \( \frac{C + W₁ - (M - X)T₁}{(N₁ + N₂)H + W₁ + 2W₂ - (M - X)(T₂ + T₁)} \) | — | 0 | saddle point |
while the decision point above tends to D (regulate strictly, cooperate positively). This shows that administrative regulation has a certain effect on B-type enterprises, but there is no guarantee that enterprises will choose to actively cooperate. After adding market-oriented regulation, the saddle point is about E₂ (0.16, 0.53) and all decision-making points can tend to D, indicating that market-oriented regulation has an obvious regulatory effect on B-class enterprises and can ensure the final choice of enterprises. Under socialized regulation, the saddle point is about E₃ (0.074, 0.56) and the decision point tends to point D earlier, but the effect is not obvious.

3.2.3. Numerical simulation of the dynamic evolution of strategic choice of government and C-class enterprises

Figures 6(a)–(c) respectively show the change in the strategic choices of C-class enterprises after the government gradually joins administrative, market-oriented, and socialized environmental regulations. At this time,
M-N1-N2 > X, so M = 21. Under the administrative regulation, the saddle point is about E1 (0.35, 0.44), the lower decision point tends to A, and the upper decision point tends to D. But compared with figure 6(a), the decision point S4 (0.4, 0.6) tends to D. This shows that the effect of government administrative regulation on C-class enterprises is better than that of B-class enterprises. Market-oriented regulation plays a certain role, making S2 (0.2, 0.65), which tends to point A under administrative regulation, tend to D. However, it is still not guaranteed that all decision points will go to D, such as S1 (0.1, 0.7). This shows that the effect of market-oriented regulation on C-class enterprises is not as good as that of B-class enterprises. Therefore, C-class enterprises also need the government to implement socialized regulatory means to ensure the final strategic choice of the enterprise.

4. Discussions

From figures 5 to 6, the same regulation will have different effects on different companies, and different regulations will also have different effects on the same company. This is consistent with the conclusions of previous studies [36–40]. Therefore, to improve the willingness of enterprises to actively cooperate, the
government needs to continuously adjust the regulatory method according to the actual situation. The actual situation here mainly refers to the number of pollutants discharged by the enterprise, which is different from the previous focus on the heterogeneity of the industry and the scale of the enterprise [33, 34].

The government can improve the willingness of enterprises to actively cooperate with regulation by establishing a diversified environmental regulation mechanism. The above research shows that different regulatory means have different realization paths and can exert different effects. Therefore, it is pointed out that in the face of the ever-changing market, a new and diversified environmental regulation mechanism including administrative regulation, market-oriented regulation, and socialized regulation should be established (as described in assumption 2). It can give full play to the synergistic advantages of various regulatory policies. While regulating the pollution behavior of enterprises, protects the legitimate interests of enterprises and improves the willingness of enterprises to cooperate.

The diversity of business types and their influence remind the government to adopt a policy of classified governance, that is, adopt a policy for an enterprise. Research showed that firm heterogeneity can also have an impact on regulatory effectiveness. Therefore, a one-size-fits-all approach cannot be adopted for all enterprises. Therefore, a one-size-fits-all approach cannot be adopted for all enterprises. The government should classify enterprises according to the standard of pollutant discharge volume, adopt differentiated environmental policies, and select the optimal policy combination of environmental regulation, to maximize the effect of environmental regulation.

There is another issue that required special attention. The rational allocation of economic performance and environmental performance is the premise guarantee for the government to choose strict regulation. Environmental regulation in China belongs to a two-tier governance system, namely the central government-local government-enterprise. Therefore, the local government has the dual pressure of economic performance and environmental regulation, which causes the local government to oscillate between strict regulation and deregulation. Therefore, in the performance evaluation of local governments, it is necessary to balance the ratio of economic performance and environmental performance, change the concept of only GDP first, guide local governments to change their economic development methods, resist extensive and abusive economic development paths, and support local governments to strictly adopt diversified environmental regulations.

5. Conclusions

Here are the answers to the questions raised above that need to be addressed:

First, this study divided environmental regulation into administrative regulation, market-oriented regulation, and socialized regulation according to the path and mechanism of public policy realization.

Second, according to the different relationship between the enterprise’s pollutant discharge volume and the government’s pollutant discharge limit, the enterprises are divided into three categories: small pollutant discharge volume, medium discharge volume, and larger discharge volume.

This study has some limitations that need to be further explored. Firstly, the fundamental nature of evolutionary games introduces some limitations. For the convenience of research, researchers ideally assumed that there were only governments and businesses in the system. However, in reality, environmental regulation involves many subjects, and the situation is more complicated and difficult to analyze clearly. Secondly, the regulation mechanism established in the model was also relatively ideal, and some factors involved may not exist in reality, and it is impossible to collect first-hand or even second-hand data, so it can only be tested by numerical simulation. Thirdly, by focusing on the heterogeneity of policies and enterprises, this study believed that the classification of regulatory policies is universal to a certain extent, and has a certain reference value for other regulations such as health care and water resources. But the classification of enterprises only focuses on their sewage volume. Therefore, to further analyze the heterogeneity of firms in other regulatory systems other than environmental issues, it is necessary to reexplore the starting point.

Acknowledgments

This research is a part of the research project funded by the Natural Science Foundation of Hunan Province (Grant No. 2021JJ30288) and the Department of Education Hunan Province (Grant No. 21A0322).

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.
Conflict of interest statement

The authors declare no conflicts of interest.

ORCID iDs

HuiLin Wang https://orcid.org/0000-0002-4301-3077

References

[1] Copeland B R and Taylor M S 1997 The trade-induced degradation hypothesis Resour. Energy Econ. 19 321–44
[2] Walter I and Ugelow J L 1979 Environmental policies in developing countries Ambio 8 102–9
[3] Dean T J and Brown R L 1995 Pollution regulation as a barrier to new firm entry: initial evidence and implications for future research Acad. Manage. J. 38 303–288
[4] Kemp R and Pontoglio S 2011 The innovation effects of environmental policy instruments — a typical case of the blind men and the elephant? Ecol. Econ. 72 36–28
[5] Guo L I, Qu Y and Tseng M-L 2017 The interaction effects of environmental regulation and technological innovation on regional green growth performance J. Clean. Prod. 162 902–894
[6] Ley M, Stucki T and Woerter M 2016 The impact of energy prices on green innovation Energy J. 37 75–41
[7] Porter M E and van der Linde C 1995 Toward a new conception of the environment-competitiveness relationship J. Econ. Perspect. 9 118–97
[8] Hu X et al 2019 The impact of environmental protection tax on sectoral and spatial distribution of air pollution emissions in China Environ. Res. Lett. 14 054013
[9] Jaffe A B and Palmer K 1997 Environmental Regulation and Innovation: a panel data study Rev. Econ. Stat. 79 610–9
[10] Li D and Zeng T 2020 Are China’s intensive pollution industries greening? An analysis based on green innovation efficiency J. Clean. Prod. 259 120901
[11] Song M, Wang S and Zhang H 2020 Could environmental regulation and R&D tax incentives affect green product innovation? J. Clean. Prod. 258 120849
[12] Von Neumann J and Morgenstern O 1944 Theory of Games and Economic Behavior (New Jersey: Princeton University Press)
[13] Weibull J 1997 Evolutionary Game Theory 22 (Massachusetts: The MIT Press)
[14] Chen Y, Zhang J, Tadikamalla P R and Gao X 2019 The relationship among government, enterprise, and public in environmental governance from the perspective of multi-player evolutionary game Int. J. Environ. Res. Public Health 16 3351
[15] Xia C, Gracia-Lázaro C and Moreno Y 2020 Effect of memory, intolerance, and second-order reputation on cooperation Chaos 30 063122
[16] Zhu Q-H and Dou Y-J 2007 Evolutionary game model between governments and core enterprises in greening supply chains Syst. Eng. Theory Pract. 27 85–9
[17] Zhu G, Pan G and Zhang W 2018 Evolutionary game theoretic analysis of low carbon investment in supply chains under governmental subsidies Int. J. Environ. Res. Public Health 15 2465
[18] Wu B, Liu P and Xu X 2017 An evolutionary analysis of low-carbon strategies based on the government–enterprise game in the complex network context J. Clean. Prod. 141 168–79
[19] Mahmoudi R and Rasti-Barzoki M 2018 Sustainable supply chains under government intervention with a real-world case study: an evolutionary game theoretic approach Comput. Ind. Eng. 116 130–43
[20] Chen W and Hu Z-H 2018 Using evolutionary game theory to study governments and manufacturers’ behavioral strategies under various carbon taxes and subsidies J. Clean. Prod. 201 123–41
[21] Fan R, Dong L, Yang W and Sun J 2017 Study on the optimal supervision strategy of government low-carbon subsidy and the corresponding efficiency and stability in the small-world network context J. Clean. Prod. 168 536–50
[22] Zhang S, Wang C and Yu C 2019 The evolutionary game analysis and simulation with system dynamics of manufacturer’s emissions abatement behavior under cap-and-trade regulation Appl. Math. Comput. 355 343–55
[23] Kang K, Zhao Y, Zhang J and Qiang C 2019 Evolutionary game theoretic analysis on low-carbon strategy for supply chain enterprises J. Clean. Prod. 230 981–94
[24] Zou B, Ju C, Bao F, Lai Y, Xu C and Zhu Y 2022 Exploring an efficient evolutionary game model for the government–enterprise–public during the double carbon policy in China Int. J. Environ. Res. Publ. Health 19 4607
[25] Yu Y, Chen L and Fan Y 2018 Research on low-carbon strategies in supply chain with environmental regulations based on differential game J. Clean. Prod. 177 527–46
[26] Kornisky D M and Teodor M P 2016 When governments regulate governments Am. J. Polit. Sci. 60 559–74
[27] James O 2000 Regulation inside government: public interest justifications and regulatory failures Public Adm. 78 327–43
[28] Hood C 1995 Control over bureaucracy: cultural theory and institutional variety J. Public Policy 15 207–30
[29] Robert B C A H 1998 A Reader on Regulation (Oxford: Oxford University Press)
[30] Georg S 1994 Regulating the environment: changing from constraint to gentle coercion Bus. Strategy Environ. 3 20–11
[31] Lee D R and Misiolek W S 1986 Substituting pollution taxation for general taxation: Some implications for efficiency in pollution taxation Journal of Environmental Economics and Management 13 338–47
[32] Anderson B, Böhmelt T and Ward H 2017 Public opinion and environmental policy output: a cross-national analysis of energy policies in Europe Environ. Res. Lett. 12 41011
[33] Aragón-Correa J A, Hurtado-Torres N, Sharma S and García-Morales V J 2008 Environmental strategy and performance in small firms: a resource-based perspective J. Environ. Manage. 86 103–88
[34] López-Gamero M D, Molina-Azorín J F and Claver-Cortés E 2010 The potential of environmental regulation to change managerial perception, environmental management, competitiveness and financial performance J. Clean. Prod. 18 963–74
[35] Friedman D 1991 Evolutionary games in economics Economica 59 657–66
[36] Atkinson S E and Lewis D H 1974 A cost-effectiveness analysis of alternative air quality control strategies J. Environ. Econ. Manag. 1 237–50
[37] Malureg D A 1989 Emission credit trading and the incentive to adopt new pollution abatement technology J. Environ. Econ. Manag. 16 52–7
[38] Mathiyazhagan K, Diabat A, Al-Refaie A and Xu L 2015 Application of analytical hierarchy process to evaluate pressures to implement green supply chain management J. Clean. Prod. 107 229–36
[39] Moledina A A, Coggins J S, Polasky S and Costello C 2003 Dynamic environmental policy with strategic firms: prices versus quantities J. Environ. Econ. Manag. 45 356–76
[40] Stavins R N 1996 Correlated uncertainty and policy instrument choice J. Environ. Econ. Manag. 30 218–32