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An Evolutionary Game Analysis on Green Technological Innovation of New Energy Enterprises under the Heterogeneous Environmental Regulation Perspective

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Abstract: In the context of economic transformation and upgrading and ecological civilization construction, green technology innovation is an inevitable choice for enterprises' sustainable development. Can environmental regulation effectively promote enterprises' green technological innovation and achieve a win–win economic growth and environmental protection situation? This paper uses evolutionary game theory and numerical simulation to analyze the influence mechanisms of command-control, market-incentive and social-will, three environmental regulation tools and different combinations of environmental regulation tools on green technology innovation behavior of new energy enterprises. The study found: (1) The effects of three types of environmental regulation tools on green technological innovation of new energy enterprises are different, in which market-incentive environmental regulation policies play the most significant role, followed by command-control environmental regulation and social-will environmental regulation tools are not very obvious. (2) Implementing a separate environmental regulation policy has a poor effect on stimulating green technology innovation of new energy enterprises. If two environmental regulation means are implemented, the combination of command-control and market-incentive environmental regulations is the most effective. (3) Combining the implementation of three environmental regulation means of high-intensity market-incentive, high-intensity command-control and low-intensity social-will is the best strategy combination, which can motivate new energy enterprises to become stable for the green technology innovation strategy in the shortest time.

Keywords: environmental regulation; green technological innovation; evolutionary game; new energy enterprises

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1. Introduction

Since the reform and opening up, China's GDP growth rate ranks among the world's leading economies and has achieved a high growth rate that has attracted worldwide attention [1]. However, the rapid growth of China's economy relies on the traditional crude industrial development model; the level of technological innovation is backward, overcapacity, there is low utilization of resources and other issues cause total factor productivity to be too low to support the quality development of the economy. The high-quality economic growth and the environmental protection level are closely related. Considering environmental and ecological protection, comprehensive promotion of green development is the only way to achieve high-quality economic growth and sustainable development [2].

Environmentally friendly technological innovation is an inevitable choice to achieve economic recovery and green development in the post-epidemic era [3]. Green technology innovation follows ecological economics' ecological principle and development law, and combines technology innovation with the ecosystem. It has the economic characteristics of improving production efficiency and enterprise competitiveness, and the social characteristics of emissions reduction and environmental protection, which can realize economic

development while considering environmental protection [4]. Compared with traditional technologies, green technological innovation's unique attributes and values determine that it can fundamentally solve the contradiction between the ecological environment and economic development and is the only way to promote green development and achieve high-quality economic development [5]. However, green technological innovation is characterized by double externalities [6], which often lead to market failure. Environmental regulation theory suggests that the government can address the dual externalities and market failures of green technology innovation by adopting effective environmental regulation policies [7–9]. The impact of environmental regulation on green technology innovation has been widely studied, but whether environmental regulation can promote green technology innovation has seen no consistent conclusion yet. The existing findings are divided into three main types.

The first type is the "restrictive hypothesis", which is based on the static perspective that strict environmental regulations will inevitably reduce the profitability of enterprises, thus preventing them from green technological innovation, provided that the level of technology, resource allocation and consumer demand remain unchanged [10]. Lots of scholars have analyzed relevant data based on various industries in different countries [11–14], and the results show that the increased costs caused by strict environmental regulations cannot be effectively offset [13], making both implicit and explicit costs of firms rise [15] and productivity decrease [11–17], thus arguing that environmental regulation constrains firms' green technological innovation behavior [12,14–16], which in turn affects their competitiveness [15,18].

The second type is the "Porter hypothesis", which focuses on the impact of environmental regulation on green technology innovation from a dynamic perspective. It is believed that well-designed environmental regulation can optimize the allocation of resources, improve technological innovation, reduce production costs, and stimulate the "innovation compensation" effect of enterprises, thus partially or even wholly offsetting the costs brought by environmental regulation and achieving a win–win situation of "environmental regulation—green technological innovation" [19]. Later, scholars verified Porter's hypothesis using different methods based on data from different countries and industries [20–24]. Jaffe and Palmer further developed the Porter hypothesis, dividing it into three versions: "strong", "weak" and "narrow" [25]. The "strong" version of the Porter hypothesis suggests that high levels of environmental regulation can encourage firms to innovate green technologies and generate an "innovation compensation" effect, thus offsetting the costs of additional environmental regulation, reducing firms' capital expenditures, promoting green innovation [26] and increasing firms' productivity and competitiveness [27–29]; the "weak" version of Porter's hypothesis suggests that appropriate environmental regulations can incentivize firms to innovate green technologies, but it is unclear whether profits from innovative behavior can offset the additional costs of environmental regulations. Some domestic scholars believe that the phenomenon of the weak Porter hypothesis currently exists in China [17,30], and the degree of environmental regulation strictness adopted must be within the appropriate range to have a positive impact on firm innovation. Otherwise, it will lead to a compliance cost effect that is greater than the innovation offset effect, thus adversely affecting enterprise innovation [3]; the "narrow" version suggests that flexible environmental regulations, especially market-incentive instruments, provide more incentivizing technological innovation than mandatory environmental regulations [31,32]. China's current environmental policy instruments can be divided into three types: command-control, market-incentive and social-will [33]. The impact of different types of environmental regulations on green technology innovation is different [8,34]. There are also significant spatial differences in the effects of different environmental policy instruments on firms' technological innovation [35,36].

The third is the "uncertainty hypothesis". First, based on different industry data and different methods, a large number of scholars have found a "U-shaped" relationship between environmental regulation and enterprise green technology innovation, which

means that as the intensity of environmental regulation increases, its effect on enterprise green technology innovation gradually shifts from inhibiting to promoting, and only when the intensity of environmental regulation reaches a certain "threshold" value can enterprise productivity be improved and enterprise green technology innovation be promoted [37–40]. Second, some scholars found that the size of the driving effect of environmental regulation on green innovation efficiency shows an "inverted U-shaped" distribution [41–43]. In China, the regional differences are obvious. The regions where the driving effect of environmental regulation on green innovation efficiency is more significant are mostly located in the central and western areas, while the driving effect is smaller in some eastern regions with higher marketization levels [41]. Third, the findings are mainly due to differences in industrial heterogeneity. It is found that environmental regulation intensity and green total factor productivity have a "positive U-shaped" relationship in low-intensity industries [44] and moderate and lightly polluting industries [45], but an "inverted U-shaped" relationship in highly carbon-intensive industries, moderately carbon-intensive industries [44] and heavily polluting industries [45].

In conclusion, scholars have conducted research on enterprise technology innovation under environmental regulation from different perspectives with various methods and have achieved positive research results. Plenty of studies agree that environmental regulation in China can have some influence on enterprise green technology innovation. Nevertheless, no consistent conclusion has been formed yet. In China, which environmental regulatory instruments effectively stimulate green technology innovation to realize enterprises' sustainable development? How can the combination of environmental regulation tools be implemented to maximize the benefits of green innovation to achieve a win–win situation between economic growth and environmental protection? These are urgent questions to be answered. Therefore, based on the previous studies, this paper introduces the command-control, market-incentive and social-will environmental regulation means into the evolutionary game model. The evolutionary stability of green technology innovation behavior of new energy enterprises under different environmental regulation means different environmental regulatory combinations, and different implementation intensities are analyzed.

The contributions of this research are as follows: (1) Innovation in research methodology, as earlier domestic and foreign scholars mainly used static analysis ideas such as empirical analysis to study the impact of government environmental regulation on technological innovation, ignoring the driving path analysis of dynamic changes. Therefore, this paper uses evolutionary game theory and numerical simulation methods to dynamically analyze the influence mechanism of heterogeneous environmental regulation tools and different combinations of environmental regulation tools on green technology innovation behavior of new energy enterprises based on the game model of multi-subject relationship analysis. A more specific research framework is provided for exploring the driving paths of green technology innovation behavior. (2) Innovation in the content of the study, as the majority of current studies focus on the impact of command-control environmental regulatory tools or market-incentive environmental regulatory tools on firms' technological innovation, often neglecting the impact of social-will environmental regulatory tools on firms' green technological innovation and the heterogeneous impact of different combinations of environmental regulatory tools on green technological innovation. Therefore, this paper integrates the three environmental regulation tools into the same framework and we conduct a differential study, and further analyze the effects of different combinations of environmental regulation and the implementation intensity of different environmental regulation tools on firms' behavior. It not only enriches the relevant literature but also explores the "optimal strategy combination" and "best execution efforts" of environmental regulations to motivate enterprises to implement green technology innovation, which is of great significance for achieving high-quality economic growth and sustainable development of enterprises. (3) The current literature mainly focuses on manufacturing, pollution-intensive industries or regionally based research, while fewer studies are conducted for energy-based

industries. There are no studies examining the impact of government regulation on green technology innovation in new energy enterprises. Therefore, this paper tries to fill this gap by focusing on new energy enterprises.

The rest of this paper is structured as follows: the second part is methods; the third part is evolutionary simulation analysis and results; the last part is the conclusions and recommendations.

2. Methods

2.1. Analysis of the Influence Mechanism of Heterogeneous Environmental Regulation and Green Technology Innovation

China's current environmental policy tools can be divided into three categories: command-control, market-incentive and social-will [8]. Command-control environmental regulation tools mainly refer to direct government control. The government restricts enterprises' pollution emissions by forcibly regulating the pollution emission behavior in the production process and setting strict technical standards. On the one hand, the formulation of rigorous technical standards requires enterprises to carry out green technological innovation; on the other hand, the increase in pollution control costs stimulates enterprises to carry out green technological innovation [46]. Market-incentive environmental regulation tools aim to guide firms to make appropriate environmental decisions through market signals such as taxes and subsidies. Under this environmental regulation, firms are more inclined to develop new technologies, transforming the external costs of pollution damage into minimal internal control costs arising from technological innovation, and thus promoting green technological innovation [32]. Social-will environmental regulation tools refer to internalizing environmental awareness and responsibility into individual behavioral decisions through direct or indirect pressure and persuasion. On the one hand, social-will environmental regulation tools are publicly disclosed through news media, and companies are forced to innovate green technologies under the pressure of public opinion. On the other hand, they publicize the concept of green consumption and environmental protection awareness to the public through news reports, to encourage enterprises to independently carry out green technology innovation [46].

2.2. Evolutionary Game Theory

Evolutionary game theory was first proposed by Maynard, based on the theory of finite rationality, combining game theory with dynamic evolutionary analysis to create evolutionary games. The evolutionary game theory states that in the real market, the behavior and strategy of each economic agent are not optimal at the initial stage, but through continuous learning and imitation of other agents, they eventually choose the strategy that is beneficial to them and promote the whole economy to reach the final stable equilibrium state [47]. Evolutionary game models commonly use differential equations to describe the evolution of strategies, and are deterministic evolutionary models. Since differential equations are mathematically analytic in nature, replicating dynamic equations is one of the most commonly used decision mechanisms in evolutionary games [48]. Therefore, the model in this paper refers to the approach of Samuelson. The basic assumptions and structure are described below [49].

2.3. Evolutionary Game Model Construction

Hypothesis 1 (H1). *In the "natural" state without considering other influencing factors, there is a system composed of government and new energy enterprises, both of which are characterized by limited rationality. The subjects cannot accurately calculate their costs and benefits and usually keep trying and imitating over time, eventually converging on a stable strategy. The government's strategy set is {implement environmental regulation, not to implement environmental regulation}, the probability of the government implementing environmental regulation is "y", the probability of not implementing environmental regulation is "(1 − y)"; the new energy enterprise's strategy set is {implement green technology innovation, not to implement green technology innovation},*

the probability of the new energy enterprise implementing green technology innovation is "x", the probability of not implementing green technology innovation is "(1 − x)".

Hypothesis 2 (H2). *The government has provided incentives or penalties for green technology innovation through three types of environmental regulation: command-control, market-incentive and social-will. This paper sets the market-incentive environmental regulation means to provide innovation incentive subsidies and impose environmental protection taxes on new energy enterprises. Innovation incentive subsidies are allocated before enterprises implement green technology innovation activities and are used to subsidize the cost of green product innovation, green process innovation and terminal technology innovation behavior of new energy enterprises. Enterprises can apply for innovation incentive subsidies from the government according to their innovation practices, which is a positive incentive behavior. The environmental protection tax is a negative incentive behavior to motivate new energy enterprises to implement green technology innovation and reduce environmental pollution.*

The command-control environmental regulation means to punish the enterprises for not implemented green technology innovation, which can reduce the "fraudulent" behavior of enterprises. The social-will environmental regulation is mainly through the publicity to the public. On the one hand, it can improve the public's willingness to purchase green products. On the other hand, it can stimulate the public to supervise the green technology innovation behavior of new energy enterprises and report their non-compliance with environmental regulations or environmental damage, supervise the enterprises from the public level and stimulate them to carry out green technology innovation. The implementation intensity factors for innovation incentive subsidies, taxing environmental protection, penalizing firms and informing the public are "α", "β", "γ", "η". The corresponding costs consumed are "αJ", "βT", "γF", "ηK".

Hypothesis 3 (H3). *The green technology innovation of new energy enterprises is divided into three dimensions: green product innovation, green process innovation and terminal technology innovation. The basic benefit is "P" when the new energy enterprise chooses traditional technology. The benefit will increase "ΔP_1" when the enterprise chooses green technology innovation and will increase "ΔP_2" when the government chooses environmental regulation.*

Hypothesis 4 (H4). *The innovation cost consumed by new energy enterprises for green technology innovation is "C_1"; the government can perceive the gain "P_m" from new energy enterprises for green technology innovation or the loss "S_m" from new energy enterprises for not implementing green technology innovation when choosing environmental regulation. Additionally, the government needs to invest extra cost "C_2" when implementing environmental regulation.*

The influence mechanism between environmental regulation and green technology innovation is shown in Figure 1, and the parameters set in Hypothesis 1 to 4 are shown in Table 1.

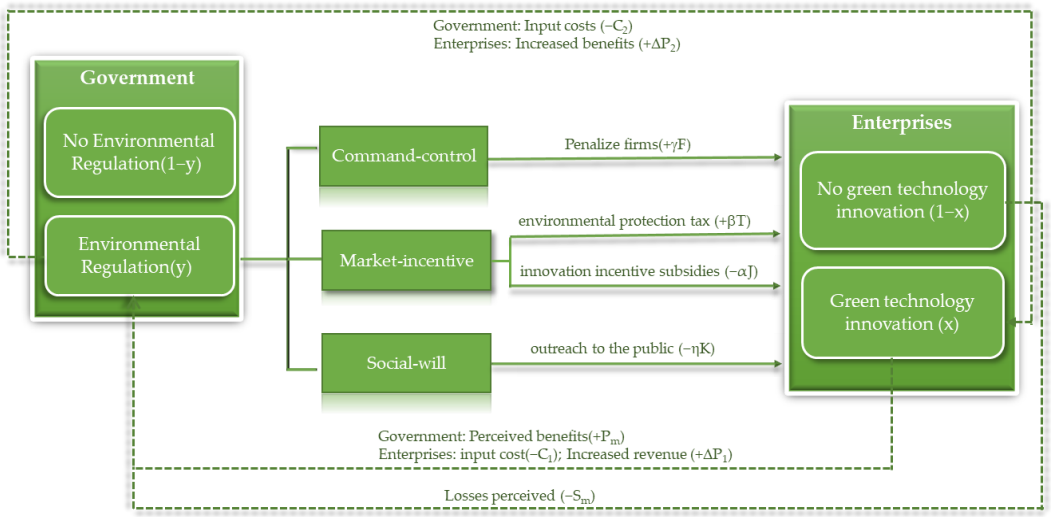


Figure 1. The influence mechanism between environmental regulation and green technology innovation.

Table 1. Parameter symbol description.

Symbols	Measure	Symbols	Measure
J	Government incentive subsidies for business innovation	α	Government subsidy implementation intensity factor for enterprises
T	Government imposes environmental protection tax on enterprises	β	Government taxation of business enforcement intensity factor
F	Government penalties for businesses	γ	Government punishment intensity factor for firms
K	Government outreach to the public	η	Government-to-public publicity enforcement intensity factor
P	Benefits when companies adopt traditional technologies	ΔP_1	Increased revenue when companies innovate green technologies
ΔP_2	Increased benefits to businesses when government imposes environmental regulations	C_1	The cost of inputs when a company engages in green technology innovation
C_2	Input costs when the government conducts environmental regulation	x, y	The choice of behavioral strategies for both government and business
P_m	Perceived benefits to the government of green innovation by firms when the government regulates	S_m	Losses perceived by the government when firms do not engage in green technology innovation when the government implements environmental regulation

Based on the above assumptions, the payoff matrix of the evolutionary game between the government and the enterprise is constructed, as shown in Table 2:

Table 2. Payoff matrix among the government and enterprises.

		Government			
		Environmental Regulation (y)		**No Environmental Regulation (1 − y)**	
		Government Payoff	**Enterprises Payoff**	**Government Payoff**	**Enterprises Payoff**
Enterprises	Green technology innovation (x)	$-\alpha J - \eta K + P_m - C_2$	$P + \Delta P_1 + \Delta P_2 + \alpha J - C_1$	0	$P + \Delta P_1 - C_1$
	No green technology innovation (1 − x)	$\beta T + \gamma F - S_m - C_2$	$P - \beta T - \gamma F$	0	P

2.4. Evolutionary Equilibrium Analysis

2.4.1. Single-Population Evolutionary Stabilization Strategy

(1) The expected utility and group utility of new energy enterprises choosing to implement green technology innovation and not to implement green technology innovation are denoted as E_{11}, E_{12}, E_1:

Expected benefits of green technology innovation by new energy enterprises:

$$\begin{aligned} E_{11} &= y(P + \Delta P_1 + \Delta P_2 + \alpha J - C_1) + (1 - y)(P + \Delta P_1 - C_1) \\ &= y(\Delta P_2 + \alpha J) + (P + \Delta P_1 - C_1) \end{aligned} \tag{1}$$

Expected benefits of no green technology innovation by new energy enterprises:

$$\begin{aligned} E_{12} &= y(P - \beta T - \gamma F) + (1 - y)P \\ &= y(-\beta T - \gamma F) + P \end{aligned} \tag{2}$$

Average expected earnings of new energy enterprises:

$$\begin{aligned} \overline{E_1} &= xE_{11} + (1 - x)E_{12} \\ &= x[y(\Delta P + \alpha J) + (P + \Delta P_1 - C_1)] + (1 - x)[y(-\beta T - \gamma F) + P] \end{aligned} \tag{3}$$

New energy firms' replication dynamic equations:

$$\begin{aligned} F(x) &= \frac{dx}{dt} = x\left(E_{11} - \overline{E_1}\right) \\ &= x(1 - x)[y(\Delta P_2 + \alpha J + \beta T + \gamma F) + (\Delta P_1 - C_1)] \end{aligned} \tag{4}$$

(2) The expected utility and group utility of government environmental regulation and no environmental regulation are denoted as E_{21}, E_{22}, $\overline{E_2}$:

Expected benefits of environmental regulation by the government:

$$\begin{aligned} &E_{21} = x(-\alpha J - \eta K + P_m - C_2) + (1 - x)(\beta T + \gamma F - S_m - C_2) \\ &= x(-\alpha J - \eta K - \beta T - \gamma F + P_m + S_m) + (\beta T + \gamma F - S_m - C_2) \end{aligned} \tag{5}$$

Expected benefits of no environmental regulation by the government:

$$E_{22} = 0 \tag{6}$$

Average expected earnings of government:

$$\begin{aligned} &\overline{E_2} = yE_{21} + (1 - y)E_{22} \\ &= y[x(-\alpha J - \eta K - \beta T - \gamma F + P_m + S_m) + (\beta T + \gamma F - S_m - C_2)] \end{aligned} \tag{7}$$

Government's replication dynamic equations:

$$\begin{aligned} F(y) &= \frac{dy}{dt} = y\left(E_{21} - \overline{E_2}\right) \\ &= y(1-y)[x(-\alpha J - \eta K - \beta T - \gamma F + P_m + S_m) + (\beta T + \gamma F - S_m - C_2)] \end{aligned} \tag{8}$$

Therefore, Equations (4) and (8) constitute a dynamic replication system between enterprises and governments.

(3) (Evolutionary stability conditions for new energy companies

Let F(x) = 0, get $y^* = \frac{C_1 - \Delta P_1}{\Delta P_2 + \alpha J + \beta T + \gamma F}$

Situation 1: If y = y^*, then F(x) = 0; all levels are stable in this situation.

Situation 2: If y $\neq$ y*, then F(x) = 0, x = 0 and x = 1 are two stable points.

Derivation of F(x) is obtained:

$$\frac{\partial F(x)}{\partial x} = (1-2x)[y(\Delta P_2 + \alpha J + \beta T + \gamma F) + (\Delta P_1 - C_1)] \tag{9}$$

When y > y^*, $\frac{\partial F(x)}{\partial x}\Big|_{x=0} > 0$, $\frac{\partial F(x)}{\partial x}\Big|_{x=1} < 0$, x = 1 is the evolutionary equilibrium point.

When y < y^*, $\frac{\partial F(x)}{\partial x}\Big|_{x=0} < 0$, $\frac{\partial F(x)}{\partial x}\Big|_{x=1} > 0$, x = 0 is the evolutionary equilibrium point.

Figure 2 shows the phase map changes in the strategic choice of new energy enterprises. When the initial state of the new energy enterprise strategy is located in space V1, x = 1 is the evolutionary equilibrium point, and the new energy enterprise chooses the "green technology innovation" strategy. When the initial state of the new energy enterprise strategy is located in space V2, x = 0 is the evolutionary equilibrium point, and the new energy enterprise chooses the strategy of "no green technology innovation". The change in space V1 and V2 is related to y*. When C_1 increases, y* will increase, and the dividing line between V1 and V2 will move up. The probability of new energy enterprises choosing green technology innovation will decrease, which is because the cost required to implement green technology innovation increases at this time and reduces the willingness of enterprises to implement green technology innovation; when "P_1", "P_2", "αJ", "βT", "γF" increase, y* will decrease, and the dividing line between V1 and V2 will move down. The probability of new energy enterprises choosing green technology innovation will increase. On the one hand, the increase in "αJ" indicates that the government's subsidy is strengthened, which has a positive incentive effect on enterprises and makes them more inclined to innovate; on the other hand, the increase in "βT" and "γF" indicates that the government's punishment and regulation for enterprises not to carry out green technology innovation are increased, so that enterprises dare not take the risk of not carrying out green technology innovation, which has a reverse incentive effect; the increase in "ΔP_1" and "ΔP_2" indicates that both the revenue brought by enterprises' technological innovation behavior and the revenue brought by the government's environmental regulation have increased, which will naturally increase enterprises' willingness to carry out green technology innovation.

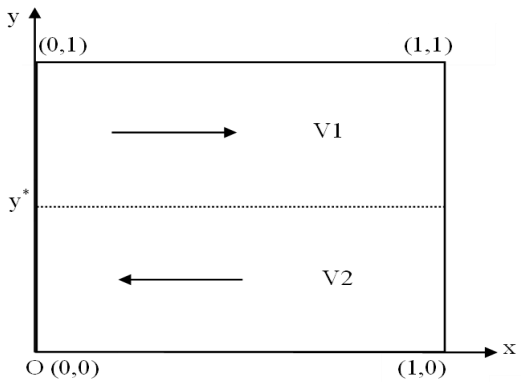


Figure 2. Phase map of new energy companies.

(4) Evolutionary stability conditions for government

Let F(y) = 0, get $x^* = \frac{-\beta T-\gamma F+C_2+S_m}{-\alpha J-\eta K-\beta T-\gamma F+P_m+S_m}$

Situation 1: If x = x*, then F(y) = 0, all levels are stable in this situation.

Situation 2: If $x \neq x^*$, then F(y) = 0, y = 0 and y = 1 are two stable points.

Derivation of F(y) is obtained:

$$\frac{\partial F(y)}{\partial y} = (1-2y)[x(-\alpha J - \eta K - \beta T - \gamma F + P_m + S_m) + (\beta T + \gamma F - S_m - C_2)] \quad (10)$$

When $x > x^*$, $\left.\frac{\partial F(y)}{\partial y}\right|_{y=0} > 0$, $\left.\frac{\partial F(y)}{\partial y}\right|_{y=1} < 0$, y = 1 is the evolutionary equilibrium point.

When $x < x^*$, $\left.\frac{\partial F(y)}{\partial y}\right|_{y=0} < 0$, $\left.\frac{\partial F(y)}{\partial y}\right|_{y=1} > 0$, y = 0 is the evolutionary equilibrium point.

Figure 3 shows the phase map change in government strategy selection, when the initial state of the government strategy is situated in space V4, y = 1 is the evolutionary equilibrium point and the government chooses the "environmental regulation" strategy; when the initial state of the government strategy is situated space V3, y = 0 is the evolutionary equilibrium point, and the government chooses the "no environmental regulation" strategy. The change in space V3 and V4 is related to x*, and the increase in "βT", "γF" and "P_m" will increase x*, causing the rightward shift of the dividing line between V4 and V3. It means that the imposition of a fine and an environmental tax on firms when they do not implement green technology innovation can help promote the government's environmental regulation, and the increase in perceived benefits to the government when firms innovate technology can also help promote government's environmental regulation. The increase in "αJ", "ηK", "C_2" and "S_m" will make x* decrease subsequently, causing the leftward shift of the dividing line between V4 and V3. That is, the increase in innovation incentive subsidies, public publicity costs and other input costs will reduce the government's willingness to impose environmental regulation, and the loss brought by enterprises not implementing green technology innovation is more unfavorable to the government's environmental regulation.

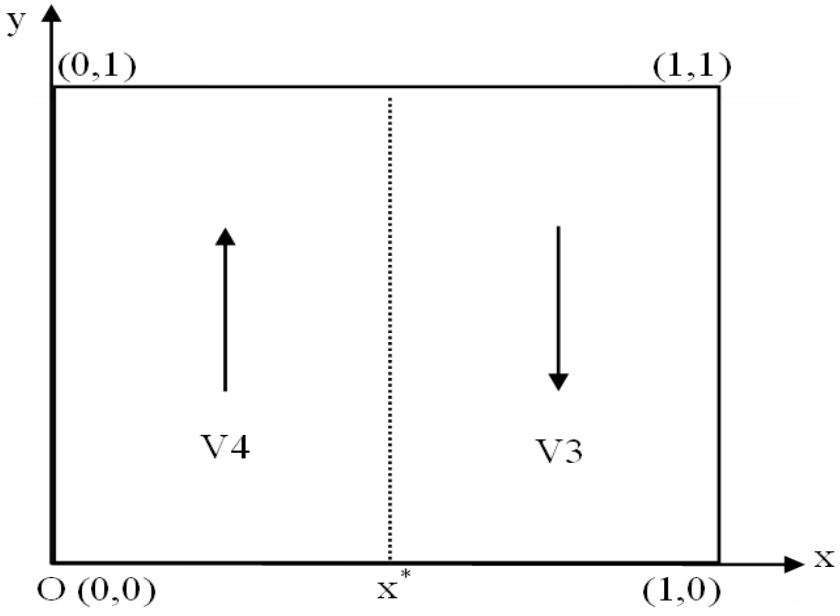


Figure 3. Phase map of government.

2.4.2. Stability Analysis of the Government: Firm Evolutionary Game Replication Dynamics System

Friedman's study shows that the evolutionarily stable equilibrium solution of the replicating dynamical system can be given by the local stability analysis of the Jacobi

matrix of the system [50], as shown in Equation (11), which is the Jacobi matrix of the replicating dynamical system of the government and the new energy enterprise. To find the evolutionary equilibrium point, let $F(x) = 0$ and $F(y) = 0$, and the evolutionary stabilization equilibrium points of the government and enterprises can be obtained, respectively: $E_1 = (0, 0)$, $E_2 = (0, 1)$, $E_3 = (1, 0)$, $E_4 = (1, 1)$, $E_5 = (x^*, y^*)$, and, $x^* = \frac{-\beta T-\gamma F+C_2+S_m}{-\alpha J-\eta K-\beta T-\gamma F+P_m+S_m}$, $y^* = \frac{C_1-\Delta P_1}{\Delta P_2+\alpha J+\beta T+\gamma F}$.

According to the evolutionary game theory, the determinant and traces of the Jacobi matrix are used to determine the evolutionary stability of the five local stability points. When the evolutionary stability set of the enterprise green innovation replication dynamics system obeys the condition that the eigenvalues of the Jacobi matrix are all negative, the point is the evolutionary stability point of the system, and the corresponding strategy is the evolutionary stability strategy (ESS). The constructed Jacobi matrix is shown in Equation (12).

$$\begin{cases} F(x) = x(1-x)[y(\Delta P_2 + \alpha J + \beta T + \gamma F) + (\Delta P_1 - C_1)] \\ F(y) = y(1-y)[x(-\alpha J - \eta K - \beta T - \gamma F + P_m + S_m) + (\beta T + \gamma F - C_2 - S_m)] \end{cases} \tag{11}$$

$$\begin{aligned} J &= \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{bmatrix} \\ &= \begin{bmatrix} (1-2x)[y(\Delta P_2 + \alpha J + \beta T + \gamma F) + (\Delta P_1 - C_1)] & x(1-x)(\Delta P_2 + \alpha J + \beta T + \gamma F) \\ y(1-y)(-\alpha J - \eta K + P_m - \beta T - \gamma F + S_m) & (1-2y)[x(-\alpha J - \eta K + P_m - \beta T - \gamma F + S_m) + (\beta T + \gamma F - S_m - C_2)] \end{bmatrix} \end{aligned} \tag{12}$$

The complex influencing factors in the eigenvalues of the Jacobi matrix of the corporate green innovation replication dynamics system and the changes in heterogeneous parameters can have a more significant impact on the evolutionary stability of the enterprise green innovation replication dynamics system. Therefore, constraints are added based on reality. As a finite rational economy agent, the government's investment in environmental regulation should be less than the perceived benefits brought to the government by enterprises in green technology innovation, setting $P_m - \alpha J - \eta K - C_2 > 0$; when the government supports the new energy enterprises to implement green technology innovation, the benefits obtained by enterprises for green technology innovation must be greater than the cost of their green technology innovation. Otherwise, the enterprises will not choose to innovate green technology, $P_1 + P_2 > C_1$.

Each of the five equilibria is brought into the Jacobi matrix to obtain the eigenvalues of the Jacobi matrix, as shown in Table 3. Then, the evolutionary game stability is discussed by the situation, as shown in Table 4.

Table 3. Eigenvalues of Jacobi matrix.

Equilibrium Points	λ_1	λ_2
$E_1 = (0, 0)$	$\Delta P_1 - C_1$	$\beta T + \gamma F - S_m - C_2$
$E_2 = (0, 1)$	$\Delta P_2 + \alpha J + \beta T + \gamma F + \Delta P_1 - C_1$	$-(\beta T + \gamma F - S_m - C_2)$
$E_3 = (1, 0)$	$C_1 - \Delta P_1$	$P_m - \alpha J - \eta K - C_2$
$E_4 = (1, 1)$	$-(\Delta P_2 + \alpha J + \beta T + \gamma F + \Delta P_1 - C_1)$	$-(P_m - \alpha J - \eta K - C_2)$
$E_5 = (x^*, y^*)$	Saddle point	

Combined constraints: $P_m - \alpha J - \eta K - C_2 > 0$, $\Delta P_1 + \Delta P_2 > C_1$.

Situation I. When $\Delta P_1 - C_1 > 0$ and $\beta T + \gamma F - S_m - C_2 > 0$, the equilibrium stabilization solution of the system is (1, 1), that is, {Green technology innovation, Environmental regulation}. At this point, the conditions $\Delta P_2 + \alpha J + \beta T + \gamma F + \Delta P_1 - C_1 > 0$ and $P_m - \alpha J - \eta K - C_2 > 0$ are satisfied. That is, the sum of the benefits brought by green technology innovation and the additional benefits brought by the government's environmental regulation are greater than the costs of green technology innovation. Enterprises can make more profits by carrying out green technology innovation, so they will choose to implement

green technology innovation. When $P_m > \alpha J + \eta K + C_2$, the benefits that the government can derive from the effects of technological innovation by the firm are greater than the sum of the costs it invests in enterprises. Therefore, the government will choose to implement environmental regulation.

Table 4. Stability of the replicated power system.

Situation I: $\Delta P_1 - C_1 > 0$, $\beta T + \gamma F - S_m - C_2 > 0$				**Situation II: $\Delta P_1 - C_1 > 0$, $\beta T + \gamma F - S_m - C_2 < 0$**		
Equilibrium points	λ_1	λ_2	State	λ_1	λ_2	State
(0, 0)	+	+	Saddle point	+	−	Instability point
(0, 1)	+	−	Instability point	+	+	Saddle point
(1, 0)	−	+	Instability point	−	+	Instability point
(1, 1)	−	−	ESS	−	−	ESS
(x*, y*)	$\mathrm{Det}J < 0 \cap \mathrm{Tr}J = 0$		Saddle point	$\mathrm{Det}J < 0 \cap \mathrm{Tr}J = 0$		Saddle point
Situation III: $\Delta P_1 - C_1 < 0$, $\beta T + \gamma F - S_m - C_2 > 0$				**Situation IV: $\Delta P_1 - C_1 < 0$, $\beta T + \gamma F - S_m - C_2 < 0$**		
Equilibrium points	λ_1	λ_2	State	λ_1	λ_2	State
(0, 0)	−	+	Instability point	−	−	ESS
(0, 1)	+	−	Instability point	+	+	Saddle point
(1, 0)	−	+	Instability point	+	+	Saddle point
(1, 1)	−	−	ESS	−	−	ESS
(x*, y*)	$\mathrm{Det}J < 0 \cap \mathrm{Tr}J = 0$		Saddle point	$\mathrm{Det}J < 0 \cap \mathrm{Tr}J = 0$		Saddle point

Situation II and Situation III. The system's equilibrium stabilization solution is (1, 1). That is, {Green technology innovation, Environmental regulation}, which is approximately the same as Situation I. Therefore, we do not expand the discussion.

Situation IV. When $\Delta P_1 - C_1 < 0$ and $\beta T + \gamma F - S_m - C_2 < 0$, the equilibrium stabilization solutions (ESSs) of the system are (0, 0) and (1, 1). That is, {No green technology innovation, No environmental regulation} and {Green technology innovation, Environmental regulation}. First, when $\Delta P_1 - C_1 < 0$ and $\beta T + \gamma F - S_m - C_2 < 0$ are satisfied, (0, 0) is the equilibrium stable solution of the system. When $\Delta P_1 < C_1$, the cost of green technology innovation is greater than the benefits brought by green technology innovation, and green technology innovation does not bring more profit to the enterprise. However, a large amount of cost investment will cause more financial tension, so the enterprise chooses ot not implement green technology innovation. When $\beta T + \gamma F < S_m + C_2$, although the government imposes certain fines and environmental taxes on enterprises for not implementing green technology innovation, it is difficult to compensate for the sum of the government's investment in environmental regulation and the perceived loss caused by enterprises not implementing green technology innovation. Therefore, the government's behavior evolves into non-environmental regulation. Second, when $\Delta P_2 + \alpha J + \beta T + \gamma F + \Delta P_1 - C_1 > 0$ and $P_m - \alpha J - \eta K - C_2 > 0$, (1, 1) is the equilibrium stable solution (ESS) of the system. This is consistent with Situation I, so we will not discuss it further.

Visibly whether new energy enterprises carry out green technology innovation is mainly based on cost–benefit analysis. When the benefits of technological innovation are more significant than the costs, green technology innovation can make more profits flow into enterprises. New energy enterprises are likely to choose green technology innovation. In addition to social responsibility, the government should also consider the fiscal balance when it decides to regulate the environment. The government will not choose environmental regulation when the cost of subsidies and other environmental regulations is much

greater than the benefit of green technology innovation to the government or when the government's penalty for enterprises not implementing green technology innovation is less than the sum of the loss and input costs brought by enterprises not implementing green technology innovation behaviors to the government.

3. Evolutionary Simulation Analysis and Results

To further analyze and explore the influence of command-control, market-incentive and social-will environmental regulatory instruments on the green technology innovation of new energy enterprises, the evolutionary trajectory of the system when the government and new energy enterprises interact with each other, and the evolutionary trajectory of green technology innovation behavior of new energy enterprises under the effect of different environmental regulatory instruments of the government, are visually and clearly represented through parameter setting and simulation with MATLAB software. To compare and analyze the heterogeneous effects of different choices of command-control, market-incentive and social-will environmental regulation strategies on the evolution of the system, an upper limit is set for penalizing firms for not innovating green technologies (command-control environmental regulation), providing subsidies to firms for innovation and levying environmental protection taxes (market-incentive environmental regulation) and the publicity behavior (social-will environmental regulation): F = J = T = K = 2. On this basis, we ensure the robustness of the system evolution results and that they are in line with the reality of China and the actual operational structure and interest relations. The benefits of green technology innovation by new energy enterprises in the short term will be smaller than the costs of their inputs, so $P_1 - C_1$ is set to negative values. Other parameters are set concerning the previous assumptions and constraints to ensure that the parameters and fundamental relationships that affect the structure and nature of the model are consistent with the actual situation: P = 10, ΔP_1 = 6, ΔP_2 = 4, C_1 = 8, C_2 = 4, P_m = 9, S_m = 6.

3.1. Heterogeneous Effects of Three Types of Environmental Regulations on the Strategies of New Energy Companies

The strategy choices of new energy companies in different situations when the government separately implements command-control, market-incentive and social-will environmental regulations are shown in Table 5.

Table 5. Impact of an environmental regulation tool on the strategy of new energy companies.

Type of Environmental Regulation	α	β	γ	η	Final Corporate Strategy
Command-control	0	0	0.2	0	Traditional Technology
	0	0	0.4	0	Traditional Technology
	0	0	0.6	0	Traditional Technology
	0	0	0.8	0	Traditional Technology
	0	0	1.0	0	Traditional Technology
Market-incentive	0.2	0.2	0	0	Traditional Technology
	0.4	0.4	0	0	Traditional Technology
	0.6	0.6	0	0	Traditional Technology
	0.8	0.8	0	0	Traditional Technology
	1.0	1.0	0	0	Traditional Technology
Social-will	0	0	0	0.2	Traditional Technology
	0	0	0	0.4	Traditional Technology
	0	0	0	0.6	Traditional Technology
	0	0	0	0.8	Traditional Technology
	0	0	0	1.0	Traditional Technology

3.1.1. Only Implementing the Command-Control Environmental Regulation Policy

The evolutionary process when the government implements only the command-control environmental regulation policy is shown in Figure 4. As the intensity of punishment increases, the willingness of new energy firms to implement green technology innovation will strengthen. This is because the more robustly the government penalizes the enterprises for not implementing green technology innovation, the more it will increase the additional burden on the enterprises, and in this case, the new energy enterprises have to consider green technology innovation. However, from the perspective of the long-term evolution of the system, the new energy companies will not choose to carry out green technology innovation in the end but choose the traditional technology strategy for production and operation. Thereby, the government can increase enterprises' willingness to innovate green technology only by implementing command-control environmental regulatory tools. The cost of green technology innovation is so significant that it far exceeds the fines levied by the government for not implementing green technology innovation, so firms may initially choose green technology innovation when the penalties levied by the government are large. However, due to the increasing investment in innovation over time, the difference between the benefits and the investment is too large, so companies will change their strategy to choose traditional technologies. Therefore, in the long run, the government's implementation of only the command-control type of environmental regulation policy is not enough to promote new energy enterprises to implement green technology innovation.

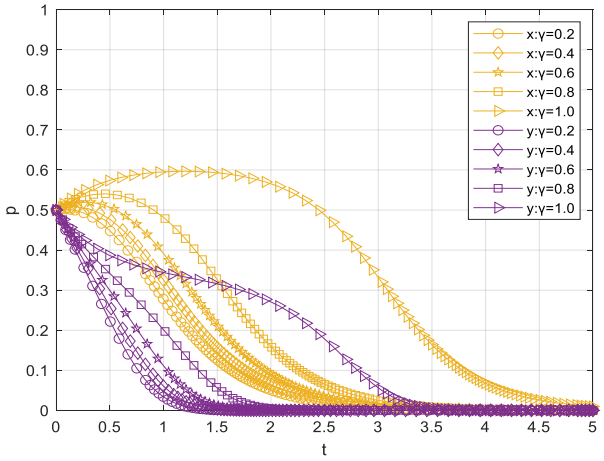


Figure 4. System evolutionary trajectory when only command-control environmental regulation is implemented.

3.1.2. Only Implementing Market-Incentive Environmental Regulation Policy

The evolutionary process when the government implements only the market-incentive environmental regulation policy is shown in Figure 5. If new energy enterprises implement green technology innovation, they can obtain partial input cost compensation from the government's innovation incentive subsidies, reducing the actual investment in green technology innovation. However, from the perspective of the long-term evolution of the system, enterprises will not choose to implement green technology innovation. This is because a high government innovation incentive subsidy can generate an "innovation compensation" effect, which can offset part of the cost of green technology innovation, so in the early stage, enterprises are more willing to carry out green technology innovation. Additionally, the strengthening of the government's environmental tax on enterprises will also have a reverse incentive effect on enterprises' green technology innovation behavior. However, over time, the benefits obtained by new energy enterprises from green innovation are lower than those of enterprises that choose traditional technology strategies, so they will change their strategy to choose traditional technology. Therefore, in the long run, the gov-

ernment's implementation of only market-incentivized environmental regulation policies is also insufficient to promote green technology innovation by new energy enterprises.

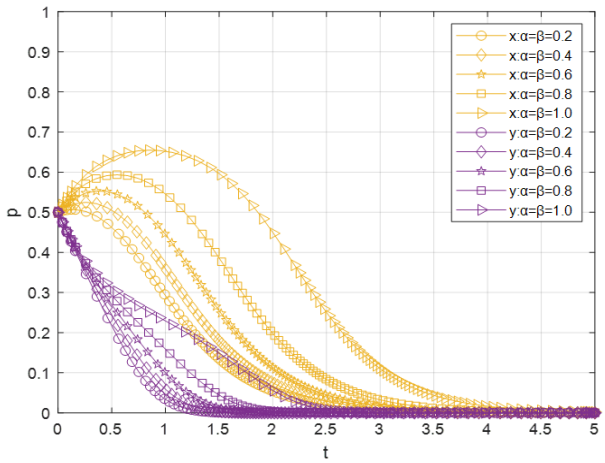


Figure 5. System evolution trajectory when only market-incentive environmental regulation is implemented.

3.1.3. Only Implementing Social-Will Environmental Regulation Policy

The evolutionary process when the government implements only the social-will environmental regulation policy is shown in Figure 6. Social-will environmental regulation is not directly invested in enterprises, but a disclosure to the public through the news media. First, it helps enterprises establish a good corporate image in the public mind, thus attracting consumers to gain more revenue. Second, it exerts public opinion pressure on enterprises and uses public supervision to force new energy enterprises to implement green technology innovation. The implementation is influenced by environmental factors, so the change in implementation intensity does not substantially impact the choice of enterprise strategy, and the final strategy of new energy enterprises is not implementing green technology innovation. Therefore, the implementation of only social-will environmental regulation policies cannot promote green technology innovation of new energy enterprises.

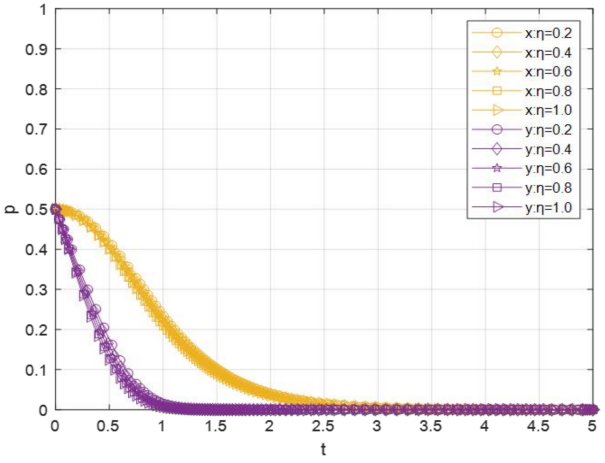


Figure 6. System evolution trajectory when only social-will environmental regulation is implemented.

In conclusion, neither command-control nor market-incentive nor social-will environmental regulation policy alone is sufficient to drive new energy enterprises to choose green technology innovation strategies. When the implementation of command-control environmental regulation policies or market-incentive environmental regulatory policies is strong enough, it can increase the willingness of new energy enterprises to implement

green technology innovation in the initial stage. Moreover, high-intensity market-incentive environmental regulations are more effective in increasing the willingness of enterprises to implement green technology innovation, while high-intensity command-control environmental regulations incentivize enterprises to carry out green technology innovation for a longer time. Implementing social-will environmental regulations alone will not promote green technology innovation in new energy enterprises.

3.2. Impact of Two Combinations of Environmental Regulations on the Strategy of New Energy Enterprises

The strategic choices of new energy enterprises in different situations when the government chooses to implement two of the environmental policies of command-control, market-incentive and social-will are shown in Table 6.

Table 6. Impact of the combination of the two environmental regulation tools on the strategy.

Type of Environmental Regulation	α	β	γ	η	Corporate Strategy	α	β	γ	η	Corporate Strategy
Command-control and market-incentive				(1)					(2)	
	0.4	0.4	0.2	0	Traditional Technology	0.2	0.2	0.4	0	Traditional Technology
	0.4	0.4	0.4	0	Traditional Technology	0.4	0.4	0.4	0	Traditional Technology
	0.4	0.4	0.6	0	Traditional Technology	0.6	0.6	0.4	0	Traditional Technology
	0.4	0.4	0.8	0	Traditional Technology	0.8	0.8	0.4	0	**Green Technology**
	0.4	0.4	1.0	0	Traditional Technology	1.0	1.0	0.4	0	**Green Technology**
				(3)					(4)	
	0.2	0.4	0.4	0	Traditional Technology	0.4	0.2	0.4	0	Traditional Technology
	0.4	0.4	0.4	0	Traditional Technology	0.4	0.4	0.4	0	Traditional Technology
	0.6	0.4	0.4	0	Traditional Technology	0.4	0.6	0.4	0	Traditional Technology
	0.8	0.4	0.4	0	Traditional Technology	0.4	0.8	0.4	0	**Green Technology**
	1.0	0.4	0.4	0	Traditional Technology	0.4	1.0	0.4	0	**Green Technology**
Command-control and social-will				(1)					(2)	
	0	0	0.2	0.4	Traditional Technology	0	0	0.4	0.2	Traditional Technology
	0	0	0.4	0.4	Traditional Technology	0	0	0.4	0.4	Traditional Technology
	0	0	0.6	0.4	Traditional Technology	0	0	0.4	0.6	Traditional Technology
	0	0	0.8	0.4	Traditional Technology	0	0	0.4	0.8	Traditional Technology
	0	0	1.0	0.4	Traditional Technology	0	0	0.4	1.0	Traditional Technology
Market-incentive and social-will				(1)					(2)	
	0.2	0.2	0	0.4	Traditional Technology	0.4	0.4	0	0.2	Traditional Technology
	0.4	0.4	0	0.4	Traditional Technology	0.4	0.4	0	0.4	Traditional Technology
	0.6	0.6	0	0.4	Traditional Technology	0.4	0.4	0	0.6	Traditional Technology
	0.8	0.8	0	0.4	Traditional Technology	0.4	0.4	0	0.8	Traditional Technology
	1.0	1.0	0	0.4	Traditional Technology	0.4	0.4	0	1.0	Traditional Technology
				(3)					(4)	
	0.2	0.4	0	0.4	Traditional Technology	0.4	0.2	0	0.4	Traditional Technology
	0.4	0.4	0	0.4	Traditional Technology	0.4	0.4	0	0.4	Traditional Technology
	0.6	0.4	0	0.4	Traditional Technology	0.4	0.6	0	0.4	Traditional Technology
	0.8	0.4	0	0.4	Traditional Technology	0.4	0.8	0	0.4	Traditional Technology
	1.0	0.4	0	0.4	Traditional Technology	0.4	1.0	0	0.4	Traditional Technology

3.2.1. Combination of Command-Control and Market-Incentive Environmental Regulation

The system evolution when the government implements both command-control and market-incentive types of environmental regulation means is shown in Figure 7.

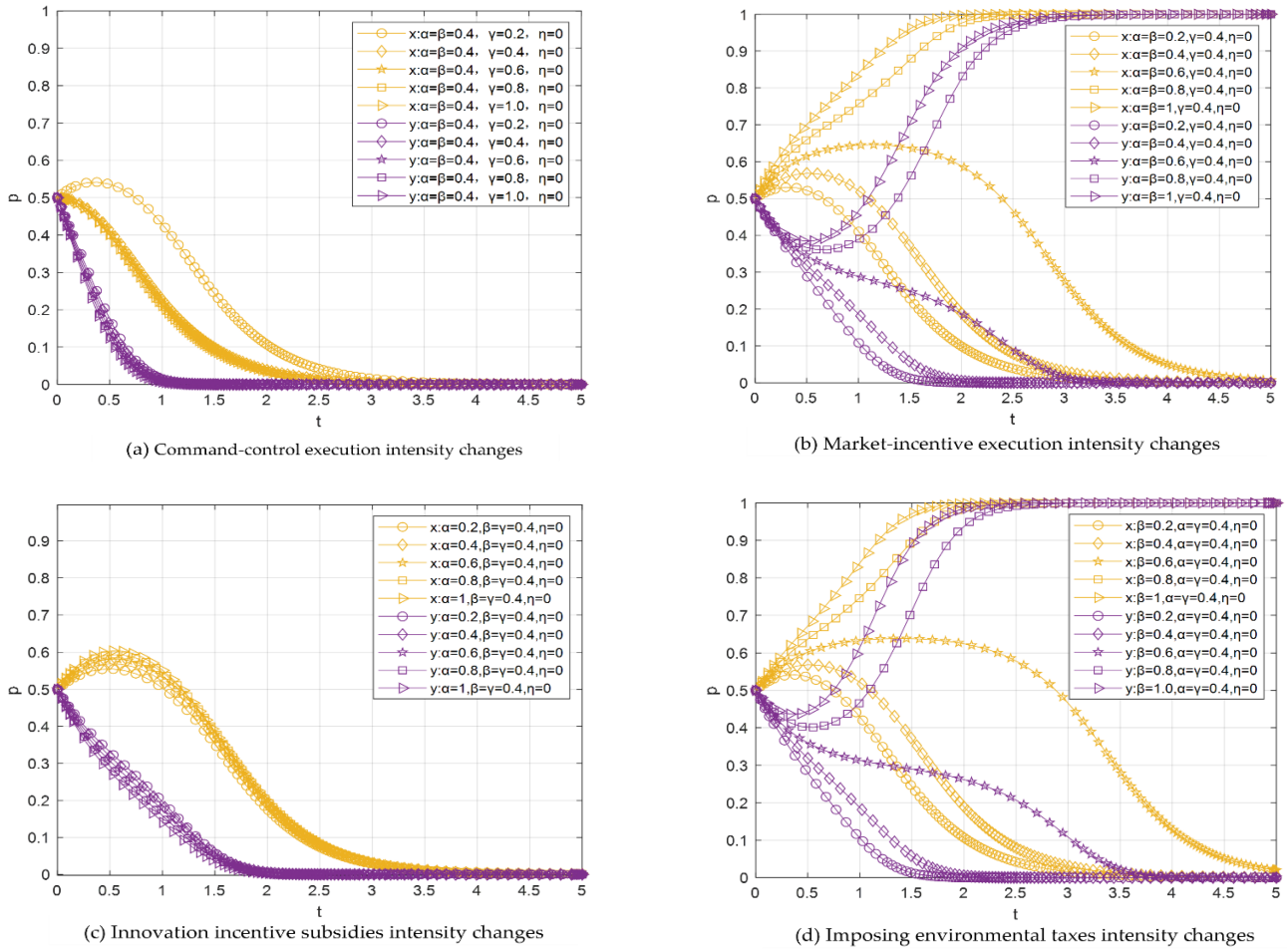


Figure 7. Command-control and market-incentive environmental regulations' evolutionary paths.

When the intensity factor of market-incentive environmental regulation means enforcement is set to a fixed value of 0.4, the intensity factor of command-control environmental regulation means enforcement is set to vary between 0.2, 0.4, 0.6, 0.8 and 1, as shown in Figure 7a. It is found that when the penalty intensity factor is 0.2, the willingness of new energy enterprises to implement green technology innovation in the early stage is briefly improved, but in the long run, new energy enterprises eventually evolve to choose traditional technology. When the penalty intensity factor is other coefficients, they do not promote green technology innovation of new energy enterprises, and new energy enterprises will eventually stabilize in choosing traditional technology. When the intensity factor of command-control environmental regulation means enforcement is set to a fixed value of 0.4, the intensity factor of market-incentive environmental regulation means enforcement is set to vary between 0.2, 0.4, 0.6, 0.8 and 1, as shown in Figure 7b. It is found that when the intensity of innovation incentive subsidies and the intensity of environmental taxes are 0.2, 0.4 and 0.6, with the increase in implementation intensity, the willingness of new energy enterprises to implement green technology innovation gradually increases, but from the perspective of the long-term evolution of the system, new energy enterprises will eventually choose traditional technologies. New energy enterprises will eventually choose green technology innovation when the execution intensity is large enough (reaching 0.8, 1.0). Thus, it seems that market-incentive environmental regulations play an important role in pro-

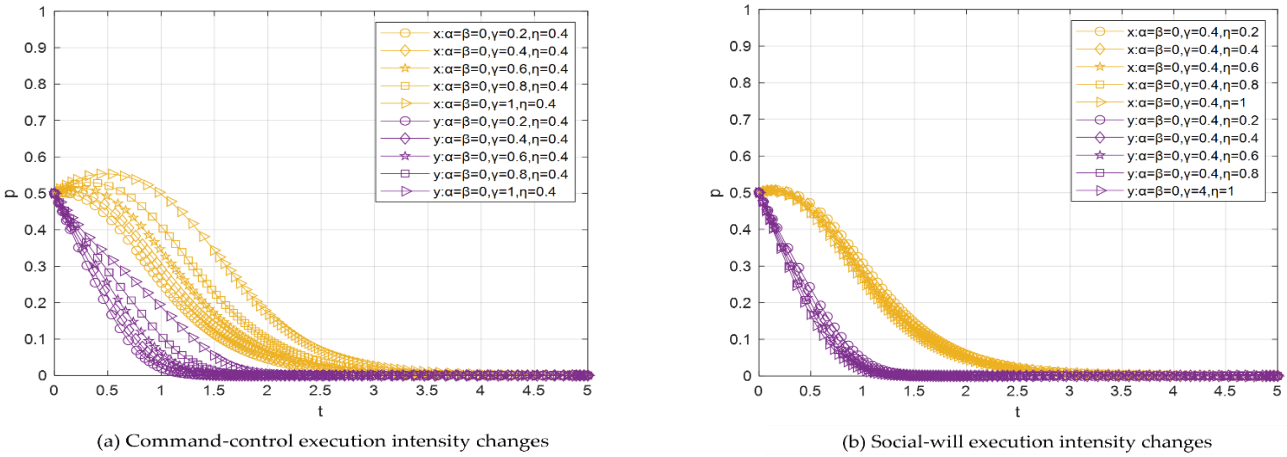
moting green technology innovation, and the larger the enforcement factor, the greater the incentive for green technology innovation. This is because the "innovation compensation" effect is greater when the government provides sufficient innovation incentives to new energy companies to offset the cost of innovation inputs, resulting in a greater willingness to engage in green technology innovation. Moreover, as the intensity of environmental taxes increases, the more constrained enterprises are, and the stronger their willingness to implement green technology innovation.

When the enforcement intensity factor of the command-control environmental regulation means and the market-incentive environmental regulation means of imposing environmental taxes are set to a fixed value of 0.4, the enforcement intensity factor of the market-incentive environmental regulation means of implementing innovation incentive subsidies is set to vary between 0.2, 0.4, 0.6, 0.8 and 1, as shown in Figure 7c. It is found that with the increase in the implementation intensity of innovation incentive subsidies, the willingness of new energy enterprises to innovate in green technology is increased, but in terms of long-term system evolution, new energy companies will eventually choose traditional technology. When the enforcement intensity factor of the command-control environmental regulation means and the innovation incentive subsidy of the market-incentive environmental regulation means are set to a fixed value of 0.4, the enforcement intensity factor of the environmental taxation of the market-incentive environmental regulation means is set to vary between 0.2, 0.4, 0.6, 0.8 and 1, as shown in Figure 7d. It is found that as the intensity of environmental taxation increases, the willingness of new energy enterprises to carry out green technology innovation increases, and finally, new energy enterprises evolve to carry out green technology innovation when the intensity factor of environmental taxation reaches 0.8 and 1.0.

In conclusion, the combination of command-control and market-incentive environmental regulation tools has a significant role in promoting the green technology innovation of new energy enterprises. Moreover, the incentive effect of market-incentive environmental regulations on green technology innovation of new energy enterprises is more obvious than that of command-control environmental regulations, which also verifies the "narrow" version of Porter's hypothesis. In addition, among the market-incentive environmental regulation means, the government levies environmental taxes more effectively to promote green technology innovation in new energy enterprises than the implementation of innovation incentive subsidies.

3.2.2. Combination of Command-Control and Social-Will Environmental Regulation

The system evolution when the government implements both command-control and social-will types of environmental regulation means is shown in Figure 8.



(a) Command-control execution intensity changes (b) Social-will execution intensity changes

Figure 8. Command-control and social-will environmental regulations' evolutionary paths.

When the enforcement intensity factor of social-will environmental regulation means is set to a fixed value of 0.4, the enforcement intensity factor of command-control environmental regulation means is set to vary between 0.2, 0.4, 0.6, 0.8 and 1, as shown in Figure 8a. When the penalty intensity reaches 0.8 and 1.0, it can briefly increase the willingness of new energy enterprises to carry out green technology innovation. However, in the long-term system evolution, new energy enterprises will still choose traditional technology eventually. When the enforcement intensity factor of command-control environmental regulation means is set to a fixed value of 0.4, the enforcement intensity factor of social-will environmental regulation means is set to vary between 0.2, 0.4, 0.6, 0.8 and 1, as shown in Figure 8b. When the penalty intensity factor is fixed, the change in public publicity intensity does not motivate new energy enterprises to implement green technology innovation. Even the government's investment cost in social-will environmental regulation is not proportional to the benefit obtained, which also dramatically reduces the government's willingness to implement environmental regulation.

In conclusion, the combination of command-control and social-will environmental regulations is not sufficient to promote green technology innovation in new energy enterprises.

3.2.3. Combination of Market-Incentive and Social-Will Environmental Regulation

The system evolution when the government implements both the market-incentive and social-will types of environmental regulation means is shown in Figure 9.

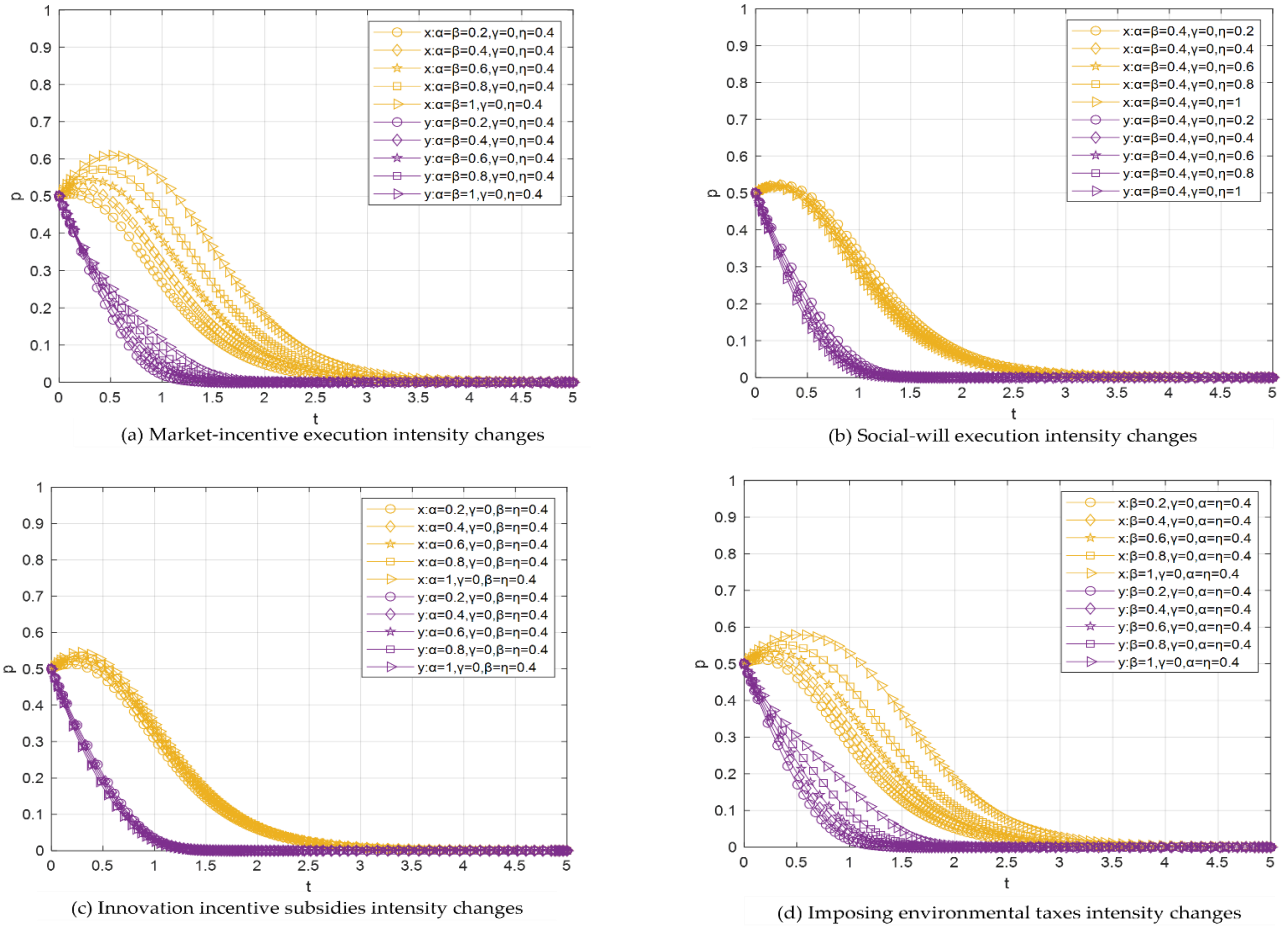


Figure 9. Market-incentive and social-will environmental regulations' evolutionary paths.

When the enforcement intensity factor of social-will environmental regulation means is set to a fixed value of 0.4, the enforcement intensity factor of market-incentive environmental regulation means is set to vary between 0.2, 0.4, 0.6, 0.8 and 1, as shown in Figure 9a.

When the penalty intensity reaches 0.6, 0.8 and 1.0, it can briefly increase the willingness of new energy enterprises to implement green technology innovation. However, in terms of long-term system evolution, new energy enterprises will still eventually choose traditional technologies. When the enforcement intensity factor of market-incentive environmental regulation means is set to a fixed value of 0.4, the enforcement intensity factor of social-will environmental regulation means is set to vary between 0.2, 0.4, 0.6, 0.8 and 1, as shown in Figure 9b. When the implementation intensity factors of both innovation incentive subsidies and environmental taxation are fixed, the change in public publicity intensity does not motivate new energy enterprises to implement green technology innovation, and the higher the public publicity intensity factor, the lower the willingness of new energy enterprises to implement green technology innovation.

When the enforcement intensity factor of the social-will environmental regulation means and the market-incentive environmental regulation means of imposing environmental taxes are set to a fixed value of 0.4, the enforcement intensity factor of the market-incentive environmental regulation means of implementing innovation incentive subsidies is set to vary between 0.2, 0.4, 0.6, 0.8 and 1, as shown in Figure 9c. With the increase in innovation incentive subsidies, the willingness of new energy enterprises to implement green technology innovation is slightly improved in the early stage, but with the passage of time, new energy enterprises will choose traditional technologies. This is because, in the case of the government levies, environmental taxes and public publicity being relatively small, and the "innovation compensation" effect generated by the government's innovation incentive subsidy for enterprises is far from offsetting the cost of green technology innovation investment by enterprises, so enterprises will not choose to carry out green technology innovation in the end. When the enforcement intensity factor of the social-will environmental regulation means and the environmental taxation of the market-incentive environmental regulation means are set to a fixed value of 0.4, the enforcement intensity factor of the innovation incentive subsidy of the market-incentive environmental regulation means is set to vary between 0.2, 0.4, 0.6, 0.8 and 1, as shown in Figure 9d. Similarly, in the short term, the willingness of new energy firms to implement green innovation technologies will increase with the imposition of environmental taxes, but it will eventually evolve and stabilize at traditional technologies over time. Comparing Figure 7c with Figure 7d, it can be found that the imposition of environmental taxes is more effective than subsidies for innovation incentives in market-incentive environmental regulation.

In conclusion, the combination of market-incentive environmental regulation and social-will environmental regulation is insufficient to promote green technology innovation in new energy enterprises. Even when the implementation intensity of market-incentive environmental regulation policies is small, the increase in social-will implementation will hinder the green technology innovation of enterprises.

In summary, only combining the two environmental regulatory means of command-control and market-incentive can effectively promote green technology innovation in new energy enterprises, while social-will environmental regulation tools do not play a significant role in this regard. Moreover, only when the market-incentive environmental regulation tools are implemented strongly enough can new energy enterprises be encouraged to finally choose green technology innovation, and the environmental tax is more effective than the innovation incentive subsidy for green technology innovation.

3.3. The Impact of the Combination of Three Environmental Regulations on the Strategy of New Energy Enterprises

The strategy choices when the government implements command-control, market-incentive and social-will environmental regulations of new energy companies in different situations are shown in Table 7.

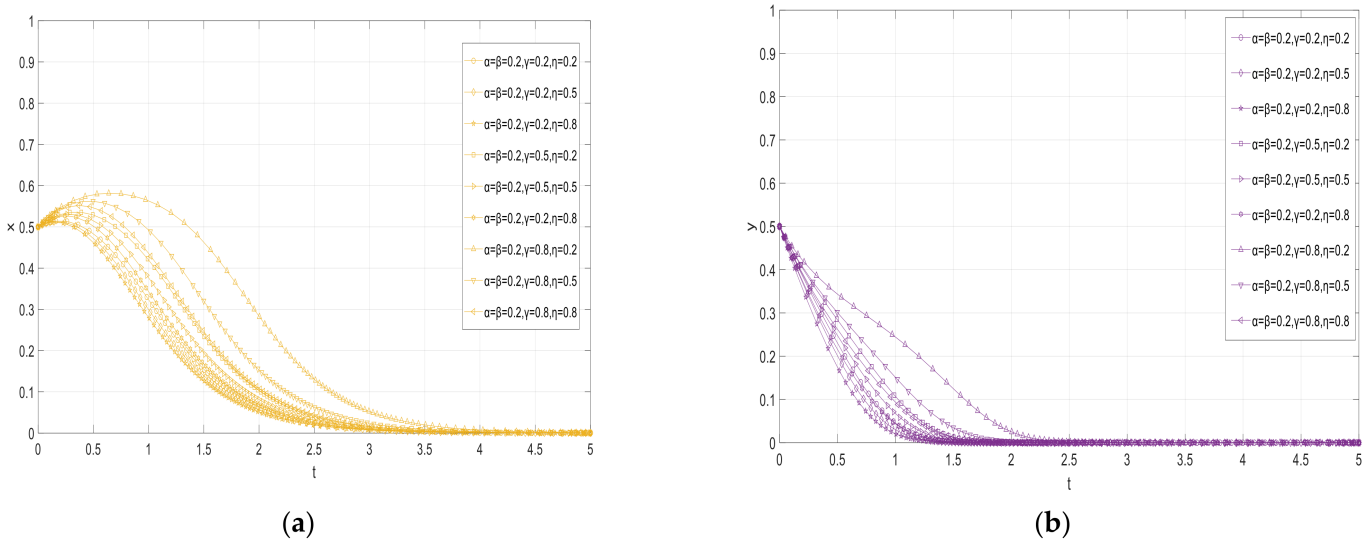
Table 7. The impact of three combinations of environmental regulatory tools on the strategies of new energy enterprises.

	(1)					(2)					(3)				
Type of Environmental Regulation	**α**	**β**	**γ**	**η**	**Corporate Strategy**	**α**	**β**	**γ**	**η**	**Corporate Strategy**	**α**	**β**	**γ**	**η**	**Corporate Strategy**
Command-control, market-incentive and social-will	0.2	0.2	0.2	0.2	Traditional Technology	0.5	0.5	0.2	0.2	Traditional Technology	0.8	0.8	0.2	0.2	Traditional Technology
	0.2	0.2	0.2	0.5	Traditional Technology	0.5	0.5	0.2	0.5	Traditional Technology	0.8	0.8	0.2	0.5	Traditional Technology
	0.2	0.2	0.2	0.8	Traditional Technology	0.5	0.5	0.2	0.8	Traditional Technology	0.8	0.8	0.2	0.8	Traditional Technology
	0.2	0.2	0.5	0.2	Traditional Technology	0.5	0.5	0.5	0.2	Traditional Technology	0.8	0.8	0.5	0.2	**Green Technology**
	0.2	0.2	0.5	0.5	Traditional Technology	0.5	0.5	0.5	0.5	Traditional Technology	0.8	0.8	0.5	0.5	Traditional Technology
	0.2	0.2	0.5	0.8	Traditional Technology	0.5	0.5	0.5	0.8	Traditional Technology	0.8	0.8	0.5	0.8	Traditional Technology
	0.2	0.2	0.8	0.2	Traditional Technology	0.5	0.5	0.8	0.2	**Green Technology**	0.8	0.8	0.8	0.2	**Green Technology**
	0.2	0.2	0.8	0.5	Traditional Technology	0.5	0.5	0.8	0.5	Traditional Technology	0.8	0.8	0.8	0.5	**Green Technology**
	0.2	0.2	0.8	0.8	Traditional Technology	0.5	0.5	0.8	0.8	Traditional Technology	0.8	0.8	0.8	0.8	Traditional Technology

When the government implements all three types of environmental regulations at the same time, but the implementation intensity of market-incentive environmental regulation tools is very low, regardless of the changes in the implementation intensity of command-control and social-will environmental regulations, new energy companies will eventually not choose to implement green technology innovation. The government will ultimately evolve to not implement environmental regulations, as shown in Figure 10. When the implementation intensity of market-incentive environmental regulation is set to 0.2, the higher the command-control environmental regulation intensity, and the more it can improve the willingness of new energy enterprises to implement green technology innovation in the early stage, while a higher implementation intensity of social-will environmental regulation is not conducive to new energy enterprises implementing green technology innovation. Eventually, all situations will evolve into no green technology innovation by new energy companies and no environmental regulation by governments.

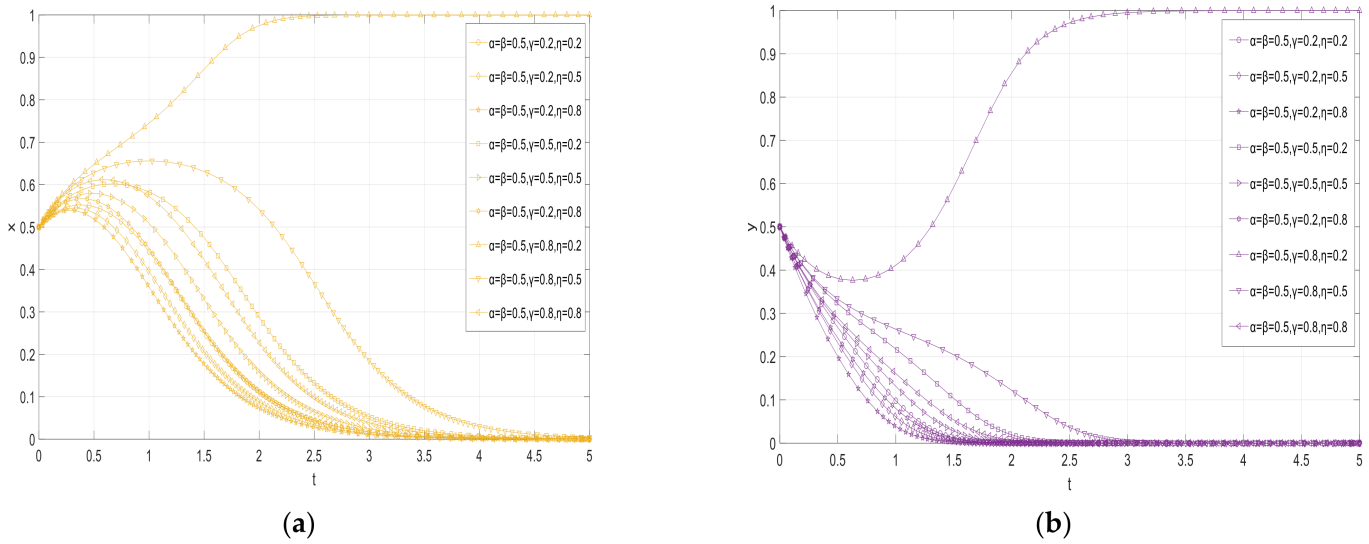
When the implementation intensity of market-incentive environmental regulation tools is moderate, the command-control environmental regulation is strong, and the intensity of social-will environmental regulation is weak, so new energy enterprises will eventually choose green technology innovation, and the government will choose environmental regulation, as shown in Figure 11. When the market-incentive environmental regulation is set at 0.5, new energy enterprises will only evolve to choose green technology innovation when the enforcement intensity of the command-control environmental regulations reaches 0.8, and the enforcement intensity of the social-will environmental regulations is 0.2. Under the premise that the market-incentive environmental regulation implementation intensity is strong (the implementation intensity factor reaches 0.8), three scenarios can motivate the steady state in which new energy companies eventually choose the green technology innovation strategy, and the government chooses to carry out the environmental regulation strategy. One is when the implementation intensity of command-control environmental regulation reaches 0.5, and the implementation intensity of social-will environmental

regulation is 0.2; the second is when the implementation intensity of command-control environmental regulation reaches 0.8, and the implementation intensity of social-will environmental regulation is 0.2; and the third is when the implementation intensity of command-control environmental regulation reaches 0.8, and the implementation intensity of social-will environmental regulation is 0.5, as shown in Figure 12.



(**a**) (**b**)

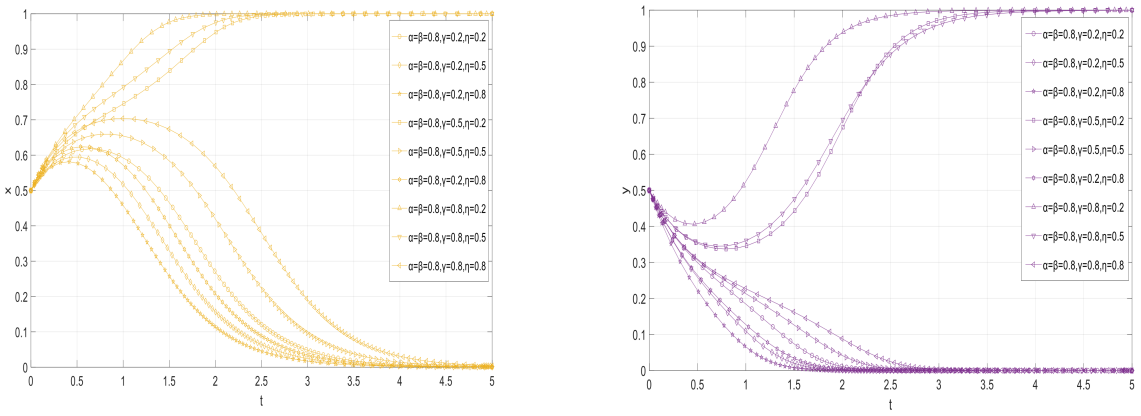
Figure 10. The evolutionary path of business (**a**) and government (**b**) under low-intensity market-incentive environmental regulation.



(**a**) (**b**)

Figure 11. The evolutionary path of business (**a**) and government (**b**) under moderate-intensity market-incentive environmental regulation.

In conclusion, combining three environmental regulatory policies can promote green technology innovation of new energy enterprises under certain circumstances. Only when the market-incentive environmental regulations and command-control environmental regulations reach a certain intensity can they promote new energy enterprises to choose green technology innovation strategies. Market-incentive environmental regulations play the strongest role in promoting new energy enterprises' green technology innovation, while social-will environmental regulations are not conducive to it when they are implemented too strongly.



(**a**) (**b**)

Figure 12. The evolutionary path of business (**a**) and government (**b**) under high-intensity market-incentive environmental regulation.

3.4. Summary

On the whole, the combination of two environmental regulation tools (command-control and market-incentive tools) or the combination of three environmental regulatory means (command-control, market-incentive and social-will tools) all can motivate new energy enterprises to choose green technology innovation, as shown in Figure 13. The market-incentive environmental regulation tool plays the most significant role, followed by the command-control environmental regulation tool, while the social-will environmental regulation tool does not have a significant effect and is not conducive to the choice of green technology innovation when the intensity is higher. Additionally, among the market-incentive environmental regulation tools, environmental taxes are more effective in motivating new energy enterprises to carry out green technology innovation.

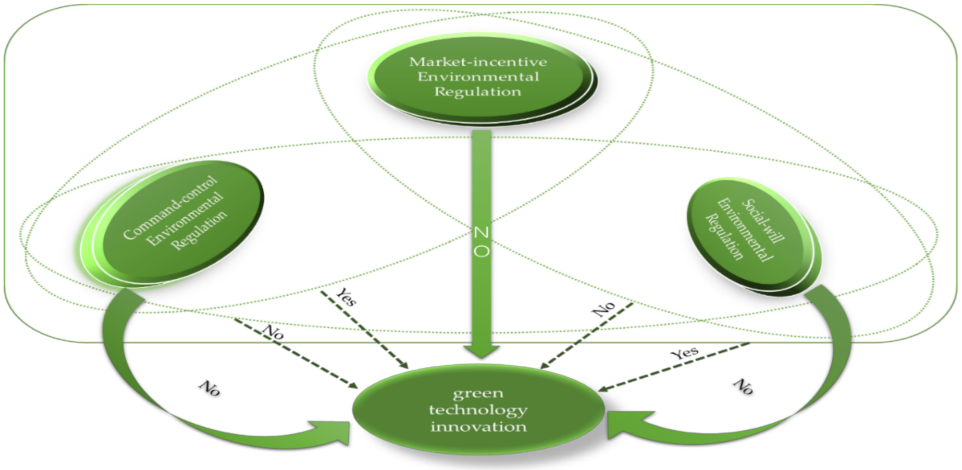


Figure 13. Results of heterogeneous environmental regulations and the impact of different combinations of environmental regulations on green technology innovation.

Comparing Figure 7b,d with Figures 11a and 12a, it can be found that when the enforcement intensity factor of command-control and market-incentive environmental regulations reaches 0.8 and the social-will environmental regulation is 0.2, they can promote new energy enterprises to stabilize their green technology innovation strategy choice the fastest. In other words, the government's selection of the appropriate government regulatory combination strategy and the appropriate enforcement intensity can more effectively and rapidly promote the green technology innovation of new energy enterprises.

4. Conclusions and Recommendations

Based on the theory of green technology innovation, this paper uses the theory of information asymmetry and finite rationality as the premise. It constructs an evolutionary game model between the government and new energy enterprises. By analyzing and copying the dynamic equation, we obtain the evolutionary stability strategy of the system. Finally, numerical simulations are conducted to study the heterogeneous effects of three types of environmental regulations on green technology innovation of new energy enterprises: command-control, market-incentive and social-will, and the effects of different combinations of environmental regulations on the evolution of green technology innovation behavior of new energy enterprises.

The results show that: (1) The implementation of a single environmental regulatory tool is not enough to incentivize new energy enterprises to eventually evolve green technology innovation strategies. High-intensity market-incentive environmental regulation means are more significant in increasing firms' willingness to carry out green technology innovation, while high-intensity command-control environmental regulatory measures incentivize enterprises to carry out green technology innovation for a longer time. Implementing social-will environmental regulatory measures alone will not promote green technology innovation by new energy enterprises. (2) The combination of command-control environmental regulation tools and market-incentive environmental regulation tools significantly promotes the green technology innovation of new energy enterprises. In addition, compared with the command-control environmental regulation tools, the incentive effect of market-incentive environmental regulation tools on green technology innovation of new energy enterprises is more obvious, which also verifies the "narrow" version of Porter's hypothesis. Among the market-incentive environmental regulatory instruments, government environmental taxes are more effective in promoting green technology innovation in new energy enterprises than the implementation of innovation incentive subsidies. (3) The combination of three environmental regulatory policies can promote green technology innovation of new energy enterprises under certain circumstances. Only when the market-incentive environmental regulations and command-control environmental regulations reach a certain intensity can they promote new energy enterprises to choose green technology innovation strategies. Market-incentive environmental regulations play the strongest role in promoting new energy enterprises' green technology innovation, while social-will environmental regulations are not conducive to this when they are implemented too strongly. (4) The government's selection of the appropriate government regulatory combination strategy and the appropriate enforcement intensity can more effectively and rapidly promote the green technology innovation of new energy enterprises. The "optimal strategy combination" and "best enforcement" of the government's implementation of environmental regulation are the combination of high-intensity command-control environmental regulation tools, high-intensity market-incentive environmental regulation tools and low-intensity social-will environmental regulation tools.

Based on the analysis of stabilization strategies and numerical simulation results, this paper proposes the following recommendations: (1) Scientific combination of environmental regulation tools. In the long run, implementing one type of environmental regulation tool alone does not encourage new energy companies to choose and stabilize their green technology innovation strategy. Moreover, in the long run, the combination of social-will environmental regulation tools and the other two types of environmental regulation tools has a limited incentive effect on new energy enterprises. The government should implement a combination of command-control and market-incentive environmental regulation tools or a combination of three environmental regulation tools. This will provide long-term incentives for new energy enterprises to implement green technology innovation. (2) The intensity of environmental regulation enforcement should be appropriate. Different environmental regulation tools should be selected with appropriate implementation intensity to encourage new energy enterprises to choose green technology innovation strategies in the long run. Specifically, if two environmental regulation tools are introduced, the imple-

mentation of command-control and market-incentive environmental regulation tools, the role of environmental taxation is strengthened; if three environmental regulation tools are introduced, the role of command-control and market-incentive environmental regulation tools should be strengthened, and the role of social will environmental regulation tools should be weakened. (3) Stimulate the motivation of green technology innovation in new energy enterprises. Whether new energy enterprises choose green technology innovation has a great relationship with their own input costs and benefits. Therefore, by reducing the cost of green technology innovation of new energy enterprises and improving their revenues, we can stimulate them to carry out green technology innovation. Firstly, this can reduce the cost of green technology innovation by enterprises commercializing and patenting their own green technology innovation results; secondly, it can make new energy enterprises realize that the potential of public benefits and environmental benefits brought by green technology innovation is huge through publicity and education.

This paper analyzes the impact of different environmental regulations on green technology innovation of new energy enterprises using the evolutionary game approach. This paper explores the "optimal strategy combination" and "best execution" of the government's implementation of environmental regulation, which can maximize the benefits of enterprise green technology innovation. This is to promote the organic unity of the three major benefits of the best economic benefit, the best ecological benefit and the best social benefit. This not only provides guiding suggestions for promoting the sustainable innovation of new energy enterprises, but also has important significance for the sustainable development of the economy including micro-unit enterprises and the whole of society. However, no further analysis has been carried out on regional differences and industrial heterogeneity differences, which is the direction of our future research.

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