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Mandatory ESG Information Disclosure Policy:"Safeguarding" the Development of Green Finance—An Evolutionary Game Model Based on Local Governments and Greenwashing Behavior of Heavily Polluting Enterprises

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Abstract: China is in the early stages of green finance development, with some listed companies engaging in greenwashing—misleading practices to appear environmentally friendly. To address this, the paper develops an evolutionary game model involving local governments and heavily polluting enterprises. It explores how mandatory ESG disclosure influences corporate strategy, finding that it can curb greenwashing when local governments enforce higher fines and higher-level governments provide stronger incentives. The case of Shendong Coal Group demonstrates the effectiveness of combining government penalties and incentives. A robust penalty system and high-level government incentives are essential for successful ESG disclosure policies to mitigate corporate greenwashing.

Keywords: ESG information disclosure; greenwashing; green finance; evolutionary game model

1. Introduction

Sustainable energy use is increasingly critical. In 2015, the United Nations introduced the Sustainable Development Goals (SDGs), including Goal 7 for sustainable energy and Goal 13 for climate change. ESG (Environmental, Social, and Governance) factors, introduced by the UN Principles for Responsible Investment (UNPRI), guide corporate responsibility and have become a vital investment and evaluation standard. However, some companies engage in greenwashing, making misleading ESG disclosures to improve their image and attract financial support. While ESG disclosure reduces information asymmetry, it can also promote greenwashing [1]. Strengthening government oversight and mandating ESG disclosure can help curb this behavior. Some studies suggest that mandatory disclosure and stronger regulatory systems in China can reduce greenwashing [2-5].

In China, local governments are responsible for implementing environmental governance policies. However, due to the hidden nature of greenwashing and early-stage green finance development, policy implementation faces challenges. Environmental governance is costly and delayed, with local governments often failing to meet central government requirements without sufficient incentives [6]. Figure 1 illustrates the paper structure.

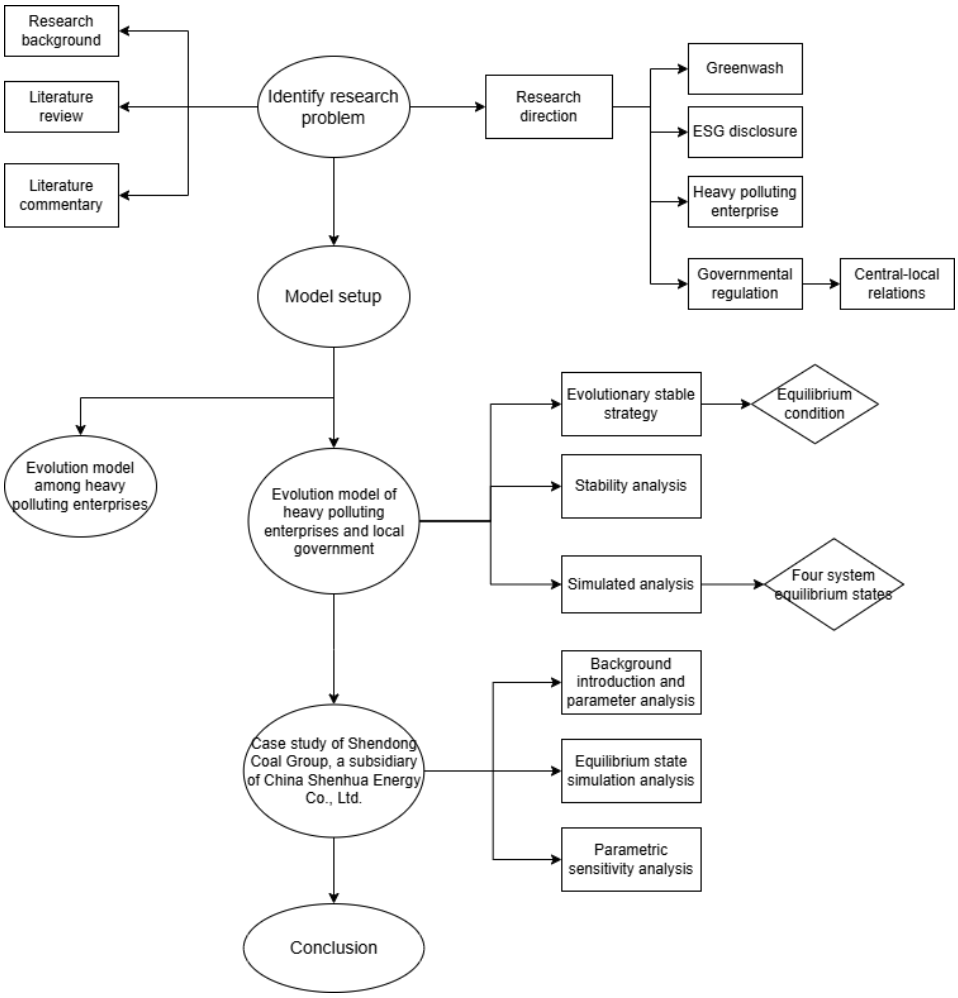

Figure 1. Paper Structure.

2. Literature Review and Hypotheses

Many studies show that strong ESG performance alleviates financing constraints, enhances risk management, and improves stock returns, thereby increasing corporate value [1,7]. ESG disclosure also promotes transparency and social responsibility performance [8], potentially reducing greenwashing. Strong ESG practices signal lower risks and may reduce loan risks. However, excessive emphasis on ESG can lead to greenwashing, where companies superficially engage in environmental actions without substantive efforts [9]. Financial analysis may show greenwashing secures subsidies and boosts performance [10], making it an appealing strategy. Yet, if exposed, it can harm consumer trust and cause non-economic losses [9,11], and reduce investor willingness [12,13]. Thus, ESG disclosure can both inhibit and promote greenwashing.

H1: Mandatory ESG information disclosure has a greater positive than negative impact on corporate greenwashing.

H2: Mandatory ESG information disclosure reduces corporate greenwashing by increasing penalties.

H3: Mandatory ESG information disclosure reduces corporate greenwashing by enhancing government penalties.

2.1. Review of the Relationship between Greenwashing and Esg Information Disclosure

Improving ESG information disclosure can reduce corporate greenwashing. In the bond market, greater transparency helps investors access green bond details efficiently [14]. Effective ESG evaluation mechanisms can optimize China's disclosure system and

reduce greenwashing [15]. Severe information asymmetry increases greenwashing risks for investors [16]. Clearer disclosure systems also reduce policy uncertainty, encouraging compliance [17]. However, greenwashing may still occur. Some governments may exaggerate environmental efforts to boost global image [18]. In China, ESG disclosure is based on both financial and non-financial data, but selective reporting can lead to overstated achievements to gain investor trust [19].

2.2. Literature Review on Evolutionary Game Models

Evolutionary game theory, derived from biology, is widely used to study stakeholder interactions due to its dynamic equilibrium and bounded rationality assumptions. It simulates the strategic evolution of greenwashing behavior under changing environmental policies and market conditions. This approach reflects how heavily polluting firms and local governments make decisions based on limited information, market competition, and policy constraints. Evolutionary game theory thus provides a realistic framework for analyzing greenwashing motivations and strategies. It captures adaptation and learning processes in social systems more accurately than static models. In recent studies, Liu et al. constructed an evolutionary game model involving manufacturers, certification bodies, and governments to analyze electric vehicle certification collusion [20]. Yang et al. used such models to examine eco-innovation diffusion in green entrepreneurship under market and policy influences [21].

3. Evolutionary Game Analysis of Greenwashing Dilemmas in Heavily Polluting Enterprises and Their Resolution

3.1. Problem Statement

Heavily polluting enterprises significantly impact China's environmental performance and must be prioritized in policymaking. An analysis of the A-Share Environmental Risk List reveals that most listed companies belong to heavily polluting industries. This paper focuses on these enterprises, as defined in the 2010 Environmental Information Disclosure Guidelines for Listed Companies.

In China's multi-level governance structure, central authorities set national goals, while local governments are responsible for enforcement. Local governments have a greater influence on corporate behavior, developing and implementing ESG disclosure standards tailored to local conditions. This paper examines the role of government in regulating ESG disclosure and analyzes whether enterprises choose greenwashing or comply with mandatory disclosure.

With the "Dual Carbon" policy, environmental concerns in the green finance market have gained urgency. Greenwashing, driven by high costs and limited resources for green innovation, can hinder regulatory effectiveness and distort ESG disclosures. This paper addresses two key research questions:

RQ1: Under a pure market mechanism, will heavily polluting enterprises choose greenwashing?

RQ2: Can reasonable ESG information disclosure incentivize honest reporting by such enterprises?

3.2. Basic Assumptions

In the ESG information disclosure evolutionary game model, two new enterprises in a region with heavy pollution compete using two strategies: greenwashing (with probability p) or no greenwashing (with probability 1-p). Enterprises aim to maximize profit under bounded rationality. "Greenwashing" involves misleading environmental claims, while "no greenwashing" focuses on genuine environmental actions. Local governments choose between mandatory or voluntary ESG disclosure, with mandatory disclosure requiring firms to submit reports, with penalties for violations and subsidies for compliance, and voluntary disclosure allowing firms to choose without penalties.

Payoffs are defined as follows: if both enterprises greenwash, they receive w1; if one greenwashes, the greenwasher earns w2, and the other earns w3; if neither greenwashes, they receive w4. Under mandatory disclosure, greenwashing enterprises are fined G, and the government incurs supervision cost I and social loss S. With voluntary disclosure, greenwashing incurs a higher loss, kS, due to weaker oversight. Higher-level governments provide incentives F, and local governments can gain opportunity cost N if firms disclose truthfully.

For enterprises, greenwashing under mandatory disclosure yields profit W1, offset by costs C1 (falsification), C2 (psychological), bC3 (environmental cost reduction), C4 (reputation), and cS (social loss). Under relaxed policies, losses increase to ckS, while psychological costs fall to aC2. Honest enterprises receive W2 and pay full environmental cost C3. All parameters are positive, as summarized in Table 1.

Table 1. Model Parameter Descriptions.

Parameter	Description
G	Government fines for greenwashing enterprises
I	The information cost of government regulation
S	The negative impact of greenwashing on society
F	Incentives from higher-level governments to local governments
N	The opportunity cost of mandatory closure measures taken by the government
W1	The production profit of enterprises without greenwashing
W2	The production profit of enterprises under greenwashing
C1	Greenwashing cost
C2	The psychological cost of greenwashing
C3	The environmental governance cost of non greenwashing enterprises
C4	The reputation loss of corporate greenwashing
a	The coefficient of reducing the psychological cost of enterprises under government relaxation policies (a<1)
b	The ratio of environmental governance with and without bleaching (b<1)
c	The conversion coefficient of environmental benefits between government and enterprises (c<1)
k	Amplification coefficient of social benefits under government relaxation policies (k>1)

3.3. Model Construction and Calculation Solution

In the symmetric evolutionary game model for heavily polluting enterprises, two identical enterprises in the same industry choose between two strategies: greenwashing (with probability p) or no greenwashing (with probability 1-p). Enterprises aim to maximize profits, and the payoffs are analyzed based on the parameter settings.

When both enterprises choose greenwashing or no greenwashing, they receive payoffs w1 and w4, respectively. Due to the lack of government-regulated ESG systems, detecting greenwashing becomes harder. Greenwashing enterprises incur lower costs and achieve better benefits, so w1 > w4. If one enterprise greenwashes while the other does not, the greenwashing enterprise gains the highest payoff (w2), as it faces lower environmental and innovation costs and improves its image. The non-greenwashing enterprise incurs higher costs and faces a more competitive market, resulting in the lowest profit (w3). Therefore, the payoff ranking is w2 > w1 > w4 > w3, as shown in Table 2.

Table 2. Payment Matrix for Heavy Polluting Enterprises A and B Without Government Regulation.

		Enterprise 2	
		Greenwashing	No Greenwashing
Enterprise 1	Greenwashing	w1,w1	w2,w3
	No Greenwashing	w3,w2	w4,w4

The adaptability of heavy polluting enterprises adopting greenwashing strategies is:

$$A1 = pw1 + (1-p)w2 \quad (1)$$

The adaptability of honest production strategy adopted by heavily polluting enterprises is:

$$A2 = pw3 + (1-p)w4 \quad (2)$$

The average fitness of the group of heavily polluting enterprises is:

$$A = pA1 + (1-p)A2 \quad (3)$$

The dynamic equation for enterprise replication is:

$$f(p) = \frac{dp}{dt} = p(A1 - A) = p(1-p)(A1 - A2)$$
$$= p(1-p)[(w1 - w3)p + (w2 - w4)(1+p)] \quad (4)$$

$f(p) = 0$, then there are:

$$p_1^* = 0, p_2^* = 1, p_3^* = \frac{w4 - w2}{w1 - w3 - w4 + w2}$$

$f(p)' < 0$, p^* is the Evolution Strategy of Commercial Banks (ESS), then there are:

$$f(p^*)' = 2p(w1 - w3) - 3p^2(w1 - w3 + w2 - w4) + w2 - w4 \quad (5)$$

When w2>w1>w4>w3,Verified separately $p_1^* = 0, p_2^* = 1, p_3^* = \frac{w4-w2}{w1-w3-w4+w2}$:

$$f(0)' = (w2 - w4) > 0$$
$$f(1)' = (w3 - w1) < 0$$
$$f(\frac{w4 - w2}{w1 - w3 - w4 + w2})' > 0$$

Only $p_2^* = 1$Meets stability requirements. Therefore, in the absence of market regulation, the optimal strategy for heavily polluting enterprises is to engage in greenwashing, which creates a dilemma for the enterprises and indirectly reflects the necessity and importance of the government adopting regulatory strategies for green production of enterprises. Therefore, the research question has been proven successful, that is, under a pure market mechanism, heavily polluting enterprises will ultimately lead to greenwashing.

3.4. Resolving the Green Drifting Dilemma of Heavy Polluting Enterprises

We have demonstrated that in the absence of market regulation, heavily polluting enterprises will face greenwashing due to market competition such as competition for consumers. Next, we will introduce the role of the government and refer to China's policies from 2020 to 2023 and future policy directions, giving it two environmental regulatory options for corporate ESG information disclosure (mandatory ESG disclosure and voluntary ESG information disclosure). The combination of these options is marked as（$g1, g2$）, The selection probabilities are as follows: $(\beta, 1-\beta), 0 < \beta < 1$. According to parameter design (2), the following group benefit matrix can be obtained:

Table 3. Payment Matrix of the Government Enterprise Game Model.

		Government	
		ESG mandatory disclosure(β)	ESG voluntary disclosure$(1-\beta)$
enterprise	Greenwashing(α)	W1-C1-C2-C4-G-cS , G-I-S	W1-aC2-C4-ckS , N-kS
	NoGreenwashing $(1-\alpha)$	W2-C3-bG , -I+F	W2-C3 , N

3.5. Dynamic Evolution Analysis

The analysis of the evolution of benefits for heavy polluting enterprises adopting different strategies is as follows.

The adaptability of heavy polluting enterprises adopting greenwashing strategies is:

$$U_{e1} = \beta(W1 - C1 - C2 - C3 - C4 - G - cS1) + (1-\beta)(W1 - aC2 - C4 - ckS)$$
$$= \beta[-C1 - (1-a)C2 - G + cS1(k-1)] + (W1 - aC2 - C4 - ckS1) \quad (6)$$

The adaptability of non greenwashing strategies adopted by heavily polluting enterprises is:

$$U_{e2} = \beta(W2 - C3 - bG) + (1-\beta)(W2 - C3) = -\beta(bG) + (W2 - C3) \quad (7)$$

The average fitness of the group of heavily polluting enterprises is:

$$\overline{U_e} = \alpha U_{e1} + (1-\alpha)U_{e2} \quad (8)$$

The dynamic equation for enterprise replication is:

$$F_E(\alpha) = \frac{d\alpha}{dt} = \alpha(U_{e1} - \overline{U_e}) = \alpha(1-\alpha)(U_{e1} - U_{e2})$$
$$= \alpha(1-\alpha)\{[W1 - W2 - aC2 + C3 - C4 - ckS] + \beta[bG - C1 - (1-a)C2 - G + c(k-1)S]\} \quad (9)$$

Let $F_E(\alpha) = 0$, then $\alpha^*_1 = 0,\ \alpha^*_2 = 1, \beta^* = -\frac{[W1-W2-aC2+C3-C4-ckS]}{[bG-C1-(1-a)C2-G+c(k-1)S]}$

Let $F_E(\alpha) = 0$, then $\alpha^*_1 = 0,\ \alpha^*_2 = 1,\ \beta^* = -\frac{[W1-W2-aC2+C3-C4-ckS]}{[bG-C1-(1-a)C2-G+c(k-1)S]}$

The analysis of the evolution of benefits from different strategies adopted by the government is as follows.

The adaptability of the government's mandatory ESG disclosure strategy is:

$$U_{g1} = \alpha(G - I - S1) + (1-\alpha)(F - I) = \alpha(G - S - F) + (F - I) \quad (10)$$

The adaptability of the government's voluntary ESG disclosure strategy is:

$$U_{g2} = \alpha(N - kS1) + (1-\alpha)N = \alpha(-kS) + N \quad (11)$$

The average fitness of the government group is:

$$\overline{U_g} = \beta U_{g1} + (1-\beta)U_{g2} \quad (12)$$

The government replicates the dynamic equation as follows:

$$F_G(\beta) = \frac{d\beta}{dt} = \beta(U_{g1} - \overline{U_g}) = \beta(1-\beta)(U_{g1} - U_{g2})$$
$$= \beta(1-\beta)\{\alpha[G + (k-1)S - F] + (F - I - N)\} \quad (13)$$

Let $F_E(\beta) = 0$, then $\beta^*_1 = 0,\ \beta^*_2 = 1,\ \alpha^* = -\frac{(F-I-N)}{[G+(k-1)S-F]}$

According to the theorem of differential equations, the evolutionary stable strategy needs to satisfy the condition that the replicator dynamic equation is equal to zero and the first derivative is less than zero, and that both evolutionary agents influence each other. If the initial value chosen by one of the game agents changes, the other will tend towards a different evolutionary stable strategy. Therefore, starting from both enterprises and governments, we will consider:

In order to obtain the evolutionary stable strategy of the enterprise, the first-order derivative of the probability of enterprise greenwashing in formula (9) is obtained:

$$F_E(\alpha)' = (1-2\alpha)\{(W1 - W2 - aC2 + C3 - C4 - ckS) + \beta[bG - C1 - (1-a)C2 - G + c(k-1)S]\} \quad (14)$$

Substitute $\alpha^*_1 = 0, \alpha^*_2 = 1,\ \beta^* = -\frac{(W1-W2-aC2+C3-C4-ckS)}{[bG-C1-(1-a)C2-G+c(k-1)S]}$, and discuss the situation separately.

Scenario 1: When $\beta < \beta^*,\ F_E(0)' > 0,\ F_E(1)' < 0,\ \alpha^* = 1$ is the only evolutionary stable strategy of the system, indicating that when the probability of mandatory ESG disclosure by the government is lower than β^*, companies will shift from non greenwashing to greenwashing in ESG disclosure, that is, by disclosing untrue information through data falsification or selective disclosure. At this point, although heavily polluting enterprises face a certain probability of punishment, considering that the benefits obtained from greenwashing will cover the possible losses, they still choose greenwashing.

Scenario 2: When $\beta > \beta^*,\ F_E(1)' > 0,\ F_E(0)' < 0,\ \alpha^* = 0$ is the only evolutionary stable strategy of the system, indicating that when the government enforces ESG disclosure with a probability higher than β^*, companies shift from greenwashing to non greenwashing. At this point, although companies may experience a decrease in profits and pay higher environmental remediation fees when engaging in greenwashing, overall, the losses incurred by greenwashing outweigh their profits. At the same time, the government will provide incentives for companies to choose not to engage in greenwashing production.

Scenario 3: In case $\beta = \beta^*$, heavy polluting enterprises have the same returns under both strategies, with no difference. However, in terms of the overall ESG development trend and China's future environmental goal planning, it is highly likely that China will implement mandatory ESG disclosure in the future. Therefore, for heavy polluting enterprises' own development, greenwashing is not conducive to achieving their green transformation and low-carbon development goals. Therefore, only by actively disclosing honest ESG information by heavily polluting enterprises can we promote greener and more environmentally friendly development for both the enterprise and society.

Similarly, to obtain the government's evolutionary stability strategy, the first-order derivative of formula (13) for mandatory ESG disclosure by the government is obtained:

$$F_G(\beta)' = (1-2\beta)\{\alpha[G+(k-1)S-F]+(F-I-N)\} \quad (15)$$

Substitute $\beta^*_1 = 0$, $\beta^*_2 = 1$, $\alpha^* = -\frac{(F-I-N)}{[G+(k-1)S-F]}$, and discuss the situation separately.

Scenario 1: When $\alpha < \alpha^*$, $F_G(1)' > 0$, $F_G(0)' < 0$ is the only evolutionary stable strategy of the system, indicating that when the probability of heavy polluting enterprises drifting green is lower than α^*, the government shifts from mandatory requirements to voluntary ESG disclosure and does not impose strict requirements on enterprises. At this time, heavy polluting enterprises have relatively less greenwashing behavior, saving the government's environmental governance expenses. The cost of implementing mandatory disclosure policies by the government, such as information cost I, exceeds the economic and social benefits, therefore the mandatory disclosure policy will not be implemented.

Scenario 2: When $\alpha > \alpha^*$ occurs, $F_G(0)' > 0$, $F_G(1)' < 0, \beta^* = 1$ is the only evolutionary stable strategy of the system, indicating that when the probability of a company engaging in greenwashing in ESG reports is higher than α^*, the government shifts from mandatory to mandatory and imposes strict requirements on the disclosure of ESG reports by companies. When heavily polluting enterprises produce large-scale greenwashing, it will have a serious negative impact on society and requires the government to strengthen management. At this time, the cost of implementing mandatory enforcement strategies by the government is greater than the fines it charges from heavily polluting enterprises, and it can maintain expenses and enforce mandatory ESG disclosure policies.

Scenario 3: When $\alpha = \alpha^*$, the government benefits equally under both strategies. Based on a comprehensive analysis of the regulations on ESG disclosure issued by the Chinese government from 2020 to 2023, ESG disclosure plays an important role in the healthy development of the green finance market. At the same time, the pilot situation of mandatory ESG disclosure in China is relatively good. Therefore, the future trend in China is likely to require mandatory ESG disclosure for heavily polluting enterprises. At the same time, under voluntary disclosure, it is relatively more difficult for the government to obtain the true information of enterprises under mandatory disclosure, resulting in weaker regulatory efforts and indirectly encouraging the occurrence of greenwashing behavior. Therefore, if the government does not enforce mandatory disclosure, it will be detrimental to achieving environmental goals in the long run.

3.6. Local Equilibrium Point and Its Stability Analysis

In this model, there is a game between enterprises and governments. Therefore, to solve the systematic equilibrium point, a two-dimensional replicated dynamic equation system is constructed by combining formula (9) and formula (13):

$$\begin{cases} F_E(\alpha) = \alpha(1-\alpha)\begin{Bmatrix}(W1-W2-aC2+C3-C4-ckS)+\\ \beta[bG-C1-(1-a)C2-G+c(k-1)S]\end{Bmatrix} = 0 \\ F_G(\beta) = \beta(1-\beta)\{\alpha[G+(k-1)S-F]+(F-I-N)\} = 0 \end{cases}$$

By solving the system, five dual population pure strategy equilibrium points can be obtained: (0,0), (1,0), (1,1), (0,1), (α^*, β^*)

The above five equilibrium points may not necessarily have stability. According to the stability condition of the two party evolutionary game model, if the local equilibrium

point satisfies $|J| > 0, \mathrm{tr}(J) < 0$, then the system evolutionary stability strategy is the equilibrium point (ESS), and the behavior of the game subject at this point tends to be stable after long-term learning. The two-dimensional Jacobian matrix of this system is calculated as follows:

$$J = \begin{bmatrix} \frac{dF_E(\alpha)}{d\alpha}(1) & \frac{dF_E(\alpha)}{d\beta}(2) \\ \frac{dF_G(\beta)}{d\alpha}(3) & \frac{dF_G(\beta)}{d\beta}(4) \end{bmatrix}$$

$$(1-2\alpha)\{(W1-W2-aC2+C3-C4-ckS)+\beta[bG-C1-(1-a)C2-G+c(k-1)S]\}$$
$$\alpha(1-\alpha)(W1-W2-aC2+C3-C4-ckS)$$
$$\beta(1-\beta)[G+(k-1)S-F]$$
$$(1-2\beta)\{\alpha[G+(k-1)S-F]+(F-I-N)\}$$

By judging each item, we bring in five dual population pure strategy equilibrium points for verification.

The remaining equilibrium points (0,0), (1,0), (1,1), and (0,1) respectively conform to the stable strategy of the two-dimensional fireworks game system under certain conditions, that is, there are four possible ESS scenarios for enterprises and governments: (greenwashing, relaxed disclosure), (greenwashing, mandatory disclosure), (non greenwashing, mandatory disclosure), and (non greenwashing, relaxed disclosure).

3.7. Numerical Simulation Model Experiment and Result Analysis of Evolutionary Game Model

This section uses MATLAB simulations to analyze the evolutionary game model, examining how different parameters influence the dynamic evolution between local governments and heavily polluting enterprises. The evolution process is divided into four stages: initial market state, initial policy implementation, mature policy implementation, and ideal system state. The final strategic choices of both parties depend on the initial parameter values, with the analysis based on critical parameter settings and real-world conditions.

Scenario 1: System status before policy implementation. According to Table 4, the initial equilibrium point of the system is (1,0), which means that if the enterprise chooses to go green and the government does not require ESG information disclosure, the system must meet the following conditions:

$$-(W1-W2-aC2+C3-C4-ckS)<0 \overset{\text{Equal}}{\Longleftrightarrow} (W1-aC2-C4-ckS)>W2-C3,$$
$$G+(k-1)S-I-N<0 \overset{\text{Equal}}{\Longleftrightarrow} G<I+N-(k-1)S$$

Greenwashing enterprises profit by avoiding environmental costs, despite reputational damage. Non-greenwashing enterprises incur full environmental costs and lower profits. Before policy implementation, greenwashing is more profitable due to weak regulation and low fines. In the early green finance market, enterprises focus on profit and image, while the government, still developing policy, lacks a complete ESG framework, allowing greenwashing to continue.

Table 4. Stability condition of equilibrium point.

Equilibrium	A11	A12	B11	B12	Stability
(1,0)	$-(W1-W2-aC2+C3-C4-CkS)$	0	0	$G+(k-1)S-I-N$	Situation1
(1,1)	$-(W1-W2-C1-C2+C3-C4-cS-(1-bG))<0$	0	0	$-[G+(k-1)S-I-N]$	Situation2
(0,1)	$[W1-W2-C1-C2+C3-C4-cS-(1-bG)]>0$	0	0	$-(F-I-N)$	Situation3
(0,0)	$W1-W2-aC2+C3-C4-CkS$	0	0	$F-I-N$	Situation4
(α^*, β^*)	0	A	A	0	Saddle Point

The stability of the evolution trajectory of government and enterprises will be verified using MATLAB software. Based on existing research analysis and actual conditions, the parameters in the initial market situation are shown in the following table 5:

Table 5. Parameters temporarily introduced into the model based on the situation.

W1=3	W2=0.2	C1=0.35	C2=0.1	C3=1.5
C4=1.5	a=0.59	b=0.55	C=0.27	K=1.8
S=0.98	G=0	I=0.5	N=1.2	F=0

We assume that companies that do not engage in greenwashing in the early stages of the market have lower production profits, while those that engage in greenwashing have higher profits; At the same time, for enterprises in the early stages of environmental governance, the cost of governance is relatively high due to their lack of advanced technology. We assign five initial values (0.1, 0.6), (0.3, 0.5), (0.5, 0.1), (0.4, 0.9), (0.6, 0.5), and (0.9, 0.3) to α and β. The dynamic evolution process of participating in the selection of the main strategy under the initial parameter values is shown in Figure 2. From the figure, it can be seen that all curves in the evolutionary system converge to point E1 (1,0), indicating that the equilibrium of the system is {Greenwashing, voluntary disclosure}, which is consistent with the previous model results. However, with the continuous improvement of the green finance market, the increasing punishment for corporate greenwashing behavior, and the continuous increase in the cost of corporate greenwashing, after a long-term choice game, the state of E1 (1,0) cannot be sustained for a long time.

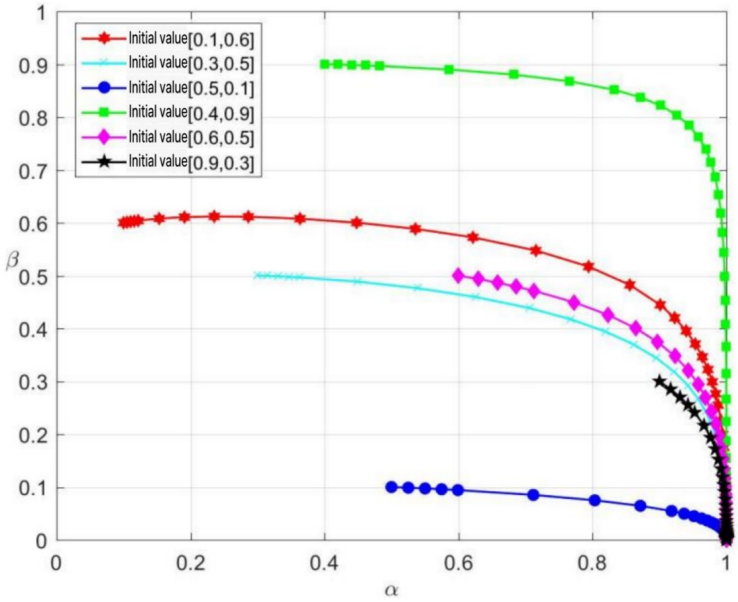

Figure 2. The evolution process of the initial state of the system at different values of α and β.

Scenario 2: System status during the initial stage of policy implementation. Based on the reality, we assume that the development of the green finance market and the popularization of the concept of greenwashing are a gradual and constantly improving process, which means that the implementation of policies is also a process event. With the continuous development of the green finance market and the increasing awareness of greenwashing by the government, some greenwashing behaviors have been reviewed and punished, and strict mandatory measures have been taken. However, companies still choose greenwashing. At this point, the stable point of the system is (1,1), which means that the enterprise is greenwashing and the government is forcing ESG disclosure. According to Table 4, the conditions for system equilibrium are:

$$\begin{cases} -[W1 - W2 - C1 - C2 + C3 - C4 - cS - (1 - b)G] < 0 \\ -[G + (k - 1)S - I - N] < 0 \end{cases}$$
$$\overset{\text{Equal}}{\Longleftrightarrow} I + N - (k - 1)S < G < \frac{[(W1 - W2) + (C3 - C1) - C2 - C4 - cS]}{1 - b}, 0 < b < 1$$

At this point, the amount of penalties imposed by the government on greenwashing enterprises is sufficient to cover the cost of implementing policies, and thus the government begins to enforce ESG disclosure. Compared to relaxing regulatory conditions, greenwashing companies will face fines from the government, but the amount is still less than the sum of the production income brought by greenwashing and the environmental costs not paid by the company due to greenwashing minus the various costs of greenwashing, that is, the final benefit of the company adopting greenwashing. At this time, under the intensity of government environmental regulations, enterprises have no incentive to change their strategies, and even if the incentive measures of the higher-level government are ineffective, the government will continue to take stable measures.

Similarly, we validated the stability of scenario 2 using MATLAB. At this time, local governments are gradually strengthening their mandatory review of ESG information. At the same time, in order to ensure transparency in the green finance market, higher-level governments are also taking measures to encourage the implementation of their mandatory disclosure system. At this point, we adjust it to G=2, F=1, Other parameters remain unchanged and sympathize with form one. From Figure 3, it can be observed that all six lines are approaching E2 (1,1) after evolution, and the stable point of the system is consistent with the model results: {Greenwashing, mandatory disclosure}. Therefore, the evolutionary system of scenario 2 will stabilize at E2 (1,1) after a certain period of time and be in a staged equilibrium.

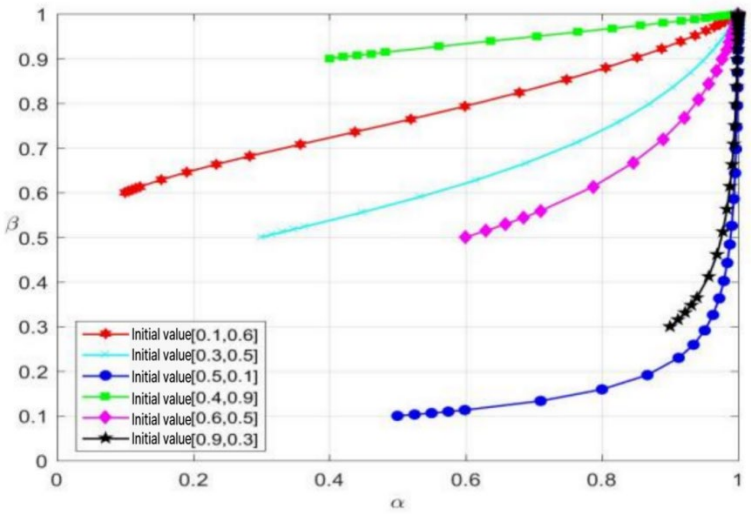

Figure 3. The evolution process of the initial state of policy implementation when α and β have different values.

Scenario 3: Policy maturity and implementation status. With the development and regulation of the green finance market and the increasing attention of higher-level governments to ESG information, government policy implementation can be adjusted and adapted to effectively review and promptly punish greenwashing enterprises, which will encourage enterprises to actively engage in green innovation, improve production, and reduce pollution. At this point, the system equilibrium point is E3 (0,1), which means that heavily polluting enterprises will not be greenwashing, and the government will strictly supervise them. According to Table 4, the equilibrium conditions are:

$$[W1 - W2 - C1 - C2 + C3 - C4 - cS - (1 - bG)]$$
$$> 0 \overset{\text{Equal}}{\Longleftrightarrow} (1 - b)G < (W1 - W2) + (C3 - C1) - C2 - C4 - cS$$

$$-(F-I-N)<0 \overset{Equal}{\Longleftrightarrow} F>I+N$$

At this time, the difference in penalties imposed by the government on greenwashing enterprises and non greenwashing heavy polluting enterprises is greater than the sum of the five greenwashing costs, so enterprises will be more inclined to choose non greenwashing. At the same time, the incentives provided by the higher-level government to local governments are greater than the information cost and opportunity cost of investment made by local governments under mandatory disclosure, and the incentive benefits are effective, further promoting the implementation of penalties for corporate greenwashing and ESG mandatory disclosure measures by local governments.

Next, MATLAB will be used to simulate this situation. With the development of the ESG market, the means of identifying greenwashing behavior are becoming increasingly mature, and as a result, the government will implement more effective punishment mechanisms; At the same time, we found that the government needs a certain incentive mechanism to implement mandatory disclosure, so the higher-level government will implement incentives for local governments. At this point, adjust G and F up to G=5.8, F=2； From Figure 4, it can be seen that at this point, all six lines approach E3 (0,1) after a certain period of evolution, and the stable point of the system is consistent with the model results: (Greenwashing, mandatory disclosure).

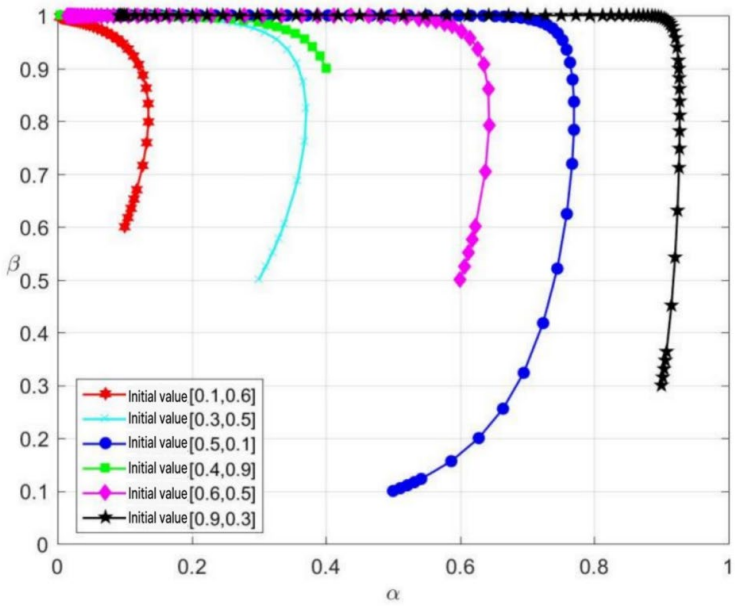

Figure 4. The evolution process of policy maturity in real-time when α and β take different values.

Scenario 4: The ideal state of the system in the later stage of policy implementation. Considering the procedural nature of policy implementation, based on scenario three and scenario four, the green finance market will be further improved, and significant achievements in green innovation will be made by enterprises. Most heavy polluting types of production have been transformed and upgraded, and they will actively take on environmental responsibilities. In this relatively mature green finance market, the equilibrium point is E4 (0,0), which means that companies will not choose greenwashing production and local government regulation is relatively relaxed. According to Table 4, the equilibrium conditions are:

$$W1-W2-aC2+C3-C4-CkS<0 \overset{Equal}{\Longleftrightarrow} (W1-aC2-C4-ckS)<W2-C3$$

$$(F-I-N)<0 \overset{Equal}{\Longleftrightarrow} F<I+N$$

As environmental governance costs decrease and awareness of greenwashing risks grows, the benefits of non-greenwashing production increase. Heavily polluting enterprises are more likely to disclose ESG information honestly to attract investors, reducing

reliance on government fines. Meanwhile, the cost of mandatory disclosure exceeds incentives from higher-level governments, leading local governments to relax regulations. Supervision shifts to mature green finance markets, creating an ideal regulatory environment.

To simulate this state, MATLAB was used with parameters set as W2 = 2 and C3 = 0.2, and both G and F reduced to 0. The system stabilizes at E4 (0,0), representing {no greenwashing, voluntary disclosure}, as shown in Figure 5, indicating the system's evolution toward this ideal state.

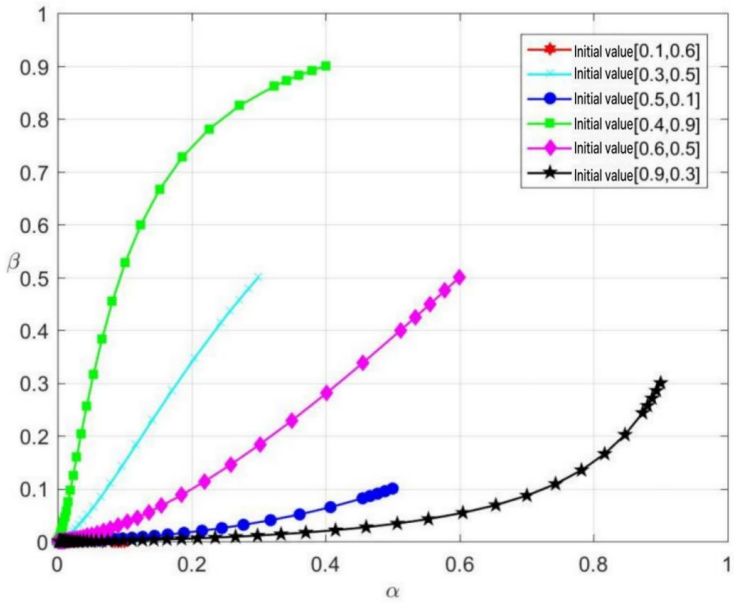

Figure 5. The evolution process of the ideal state of the system in the later stage of pollicy implemention under different values.

This section outlines the four stages of market evolution for heavily polluting enterprises: initial market state, initial policy implementation, mature policy implementation, and ideal system state. These stages correspond to four stable states: E1 (1,0), E2 (1,1), E3 (0,1), and E4 (0,0). Using MATLAB, a two-dimensional dynamic evolution process was simulated with different parameters for each scenario, showing stability over time. Notably, China's green finance market is still developing, with ESG information and disclosure systems for polluting enterprises still in progress. This highlights the importance of analyzing local government punishment mechanisms and incentive policies for addressing greenwashing. The next section explores the system's convergence using China Shenhua's Shendong Coal Group as a case study.

4. Case Study on Greenwashing Behavior of Shendong Coal Group

4.1. Parametric Analysis of Shendong Coal Group's Greenwashing Behavior

This section uses data from corporate reports, national policies, and literature to quantify parameters and validate the "government-enterprise" evolutionary game model. It provides recommendations for policy implementation and duration to optimize social welfare.

4.1.1. Objective Parameter Analysis

China's 2022 mandatory environmental disclosure marked a key regulatory milestone, with China Shenhua and its subsidiaries fined 828,658 yuan during the initial policy phase. It is assumed that full compliance would lead to higher fines. Regional GDP in Shenmu, Baode, and Yijinhuoluo totaled 8661.982 billion yuan (2019–2022), compared to

the company's revenue of 2348.77 billion yuan, yielding a government-enterprise welfare ratio of 0.26. Since no ESG disclosure incentives were identified, F is set to 0, and the opportunity cost N is estimated at 25, based on an 8% return in environmental industries. Given China Shenhua's appearance on the 2022 Greenwashing List and its ESG award in 2023, greenwashing occurred from 2020–2021, was exposed in 2022, and began being addressed in 2023. The social impact SS is estimated at 0.98.

4.1.2. Subjective Data

Reputational loss from greenwashing is estimated using stock price fluctuations between April 11 and April 22, 2022. A decrease in both stock price and trading volume during the penalty announcement suggests reputational damage, with an estimated loss of 1.5 million yuan. Greenwashing costs (C1) and psychological costs (C2) are quantified subjectively. Greenwashing costs, including report falsification and governance costs, are estimated at 0.35. Psychological costs, based on employee training and production losses, have a reduction coefficient (a) of 0.56 under relaxed regulation. The game parameters are summarized in Table 6.

Table 6. Quantitative Table of Game Parameters for Shendong Coal Enterprise.

Parameter	Description	Value
G	Government fines on greenwashing companies	1
I	The information cost of government regulation	1
S	The negative impact of greenwashing on society	0.98
F	Incentives from higher-level governments to local governments	0
N	The opportunity cost of mandatory disclosure measures taken by the government	0.25
W1	The production profit of enterprises under greenwashing	3.03
W2	The production profit of enterprises without greenwashing	2.12
C1	The economic cost of greenwashing	0.35
C2	The psychological cost of greenwashing	0.1
C3	The environmental governance cost of non greenwashing enterprises	0.19
C4	The reputation loss of corporate greenwashing	0.15
a	The coefficient of psychological cost reduction for enterprises under government relaxation policies (a<1)	0.56
b	The ratio of environmental governance with and without bleaching (b<1)	0.55
c	The conversion coefficient of social benefits between government and enterprises (c<1)	0.26
k	Amplification coefficient of social benefits under government relaxation policies (k>1)	1.8

4.2. Analysis of the Evolution Path of Both Parties in the Game: Based on the Current Development Status of Shendong Coal Group

4.2.1. Equilibrium State Simulation Analysis

Translate the quantified values of the parameters in Table 6 into the two party evolutionary game model of "enterprise government" constructed in this article. The replicated dynamic equation system of its two-dimensional dynamical system is:

$$\begin{cases} F_E(\alpha) = \alpha(1-\alpha)(-0.64016\beta + 0.43536) = 0 \\ F_G(\beta) = \beta(1-\beta)(1.784\alpha - 1.25) = 0 \end{cases}$$

In this situation, although the fines imposed by local governments on greenwashing enterprises are equivalent to the information cost of mandatory government supervision,

due to the investment cost of implementing mandatory information disclosure, even if local governments pay attention to the environmental governance of heavily polluting enterprises, the regulatory intensity is not strict. For enterprises, the difference between the production profit of greenwashing and the production profit of non greenwashing is greater than the sum of greenwashing cost and reputation loss. In addition, compared to social benefits, enterprises pay more attention to their actual profits, which leads to a tendency for information disclosure to be greenwashing.

To further verify the stability of the evolutionary game model, this paper conducted numerical simulation experiments on the ESG greenwashing behavior of Shendong Group using MATLAB software. The simulation results are shown in Figure 6.

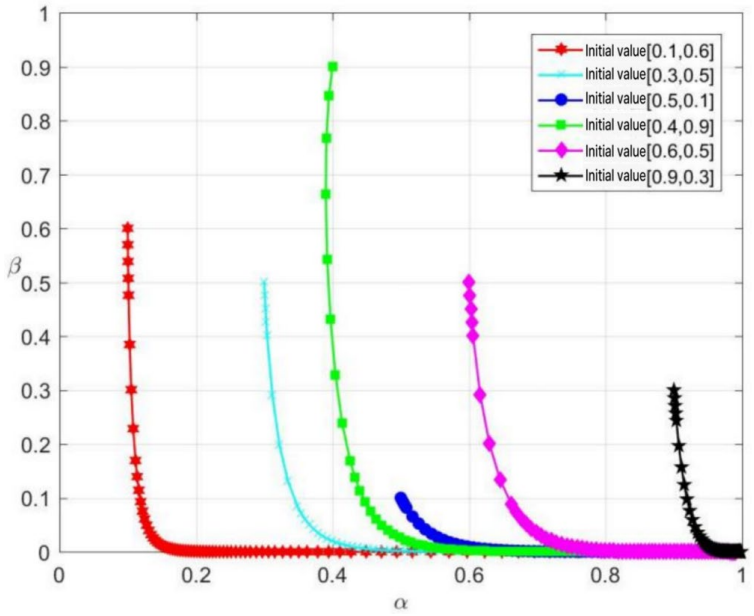

Figure 6. The evolution process of the case enterprise under different values of α and β.

As shown in Figure 6, it can be seen that the final stable state of the case enterprise is to choose greenwashing, and the government chooses voluntary disclosure.

4.2.2. Parameter Sensitivity Analysis

To reflect real conditions, this section uses the same parameters as the case analysis, where α represents the probability of enterprises adopting green behavior, and β represents the probability of local governments choosing mandatory disclosure. Figure 6 shows that the game converges to a single stable point E1 (1,0), indicating that enterprises prefer greenwashing while governments opt for voluntary disclosure, regardless of initial values. However, the initial probability affects the speed of convergence. As shown in Figures 7(a) and 7(b), higher short-term greenwashing probabilities or voluntary disclosure rates accelerate convergence. The t-axis shows that local governments tend to reach equilibrium faster than enterprises. Thus, while initial probabilities do not change the final equilibrium, they influence the convergence time. The following analysis uses initial probabilities to simulate a faster convergence process.

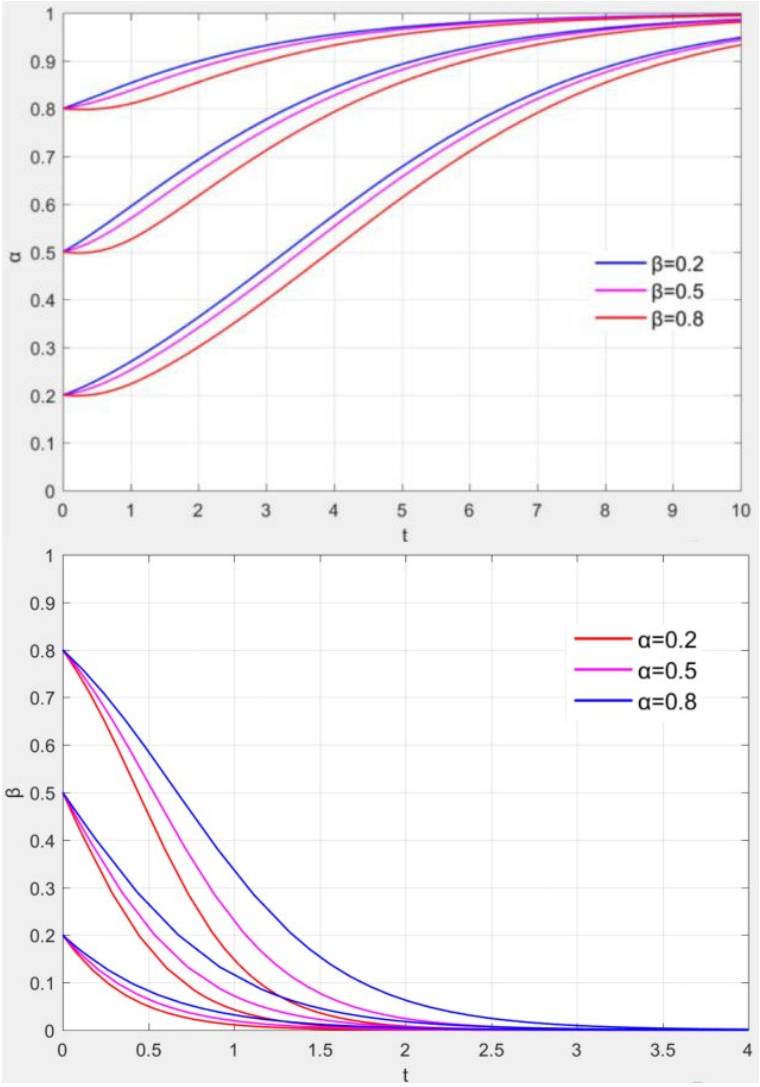

Figure 7. (a) The impact of government strategy selection probability β on platform evolution path. (b) The impact of the initial probability α of enterprise strategy selection on the platform evolution path.

Analysis of the impact of fines G and incentive mechanisms F on the evolution path of corporate greenwashing under the government governance matrix

To further determine the impact of G and F on corporate decision-making, we analyze the evolutionary game path of the company's strategy as the punishment intensity increases under the regulatory penalty mechanism alone. Based on the analysis in the previous text, we conducted a scenario analysis of the Shendong Coal Group case and found that the company's greenwashing trend is more obvious. Therefore, we set the initial probability of α as 0.8, $F = 0, 1 < G < 5$. From the analysis of Figure 8, it can be concluded that when G<3, there exists a unique stable point E2 (1,1) in the game, where the enterprise chooses greenwashing and the government chooses mandatory disclosure. As the strength of the regulatory penalty mechanism decreases, the convergence speed of the system increases, indicating that the government penalty mechanism plays a minor inhibitory role here and is still insufficient to change enterprise decisions; When G>3, there is no stable point in the game. In the initial stage, the government's punishment mechanism does reduce the tendency of enterprises to go green to a certain extent, and this effect increases with the intensity of punishment. However, after long-term evolution of both parties in the game, the benefits of enterprise greenwashing not only cover the various

costs of greenwashing in the long run, but also exceed the benefits of enterprise non greenwashing. Under the drive of interests, enterprise a will not converge to 0, that is, will not choose the non greenwashing strategy.

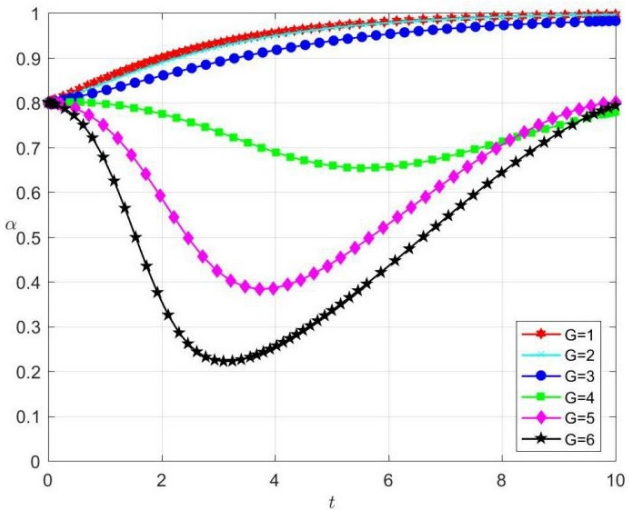

Figure 8. The impact of government fine G on corporate strategic choices (F=0).

We set G=0 and examine the evolutionary game path with increasing incentive intensity under the higher-level government's incentive mechanism. As shown in Figure 8, the system stabilizes at E2 (1,1), where the enterprise continues greenwashing and the government enforces mandatory ESG disclosure. The analysis shows that increasing F does not significantly affect the enterprise's strategy, indicating that the higher-level government's incentives to local governments have no direct impact on the enterprise's choice of greenwashing.

Based on the above two situations, although the punishment mechanism has a greater impact on the strategic choices of enterprises compared to the incentive mechanism, using either method alone cannot make enterprises shift from greenwashing to non greenwashing. Next, we will further characterize the synergistic governance effect of punishment mechanism and regulatory mechanism. To this end, we analyze and predict the future development status of China's green finance market and changes in relevant policy regulations, and discuss incentive mechanisms into low, medium, and high levels, corresponding to each $F \in \{2,3,4\}$ (Figure 9).

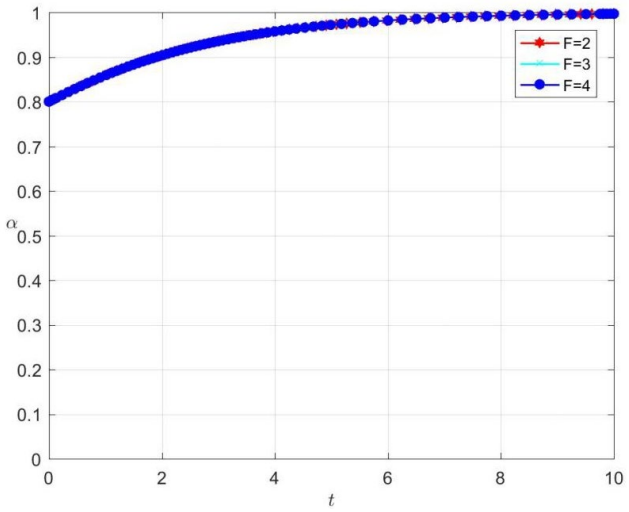

Figure 9. The impact of superior government incentives F on corporate strategic choices (G=0).

We combine the low incentive mechanism of superiors with the severity of government penalties, take $F = 2, 1 < G < 5$. According to Figure 10, the critical value of the system is 3. When G ≤ 3, the only stable point in the game is E2 (1,1), and the government's punishment mechanism is weak. Under the influence of government measures, enterprises still tend to drift towards greenwashing in the end; G> At 3 o'clock, the probability of enterprises choosing to produce green products first rapidly decreases, indicating that the punishment mechanism has a certain effect. However, the probability of green products quickly shows an increasing trend, and ultimately the enterprise will not choose the non green strategy. In summary, in the long-term evolution, the combination of low incentives and punishment mechanisms adopted by the government cannot stop the greenwashing behavior of enterprises.

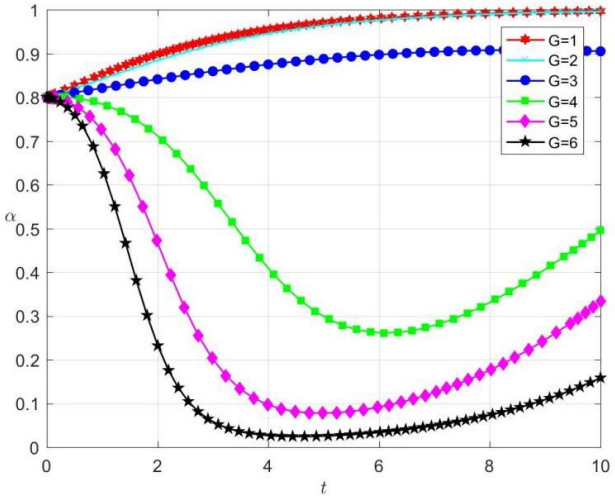

Figure 10. The impact of low incentives (F=2)+government fines on corporate strategy choices.

Under medium to high incentive levels (F > 2), as shown in Figure 11, the system has two stable points. With increasing punishment, the stable point shifts from E2 (1,1) to E3 (0,1), indicating a shift from greenwashing to non-green production. The critical value remains G = 3. When G < 3, the punishment mechanism is weak, and the system stabilizes at E2 (1,1). When G > 3, the stable point shifts to E3 (0,1), where the probability of greenwashing decreases and stabilizes in a non-green state, with stronger penalties intensifying this effect.

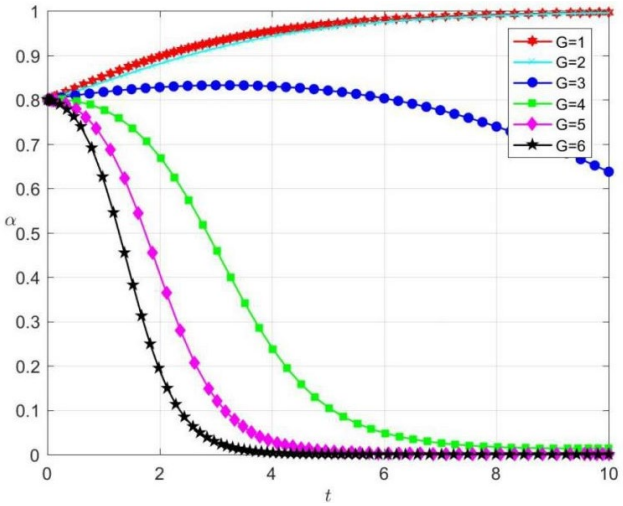

Figure 11. The impact of high incentives (F>2) and government fines on corporate strategic choices.

In summary, simulation analysis concludes that mandatory disclosure policies and severe penalties for greenwashing are effective when higher-level governments provide medium to high incentives to local governments, prompting enterprises to shift from greenwashing to non-greenwashing.

5. Conclusions, Policy Recommendations, and Future Prospects

5.1. Main Research Conclusions

This paper uses evolutionary game theory to analyze greenwashing behavior and its regulation. The model shows that, without regulation, heavily polluting firms adopt greenwashing to maximize profit. A two-party game model between enterprises and governments evaluates the impact of mandatory ESG disclosure, identifying four stable equilibrium points. The simulation reveals that government regulation, through incentives and penalties, can reduce greenwashing.

The case study of Shendong Coal Group shows that enterprises tend to greenwash, while governments favor voluntary disclosure. This reflects the current situation in China, where enterprises lack green innovation and local governments don't enforce strict ESG disclosure. The study finds that penalties or incentives alone are insufficient to eliminate greenwashing; a combination of sustained incentives and stronger penalties is more effective.

5.2. Policy Recommendations

First, promote clear ESG disclosure policies with industry-specific standards to improve quality and comparability. Local governments should strengthen ESG report assessments, particularly for polluting industries.

Second, establish incentives and penalties at higher levels to encourage local action. Financial support and governance evaluations should be tied to ESG implementation, and penalties for greenwashing should be enforced.

Third, raise green awareness and income through media campaigns to promote green consumption. Develop an industry-wide ESG platform to enhance transparency, helping investors identify green enterprises and guide capital to the green finance sector.

5.3. Research Limitations and Future Prospects

This paper shows that in the absence of regulation, enterprises often adopt greenwashing, while current government strategies lean toward voluntary disclosure. Penalties or incentives alone are not enough to eliminate greenwashing. Effective regulation requires coordination between higher-level and local governments.

Future research should improve model accuracy by quantifying ESG-related psychological costs and identifying the conditions under which firms shift to honest disclosure. More actors, such as consumers and third-party institutions, should be included in the game model to better reflect real market dynamics. This will help promote the development of China's green financial market and support sustainable enterprise growth.

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