Simulation Research on ESG Information Disclosure Stakeholder Cooperation and Win-Win Strategy Based on Evolutionary Game Model

Dandan Qi, Ge Gao, Jingwen Zhang, Mingliang Li, Zeguo Qiu and Mingzhe Wang

Abstract—**In recent times, the notion of Environment, Society, and Governance (ESG) has been garnering growing public interest. As of now, the Chinese government has not implemented comprehensive enforcement measures for ESG information disclosure by listed companies. The frequent occurrence of "greenwashing" in ESG disclosures poses a threat to the interests of investors. Therefore, this study develops evolutionary game models involving the government, listed companies, and investors based on stakeholder theory to explore the equilibrium conditions among these entities. By using MatlabR2021a for numerical simulation, the study examines the factors influencing the decision-making behaviors of each entity and analyzes their optimal decisions. Based on the evolution results of stakeholders, policy recommendations are put forward for the effective implementation of ESG information disclosure in China. The Stackelberg game model is employed for further analysis. It is observed that government subsidies provided to investors are more effective in promoting the ESG performance of enterprises compared to direct subsidies given to listed companies.**

Index Terms—**ESG information disclosure; ESG investment; government decision-making; evolutionary game analysis; Stackelberg game model**

I. Introduction

IN 2004, the United Nations Global Compact released a report titled "Those Who Care Win," which initially introduced the concept of ESG (Environmental, Social, and Governance). This concept demands that companies enhance governance, fulfill environmental and social responsibilities, and raise the level of non-financial information disclosure. As global climate change continues to gain prominence, China has made a commitment to attaining the dual carbon targets: peaking carbon emissions by 2030 and achieving carbon neutrality by 2060. In this context, ESG (Environment, Social, and Governance) has emerged as a novel model for ESG information disclosure among Chinese listed companies and the ESG investment strategy of investors. It has become a focal point for decision-making by the Chinese government, company management, and investors. The implementation of ESG policies in China is still in the continuous improvement and implementation stage. Regulatory authorities and enterprises are gradually adapting to and promoting the relevant policies. Currently, China's ESG information disclosure system exhibits different disclosure modes across various dimensions, generally characterized by voluntary disclosure as the primary method and mandatory disclosure as a supplementary approach [1]. On April 12, 2024, the Shanghai, Shenzhen, and Beijing Stock Exchanges officially issued the pilot version of the Guidelines for Sustainability Reports of Listed Companies (hereinafter referred to as the "Guidelines"). These guidelines aim to guide and regulate listed companies in publishing "Sustainability Reports" or "ESG Reports." Companies included in the Shanghai Stock Exchange 180 Index, the Science and Technology Innovation 50 Index, the Shenzhen Stock Exchange 100 Index, the ChiNext Index, and those listed both domestically and abroad are required to disclose this information compulsorily. Other companies are encouraged to disclose voluntarily; however, if they choose to do so, they must adhere to the relevant requirements of the Guidelines. To cope with government regulatory pressure, attract investment, and obtain policy benefits, listed companies may label their products or production and operation activities as green, which introduces certain "greenwashing" risks in the ESG reports they disclose. For instance, Tesla, a global leader in new energy vehicles, has long promoted a low-carbon strategy and "sold carbon credits" to earn substantial revenue worldwide. However, Tesla was removed from the S&P 500 ESG Index in May 2022 due to the lack of a comprehensive low-carbon development strategy. Currently, both domestic and foreign governments have not yet to formulate clear punitive regulations for the "greenwashing" phenomenon among listed companies. The relatively low cost of violations poses a hidden danger of inconsistent goals between investors' investment strategies and listed companies'

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publicity strategies. Therefore, relying on stakeholder theory, this paper establishes an evolutionary game model that pertains to the government and listed companies, as well as between listed companies and investors. Simultaneously, by building Stackelberg game models, it thoroughly investigates the most favorable subsidy orientation of the government and offers a reference for the government to devise more scientific and rational policies.

II. Literature Review

Centered around sustainable development, it encompasses three aspects: environment, society, and corporate governance. ESG is conducive to enhancing enterprise competitiveness, attracting investment, building a favorable brand image, mitigating risks, and facilitating technological innovation and the exploration of new markets. At the social and environmental tiers, ESG can curtail resource consumption and pollutant emissions, foster ecological balance, propel social progress, enhance employment and employee welfare, and promote community development [2]. In the financial realm, ESG directs capital to flow into sustainable domains and promotes the realization of global sustainable development goals [3]. It thoroughly embodies the value of sustainable and harmonious development, balances the advantages of economy, environment, society, and governance, and aids in achieving long-term value growth. Escrig-Olmedo E et al. proposed that ESG rating agencies should incorporate sustainable development principles into their assessment procedures and practices to improve the measurement level of corporate sustainability performance [4]. Broadstock C D et al. found that ESG performance was positively correlated with the short-term cumulative returns of CSI 300 stocks during the COVID-19 crisis period, indicating that stocks with high ESG performance are robust during market financial crises [5]. The green finance research team of Industrial and Commercial Bank of China constructed the first ESG green rating system among domestic commercial banks. This system has significant application value for banks in identifying customers and guiding sustainable investment [6]. Cao Qun and Xu Qian explored incorporating the environment into evaluation criteria can prompt enterprises to pay more attention to environmentally friendly production, reduce pollutant emissions, and improve resource utilization efficiency [7] introduced their research. Bai Murong and Zhang Jiaxin discovered including the environment in evaluation standards can lead the government to design more scientific and rational policies, boost the growth of green industries, and propel society to shift towards a low-carbon and eco-friendly orientation. [8]. Rongli Yuan et al. identified issues in existing studies, such as unclear ESG connotations, lack of consensus on ESG measurement methods, and insufficient depth and breadth of ESG-related research [9]. Yao Lu suggested that the legal responsibilities of financial institutions for ESG information disclosure should be categorized into three levels: mandatory disclosure, semi-mandatory disclosure, and voluntary disclosure, with system design embedded in a three-level legal responsibility framework for typological improvement [10]. Yuchen Peng found that the EU faces similar institutional and social challenges as China, and its latest legislation, the Corporate Sustainability Reporting Directive, offers institutional innovations that can provide targeted solutions for China's issues [11].

From the perspective of enterprises, stakeholders include shareholders, employees, customers, suppliers, communities, and others. Under the ESG framework, enterprises need to consider the interests and expectations of these stakeholders. Stakeholders aim to understand a company's efforts and performance in these areas through ESG disclosures, which enhance transparency and build trust while meeting growing social and investor demand for sustainable development. Van Duuren E et al. found that ESG investors prefer analyzing individual companies over industry-level analysis, with corporate governance being the most critical factor due to its close relation to management quality [12]. Torre L M et al. pointed out that at this stage, investing in and communicating ESG strategies has a positive impact on the returns of some companies, mainly in specific industries like energy and utilities [13]. The survey results of Sang K and (Frank) Z L confirmed that ESG factors are essential for corporate financial performance and risk. Nevertheless, the impact differs depending on ESG category, strengths and weaknesses, as well as company size [14]. Nils E et al. highlighted that engaging in corporate social responsibility can lead to better stock performance, especially during crises [15]. Qiaoliang Zhang and Ruijuan Sun found an asymmetric anchoring effect when investors process ESG information disclosed by companies, with the effect being mitigated when both financial and ESG information are considered [16]. Yue Qi et al. observed that QDII funds with ESG concepts could achieve better returns without significant risk differences from market indices [17]. Kai Wang and Zhiwei Zhang studied the status of domestic and foreign ESG ratings and summarized the core issues of China's existing ESG rating system, proposing future development suggestions [18]. Tianhang Xue et al. concluded that improving ESG performance positively impacts corporate value by reducing financing costs, enhancing profitability, increasing innovation investment, and boosting institutional investors' willingness to invest [19]. Yisen Qian et al. used the DPSIR analysis framework to study the perspectives of government, enterprises, and investors, highlighting the significant future potential and value of ESG in China [20]. Chuyao Deng et al. discovered a positive correlation between institutional investors' holdings and corporate ESG performance, which supports the "effective supervision hypothesis" of institutional investors [21].

Research on the "greenwashing" phenomenon in ESG reports reveals that "greenwashing" refers to companies misleading stakeholders into believing their ESG performance is better than it is, often through exaggerated or falsified claims. Lin et al. conducted an empirical examination on the impact of ESG greenwashing on equity mispricing and its transmission path and found a significant positive effect [22]. Peng Hu et al. argued that the diversity of greenwashing concepts and methods complicates stakeholders' ability to judge whether a company is involved in greenwashing. By linking ESG disclosure readability to greenwashing, they provided a preliminary method for identifying such behavior [23]. Shizhong Huang analyzed the

origins and causes of "greenwashing" in ESG reports by companies and financial institutions [24]. Dongwei Su and Ziming Liu found that green finance reform significantly promotes corporate ESG performance but also increases greenwashing risks, which in turn inhibit corporate green performance [25]. Dan Zhang et al. noted that state-owned enterprises have a higher willingness to disclose ESG information than private enterprises, though both exhibit "greenwashing" to some degree [26]. Yadong Wen and Yan Chen argued that digital finance can suppress ESG greenwashing and reduce greenhouse gas emissions, with no "greenwashing" observed in Chinese companies' ESG practices [27]. Yuxi Wang summarized "greenwashing" types and risk mechanisms, offering regulatory recommendations [28]. Jianxin Wang and Zhiming Cao found that digital transformation reduces corporate "greenwashing" by improving accounting information quality, internal control, and alleviating financing constraints [29].

The potential marginal contributions of this article are presented as follows:

1. **Theoretical Framework Development**: This study focuses on the specific context of mandatory implementation of ESG information disclosure. It explores the interaction and influence mechanism of different subjects in this process, including but not limited to the decision-making basis, behavior patterns, and feedback mechanisms of each subject. On this basis, a relevant theoretical framework is constructed. This framework will comprehensively consider various factors and provide solid theoretical support for further promoting China's green development and sustainable economic activities.

2. **Game Model Establishment**: The research establishes a game model to simulate the interactions between the government and listed companies as well as those between listed companies and investors. It identifies the influencing factors that affect the decision-making behaviors of these entities and seeks the conditions necessary for achieving strategic equilibrium among them.

3. **Integration of Theory and Practice**: This study emphasizes the combination of theory and practice by examining the impact of the "greenwashing" phenomenon on decision-making behaviors, depending on whether ESG information is disclosed. A comprehensive simulation analysis will be conducted to refine the research questions and conclusions presented in the study, ensuring that each conclusion is both realistic and instructive.

4. **Analysis of fiscal pressure from government subsidies**: When it is determined that the government, listed companies, and investors are in a state of equilibrium while making ESG decisions, this study takes a deeper dive into the rational allocation of government subsidy factors. By examining the impact of government subsidies on the actions of listed companies and the reactions of investors, it is uncovered that government subsidies to investors can significantly boost the ESG performance and sustainable development of companies. Hence, taking into account the long-term impact of government fiscal pressure, this study offers suggestions for optimizing subsidy allocation to create a win-win scenario for the government, listed companies, and investors.

III. Game Subject Analysis and Basic Assumptions of the Model

A. Selection of Research Methods

Evolutionary game theory draws profoundly on the core concepts and principles of evolutionary biology, and cleverly transplants and creatively applies the two key concepts of genotype and phenotype in biology to the field of economics, using them as tools to deepen our cognition and understanding of the complex dynamic process of market evolution. In this framework, the evolutionary game model of bounded rationality shows its unique advantages and value. This model simulates the competition, dissemination and interaction of different strategies among various market participants, revealing the hidden and complex dynamic mechanisms behind market structure and behavior patterns. More importantly, the model does not ignore the profound impact that market uncertainty, a key factor, may have on the path of market evolution, but takes it into consideration, thereby effectively solving the problem of how market behavior is displayed under non-equilibrium conditions and how the market continues to evolve. This not only enhances our insight into the market operation mechanism, but also provides a strong theoretical support for understanding the choice of competition and cooperation strategies in the market. In view of this, this study solemnly decided to use the evolutionary game model and a series of related theories as the core tools for in-depth research and analysis. We hope that through this approach, we can discover more valuable insights into the dynamic evolution of the market, and then provide policymakers with a series of forward-looking and practical policy recommendations and decision-making support.

B. Analysis of Evolutionary Game Subjects

In the realm of government decision-making, a distinct public welfare orientation is frequently manifested. For listed companies, the objective is often to maximize profits and enhance enterprise profitability. Investors, on the other hand, are dedicated to achieving wealth growth or pursuing other quantifiable benefits. They evaluate and select different investment projects in the hope of obtaining the optimal investment return. This disparity in decision-making motives inevitably leads to interest conflicts among the government, listed companies, and investors in aspects such as exercising rights, fulfilling obligations, and engaging in economic activities. According to the theory of information asymmetry, as information providers, listed companies may withhold some crucial information or disseminate false information to the government and investors out of self-interest during the information transmission process, which is known as "greenwashing." Listed companies may overstate their ESG performance to attract investor attention and drive capital inflow, putting other stakeholders at a disadvantage in the information environment. In light of this, it is essential to establish a coordinated and complementary connection among the government, listed companies, and investors. The aim is to effectively reduce information asymmetry, promote a balance of interests among all parties, and thereby contribute to the creation of a more fair, transparent, and sustainable economic system.

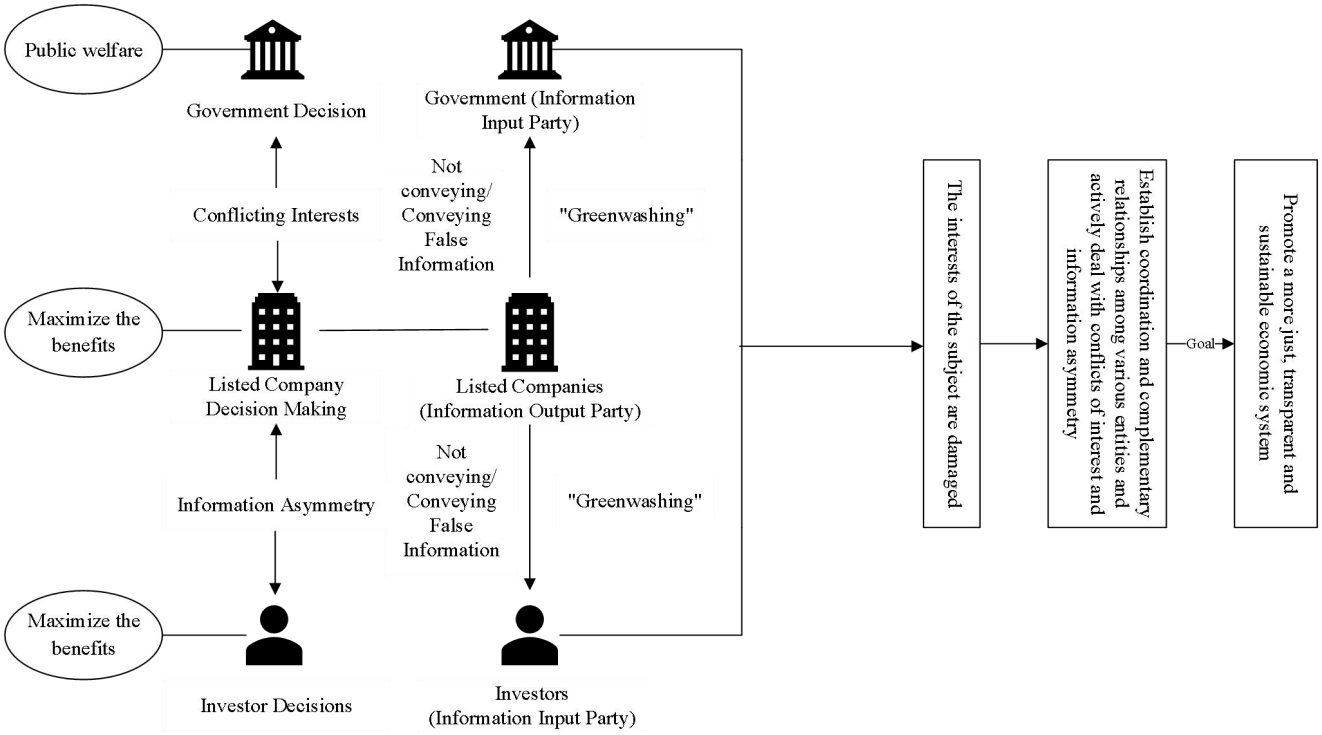


Fig. 1. ESG Information Disclosure Stakeholders' Mechanism Diagram

C. *Basic Assumptions of the Model*

Based on the theory of information asymmetry, it is understood that the government, listed companies, and investors cannot fully grasp all information about each other. Consequently, assumptions as follows are made in relation to the interactions that occur between the government, listed companies, and investors.

Government strategic behavior: active supervision or passive supervision.

Listed company strategic behavior: ESG information disclosure or traditional information disclosure.

Investor strategic behavior: ESG investment or traditional investment.

Government: When listed companies disclose information traditionally, the government tax is T_0. When they disclose information in an ESG manner, the government tax is T_1. Under active government supervision, ESG information disclosure by listed companies will result in social and environmental benefits S_1, whereas traditional information disclosure will lead to social and environmental losses L_1. The additional governance costs C_2 will be incurred by the government due to environmental pollution from traditional information disclosure, while the additional governance savings C_3 will result from environmental improvements due to ESG information disclosure by listed companies. To encourage ESG information disclosure, financial subsidies F_1 will be provided to listed companies. The fines for companies that continue to use traditional information disclosure are P_1, the government's supervision, publicity, and manpower costs are C_1, the fines for listed companies found to be engaging in "greenwashing" are bD_1, where b represents the government's punishment for greenwashing by listed companies.

Listed companies: If listed companies disclose information using traditional methods, their basic income is R, and the tax burden is T_2. Under active government supervision, listed companies are fined P_2 failing to restrict pollution caused by their production and operation activities. If companies choose to adopt ESG information disclosure strategies, they incur additional costs such as data collection and analysis technology, professional human resources, and certification audits C_4, and the tax burden is T_3. This study makes an assumption that the incremental income of listed companies has a linear relationship with the level of ESG performance. According to the scoring standard of Bloomberg ESG evaluation agency [0,100], a higher score implies better ESG performance. The ESG performance coefficient is determined by calculating the proportion of a company's ESG performance score relative to the overall total score. The profit income obtained by enterprises from using ESG investment funds for their production and operation activities is Q, and the benefits such as financing opportunities, brand image, and investor base brought to listed companies by investors are Y. When listed companies disclose ESG information but investors continue to use traditional methods to make investment decisions, the companies do not achieve the expected income, resulting in excess losses of M. Listed companies that adopt ESG information disclosure methods under active government supervision receive government financial subsidies of F_2. Due to information asymmetry, listed companies adopt "greenwashing" behaviors to meet regulatory requirements, cater to market demand and maintain their reputation and image, and are fined cD_2 by the government, where c

represents the degree of greenwashing of the company's "greenwashing" behavior. This study assumes that the fine D_2 imposed on listed companies is linearly related to the degree of greenwashing; that is, the higher the degree of greenwashing, the higher the fine.

Investors: If investors use traditional investment methods, their basic return is B_0. If investors use ESG investment methods, their incremental return is B_1, which includes additional financial benefits, reduced risk management costs, and enhanced brand image value. When listed companies disclose ESG information, the loss of investors who still use traditional investment methods is G; when listed companies disclose information in traditional ways, the loss of investors who use ESG investment strategies is W; when listed companies disclose ESG information and there is "greenwashing" behavior, the loss of investors who adopt ESG investment strategies is dE, where d represents the degree of loss caused to investors by the greenwashing behavior of listed companies.

IV. Model Construction and Analysis of the Evolutionary Game between the Government and Listed Companies

Based on the prior analysis of the relationship between the government and listed companies and the underlying assumptions, the income matrix is shown in Table I:

TABLE I
INCOME MATRIX OF GOVERNMENT AND LISTED COMPANIES

Project	Listed Company	
	ESG Information Disclosure(y)	Traditional Disclosure(1-y)
Active government supervision (x)	(T_1+S_1-F_1-C_1+C_3+bD_1, R+aZ-C_4+F_2-cD_2-T_3)	(T_0+P_1-C_1+C_2, R-P_2-T_2)
Passive government regulation (1-x)	（T_1，R+aZ-C_4-T_3）	（T_0-L_1，R-T_2）

A. Construction and Analysis of Evolutionary Models

Assume that the probability of the government opting for active supervision is x, and the probability of choosing passive supervision is $1-x$; the probability of listed companies choosing to disclose ESG information is y, and the probability of choosing traditional information disclosure is $1-y$, where $0\le x\le 1$, $0\le y\le 1$. Given these probabilities and according to the income matrix in Table I, construct and solve the replication dynamic equations for the government and listed enterprises:

The expected return of active government regulation is E_1, the expected return of passive government regulation is E_2, and the average expected return of the government is E_A:

$$E_1 = y(T_1+S_1-F_1+C_3+bD_1-T_0-P_1+C_2)+(T_0+P_1-C_1+C_2) \quad (1)$$

$$E_2 = y(T_1-T_0+L_1)+T_0-L_1 \quad (2)$$

$$E_A = xE_1+(1-x)E_2 \quad (3)$$

The listed companies that choose to disclose ESG information have an expected return of E_3, the expected return for traditional disclosure is E_4, and the average expected return for listed companies is E_B:

$$E_3 = x(F_2-cD_2)+R+aZ-C_4-T_3 \quad (4)$$

$$E_4 = x(-P_2)+R-T_2 \quad (5)$$

$$E_B = yE_3+(1-y)E_4 \quad (6)$$

Therefore, the replicator dynamic equation for the government's decision of active supervision is $F(x)$ and companies' choice to disclose ESG information $F(y)$ is as follows:

$$\begin{aligned} F(x) &= x(E_1-E_A) \\ &= x(1-x)(E_1-E_2) \\ &= x(1-x)[y(S_1-F_1+C_3+bD_1-P_1+C_2-L_1)+P_1-C_1+C_2+L_1] \end{aligned} \quad (7)$$

$$\begin{aligned} F(y) &= y(E_3-E_B) \\ &= y(1-y)(E_3-E_4) \\ &= y(1-y)[x(F_2-cD_2+P_2)+aZ-C_4-T_3+T_2] \end{aligned} \quad (8)$$

To achieve equilibrium in the evolutionary game model, the conditions for both $F(x)$ and $F(y)$ to be 0 must be satisfied simultaneously. Consequently, we obtain the following:

$$x_1 = 0, x_2 = 1, y^* = \frac{C_1-C_2-L_1-P_1}{S_1-F_1+C_3+bD_1-P_1+C_2-L_1} \quad (9)$$

$$y_1 = 0, y_2 = 1, x^* = \frac{C_4+T_3-aZ-T_2}{F_2-cD_2+P_2} \quad (10)$$

Consequently, five equilibrium points are identified:

$$(0,0),(0,1),(1,0),(1,1),(\frac{C_4+T_3-aZ-T_2}{F_2-cD_2+P_2},\frac{C_1-C_2-L_1-P_1}{S_1-F_1+C_3+bD_1-P_1+C_2-L_1})$$

B. Equilibrium Point Stability Analysis

According to equations (7) and (8), we can derive the Jacobian matrix:

$$J = \begin{pmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{pmatrix} \quad (11)$$

$$\frac{\partial F(x)}{\partial x} = (1-2x)[y(S_1-F_1+C_3+bD_1-P_1+C_2-L_1)+P_1-C_1+C_2+L_1] \quad (12)$$

$$\frac{\partial F(x)}{\partial y} = x(1-x)(S_1-F_1+C_3+bD_1-P_1+C_2-L_1) \quad (13)$$

$$\frac{\partial F(y)}{\partial x} = y(1-y)(F_2-cD_2+P_2) \quad (14)$$

$$\frac{\partial F(y)}{\partial y} = (1-2y)[x(F_2-cD_2+P_2)+aZ-C_4-T_3+T_2] \quad (15)$$

Calculate the five equilibrium points as follows: $(0,0),(0,1),(1,0),(1,1),(\frac{C_4+T_3-aZ-T_2}{F_2-cD_2+P_2},\frac{C_1-C_2-L_1-P_1}{S_1-F_1+C_3+bD_1-P_1+C_2-L_1})$ are substituted into the Jacobian matrix to obtain the corresponding determinant and trace, as shown in Table II:

TABLE II
TR(J) AND DET(J) OF THE JACOBIAN MATRIX OF THE GOVERNMENT AND LISTED ENTERPRISE GAME SYSTEMS

Equilibrium Point	det(J)	tr(J)
A (0,0)	(P_1-C_1+C_2+L_1) (aZ-C_4-T_3+T_2)	P_1-C_1+C_2+L_1+ aZ-C_4-T_3+T_2
B (0,1)	(S_1-F_1+C_3+bD_1+Y+2C_2-C_1) (C_4-aZ+T_3-T_2)	S_1-F_1+C_3+bD_1+Y+2C_2 -C_1+C_4-aZ+T_3-T_2
C (1,0)	(C_1-P_1-C_2-L_1) (F_2-cD_2+ P_2+aZ-C_4-T_3+T_2)	C_1-P_1-C_2-L_1+ F_2-cD_2+ P_2+aZ-C_4-T_3 +T_2
D (1,1)	-(S_1-F_1+C_3+bD_1+Y+2C_2-C 1) [-(F_2-cD_2+ P_2+aZ-C_4-T_3+T_2)]	-(S_1-F_1+C_3+bD_1+Y+2 C_2-C_1) - (F_2-cD_2+ P_2+aZ-C_4-T_3+T_2)
Saddle Point	(1-x) (1-y) (C_4+T_3-aZ-T_2) (C_1-C_2-L_1-P_1)	0

When the equilibrium point is $(\frac{C_4+T_3-aZ-T_2}{F_2-cD_2+P_2}, \frac{C_1-C_2-L_1-P_1}{S_1-F_1+C_3+bD_1-P_1+C_2-L_1})$ $tr(J)$=0, the point is the saddle point, and it must not be the stable point of the evolutionary game system (Table II), for the four local equilibrium points, the values of $det(J)$ and $tr(J)$ are affected by $P_1-C_1+C_2+L_1$, $aZ-C_4-T_3+T_2$, $F_2-cD_2+P_2+aZ-C_4-T_3+T_2$ and $S_1-F_1+C_3+bD_1+Y+2C_2-C_1$ respectively, and the values of the four can be divided into two cases: greater than zero and less than zero. To satisfy the conditions for the stability of the evolutionary game equilibrium point (ESS), the trace $tr(J)$ of the matrix must be less than 0, and the determinant $det(J)$ must be greater than 0[31]. That is:

$$P_1-C_1+C_2+L_1<0$$
$$aZ-C_4-T_3+T_2<0$$
$$F_2-cD_2+P_2+aZ-C_4-T_3+T_2>0$$
$$S_1-F_1+C_3+bD_1+Y+2C_2-C_1>0$$

The stability results are shown in Table III:

TABLE III
STABILITY OUTCOMES OF EVOLUTIONARY GAMES

Equilibrium Point	det(J)	tr(J)	Local Stability
A (0,0)	+	-	ESS
B (0,1)	-	+	Instability
C (1,0)	-	+	Instability
D (1,1)	+	-	ESS

C. Simulation Analysis Under Initial Parameters of the Evolutionary Game Model Between the Government and Listed Enterprises

Combined with the above analysis, the strategies of the government and listed companies reach ESS at (0,0) and (1,1), achieving the evolutionary stability strategy. Hence, relevant parameters are assigned according to the above conditions, as shown in Table IV:

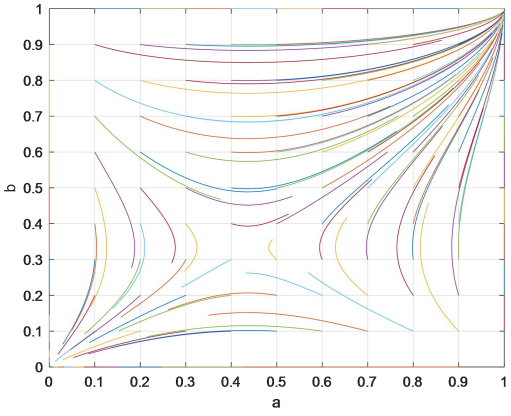
TABLE IV
PARAMETER DATA VALUES OF GOVERNMENT AND LISTED COMPANIES

Game Subject	Parameter	Numerical Value
Government	S_1	5
	L_1	2.5
	F_1	4.5
	P_1	4
	C_1	14
	C_2	5
	C_3	5
	D_1	7
	b	0.5
	T_0	1.81
	T_1	1.991
Listed Company	C_4	5
	R	10
	a	0.5
	P_2	4
	F_2	4.5
	Z	6
	c	0.5
	D_2	7
	T_2	1.81
	T_3	1.991

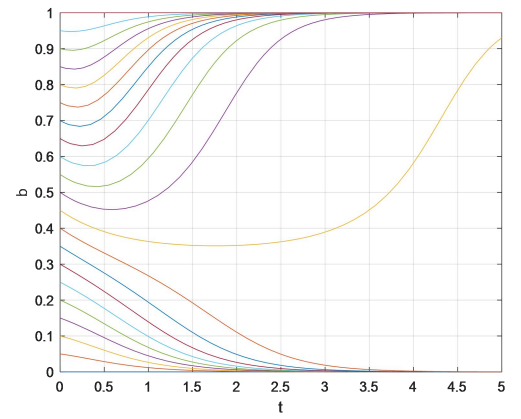
Based on Table IV and formulas (7) and (8), MATLABR2021a is used to simulate the game between the government and listed companies through the ode45 command. The data values are substituted into the replicator dynamic equations $F(x)$ and $F(y)$ to solve them:

$$F(x)=x(1-x)(7.5y-2.5) \quad (16)$$
$$F(y)=y(1-y)(5x-2.181) \quad (17)$$

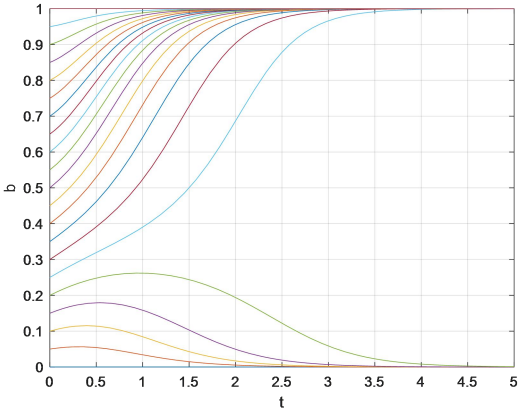
The above equations $F(x)$, $F(y)$ and related parameters into MATLABR2021a for simulation to obtain Fig. 2. The Fig. 2a) shows the dynamic evolution path diagram of the game between listed companies and investors when the initial values of x and y are 0 and the cycle step size is 0.1. The probability of the government opting for active supervision is assigned values of 0.3, 0.6, and 0.9 respectively. Supposing that the simulation experiment commences at time 0 and concludes at time 5, the evolution routes of listed companies are depicted in Fig. 2b), 2c), and 2d).



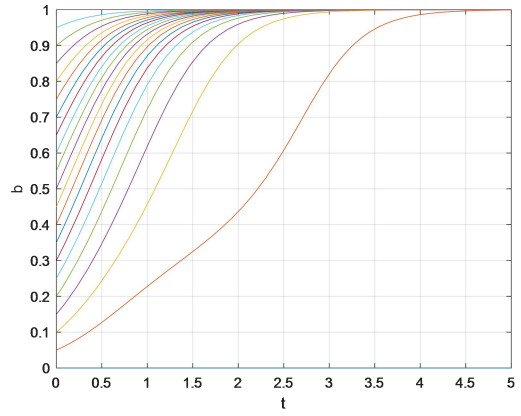
a) evolutionary path



b) enterprise evolutionary (x=0.3)



c) enterprise evolutionary (x=0.6)



d) enterprise evolutionary (x=0.9)

Fig. 2. Initial State Simulation Diagram of the Government and Listed Companies

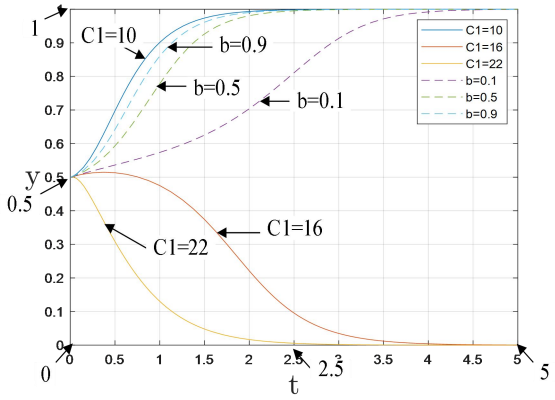
From Fig. 2a), it can be observed that in the upper right area of the saddle point $(0.4362,0.2941)$, all routes develop towards $(1,1)$ (active supervision, ESG information disclosure). In the lower left area of the saddle point, all routes develop towards $(1,1)$ (active supervision, ESG information disclosure). The paths all evolve in the direction of $(0,0)$ (passive supervision, traditional ESG information disclosure). And it can be found that based on the initial parameters, the area of the upper right side of the saddle point is significantly larger than the area of the lower left side, that is, the game between the two tends to evolve in the direction of $(1,1)$. It can be seen from Fig.2b), 2c) and 2d) that the greater the probability that the government chooses active supervision, the greater the probability that listed companies will disclose ESG information. Therefore, government decisions can affect the decisions of listed companies.

D. Dynamic Simulation Under Parameter Optimization of Government and Listed Enterprises

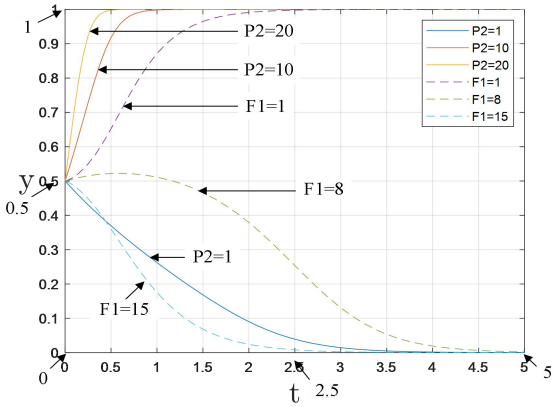
In the game process between listed companies and investors under the initial parameters, although the probability of listed companies and investor groups evolving to $(1,1)$ is greater than the probability of evolving to $(0,0)$, the game between the two is likely to evolve to an inferior equilibrium solution of $(0,0)$. From the previous analysis, the position of the saddle point can affect the evolution effect of the population. Adjusting the size of the saddle point parameters to make the saddle point close to $(0,0)$ can achieve the equilibrium solution with the greatest probability. Since the government's social environmental benefits S_1, social environmental losses L_1 and the taxes T_2 and T_3 collected by the government from listed companies cannot be controlled artificially, this article sets S_1 and L_1 to fixed values of 5 and 2.5. In 2023, China's tax revenue will be 181,112.9 billion Yuan, assuming that the tax burden of a listed company is one trillionth of the government's tax revenue, the tax burden increase after the listed company discloses ESG information is 10% of the traditional information disclosure, that is, T_2 and T_3 are 1.81 respectively, 1.991, will not be discussed in depth. Because under active government supervision, listed companies that disclose false information will be fined D_1 by the government, and the government will receive confiscated income D_2. This article sets both to a fixed value of 7; listed companies' ESG information disclosures will increase. The fixed value when the amount of income Z is 6. The remaining parameters include the government's financial subsidies to encourage listed companies to disclose ESG information F_1, the government's degree of punishment for greenwashing by listed companies b, and the fines imposed on listed companies that still conduct traditional information disclosure under active government supervision P_1, and the government's active Supervision and publicity costs during supervision C_1. Government subsidies received by listed companies for disclosing ESG information F_2. Listed companies receiving fines from the government for conducting traditional information disclosure without restricting their own production and operation activities and causing environmental pollution P_2. ESG performance coefficient of listed companies, denoted as a. The extent of greenwashing in ESG information disclosure of listed companies denoted as c. The additional governance costs imposed on the government due to environmental pollution resulting from traditional information disclosure of listed

companies denoted as C_2. The environmental pollution brought by listed companies restricting their own production and operation activities through ESG information disclosure and brought to the government. The additional governance savings C_3 and the additional costs required for listed companies to disclose ESG information C_4.

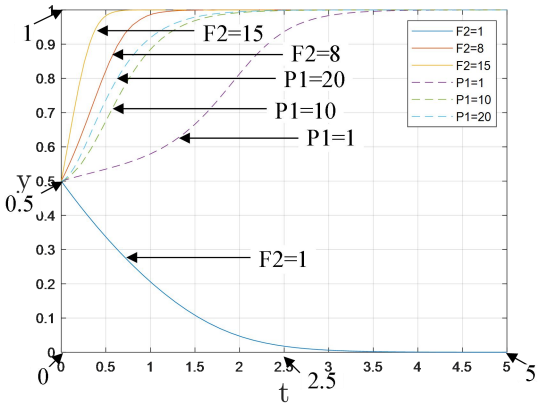
For a more in-depth examination of the function of the aforementioned parameters in the interplay between the government and listed enterprises, we utilize the control variable approach to enhance these parameters by starting from their initial values. This approach aims to facilitate the evolution of decision-making processes for both the government and listed enterprises in the favorable direction of $(1,1)$. The probabilities for the government to actively supervise and for listed companies to disclose ESG information are both set to 0.5, parameter F_1 takes 1, 8, and 15, parameter b takes 0.1, 0.5, and 0.9, parameter P_1 takes 1, 10, and 20, and parameter C_1 takes 10, 16, 22, parameter F_2 takes 1, 8, 15, parameter P_2 takes 1, 10, 20, parameter a takes 0.1, 0.4, 0.7, parameter c takes 0.1, 0.4, 0.7, parameter C_4 takes 3, 8, 13 , parameter C_2 takes 1, 4, and 7, parameter C_3 takes 1, 6, and 11. These parameters are input into MATLAB R2021a to generate the trend chart of x and y over time, as shown in Fig. 3:



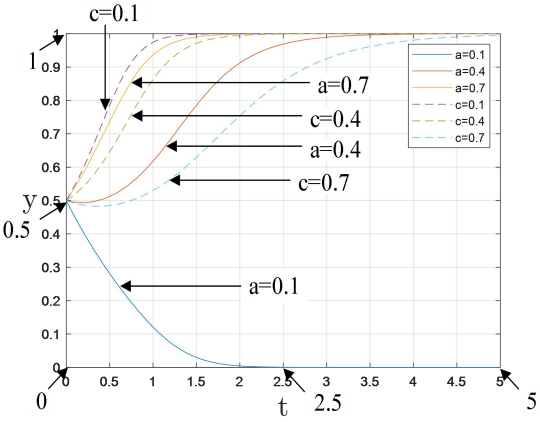
e) Evolution strategy situation of both parties (C1, b)



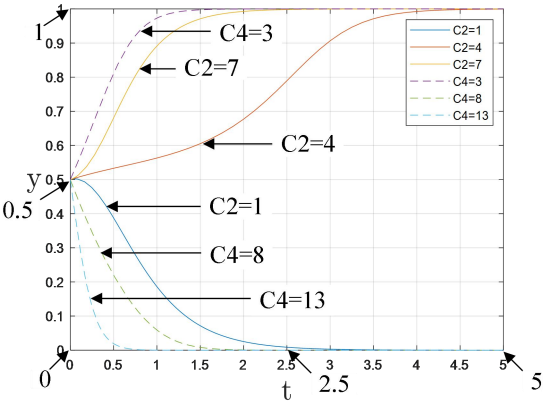
f) Evolution strategy situation of both parties (F1, P2)



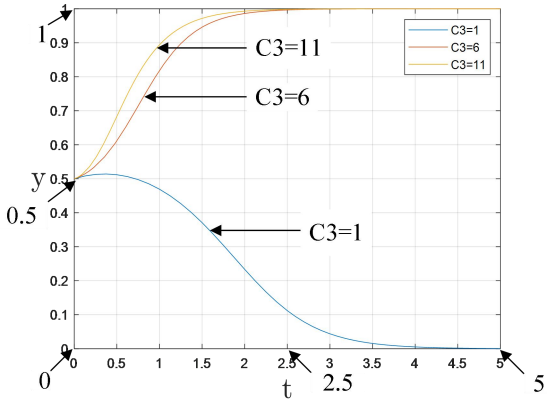
g) Evolution strategy situations of both parties (F2, P1)



h) Evolution strategy situations of both parties (a, c)



i) Evolution strategy situation of both parties (C2, C4)



j) Evolution strategy situations of both parties (C3)

Fig. 3. Strategy Evolution Diagram After Parameter Optimization for the Government and Listed Companies

Fig. 3. illustrates that changes in parameters can significantly affect the evolutionary strategy trends of the government and listed companies. By adjusting these parameters, the game process can achieve the optimal solution $(1,1)$. First, we analyze the optimization results of government-related parameters. As the government encourages listed companies to disclose ESG information, the cost of financial subsidies F_1 and government regulatory publicity, such as C_1, decreases. Consequently, the government's strategy gradually approaches 1. For listed companies, the additional governance costs C_2 due to the government by environmental pollution caused by information disclosure, and the additional governance savings C_3 obtained by the government due to environmental improvements brought about by ESG environmental information disclosure by listed companies are higher, and the strategies of both parties gradually approach 1; Under active supervision, listed companies that conduct traditional information disclosure will be charged a fine P_1 and greenwashing behavior of listed companies will be punished, and the punishment intensity is b. Therefore, the situation where P_1 and b wireless segments converge to 0 can be ignored. The larger P_1 and b, the government strategy gradually approaches 1. Secondly, the optimization results of relevant parameters of listed companies are analyzed. The smaller the additional cost C_4 required for listed companies to disclose ESG information, the strategies of both parties gradually approach 1; The greater the degree of greenwashing c when a listed company discloses ESG information and is fined by the government for causing environmental pollution P_2, and the listed company's ESG information disclosure receives financial subsidies from the government F_2, the strategy of the listed company all influence the strategy convergence of listed companies to 1. It is worth noting that the optimization results for the financial subsidy F_1 provided by the government to encourage listed companies to disclose ESG information are inconsistent with the financial subsidy F_2 obtained by the government for ESG information disclosure by listed companies. Neither excessively high nor excessively low financial subsidies and fines simultaneously satisfy the optimal strategies for both the government and listed companies. When the government's financial subsidies to listed companies are too high, companies are more willing to disclose ESG information, but this increases the government's financial burden. Conversely, when subsidies are too low, companies may face funding shortages, insufficient technological development, and weakened competitiveness, making them reluctant to disclose ESG information. Therefore, both the government and listed companies must consider the interests of all stakeholders while balancing financial subsidies and adopt appropriate policy measures to promote economic development and maintain market order.

V. Model Construction and Analysis of the Evolutionary Game Between Listed Companies and Investors

Upon analyzing the relationship between listed companies and investors and considering the underlying assumptions, the income matrix is presented in Table V:

TABLE V
INCOME MATRIX FOR LISTED COMPANIES AND INVESTORS

Project	Investor	
	ESG Investing(n)	Traditional Investment(1-n)
ESG Information Disclosure of Listed Companies (m)	(R+aZ-C_4+Q-T_3-cD_2+Y, B_0+B_1-dE)	(R-C_4-M-T_3, B_0-G)
Traditional Information Disclosure of Listed Companies (1-m)	(R+Q-T_2, B_0+B_1-W)	(R-T_2, B_0)

A. Construction and Analysis of Evolutionary Models

Assume the probability of listed companies choosing to disclose ESG information is m, and the probability of choosing traditional information disclosure is $1-m$; The probability of investors choosing to make ESG investments is n, and the probability of making traditional investments is 1-n, where $0\le m\le 1$, $0\le n\le 1$. According to the income matrix in Table V, construct and solve the replication dynamic equation of listed companies and investors.

The expected return of listed companies from ESG information disclosure is E_5, the expected return from traditional information disclosure is E_6, and the average expected return of listed companies is E_c:

$$E_5 = n(aZ+Q-M-cD_2+Y)+R-C_4-M-T_3 \tag{18}$$

$$E_6 = nQ+R-T_2 \tag{19}$$

$$\begin{aligned} E_C &= mE_5+(1-m)E_6 \\ &= nQ+R-T_2-m[n(aZ-M-cD_2+Y)-C_4-M-T_3+T_2] \end{aligned} \tag{20}$$

The expected return of investors for ESG investment is E_7, the expected return for traditional investment is E_8, the average expected return of investors is E_D:

$$E_7 = B_0+B_1-W+m(W-dE) \tag{21}$$

$$E_8 = B_0-mG \tag{22}$$

$$\begin{aligned} E_D &= nE_7+(1-n)E_8 \\ &= B_0-mG-n[B_1-W+m(W-dE+G)] \end{aligned} \tag{23}$$

Therefore, the replication dynamic equation for investors to choose ESG investments and listed companies to disclose ESG information is:

$$\begin{aligned} F(m) &= m(E_5-E_C) \\ &= m(1-m)(E_5-E_6) \\ &= m(1-m)[n(aZ-M-cD_2+Y)-C_4-M-T_3+T_2] \end{aligned} \tag{24}$$

$$\begin{aligned} F(n) &= n(E_7 - E_D) \\ &= n(1-n)(E_7 - E_8) \\ &= n(1-n)[B_1 - W + m(W - dE + G)] \end{aligned} \tag{25}$$

To achieve equilibrium in the evolutionary game model, the conditions for both $F(m)$ and $F(n)$ to be 0 must be satisfied simultaneously. Consequently, we obtain the following:

$$m_1 = 0, m_2 = 1, n^* = \frac{C_4 + M + T_3 - T_2}{aZ - M - cD_2 + Y} \tag{26}$$

$$n_1 = 0, n_2 = 1, m^* = \frac{W - B_1}{W - dE + G} \tag{27}$$

Consequently, five equilibrium points are identified:

$$(0,0),(0,1),(1,0),(1,1),\left(\frac{W - B_1}{W - dE + G}, \frac{C_4 + M + T_3 - T_2}{aZ - M - cD_2 + Y}\right)$$

B. Equilibrium Point Stability Analysis

According to equations (24), (25) we can derive the Jacobian matrix:

$$J = \begin{pmatrix} \frac{\partial F(m)}{\partial m} & \frac{\partial F(m)}{\partial n} \\ \frac{\partial F(n)}{\partial m} & \frac{\partial F(n)}{\partial n} \end{pmatrix} \tag{28}$$

$$\frac{\partial F(m)}{\partial m} = (1-2m)\,[n(aZ - M - cD_2 + Y) - C_4 - M - T_3 + T_2] \tag{29}$$

$$\frac{\partial F(m)}{\partial n} = m(1-m)(aZ - M - cD_2 + Y) \tag{30}$$

$$\frac{\partial F(n)}{\partial m} = n(1-n)(W - dE + G) \tag{31}$$

$$\frac{\partial F(n)}{\partial n} = n(1-2n)[B_1 - W + m(W - dE + G)] \tag{32}$$

Calculate the five-equilibrium points as follows: $(0,0),(0,1),(1,0),(1,1),\left(\frac{W - B_1}{W - dE + G}, \frac{C_4 + M + T_3 - T_2}{aZ - M - cD_2 + Y}\right)$ are substituted into the Jacobian matrix to obtain the corresponding determinant and trace, as shown in Table VI:

TABLE VI
TR(J) AND DET(J) OF THE JACOBIAN MATRIX OF THE GAME SYSTEM BETWEEN LISTED COMPANIES AND INVESTORS

Equilibrium Point	det(J)	tr(J)
A (0,0)	$-(C_4+M+T_3-T_2)\,[-(W-B_1)]$	$-(C_4+M+T_3-T_2)+[-(W-B_1)]$
B (0,1)	$(aZ-2M-cD_2+Y-C_4-T_3+T_2)\,(W-B_1)$	$aZ-2M-cD_2+Y-C_4-T_3+T_2+W-B_1$
C (1,0)	$(C_4+M+T_3-T_2)\,(B_1-dE+G)$	$C_4+M+T_3-T_2+B_1-dE+G$
D (1,1)	$-(aZ-2M-cD_2+Y-C_4-T_3+T_2)\,[-(B_1-dE+G)]$	$-(aZ-2M-cD_2+Y-C_4-T_3+T_2)+[-(B_1-dE+G)]$
Saddle Point	$(1-m)\,(1-n)\,(W-B_1)\,(C_4+M+T_3-T_2)$	0

When the equilibrium point is

$$\left(\frac{W - B_1}{W - dE + G}, \frac{C_4 + M + T_3 - T_2}{aZ - M - cD_2 + Y}\right)$$

$tr(J)=0$, the point is the saddle point, and it must not be the stable point of the evolutionary game system, as can be seen from Table VI, for the four local equilibrium points, the values of $det(J)$ and $tr(J)$ are affected by $aZ-2M-cD_2+Y-C_4-T_3+T_2$, $C_4+M+T_3-T_2$, $W-B_1$, and B_1-dE+G respectively, and the values of the four can be divided into two cases: greater than zero and less than zero. To satisfy the conditions for the stability of the evolutionary game equilibrium point (ESS), the trace $tr(J)$ of the matrix must be less than 0, and the determinant $det(J)$ must be greater than 0[31]. That is:

$$C_4+M+T_3-T_2>0$$
$$W-B_1>0$$
$$aZ-2M-cD_2+Y-C_4-T_3+T_2>0$$
$$B_1-dE+G>0$$

The stability results are shown in Table VII:

TABLE VII
STABILITY OUTCOMES OF EVOLUTIONARY GAMES

Equilibrium Point	det(J)	tr(J)	Local Stability
A (0,0)	+	-	ESS
B (0,1)	+	+	Instability
C (1,0)	+	+	Instability
D (1,1)	+	-	ESS

C. Simulation Analysis Under Initial Parameters of the Evolutionary Game Model Between the Government and Listed Enterprises

Combined with the above analysis, the strategies of listed companies and investors reach ESS at (0,0) and (1,1) points, that is, the evolutionary stability strategy is achieved. Therefore, the relevant parameters are assigned according to the above conditions, as shown in Table VIII:

TABLE VIII
PARAMETER DATA VALUES OF GOVERNMENT AND LISTED COMPANIES

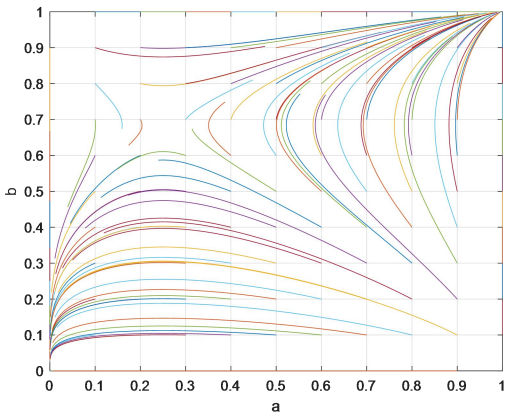
Game Subject	Parameter	Numerical Value
Listed Company	R	10
	a	0.5
	Z	6
	C_4	5
	Q	5
	T_2	1.81
	T_3	1.991
	c	0.5
	D_2	7
	M	2
	Y	13
Investor	B_0	8
	B_1	4.5
	d	0.5
	E	4
	W	6
	G	2

Based on Table VIII and formulas (24) and (25), MATLABR2021a is used to simulate the game between listed companies and investors through the ode45 command. the data values are substituted into the replicator dynamic equations $F(m)$ and $F(n)$ to solve them:

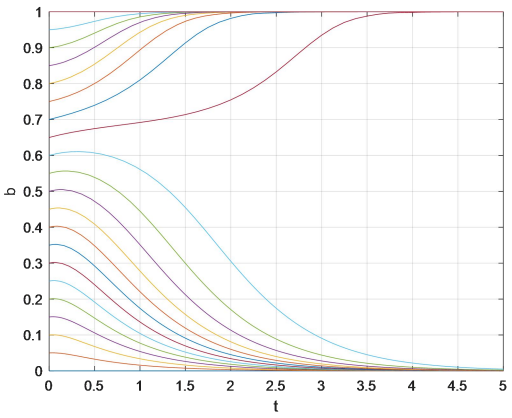
$$F(m) = m(1-m)(10.5n - 7.181) \tag{33}$$

$$F(n) = n(1-n)(6m - 1.5) \tag{34}$$

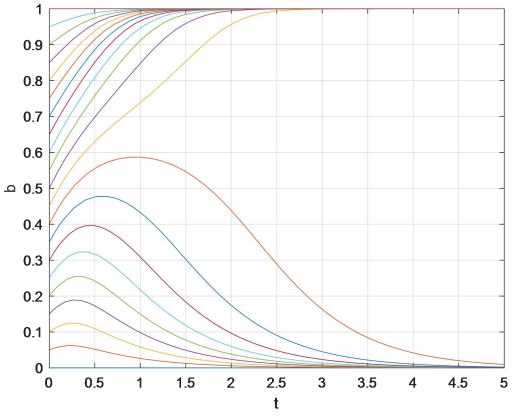
The above equations $F(m)$, $F(n)$ and related parameters into MATLABR2021a for simulation to obtain Fig. 4. The Fig. 4a) shows the dynamic evolution path diagram of the game between listed companies and investors when the initial values of m and n are 0 and the cycle step size is 0.1. The probability m of listed companies choosing to disclose ESG information is set to 0.3, 0.6 and 0.9 respectively. Assuming the simulation experiment starts at time 0 and ends at time 5, the evolution paths of listed companies are shown in Fig. 4.



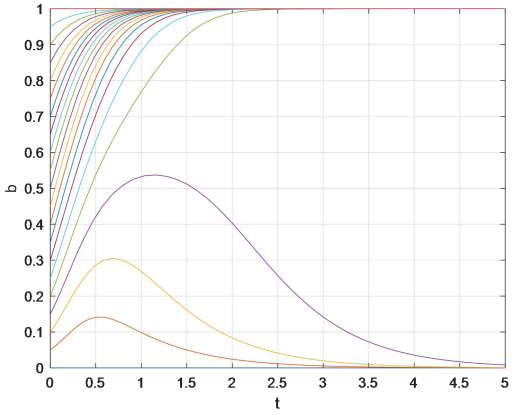
i) evolutionary path



j) enterprise evolutionary(m=0.3)



k) Investor evolutionary (m=0.6)



l) Investor evolutionary (m=0.9)

Fig. 4. Simulation Graphics of the Initial State of Listed Companies and Investors

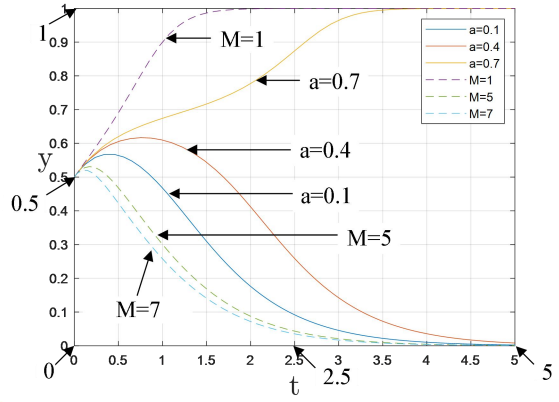
From Fig. 4i) , it can be observed that in the upper right area of the saddle point $(0.25,0.68)$, all paths evolve in the direction of $(1,1)$ (disclosure of ESG information, ESG investment), and in the lower left area of the saddle point, All paths evolve in the direction of $(0,0)$ (traditional information disclosure, traditional investment). And it can be found that based on the initial parameters, the area of the upper right side of the saddle point is significantly larger than the area of the lower left side, that is, the game between the two tends to evolve in the direction of $(1,1)$. It can be seen from Fig. 4j), k) and l) that the greater the probability that listed companies disclose ESG information, the greater the probability that investors will make ESG investments. Therefore, the decisions of listed companies can affect investor decisions.

D. Dynamic Simulation Under Parameter Optimization of Listed Companies and Investors

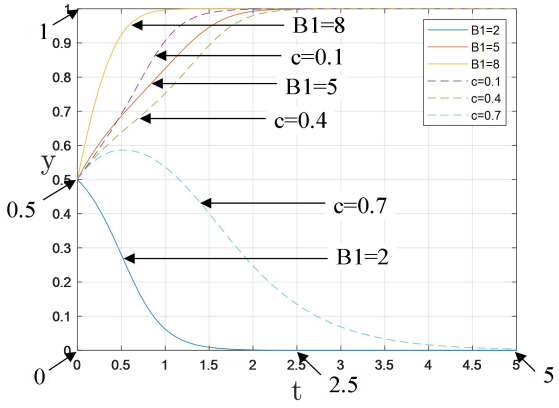
In the game process between listed companies and investors under the initial parameters, although the probability of listed companies and investor groups evolving to $(1,1)$ is greater than the probability of evolving to $(0,0)$, the game between the two is likely to evolve to an inferior equilibrium solution of $(0,0)$. From the previous analysis, the position of the saddle point can affect the evolution effect of the population. Adjusting the size of the saddle point parameters to make the saddle point close to $(0,0)$ can achieve the equilibrium solution with the greatest probability. As can be seen from the previous article, T_2, T_3, Z, and D_2 are set to fixed values of 1.81, 1.991, 6, and 7 respectively, and will not be discussed in depth. Moreover, when listed companies disclose ESG information, the financing opportunities Y brought by investors' ESG investment initiatives to listed companies are also difficult to control artificially, so it is set to a fixed value of 13; because the greenwashing behavior of listed companies will cause problems for investors. The loss E is set to 4 and will not be discussed in depth. The remaining parameters include the ESG performance coefficient of listed companies a , the excess loss M caused by listed companies making ESG

information disclosure while investors still make traditional investments, the incremental income of investors making ESG investments B_1, and the ESG information disclosure of listed companies. Degree of greenwashing c. The losses caused by listed companies' traditional information disclosure by investors who still adopt ESG investment methods W. The additional costs required for listed companies to disclose ESG information C_4. The degree of losses caused by greenwashing behavior of listed companies to investors d, listed companies ESG information disclosure investors still adopt traditional investment methods and gain G losses.

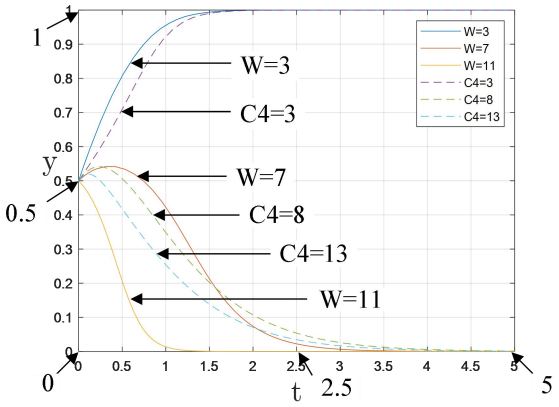
To further analyze the role of the above parameters in the interaction between the government and listed enterprises, we employ the control variable method to optimize these parameters based on their initial values. This approach aims to facilitate the evolution of decision-making processes for both the listed enterprises and investors in the favorable direction of $(1,1)$. The probability that listed companies choose to disclose ESG information and that investors choose to invest in ESG are both set to 0.5. The parameter a takes 0.1, 0.4, and 0.7, the parameter M takes 1, 5, and 7, and the parameter B_1 takes 2, 5, and 8. c takes 0.1, 0.4, 0.7, parameter W takes 3, 7, 11, parameter C_4 takes 3, 8, 13, parameter d takes 0.2, 0.5, 0.8, parameter G takes 1, 3, 5. Input the above parameters into MATLABR2021a, and get the trend chart of m and n over time, as shown in Fig. 5:



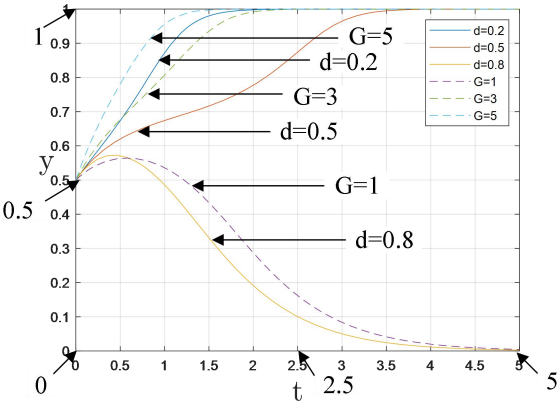
m) Evolution Strategy Situation of both Parties (a, M)



n) Evolution strategy situation of both parties (B_1, c)



o) Evolution strategy situation of both parties (W, C_4)



p) Evolution strategy situation of both parties (d, G)

Fig. 5. Strategy Evolution Diagram After Parameter Optimization of Listed Companies and Investors

Fig. 5. illustrates that changes in parameters can significantly affect the evolutionary strategy trends of the listed companies and investors. By adjusting these parameters, the game process can achieve the optimal solution $(1,1)$. First, the optimization results of relevant parameters for listed companies are analyzed. As listed companies disclose ESG information and investors still adopt traditional investments, the excess losses caused to listed companies are M. Listed companies conduct ESG information. The smaller the additional cost C_4 required for information disclosure, the strategies of both parties gradually approach 1, and as the ESG performance coefficient of listed companies goes up, the investor's strategy gradually approaches 1; Secondly, the optimization of investor-related parameters. Analyzing the results, the smaller the losses W caused by listed companies making traditional information disclosure while investors make ESG investments, and the smaller the degree of losses d caused by greenwashing behavior of listed companies to investors, the strategies of both parties gradually approach 1, while investors make ESG investments incremental income B_1. The greater the loss G caused by listed companies disclosing ESG information while investors still adopt traditional investment methods, the strategies of both parties will gradually approach 1.

VI. Analysis on the Optimal Strategy of Government Subsidy

A. Selection of Research Methods

The advantage of the Stackelberg game model is that it can enhance strategic flexibility, allowing leaders to flexibly adjust decisions based on predictions of follower behavior, thereby better responding to market changes. This dynamism also promotes strategic cooperation. Leaders can guide the responses of followers by setting favorable decisions to achieve a win-win situation. For policymakers, the Stackelberg game model can be used as an important tool to evaluate policy impacts, helping them predict the reactions of market participants under different policy decisions, thereby providing a strong basis for policy adjustments. Consequently, this research employs this model to examine the impact of government subsidies on listed companies or investors. It can not only reveal how companies can flexibly respond to policy changes, but also explore the dynamic reactions of investors, thereby providing policymakers with valuable references to optimize subsidy policies and promote sustainable economic development.

In the above discussion, we discussed that the government, listed enterprises and investors will ultimately reach ESG information disclosure choices through evolutionary games. Next, we will use Stackelberg game theoretical approach to further study the government's two different policy options in this context [30]: Subsidies to listed companies or subsidies to investors.

B. Related model settings

The above two policies will not only have a significant impact on disclosure incentives, but may also lead to different economic and environmental outcomes. Therefore, an in-depth analysis of the pros and cons of these two options will help clarify the best strategy for the government to advance ESG goals. The research method is described as follows:

Listed companies: The purpose of listed companies is to maximize their own profits. For simplicity, their profits can be set as the product of the selling price and quantity of the product minus other expenses. As this paper examines the influence of government subsidies on the ESG performance of listed companies, enhancing the ESG performance of listed companies can commence from the aspect of environmental protection. The government can intervene in the production process from the environmental factor perspective. This can not only enhance the social responsibility of enterprises but also encourage them to participate in social governance and promote them to improve their own ESG performance. Therefore, other expenses are the expenses of enterprises in improving environmental protection technology. This study assumes that the environmental protection technology improvement expenditure is $\frac{1}{2}\eta A^2$, and set P as the price of the enterprise's products, Q as the enterprise's production quantity. Then for the enterprise, its profit function is set as:

$$\pi = P \cdot Q - \frac{1}{2}\eta A^2$$

Among them, A represents the emission of the enterprise in the production process. Assume that the emission of each unit of product produced by the enterprise is a , then there is $A = a \cdot Q$. Further assume that the net emissions of the enterprise during the production process are e , then there is $e = Q \cdot (1-a)$. The cost of investment in emission reduction technology for enterprises is $\frac{1}{2}\eta A^2$, η stands for cost efficiency.

Then, the profit function of the enterprise has the following form:

$$\pi = P \cdot Q - \frac{1}{2}\eta a^2 Q^2$$

According to the producer theory of microeconomics, enterprises need to invest different types of production factors when producing. Therefore, this article assumes that the production function of the enterprise is in the classic Cobb-Douglas form. At the same time, it is assumed that the source of capital required for enterprise production is only the investment of investors, that is:

$$Q = C \cdot q^d$$

In the above formula, this study simplifies labor input and other production factor inputs as C, and uses d to represent the proportion of capital in enterprise production. Therefore, the enterprise profit function can be further changed to:

$$\pi = P \cdot Q - \frac{1}{2}\eta a^2 C^2 q^{2d}$$

Investors: The purpose of investor behavior is to maximize their own utility. In the context of this article, the utility of investors will be affected by two aspects. One is the profit return from their investment in the enterprise, which is a positive influence. The other is the investor's aversion to the environmental pollution caused by the emissions during the enterprise's production process. This is a negative influence. The following will set the function form of these two aspects:

Since the premise of this article is a two-period Stackelberg sequential game between the government, enterprises and investors, when investors obtain investment returns, it is already the second period. Therefore, when considering their own utility, investors should consider the impact of the discounted value of investment returns in the first period on the utility function. So for investors, assuming the discount rate is b , The rate of return that investors receive from a business is a percentage of its profit w , then in the second period, the dividends received by investors are $w\pi$, the present value of the profit obtained in this period in the first period is $\frac{w\pi}{1+b}$.

At the same time, in this article, investors will also weaken their confidence and preference for the company due to the company's environmental pollution behavior, and then reduce their investment in the company. Then the following utility function form assumption can be made:

$$U = \frac{w\pi}{1+b} - \varphi e q$$

Among them, U represents the investor function, φ represents the investor's emphasis on environmental protection, φe represents the proportion of investment cuts

by investors when the enterprise causes damage to the environment during the production process (i.e., for every unit of harmful substances emitted). q represents the amount of investment made by investors.

Substituting the enterprise's profit function into the investor's utility function, we can obtain:

$$U=\frac{w(P\cdot Q-\frac{1}{2}\eta a^2C^2q^{2d})}{1+b}-\varphi eq$$

For the government, as its objective is to maximize the social welfare function. According to the common setting of the social welfare function in welfare economics, this study takes the function as the sum of the objective functions of enterprises and investors and sets the weights of the two. Thus, in the three-party game environment considering only the government, enterprises, and investors, the social welfare function can be defined as follows:

$$SW=\pi+U$$

Therefore, this study can obtain a simplified description of the problem: in the Stackelberg sequential game, the government first formulates policies for subsidies, then considers the reactions of investors and enterprises, and then maximizes the social welfare function. Considering that government subsidies are usually formulated based on the amount of investment of investors and the amount of capital investment of enterprises in emission reduction technologies, this study assumes that the government subsidies are proportional subsidies. At the same time, for the sake of simplicity of calculation, the subsidy ratio here is assumed to be the same, that is, the subsidy ratio given to investors and enterprises is M .

C. Analysis of Stackelberg Game Model

In the previous settings, many parameters are involved. However, considering that the fundamental purpose of enterprises and investors is to maximize profits and maximize utility, and whether from the perspective of investment returns or aversion to corporate environmental pollution, the investor's utility function mainly involves the investor's investment amount q . Therefore, this article considers this value as the basis to solve the investment amount q that can maximize SW , and then convert it into the form of corporate emissions for comparison.

Based on this, the following will discuss the situation of government subsidies to investors and enterprises:

Subsidize investors: Assume that the government subsidizes investors according to a certain proportion of their investment amount. Assume that this proportion is M , then for investors, their actual investment at this time is $(1-M)q$.

The profit function of the enterprise at this time becomes:

$$\pi=P\cdot C\cdot[(1-M)q]^d-\frac{1}{2}\eta a^2C^2[(1-M)q]^{2d}$$

The investor's utility function becomes:

$$U=\frac{w\{P\cdot C\cdot[(1-M)q]^d}{1+b}-\frac{1}{2}\eta a^2C^2\{[(1-M)q]^{2d}$$
$$-\varphi C\cdot[(1-M)q]^d\cdot(1-a)(1-M)q\}$$

At this time, the government's objective function becomes:

$$SW=\pi+U=P\cdot C\cdot[(1-M)q]^d$$
$$-\frac{1}{2}\eta a^2C^2[(1-M)q]^{2d}+\frac{w\{P\cdot C\cdot[(1-M)q]^d}{1+b}$$
$$-\frac{1}{2}\eta a^2C^2\{[(1-M)q]^{2d}$$
$$-\varphi C\cdot[(1-M)q]^d\cdot(1-a)(1-M)q\}$$

For simplicity, this study further assumes that the production of enterprises depends on capital investment, that is $d=1$. At this time, the expression of the first-order condition of q^* is:

$$q^*=\frac{P\cdot C(1+b+w)}{\eta a^2C^2(1-M)(1+b+w)+2\varphi C(1-M)(1-a)(1+b)}$$

Subsidized listed companies: The government subsidizes enterprises in proportion to the amount of their investment in emission reduction, assuming that M . At this time, the actual emission reduction funds invested by the enterprise are

$$\frac{1}{2}(1-M)\eta A^2$$

At this time, the profit function of the enterprise becomes:

$$\pi=P\cdot C\cdot q^d-\frac{1}{2}(1-M)\eta a^2C^2q^{2d}$$

The investor's utility function becomes:

$$U=\frac{w[P\cdot C\cdot q^d-\frac{1}{2}(1-M)\eta a^2C^2q^{2d}]}{1+b}-\varphi C\cdot q^d(1-a)q$$

At this time, the government's objective function becomes:

$$SW=\pi+U=P\cdot C[(1-M)q]^d-\frac{1}{2}\eta a^2C^2[(1-M)q]^{2d}$$
$$+\frac{w}{1+b}\{P\cdot C[(1-M)q]^d-\frac{1}{2}\eta a^2C^2[(1-M)q]^{2d}\}$$
$$-\varphi C[(1-M)q]^d\cdot[(1-M)q]$$

Making the same assumptions and solving the first-order conditions, we can obtain:

$$q^*=\frac{P\cdot C(1+b+w)}{\eta a^2C^2(1-M)(1+b)+2\varphi(1-a)(1+b)}$$

D. Game Results Analysis

The government aims to enhance the environmental performance of enterprises. At this time, the net emissions of enterprises are $e=Cq^d(1-a)$. Therefore, in both cases, the net emissions of the enterprise are:

When subsidizing investors:

$$e_1=\frac{PC^2(1-a)(1+b+w)}{\eta a^2C^2(1-M)(1+b+w)+2\varphi C(1-M)(1-a)(1+b)}$$

When subsidizing listed companies:

$$e_2=\frac{PC^2(1-a)(1+b+w)}{\eta a^2C^2(1-M)(1+b)+2\varphi(1-a)(1+b)}$$

Let $L=\frac{e_1}{e_2}$, the solution is:

$$L=\frac{e_1}{e_2}$$
$$=\frac{(1+b)[\eta a^2C^2(1-M)+2\varphi(1-a)]}{\eta a^2C^2(1-M)(1+b+w)+2\varphi C(1-M)(1-a)(1+b)}$$

Easy to know $w>0$, and $0<M<1$, so $\eta a^2C^2(1-M)w>0$, this means that the denominator has one more positive term than the numerator. And although $2\varphi C(1-M)(1-a)(1+b)<2\varphi C(1-a)(1+b)$.

But generally speaking,

$$2\varphi M(1-a)(1+b)<\eta a^2C^2(1-M)w$$

Therefore, in most cases, $e_2>e_1$, leading to the ratio $L<1$, this means that the emissions caused by subsidies to investors will be smaller than those caused by direct subsidies to enterprises. Therefore, we can draw a general conclusion, that is, when the government sets a fixed M subsidy ratio, subsidies to investors will result in smaller corporate emissions, thereby improving the environmental performance of the companies. In other words, subsidizing investors will be more effective in improving the environmental performance of companies than subsidizing companies.

VII. CONCLUSION AND SUGGESTION

In recent years, the ESG concept has emerged as a new decision-making approach. The Chinese government, listed companies, and investors have gradually adopted it. However, ESG information disclosure in China remains incomplete, and the potential for "greenwashing" poses a risk to the interests of the government and investors. Against this backdrop, this study examines the benefits and fitness of each agent's strategies within the game, defines the benefit functions based on specific game conditions, and assigns relevant parameters according to the rules. Using MATLABR2021a, the study performs initial parameterization and simulation analysis under optimized conditions. And construct a Stackelberg model to explore the direction of government subsidy emphasis. The research findings are as follows:

1. As practitioners of ESG information disclosure, listed companies make strategic choices. These choices are closely related to the decisions of the government and investors. These strategic decisions are influenced by factors such as fiscal subsidies, fines, input costs, and risk losses, leading to various equilibrium states. An increase in the participation of one party can have an impact on the willingness of other participants to cooperate. This, in turn, can reduce the time required for the system to reach an optimal cooperative state.

2. As the dominant party in market policy, the government can promote ESG practices among enterprises through policy support and supervision. In the government's regulatory strategy, the connection between cost reduction and regulatory enthusiasm is of great importance. When the government effectively reduces supervision and publicity costs while encouraging listed companies to engage in traditional information disclosure under active oversight, it can decrease the environmental pollution control costs associated with production activities. Additionally, when listed companies disclose ESG environmental information, it contributes to environmental improvement, leading to additional governance savings for the government. Furthermore, the more severe the fines imposed on listed companies for failing to disclose traditional information or for engaging in corporate greenwashing, the more proactive the government's approach tends to be. However, when designing subsidy strategies for listed companies, the government should balance the interests of all stakeholders and ensure that the subsidy levels align with expected outcomes. Excessive or insufficient subsidies may not yield the desired results.

3. As the providers of information, listed companies choose to integrate strategies and develop innovative products to enhance ESG performance and market appeal. When companies disclose ESG information, their costs, the excess losses incurred by investors who continue to follow traditional investment methods, and the additional investments required for ESG disclosure become key factors. When the cost of ESG disclosure is low, and ESG disclosure effectively reduces environmental fines associated with traditional disclosure methods without impeding production and operational activities, as well as mitigates losses experienced by investors adopting ESG investment strategies, companies are more inclined to pursue ESG disclosure. These factors collectively encourage listed companies to prioritize ESG information disclosure.

4. As information recipients, investors engage in prudent decision-making. They thoroughly analyze and assess various information, weighing risks and benefits to make judicious investment choices. When the level of “greenwashing” in ESG disclosures is low, it implies that the ESG information disclosed by companies is more genuine and reliable. In such circumstances, investors can gain substantial incremental benefits from ESG investments. Additionally, a company with strong ESG performance demonstrates that it has made active efforts and contributions in ESG domains. This not only helps enhance the company's brand image and social standing but also brings more business opportunities and cooperation resources. For investors, investing in companies with excellent ESG performance can optimize investment portfolios, lower investment risks, and achieve long-term stable investment returns.

5. In the macro context of modern corporate governance and sustainable development, compared with the traditional model of directly providing subsidies to listed companies, the subsidy policies implemented by the government targeting investors demonstrate more remarkable advantages and effectiveness. In enhancing ESG performance, once subsidy policies affect the investor group. Investors, considering their own interests and policy guidelines, will place greater emphasis on the ESG performance of enterprises and view it as a crucial foundation for making investment decisions. Furthermore, through the crucial step of motivating investors, it is possible to exert an influence on the decision-making and

operations of enterprises on a broader and more in-depth level, prompting enterprises to re-examine and optimize their own decision-making and operation models from multiple dimensions such as long-term development strategies, overall market layouts, and the balance of multiple stakeholders. Consequently, it enables the coordinated enhancement of the benefits of enterprises in various aspects such as the economy, environment, and society, laying a solid foundation for constructing a sustainable business ecosystem.

Based on these conclusions, and in consideration of the evolutionary dynamics of ESG information disclosure under varying conditions and the cooperation trends among different entities, the following four policy recommendations are proposed:

Strengthen supervision and provide policy support. From a government perspective, relevant laws, regulations, and policies must be formulated. The government can boost the enthusiasm of enterprises and investors to take ESG factors into account significantly by means of legislation and policies. For example, it can introduce mandatory environmental protection regulations, social responsibility requirements, and corporate governance norms. Additionally, the government must provide robust support and incentive mechanisms. This can be achieved by stimulating companies to adopt environmentally friendly, socially responsible, and well-governed measures through tax incentives, green funds, or grants. The government can also learn from other countries' ESG information disclosure and rating standards, referring to the ESG practices of international listed companies, and cooperating and communicating with international institutions and organizations. Based on its national conditions and actual circumstances, the government should improve its own ESG information disclosure standards and requirements, and formulate unified ESG evaluation and rating standards and guidelines. Simplifying ESG reporting requirements, encouraging information exchanges between companies, and promoting digital disclosure and communication methods will facilitate the implementation of government encouragement strategies and enhance the understanding and execution by listed companies. This approach will reduce the costs associated with government supervision, publicity, compliance for listed companies, reporting, information acquisition, repetitive labor, and manual processing. Furthermore, the government should strengthen supervision by establishing ESG credit rating levels and adopting diversified punishment mechanisms to warn and penalize listed companies for varying degrees of "greenwashing".

Innovate ESG investment products and popularize ESG concepts. By incorporating ESG factors into long-term business strategies and establishing corresponding goals and indicators, companies can further popularize ESG concepts effectively. Additionally, increasing the transparency of information is crucial. Listed companies should fully disclose their ESG performance to stakeholders, which includes the regular release of ESG reports. Equally important is financial product innovation, a key driver of ESG investment growth. Listed companies should continuously innovate and develop a variety of new ESG investment products. This is needed to meet the diverse requirements of investors. In turn, it can promote the expansion of the ESG investment market. This includes creating ESG funds, ESG index funds, and social bonds, among other products, providing investors with diversified investment options and ESG opportunities. By consistently launching attractive ESG products, companies can expand the scale and influence of the ESG investment market.

Investors should incorporate ESG factors into portfolio management and enhance their ability to identify and analyze favorable and unfavorable ESG projects. This means effectively exercising due rights and paying attention to the impact of ESG factors. Additionally, strengthening investors' rights to dialogue and voting is crucial. Investors can engage in dialogue with listed companies to encourage improvements in their ESG performance and exercise their voting rights to support proposals that align with ESG standards. By exerting pressure on listed companies, investors can urge them to enhance their ESG performance, increase their ESG responsibility, foster a robust corporate ESG culture, and enhance the attractiveness of ESG investments. Moreover, investors and enterprises should embrace a long-term investment outlook. They can better leverage the potential opportunities of ESG investment. This approach enables the establishment of a stable investment portfolio, and promotes the sustainable development of ESG investment.

Build an investor-centered subsidy system. To promote corporate investment in the field of sustainable development, the government should implement an investor-centered subsidy system to encourage capital to tilt toward companies with good ESG performance. First, subsidy criteria need to be established. That is, the government should work with academic experts to formulate clear subsidy criteria, covering specific evaluation indicators of companies in terms of emission reduction, resource utilization efficiency, social contribution, etc. These criteria should be operational and accurately evaluate the ESG performance of companies. For investors who invest in companies that meet the subsidy criteria, the government can implement corresponding tax incentives. This will not only lower investment costs but also increase investors' interest in sustainable projects, thus promoting capital inflows. Secondly, the government could set up dedicated funds to offer direct financial assistance to enterprises that demonstrate outstanding performance in the field of environmental and social responsibility. This is to encourage them to further enhance their ESG performance. Such support should be directly linked to the performance of the company to ensure the effective use of funds. On this basis, the government should regularly publish successful cases under the investor-oriented subsidy policy to demonstrate the sustainable development results achieved by companies after receiving subsidies. This will encourage more companies to participate and enhance investor confidence. At the same time, a feedback mechanism should be established to enable investors and companies to provide opinions and suggestions on the implementation of the subsidy system. Continuously adjust and optimize subsidy policies based on feedback to ensure that they keep pace with market changes and social needs.

APPENDIX

TABLE IX
UNITS FOR MAGNETIC PROPERTIES

Game Subject	Parameter	Strategy Indicators Explained
Government	S_1	The social and environmental benefits brought to the government by ESG information disclosure by listed companies under the government's active supervision
	L_1	Social and environmental losses caused to the government by traditional information disclosure of listed companies under passive government supervision
	F_1	The government encourages listed companies to disclose ESG information through financial subsidies
	P_1	Fines imposed on listed companies for traditional information disclosure under active government supervision
	C_1	Regulatory costs and publicity costs when the government actively regulates
	C_2	Additional governance costs caused by environmental pollution caused by traditional information disclosure of listed companies
	C_3	Additional governance savings from environmental improvements resulting from ESG information disclosure by listed companies
	D_1	Fines imposed on listed companies for false ESG disclosures under active government supervision
	b	Government penalties for greenwashing by listed companies
	T_0	Tax revenue from traditional information disclosure by listed companies
	T_1	Tax revenue from ESG disclosure by listed companies
Listed company	C_4	The additional costs for listed companies to disclose ESG information
	R	Revenue from traditional information disclosure by listed companies
	a	The ESG performance coefficient of listed companies
	P_2	Fines for excessive pollution caused by listed companies' production and operation activities under the government's active supervision
	F_2	Subsidies received by listed companies for ESG information disclosure under active government supervision
	Q	Profits earned from ESG investment funds received by listed companies for production and operation
	M	Excessive losses when listed companies disclose ESG information while investors still adopt traditional investment
	Z	Incremental revenue from ESG information disclosure by listed companies
	c	The degree of greenwashing of ESG information disclosure by listed companies
	D_2	Fines for false ESG disclosures by listed companies under active government supervision
	T_2	The tax burden of listed companies on traditional information disclosure
	T_3	Tax burden of listed companies on ESG information disclosure
	Y	When listed companies disclose ESG information, investors' ESG investment brings financing opportunities to companies
Investor	B_0	The basic return for investors from traditional investments
	B_1	Incremental investment returns for investors through ESG investing
	G	The loss of listed companies disclosing ESG information while investors still adopt traditional investment
	W	The losses of listed companies making traditional information disclosure and investors adopting ESG investment
	E	Investors' losses due to greenwashing by listed companies
	d	The extent of losses caused to investors by greenwashing by listed companies

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