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Multi-agent game analysis on standardized discretion of environmental administrative penalty

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An environmental administrative penalty is a powerful tool to regulate environmental pollution and ecological destruction by punishing intentional violations. Still, unchecked discretion may lead to excessively low or high penalties, breaking our balance of desire for uniformity with the need for discretion. To achieve the balance, regulators may use standardized discretion to achieve greater compliance by punishing intentional violations in a standardized way. However, policymakers and scholars have different attitudes on understanding whether standardized discretion helps enforcement. For this purpose, we construct a muti-agent dynamic game under the standardized discretion of environmental administrative penalty (SDEAP). The results show that: i) SDEAP can positively affect firms' output and emission reduction efforts but negatively affect environmental quality; ii) The lower limit of SDEAP can positively affect environmental quality but negatively affects firms' output and emission reduction efforts; iii) The upper limit of SDEAP can positively affect firms' output, emission reduction efforts, and environmental quality; iv) SDEAP can restrict law enforcement and improve firms' efforts to reduce emissions. This work can be helpful both to firms and the government as the basis for developing and implementing SDEAP.

KEYWORDS

multi-agent game, standardized discretion, environmental administrative penalty, dynamic equilibrium, green development

1 Introduction

Resources shortage and environmental pollution have long restricted the sustainable development of China's economy (Yu et al., 2020; Kong et al., 2021; Ma et al., 2022; Wang et al., 2022), which requires scientific and practical implementation of environmental regulation policies (Wang & Wang, 2022). However, in the process of environmental regulation, the phenomena that different penalties for the same or similar environmental

TABLE 1 Cases of environmental administrative penalties in Heze City in 2013[2].

Case	Firm	Violation	Penalty
1)	Shandong Ruiying Xianfeng Pharmaceutical Co., Ltd.	The concentration of SO_2 in the exhaust gas is 356 mg/m^3, 0.19 times higher than the emission standard value (300 mg/m^3)	20,000RMB
2)	Heze Huanyu Thermal Power Co., Ltd.	The concentration of SO_2 in the exhaust gas is 621 mg/m^3, 1.07 times higher than the emission standard value (300 mg/m^3)	50,000RMB
3)	Heze Lukang Sheryl Pharmaceutical Co., Ltd.	The concentration of SO_2 in the exhaust gas is 1270 mg/m^3, 2.23 times higher than the emission standard value (300 mg/m^3)	30,000RMB

TABLE 2 Cases of environmental administrative penalties in Weihai City in 2015[4].

Case	Firm	Violation	Penalty
4)	Weihai Weigao Real Estate Development Co., Ltd.	Construction noise at night	5,000RMB
5)	Weihai Yinpeng Construction Group Co., Ltd.		8,000RMB
6)	Weihai Jianfeng Construction Group Co., Ltd.		10,000RMB

violations often occur. It causes unfairness (Zhang et al., 2018; Sancho, 2021). Take the cases of Heze City and Weihai City in Shandong Province as examples.

Example 1. Some cases in Heze City in 2013 are shown in Table 1. Article 48 of Law of the People's Republic of China on the Prevention and Control of Air Pollution (2000[1]) stipulates that whoever discharges[2] pollutants into the atmosphere over the national and local discharge limits shall be fined 10,000–100,000 RMB.

Example 2. Some cases in Weihai City in 2015 are shown in Table 2. Article 56 of Law of the People's Republic of China on the Prevention and Control of Ambient Noise Pollution (1997[3]) stipulates that whoever produces night construction noise in an area where noise pollution is prohibited should be fined.

The penalties in these six cases are legal but unfair. In example 1, the penalty amount in Case 2) is much higher than that in Case 3), while the SO_2 concentration in Case 2) is lower than that in Case 3). In example 2, Cases (4–6) were penalized differently when they committed the same environmental violations. The broad penalty range gives law enforcers discretionary power. The misuse of discretion causes these unfair phenomena. Still, it is just the tip of the iceberg. Only in 2021, the Chinese government issued more than 55,200 decisions of environmental administrative penalties. The total amount of fines is up to 4.33 billion RMB. The number of cases and fines is enormous. If discretion is not well used, a lot of misuses occur.

Misuses of discretion may breed corruption and unfairness, causing an indelible negative impact. An insufficient penalty is not conducive to eco-environmental protection, while an excessive penalty is not conducive to economic development (Chang et al., 2020). Therefore, the appropriateness and standardization of discretion are crucial (Kochtcheeva, 2010). China took the lead in the standardized discretion of environmental administrative penalty (SDEAP). It is one of the rules specially set to regulate environmental administrative discretion. This regulation system is vital to change the misuse of discretion. Since 2009, the Ministry of Ecology and Environment of China has issued many policies, including the Guidance on Standardizing the Exercise of the Discretion of Environmental Supervision and Law Enforcement, the Reference Guide for Refining the Discretion of Administrative Penalty for Major Environmental Violations, and the Catalogue of Administrative Penalty of Environmental Protection Administration Set by Laws. In 2019, the Ministry of Ecology and Environment issued the Guiding Opinions on Further Standardizing the Discretion of Environmental Administrative Penalty. SDEAP has become a new tool widely used in China's environmental regulation.

SDEAP aims to solve the problems of broad discretion and misuse of discretion in environmental protection. To explain the SDEAP in further detail, we take the Law of the People's Republic of China on the Prevention and Control of Air Pollution as an example. The narrowest penalty range is 500–20,00 RMB. The

1 The administrative penalties in Table 1 were made according to the law of 2000. Now the law was supplemented and revised in 2015.

2 Data is obtained from the Ecological Environment Bureau of Heze city: http://hzsthj.heze.gov.cn/col/col66818/index.html?uid=88124&pageNum=48.

3 The administrative penalties in Table 2 were made according to the law of 1997. Now the law was supplemented and revised in 2022.

4 Data is obtained from Weihai Ecological Environment Bureau: http://sthj.weihai.gov.cn/col/col81006/index.html?uid=207606&pageNum=52.

TABLE 3 Standardized discretion in article 48[6].

Indicator	Violation	Penalty amount (RMB)
Excess concentration of pollutants	0–100%	10,000–40,000
	100%–200%	40,000–60,000
	200%–300%	60,000–80,000
	Over 300%	80,000–100,000
	Extremely serious	100,000

most comprehensive penalty range is 100,000–1000,000 RMB. The upper limits of the penalties are 4–10 times the lower limits. The penalty range stipulated in the law is overbroad. SDEAP restricts discretion by refining the penalty range. As article 48[5], the standardized discretion is shown in Table 3[6].

Table 3 shows how the SDEAP restricts discretion. There are three vital elements in SDEAP: the intensity of standardized discretion and the lower and upper limits of the administrative penalty amount. The intensity of standardized discretion determines the refinement of discretion. The lower limit of the administrative penalty amount determines the minimum penalty amount. The upper limit of the administrative penalty amount determines the maximum penalty amount. Under SDEAP, violations point to different penalty ranges are refined. Misusing discretion, like in Heze City and Weihai City, will be rare. Other environmental laws like the Law of the People's Republic of China on the Prevention and Control of Water Pollution, Law of the People's Republic of China on the Prevention and Control of Soil Pollution, Law of the People's Republic of China on the Prevention and Control of Ambient Noise Pollution, and Law of the People's Republic of China on the Prevention and Control of Solid Waste Pollution are the same.

Policymakers and scholars have disagreements on the effect of SDEAP. Policymakers believe that SDEAP could balance eco-environmental protection and economic development and create a fair environment for firms[7] and provide an institutional guarantee for China's high-quality development[8]. Some scholars are skeptical about the SDEAP. They believe that administrative discretion is the space reserved for law enforcement. It allows officers to adjust penalties as new information becomes available (Habermacher and Lehmann, 2020). The control of discretion is not simply compressing the administrative discretion space as small as possible (Petersen et al., 2020). Environmental problems in China are particularly complex (Chen et al., 2019). SDEAP is a slight change in environmental policy but affects the whole situation. Government, firms, and households are all involved in it. For example, environmental penalties positively affect firms' emission reduction (He et al., 2022). Investors are sensitive to environmental penalties for firms (Wu et al., 2022). It will increase equity costs (Ding & Shahzad, 2022) and audit fees (Xin et al., 2022). That's to say, environmental penalties under SDEAP affect the firms' and households' behavior. It is a multi-agent system with a knock-on effect. It is not easy to get a conclusion consistent with reality only by discussing it from a theoretical perspective.

Given the controversy between policymakers and scholars, examining the effect of SDEAP has become a real problem for us. This study constructs a multi-agent dynamic game model, including government, firms, and households. The main contributions of this study are as follows.

1) This study solves the controversy between policymakers and scholars. There is a vague understanding of whether SDEAP helps or hinders enforcement. In this study, a multi-agent dynamic game model is constructed and simulated. The parameters in the model are estimated by the statistical data of China from 2000 to 2020. The result is persuasive for policymakers and scholars.
2) This study draws out three key elements of SDEAP. How to incorporate SDEAP into the game model is a complex problem. Few studies focus on the specific model construction of the SDEAP. This study divides SDEAP into three parts: the intensity of standardized discretion and the lower and upper limits of the administrative penalty amount. This study is an exploration from practice to the theoretical model. It is meaningful for further model construction.
3) The study conducts a multi-agent dynamic game model to assess the effect of SDEAP. Dynamic stochastic general equilibrium is applied in it. It is a methodological

5 Article 48 is shown as an example in Heze City. This article was not changed in 2015.

6 It is from the Catalogue of Administrative Penalty of Environmental Protection Administration Set by Laws.

7 30 May 2019. The Relevant Person in Charge of the Ministry of Ecological and Environment Answered the Reporter's Questions on the Guiding Opinions on Further Standardizing the Discretion of Environmental Administrative Penalty.

8 22 May 2019. The Ministry of Ecology and Environment issued One of the Bases of Guiding Opinion on Further Standardizing the Discretion of Environmental Administrative Penalty Is the Notice of the General Office of the State Council on Focusing on the Concerns of Enterprises and Further Promoting the Implementation of Policies to Optimize the Business Environment.

improvement. By solving the dynamic equilibria, we clarify the multi-agent mechanism under SDEAP. It reveals how the government, firms, and households interact. By some numerical simulations, the effects of three key elements are apparent. We put forward policy implications accordingly. It is valuable for improving environmental policy in the future.

2 Literature review

2.1 Discretion and standardized discretion of environmental administrative penalty

Since Hart proposed discretion in the mid-20th century (Hart, 1997), the debate over discretion has been protracted. The school represented by De Montesquieu (2003) advocated denying and eliminating discretion. The school represented by Frank and Bix (2017) advocated the individual initiative factor in law enforcement discretion. For all that, discretion is still applied in the legal system and evolved into two forms: judicial discretion and administrative discretion. This study reviews the literature along the research field of administrative discretion in environmental penalty.

2.1.1 Discretion of environmental administrative penalty

Discretion is unavoidable in an environmental administrative penalty (Zhang et al., 2018). Some scholars have theoretically discussed discretion. Arabadjieva (2017) believed that administrative discretion leaves space to respond to variable pollution behaviors. However, some scholars hold different views. Zhang et al.(2018) thought that discretionary power is executed differently and leads to different results, which is often controversial (Rivera & Knox, 2022). The penalty amount depends on the direction of the EPB's environmental preferences (Fang et al., 2020). The EPB pays more attention to environmental protection than economic development. The above disputes also exist in empirical studies. He et al. (2022) found an environmental deterrent effect of environmental penalties. It can encourage deterrence and improve compliance by making penalties less predictable for firms (Germani et al., 2017). There are also opposing views. Gong et al. (2019) revealed the presence of a high level of discretion and considerable inconsistency in court judgments. Kang and Silveria (2021) found heterogeneity in penalties for observably similar violations. These studies show that discretion in environmental protection may not be appropriately applied. The root of the dispute lies in the broad range of discretion.

More than that, other scholars found government firms collusion (Hu & Shi, 2021), administrative corruption (Hao et al., 2022), and other problems that lead to apparent unfairness of administrative behavior (Catalano & Pezzolla, 2017; Yamazaki & Takeda, 2017). It is inconsistent with China's high-quality development goal of both eco-environment and economic development (Jiang et al., 2022; Yuan et al., 2022).

2.1.2 Standardized discretion of environmental administrative penalty

Many scholars put forward the defect of discretion, but only a few suggested how to improve it. Duflo et al.(2018) believed regulatory discretion is extensively valued for administrative supervision. Zhu et al. (2022) thought that discretion raises concerns about weak environmental enforcement. The central government must regulate local administrative discretion. Tadaki (2020) proposed that it is necessary to reveal frontiers for formulating and engaging in discretion. This method of limiting frontiers is consistent with SDEAP. Hu and Zhu (2021) constructed an environmental penalty strategy. In this strategy, environmental protection administrative departments can use their discretion within a specific range. These studies are explorations of standardized discretion in theoretical construction.

Studies on discretion and standardized discretion are shown in Table 4. It lacks assessment for SDEAP. SDEAP has been implemented in China for several years. How effective is SDEAP? There is no conclusion so far. This study constructs a multi-agent dynamic game model to make up study gaps in the SDEAP assessment.

2.2 Multi-agent game of environmental administrative penalty

To explore the effect of environmental administrative penalties, scholars constructed game models between the government and the firm (Cai et al., 2016; Wang and Shi, 2019; He et al., 2022; Peng et al., 2022). Scholars found that the agents in the game models are multiple. Duan et al. (2016) emphasized the importance of the overall interests of society and constructed a multi-agent game model including government, firms, and social interests. Chen et al. (2019) considered consumers' supervision and analyzed the interaction among firms, governments, and the public. Jiang et al. (2019) believed that central government planners are essential. They constructed an asymmetric dynamic game model of the polluting firms, local government, and central government planners to explore the implementation process of multi-agent environmental regulation strategies. Xu et al. (2019) believed environmental services companies are essential. They built a multi-agent game model, including governments, environmental services companies, and firms. Su (2020) created a multi-agent game model among the government, waste producer, and waste recycler to study the role of government supervision. Shan et al. (2021) considered the surrounding residents' behaviors and built

TABLE 4 Studies on discretion and standardized discretion.

Perspectives	Discretion	Standardized discretion
Theoretical construction	Konstant, 2016; Arabadjieva, 2017 Zhang et al., 2018; Fang et al., 2020 Rivera & Knox, 2022	Duflo et al., 2018; Tadaki, 2020 Hu & Zhu, 2021; Zhu et al., 2022
Policy assessment	Germani et al., 2017; Yamazaki & Takeda, 2017 Gong et al., 2019; Hu & Shi, 2021 Kang & Silveira, 2021; He et al., 2022 Hao et al., 2022	This study

TABLE 5 Studies on the multi-agent game under environmental administrative penalty.

Studies	Third agent	Environmental means	Methods
Duan et al., 2016	Society	Static and dynamic punishment	Evolutionary game
Chen et al., 2019	Public	Multi-scenario punishment strategy	Evolutionary game + empirical analysis
Jiang et al., 2019	CG planners	Fiscal decentralization	Asymmetric dynamic game
Xu et al., 2019	Services companies	Third-party governance	Evolutionary game
Su, 2020	Waste recycler	Government supervision	Evolutionary game
Shan et al., 2021	Surrounding residents	Environmental NGO	Evolutionary game
Zou et al., 2022	Public	Carbon labeling system	Evolutionary game
This study	Households	SDEAP	Dynamic stochastic general equilibrium

a multi-agent game model among the government, firms, and surrounding residents. Zou et al. (2022) considered consumers' willingness to buy low-carbon products and built a 'government-firm-public' multi-agent game model. Studies are shown in Table 5.

The above studies have two weaknesses. Firstly, the environmental administrative penalty is simplified to a fixed amount. It is inconsistent with the actual situation in China. Like the example of Heze City, there are different penalties for environmental violations. In addition, households' behavior is often set as exogenous variables. However, it has been confirmed households' behavior would be affected by environmental administrative penalties (Wu et al., 2022). And it will affect firms' costs (Ding & Shahzad, 2022). To assess the SDEAP policy effectiveness, this study improves the model by dynamic stochastic general equilibrium.

2.3 Summary

As a powerful tool for environmental protection, an environmental administrative penalty has attracted extensive academic attention. The dispute has never stopped, whether it is about discretion or standardized discretion. From the perspective of study contents, variable theoretical constructions and policy assessments about the discretion of environmental administrative penalty are carried out. Scholars have been skeptical of environmental administrative discretion. It indicates that SDEAP is meaningful. However, the study on SDEAP, a new, widely practiced tool in China, is not enough. Only a few scholars studied it, and it lacks SDEAP assessment. Therefore, our study has theoretical significance. From the perspective of study methods, multi-agent game models under different environmental means were built. It provides us with a method for solving the problem. However, simplifying some variables cannot truly reflect the strength and impact of the environmental administrative penalty.

This study constructs a "government-firms-households" multi-agent game model to fill the gap. To improve the study methods, we adopt dynamic stochastic general equilibrium theory referring to Evstigneev et al. (2020). By seeking dynamic equilibrium equations and simulating the policy effect, we try to find the mechanism of SDEAP's impact on the eco-environment and economy.

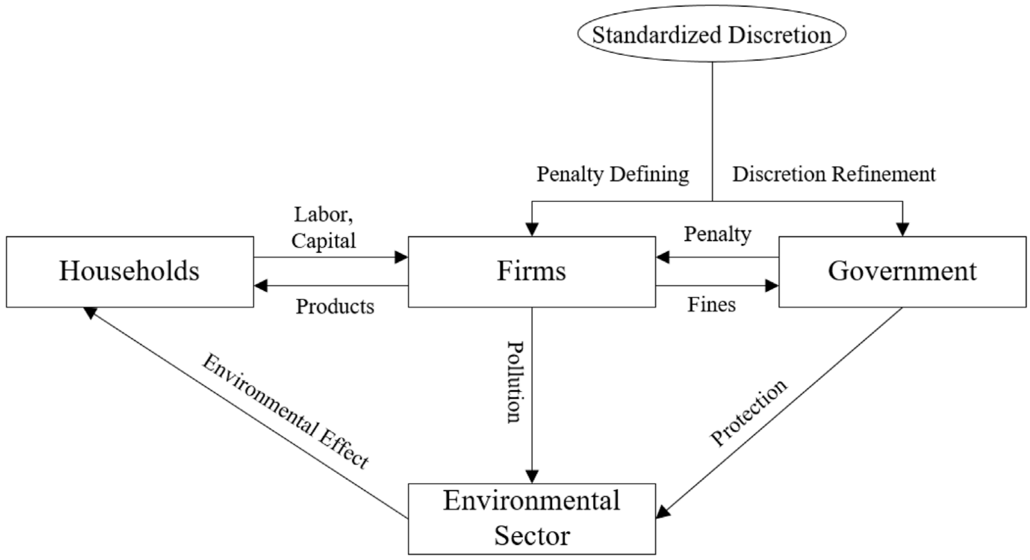

FIGURE 1
Mechanism of SDEAP.

3 The model

SDEAP has three essential elements: the intensity of standardized discretion and the lower and upper limits of the administrative penalty amount. It refines the discretion employing "Discretion Table + Formula". It can restrict the government's discretion and enable the firms to understand the consequences of pollutant emissions.

The operation mechanism is shown in Figure 1. i) For the households, they provide capital and labor for the firms. The households consume the products the firms produce and are affected by the quality of the eco-environment. ii) For the firms, they produce products by renting capital and labor. It also generates and discharges pollutants to the environmental sector, which the government penalizes. The firms will maximize their profits by coordinating output and emission reduction efforts. iii) The government puts fines according to SDEAP and enhances SDEAP construction, which can restrict firms' pollutant discharge behavior. The environmental sector is affected by the pollutants discharged. The eco-environment quality has an impact on households.

3.1 Model construction

According to Figure 1, the multi-agent model is constructed as follows.

3.1.1 Households

In the model, the households are homogeneous. Each has the same preference and can survive indefinitely. The households' utility is affected by consumption, labor, and eco-environment quality (Gao & Xin, 2022). The utility function is the Coefficient of Relative Risk Aversion (CRRA). It is given by

$$U(C_t, N_t, Q_t) = \frac{C_t^{1-\theta_1}}{1-\theta_1} - \frac{N_{f,t}^{1+\theta_2}}{1+\theta_2} + \eta \ln Q_t \tag{1}$$

where C_t and $N_{f,t}$ are the consumption and labor supply, $\theta_1 > 0$ and $\theta_2 > 0$ are the inverse of consumption elasticity and inverse of labor supply elasticity, η is the utility coefficient of eco-environment quality, Q_t represents the eco-environmental quality. We assume the relative risk aversion elasticity to the eco-environmental quality is 1. Therefore, the CRRA utility function is logarithmic. For households, expenditure includes consumption and investment. Income has capital interests and labor earnings. The households maximize lifetime utility under the constraint. It is given by

$$\max E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\theta_1}}{1-\theta_1} - \frac{N_{f,t}^{1+\theta_2}}{1+\theta_2} + \eta \ln Q_t \right) \tag{2}$$

$$\text{s.t. } C_t + I_t = R_t K_{f,t} + W_t N_{f,t} \tag{3}$$

where E_0 is the conditional expectation operator, $\beta\,(0 < \beta < 1)$ is the discount factor, $K_{f,t}$ is the capital investment of households, R_t and W_t are the return on capital, and the wage rate, I_t is the investment. The capital stock evolves as

$$I_t = K_{f,t+1} - (1-\delta) K_{f,t} \tag{4}$$

where $0 < \delta < 1$ is the depreciation rate of capital.

3.1.2 Firms

We use the Cobb-Douglas function for the firm's production function as follows:

$$Y_t = A_t K_{m,t}^{\alpha} N_{m,t}^{1-\alpha} \tag{5}$$

where Y_t is the output, $\alpha (0 < \alpha < 1)$ is the capital elasticity, $K_{m,t}, N_{m,t}$ are the capital and labor invested by firms, A_t denotes an aggregate technical shock, which follows the stationary stochastic process:

$$\ln A_t = (1 - \rho_A) \ln A^* + \rho_A \ln A_{t-1} + \varepsilon_{A,t} \tag{6}$$

where ρ_A is the coefficient of the technology shock, A^* is the steady-state value of technology, $\varepsilon_{A,t} \sim N(0, \sigma_A^2)$ denotes the technical shock.

The pollutant emission X_t of the firms is given by

$$X_t = \frac{\kappa Y_t}{PR_t} \tag{7}$$

where PR_t is the emission reduction efforts, κ is the pollutant emission coefficient, which measures pollutant emission per unit of output.

$f(X_t)$ is the fines of environmental administrative penalty. The government makes it based on SDEAP. We learned from the Shandong Province Standardized Discretion of Environmental Administrative Penalty to construct the equation. It is given by

$$f(X_t) = L_t + \frac{1}{2}(H_t - L_t)\frac{O_t - 1}{B_t - 1} \tag{8}$$

where L_t and H_t are the lower limit and upper limit of the penalty amount, B_t is the refinement level of SDEAP, and O_t is the level of pollutant emissions in the *Discretion Table*. Since the upper and lower limits of the penalty amount are parts of SDEAP. We suppose it follows the stationary stochastic process:

$$\ln L_t = (1 - \rho_L) \ln L^* + \rho_L \ln L_{t-1} + \varepsilon_{L,t} \tag{9}$$

$$\ln H_t = (1 - \rho_H) \ln H^* + \rho_H \ln H_{t-1} + \varepsilon_{H,t} \tag{10}$$

where ρ_L and ρ_H are the coefficients of the lower and upper limits shocks, L^* and H^* are the steady-state values of the lower and upper limits, $\varepsilon_{L,t} \sim N(0, \sigma_L^2)$ and $\varepsilon_{H,t} \sim N(0, \sigma_H^2)$ are the shocks of the lower and upper limits.

The refinement level B_t depends on the intensity of standardized discretion DS_t. It is given by

$$B_t = \lambda \ln DS_t \tag{11}$$

where λ is a coefficient of refinement level. We assume that it follows the stationary stochastic process

$$\ln DS_t = (1 - \rho_{DS}) \ln DS^* + \rho_{DS} \ln DS_{t-1} + \varepsilon_{DS,t} \tag{12}$$

where ρ_{DS} is a coefficient of standardized discretion, DS^* is the steady-state value of the intensity of standardized discretion, $\varepsilon_{DS,t} \sim N(0, \sigma_{DS}^2)$ is the shock of the intensity of standardized discretion.

The level of pollutant emissions O_t follows the principle of administrative discretion standards. The relationship between administrative penalties and pollutant emissions exceeding the regulations is approximately linear within a specific range. It is given by

$$O_t = \psi \frac{X_t}{X_l} \tag{13}$$

where X_l is the length of the standardized penalty range, ψ represents the adjustment coefficient.

The firms maximize their profits by adjusting production and emission reduction. The firm's profit is given by

$$\pi_t = Y_t - K_{m,t}R_t - N_{m,t}W_t - \chi PR_t - f(X_t) \tag{14}$$

where χ is the unit cost of emission reduction efforts.

3.1.3 Government

The government gets revenue by collecting environmental penalties and then puts it under standardized discretion. The constraint function is given by

$$f(X_t) = DS_t \tag{15}$$

3.2 Model solution

To fully consider the impact of eco-environment quality on households, firms, and government, we assume that.

1) The eco-environment quality is a dynamic evolution process with self-purification ability.

$$Q_t = h\bar{Q} + (1 - h)Q_{t-1} - X_t \tag{16}$$

where $\bar{Q}$ is the initial eco-environmental quality with no pollutant emission, $h(0 < h < 1)$ is the self-purification ability, Q_{t-1} is the eco-environmental quality at the last period.

2) The market-clearing state of production is given by

$$Y_t = C_t + I_t + DS_t \tag{17}$$

3) The market-clearing state of labor is given by

$$N_t = N_{f,t} = N_{m,t} \tag{18}$$

4) The market-clearing state of capital is given by

$$K_t = K_{f,t} = K_{m,t} \tag{19}$$

The model is solved by the Lagrange multiplier method. The evolutionary equilibrium solution of this multi-agent dynamic game model meets the following equations.

TABLE 6 Values of equilibrium solution parameters.

Parameter	Definition	Value	References
β	Discount factor	0.98	Zhang, 2009
δ	The depreciation rate of capital	0.035	Li and Liu, 2017
θ_1	The inverse of consumption elasticity	0.8	Zhao et al., 2020
θ_2	The inverse of labor supply elasticity	2	Tu & Wang, 2022
α	Capital elasticity	0.5	Liu and He, 2021
κ	Pollutant emission coefficient	0.5	Liu and He, 2021
X_l	Standardized penalty range	3	SDEAP of Shandong Province in China
h	Self-purification ability	0.1	Angelopoulos et al., 2010

TABLE 7 The prior distribution of parameters and Bayesian estimation results.

Parameter	Definition	Prior mean	Prior distribution	Post mean	90% CI
η	Coefficient of eco-environment quality	2	Normal	2.0000	[1.9988 2.0013]
λ	Coefficient of refinement level	0.5	Normal	0.4999	[0.4983 0.5018]
ψ	Adjustment coefficient	1.1	Normal	1.1001	[1.0991 1.1013]
χ	The unit cost of emission reduction efforts	0.045	Normal	0.0451	[0.0437 0.0466]
$\bar{Q}$	Initial eco-environmental quality	1	Normal	1.0003	[0.9985 1.0016]
ρ_A	Coefficient of the technology shock	0.7	Beta	0.6997	[0.6979 0.7015]
ρ_{DS}	Coefficient of the intensity of standardized discretion shock	0.7	Beta	0.7001	[0.6985 0.7022]
ρ_L	Coefficient of the lower limits shock	0.7	Beta	0.7000	[0.6984 0.7015]
ρ_H	Coefficient of the upper limits shock	0.7	Beta	0.7000	[0.6979 0.7016]
$e_{A,t}$	Technical shock	0.5	Inv. Gamma	0.5001	[0.4986 0.5020]
$e_{DS,t}$	The intensity of standardized discretion shock	0.5	Inv. Gamma	0.5002	[0.4983 0.5018]
$e_{L,t}$	Lower limit shock	0.5	Inv. Gamma	0.4998	[0.4981 0.5015]
$e_{H,t}$	Upper limit shock	0.5	Inv. Gamma	0.5002	[0.4987 0.5019]

1) The relationship between wage rate, consumption, and labor supply is expressed as

$$W_t = N_t^{\theta_2} C_t^{\theta_1} \tag{20}$$

2) The relationship between consumption change rate and return on capital is expressed as

$$\frac{C_{t-1}^{-\theta_1}}{C_t^{-\theta_1}} = \beta(R_t + 1 - \delta) \tag{21}$$

3) The relationship between capital, return on capital, output, lower limit, upper limit, refinement level of SDEAP, and emission reduction efforts are expressed as

$$K_t = \frac{1}{R_t}\alpha Y_t\left(1 - \frac{\psi\kappa(H_t - L_t)}{2(B_t - 1)X_l PR_t}\right) \tag{22}$$

4) The relationship between labor supply, wage rate, output, lower limit, upper limit, refinement level of SDEAP, and emission reduction efforts is expressed as

$$N_t = \frac{1}{W_t}(1-\alpha)Y_t\left(1 - \frac{\psi\kappa(H_t - L_t)}{2(B_t - 1)X_l PR_t}\right) \tag{23}$$

5) The relationship between emission reduction efforts, output, lower limit, upper limit, and refinement level of SDEAP is expressed as

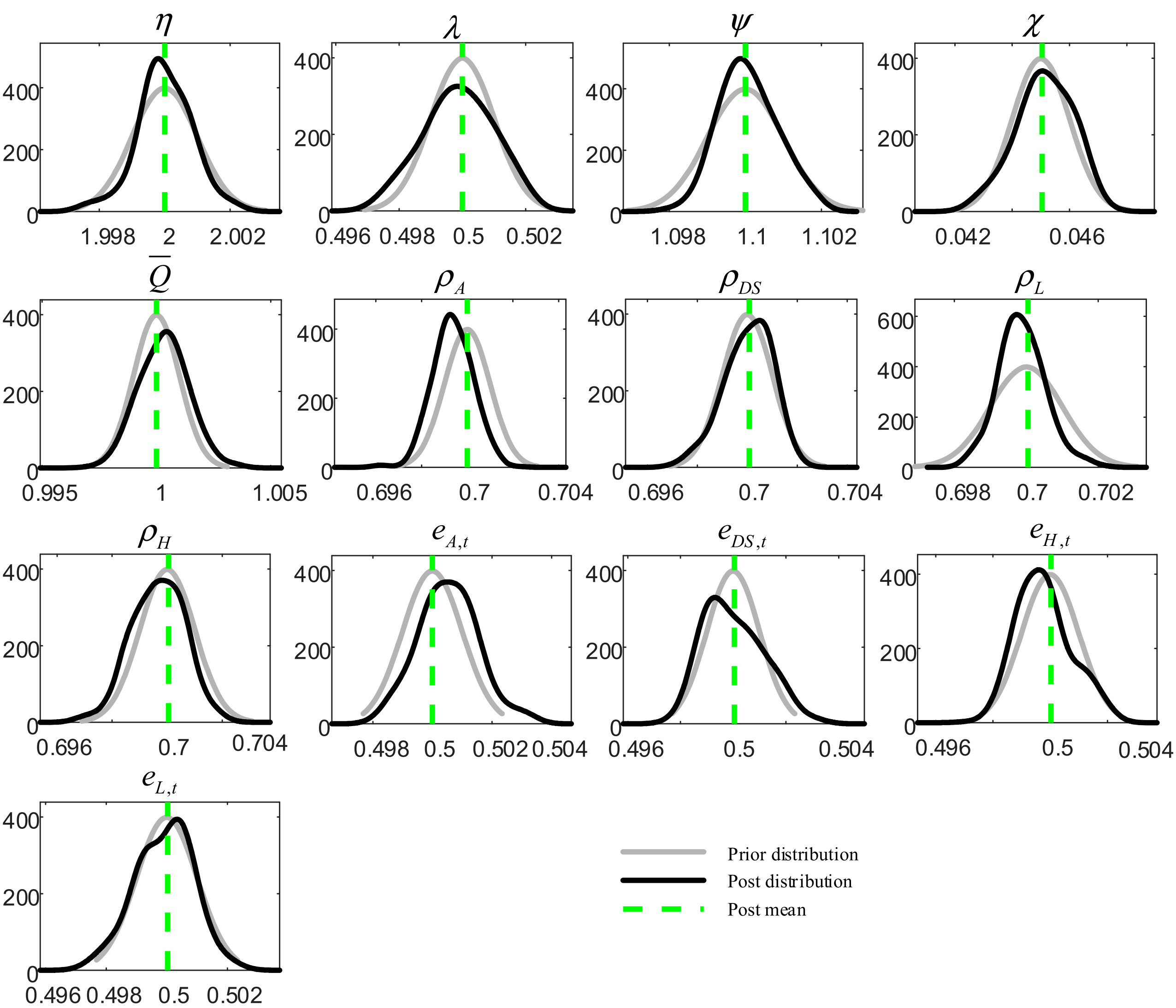

FIGURE 2
Results of bayesian estimation.

$$PR_t = \sqrt{\frac{\psi\kappa Y_t (H_t - L_t)}{2X_l\chi(B_t - 1)}} \tag{24}$$

4 Parameters calibration and estimation

The above solutions are implicit. Therefore, we need to calibrate and estimate the parameters. The parameter values such as $\beta, \delta, \theta_1, \theta_2, \alpha, \kappa, X_l, h$ are available in previous studies. We calibrate these parameters based on existing studies. Other parameter values are unavailable. We use the Bayesian method to estimate the rest parameters by the statistical data of China from 2000 to 2020.

4.1 Parameters calibration

Regarding the existing studies, we calibrate the parameters. The results are shown in Table 6.

4.2 Parameters estimation

We set $\eta = 2$, $\lambda = 0.5$, $\psi = 1.1$, $\chi = 0.045$. It is assumed that these parameters obey Normal Distribution. We set $\rho_A, \rho_{DS}, \rho_L, \rho_H$ at 0.7 and set $e_{A,t}, e_{DS,t}, e_{L,t}, e_{H,t}$ at 0.5. Referring to Smets & Wouters (2004), it is assumed that the prior means of coefficients obey Beta Distribution and the prior means of shocks follow Inv. Gamma Distribution. The results are shown in Table 7; Figure 2.

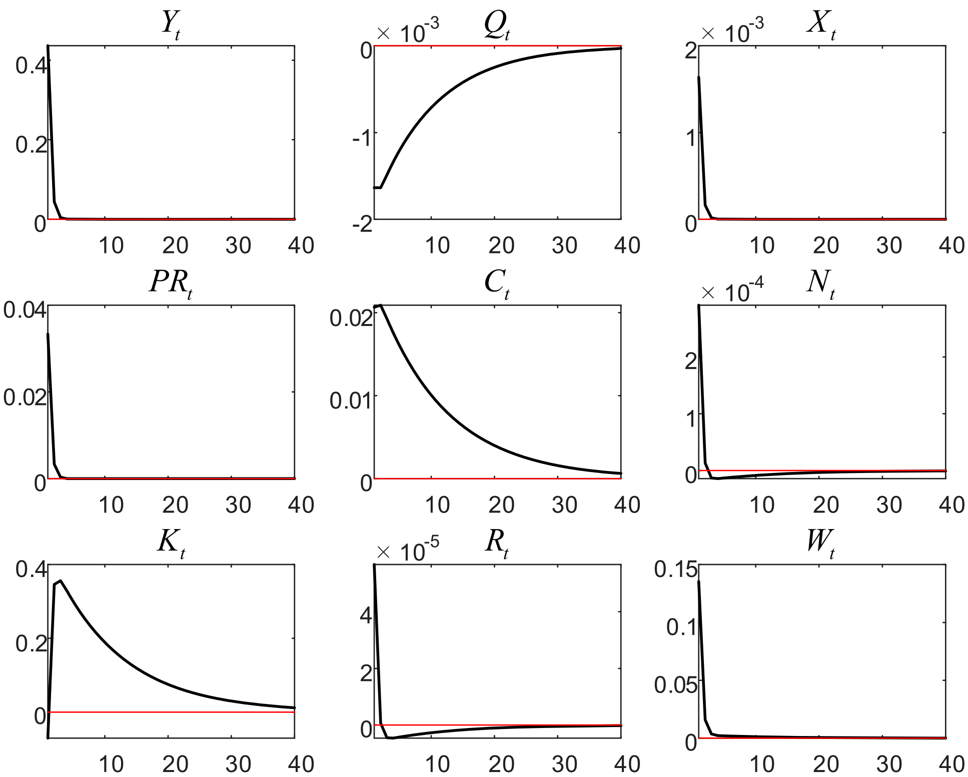

FIGURE 3
The impulse response of intensity of standardized discretion.

5 Dynamic effect and conduction mechanism

After estimating parameters, the dynamic numerical simulations of SDEAP are carried out. We analyze the impulse responses of the intensity of standardized discretion and the lower and upper limits of the administrative penalty amount.

5.1 Dynamic effect analysis of intensity of standardized discretion

The dynamic effect of the intensity of standardized discretion is shown in Figure 3. i) For the government, the balance between eco-environment protection and economic development matters. The intensity of standardized discretion shock has a positive effect on output but a negative effect on eco-environment quality in the short term. In the long term, the negative effect on the eco-environment quality will gradually decrease and close to zero. ii) For the firms, a fair business environment under standardized discretion promotes firms to increase output. So, the capital increases, and labor demand increases first and then decreases. At the same time, the wage increases, and the return on capital increases first and then decreases. Firms will improve their emission reduction efforts. However, the pollution reduction due to emission reduction efforts is less than the pollution generated by output. Therefore, pollutant emissions will still increase in the first three periods. iii) For the households, total incomes increase with labor supply and capital investment. The increased income is partly used for capital investment and partly for consumption.

In the short term, standardized discretion increases output but decreases eco-environment quality. It is explained as follows. A fair business environment is created for firms under standardized discretion. A suitable business environment helps promote the output of firms (Qi et al., 2022). Pollutants will inevitably be generated in the production process (Grossman and Krueger, 1992). As Germani et al. (2017) proposed, standardized discretion reduces the unpredictability of the penalty amount. The deterrent effect is weakened (He et al., 2022), causing firms may not to make efforts to reduce emissions. Due to insufficient emission reduction efforts, production will inevitably lead to pollutant emissions. Under this condition, the pollutant emissions exceed the self-purification ability of the eco-environment. Therefore, the increase in output in the short term leads to the rise of pollutant emissions. The negative

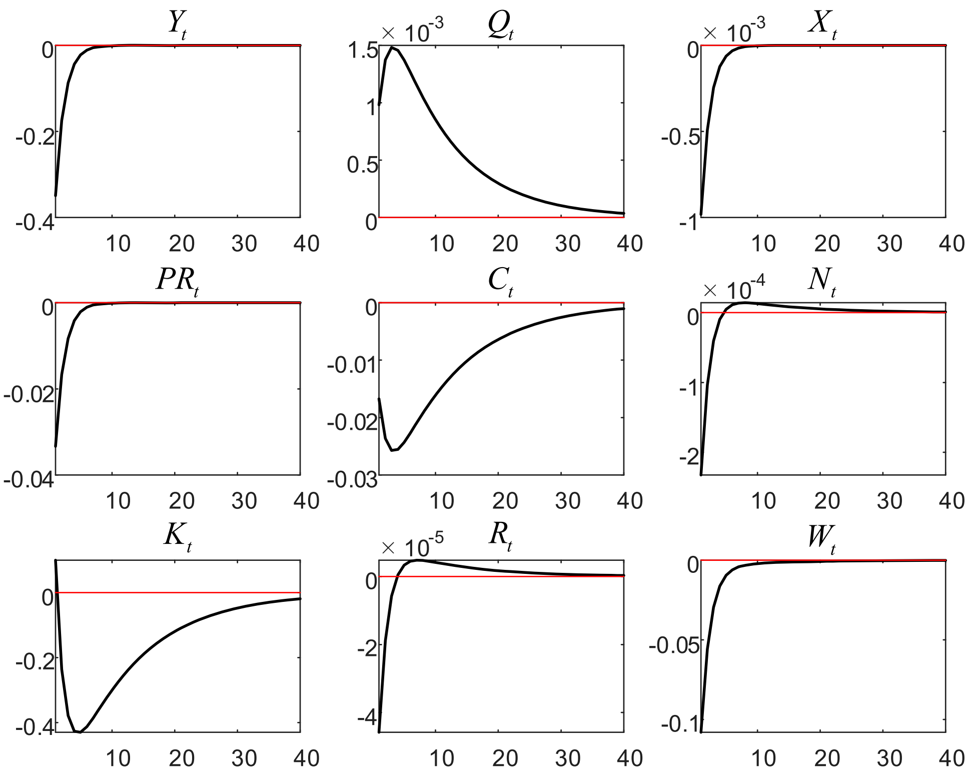

FIGURE 4
The impulse response of lower limit.

effect on the eco-environment quality is evident at the beginning. In a short period, The effect is not very ideal. The result is different from that of Duflo et al.(2018), Tadaki (2020), Kang and Silveria (2021), etc.

In the long term, it is consistent with the Environmental Kuznets Curve (EKC). As the effect on output gradually weakens, pollutant emissions will no longer increase. In addition, the eco-environment has a self-purification ability. The negative impact on the eco-environment will eventually be eliminated. Since China's development stage is still on the left side of EKC, the eco-environment has slightly deteriorated with the economic growth. After reaching the 'inflection point', the eco-environment will be significantly improved.

5.2 Dynamic effect analysis of lower limit of administrative penalty amount

The dynamic effect of the lower limit is shown in Figure 4. i) For the government, the lower limit has a positive impact on eco-environment quality but a negative effect on the output. This negative effect gradually disappears in the third period. ii) For the firms, the output will be reduced so as not to touch the lower limit of punishment. So, the capital decreases, and labor demand decreases first and then increases. At the same time, the wage decreases, and the return on capital decreases first and then increases. Although firms reduce their emission reduction efforts, pollutant emissions still decrease due to the reduction of output. iii) For the households, total incomes decrease with the decreases in labor supply and capital investment. The consumption also decreases.

In the short term, setting the lower limit increases eco-environment quality but decreases output. It is explained as follows. The lower limit sets the minimum violation cost. The penalty amount is lower than the cost of clean technology innovation. Firms have no motivation to carry out cleaner production. However, pollution emissions without cleaner production will exceed the standard and result in penalties. Firms would reduce output to reduce pollutant emissions to avoid the lower limit. Furtherly, emission reduction efforts are meaningless when the emissions are below the lower limit. Firms want to minimize emission reduction efforts and decrease costs to maximize profits.

In the long term, the output reduction will gradually disappear because the firms will find the most considerable output under the constraint of the lower limit. A balance will be formed in the long term.

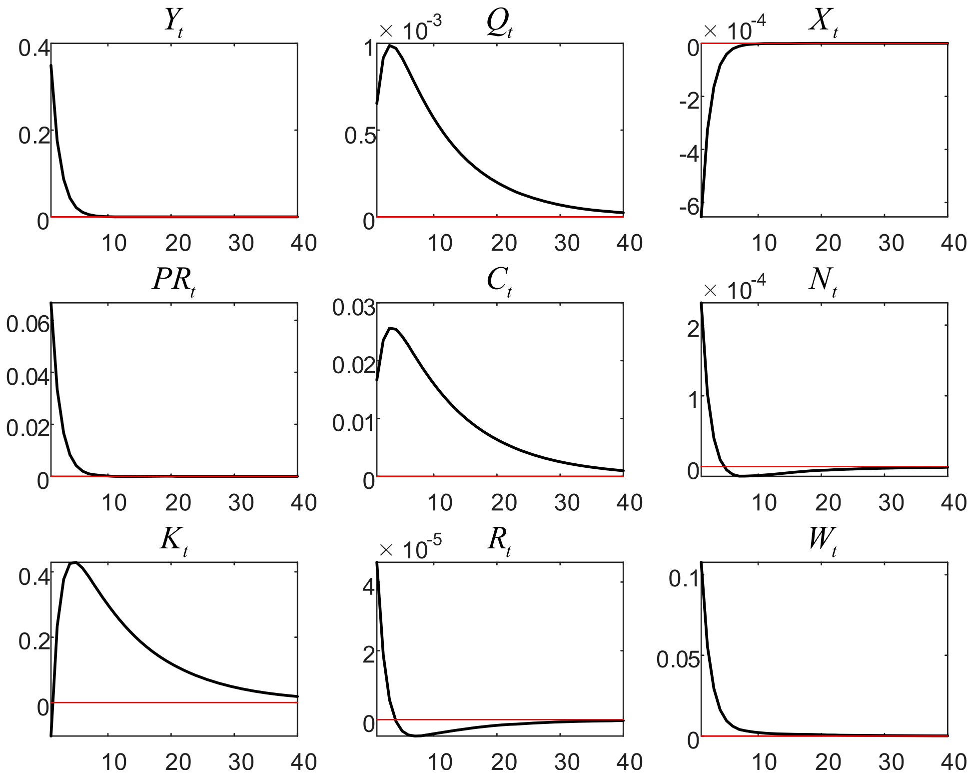

FIGURE 5
The impulse response of the upper limit.

5.3 Dynamic effect analysis of upper limit of administrative penalty amount

The dynamic effect of the upper limit is shown in Figure 5. i) The upper limit positively affects eco-environment quality and output for the government. It balances eco-environment protection and economic development. ii) For the firms, they increase output and emission reduction efforts. So, the capital increases, and labor demand increases first and then decreases. At the same time, the wage increases, and the return on capital increases first and then falls. Under the upper limit, the pollutant reduction due to emission reduction efforts is more than the pollutant generated by output. Therefore, the pollutant emission is reduced. iii) For the households, total incomes increase with labor supply and capital investment. The increased income is partly used for capital investment and partly for consumption.

In the short term, the upper limit will promote output and emission reduction efforts at the same time. The result coincides with Cai et al. (2016). A high penalty amount has a deterrent effect. It is unrealistic to reduce pollution emissions simply by reducing output. High penalty amounts can force firms to reduce emissions by promoting clean energy and increasing pollution control equipment and product process innovation (Bu & Shi, 2021). These are firms' emission reduction efforts. Then the pollutant emission will be greatly reduced. Under the eco-environmental self-purification ability, eco-environmental quality is improved significantly in the short term. Therefore, it can reduce pollutant emissions, improve the eco-environment quality, and achieve dual benefits for the eco-environment and economy.

In the long term, the positive effect on output gradually decreases, while the positive impact on the eco-environment lasts. It is because the use of clean energy, pollution control equipment, and product process innovation could reduce pollutant emissions for a long time.

5.4 Sensitivity analysis

This chapter examines the robustness of the model. We selected three key variables: output, eco-environment quality, and pollutant emissions. The dynamic effects are shown in Figure 6 when the shocks fluctuate up and down by 15%. In Figure 6, lines 1–3 respectively correspond to the

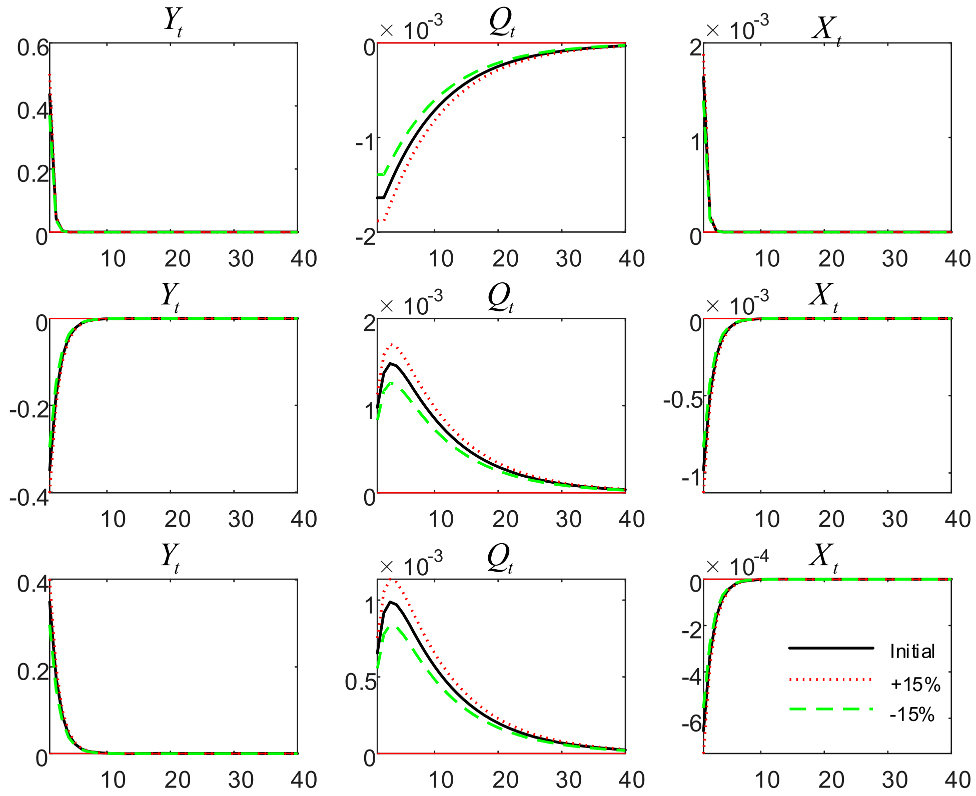

FIGURE 6
Sensitivity analysis.

impact of a 15% fluctuation in the intensity of standardized discretion, the lower limit, and the upper limit. We find that when each shock fluctuates up and down by 15%, the effect directions do not change. The selection of the initial value of external impact does not vary the overall change trend of variables. The research conclusion has high reliability.

6 Conclusion and implications

6.1 Conclusion

From the legal rules and enforcement process, we draw out three key elements of SDEAP: the intensity of standardized discretion and the lower and upper limits of the administrative penalty amount. By constructing a multi-agent dynamic game model, we studied the dynamic effect of SDEAP on the economy and eco-environment. The results show that i) The intensity of standardized discretion will promote output growth and improve emission reduction efforts. But it has a specific adverse effect on eco-environmental quality. This negative effect is mainly because the emission reduction efforts of firms are lower than the output increase. The negative effect on eco-environmental quality will gradually disappear in the long run. ii) The lower limit will simultaneously reduce output and emission reduction efforts. The output decline will reduce pollutant emissions and positively affect the eco-environment. It is not conducive to economic development in the short term. The negative effect on economic development will gradually disappear in the long run. iii) The upper limit has a positive effect on the eco-environment and output simultaneously. It is conducive to the joint development of the economy and eco-environment.

6.2 Policy implications

Overall, SDEAP restricts the broad range of discretion. It can promote economic growth, but discretion should not be excessively squeezed. In the short term, SDEAP cannot achieve the high-quality development goal of the joint development of the economy and eco-environment. In a long time, it can balance eco-environment quality and economic development. The following policy implications are put forward.

1) As a new constraint method, there are still many problems in SDEAP. In the current SDEAP construction, more attention is paid to standardized discretion. The other two key elements (lower and upper limits) are not concerned they deserved. The lower and upper limits of the administrative penalty amount need to be adjusted in time with the economic development. Especially the upper limit, it can achieve the dual goals of eco-environment protection and economic development. It plays an essential role in harmonizing eco-environment protection and economic development.
2) It is a long way to achieve the high-quality development goal of the joint development of the economy and eco-environment. At the initial stage of policy adjustment, it may be impossible to consider eco-environment protection and economic development. In an extended period, the high-quality development goal can be achieved. Therefore, we should look at short-term and long-term effects.

6.3 Limitations and further researches

This study contends with several limitations. To highlight the effect of SDEAP, we simplified governments into one department. In reality, governments in China are divided into central and local governments. They have different government powers. For example, the Central Regulations on Supervision of Ecological Environment Protection was issued in 2019. The central government supervises local governments. Future works could study the role of central government supervision in SDEAP. Besides, environmental non-governmental organizations (ENGOs) are critical social forces. ENGOs are effective bridges connecting the government, firms, and households. Future work could take ENGO as a player in the multi-agent game model.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

XM: Methodology, Formal analysis, Software, Data processing, Writing-original draft, Investigation. BX: Conceptualisation, Methodology, Investigation, Writing-review and editing, Supervision, Validation, Resources. GW: Conceptualisation, Investigation, Validation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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