The Evolutionary Game Model of Local Government Environmental Regulation with Media Participation

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Abstract. The battle for pollution prevention and control has been promoted in an all-round way, and the quality of the ecological environment has been significantly improved, but the results are not stable, and environmental problems are still prominent. With the development of social economy, media supervision is playing an increasingly important role in government actions and environmental issues. This paper considers the role of media supervision, constructs an evolutionary game model between local governments and enterprises, analyzes and explains the evolutionary equilibrium. The results show that the media exposure of corporate pollution and local government inaction is conducive to achieve evolutionary equilibrium {regulation, cleaner production}. Local governments give enterprises pollution control subsidies and environmental protection rewards, which can promote green and clean production of enterprises. The paper provides a useful reference for promoting clean production of enterprises and achieving high-quality development.

1 Introductuon

With the acceleration of urbanization and industrialization, environmental pollution has become increasingly serious. In recent years, the government has continuously promulgated environmental policies and regulations to strengthen environmental governance, and the quality of the ecological environment has been significantly improved, but the results are not stable, and pollution problems are still prominent. The construction of ecological civilization is in a critical period of superimposing pressure and moving forward with heavy burdens.With the rapid development of social economy, the role of news media in the supervision of public opinion is becoming more and more important, especially for some environmental violations, news media plays an important role. Studying environmental problems from the perspective of media can provide new theoretical reference for the government's environmental regulation.

Existing environmental pollution literature mainly studies environmental pollution problems such as air pollution[1], water pollution[2], and land pollution[3], focusing on pollution prevention, improvement, governance, and emergency strategies. Evolutionary game theory provides a suitable analysis method for social population participants to imitate each other and adjust strategies for adaptation. It is widely used in biology[4,5], coal mine safety supervision [6] , Environmental pollution[7,8] . Liu[7] From the perspective of the co-evolution of information diffusion and right game, deconstructed the evolution process of environmental pollution mass emergencies. Cui[8] constructed an evolutionary game model of environmental credit supervision with the participation of enterprise subject, public subject and regulatory subject, and studied the participation degree of collaborative governance and the key points of policy implementation. The above-mentioned literature mainly conducts relevant research from participants such as local government, central government, enterprises, and the public.The media is less involved in researching environmental pollution issues. This paper considers the impact of media exposure on corporate emissions and government regulation, which is an innovative attempt in the field of environment.

In this paper, considering the role of media supervision, we build an evolutionary game model between local government and enterprises, and analyze and explain the evolutionary equilibrium. It is suggested that enterprises should carry out cleaner production and the government should regulate the environment. This study provides a useful reference for promoting cleaner production and achieving high-quality development of enterprises.

2 The evolutionary game model of local governments and enterprises

2.1 Symbol descriptions and basic assumptions

This paper selects local governments and heavy chemical industries enterprises as the research objects.The main variables and parameters symbol definitions in this paper are shown in Table 1.

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Table 1 Variables and parameters symbol definitions

Symbol	Definition	Symbol	Definition
A	Cleaner production strategy	E	Local government regulation cost, $E>0$
B	Traditional production strategy	H	Local government fined Enterprises, $H>0$
I	Regulation strategy	θ	Environmental damage coefficient, $0<\theta<1$
NI	Non-regulation strategy	F	Environmental conditions, $F>0$
z	Media exposure probability, $0 \le z \le 1$	C_1	Cost of green technology innovation, $C_1>0$
R	Enterprise revenue, $R>0$	C_2	Cost of pollution control, $C_2>0$

Assumption 1: Limited rational behavior of enterprises and local governments. In environmental regulation, enterprises belong to a disadvantaged population, and their behavior has limited rational characteristics such as imitation, experimentation, and short-sightedness in order to maximize benefits. Local governments belong to a strong population. In the process of decision-making, local governments will refer to other regional governments to make decisions. Local governments have the characteristics of mutual learning and imitation, which are in line with the basic assumptions of the evolutionary game theory. Enterprises in this article refer to high-pollution enterprises such as heavy and chemical industries.

Assumption 2: The social learning mechanism of the participant population. Due to the long-term, complex, and difficult-to-manage characteristics of environmental issues, it is difficult for participants to determine the optimal strategy. The participant populations adjust their own strategies through continuous observation, learning and imitation, so as to maximize their own interests. There is an evolutionary process of population learning behavior in enterprises and local governments. Regarding the application of evolutionary game theory to the analysis of the evolution of social and economic systems, generally copy dynamic equations are used to describe the evolution of population learning behavior [7].

2.2 Factor game model

The strategy space of the enterprise i {cleaner production, traditional production}, defined as $S_i=\{A, B\}$. Among them, Cleaner Production Strategy A refers to the company's green technology innovation, and pollutants are discharged after the treatment reaches the standard. Traditional production strategy B means that the company does not carry out green technological innovation, does not use pollution control equipment or only displays the pollution control equipment, and the pollutants are directly discharged without treatment. The strategy space of the local government g {regulation, non-regulation}, defined as $S_j=\{I, NI\}$. Assuming that the enterprise's revenue is R, the cost of green technology innovation for clean production enterprise is C_1, the cost of pollution control is C_2, and the cost of local government regulations is E. If the enterprise conducts traditional production and directly discharges pollutants, the local government finds that the enterprise has illegally discharged pollution. The government will fine the enterprise and record it as H. The cleaner production of the enterprise increases the social welfare to W, and the traditional production of the enterprise will damage the environment. Assuming that the environmental condition is F and the environmental damage coefficient is θ, the social welfare loss caused by environmental damage is θF. If the enterprise conducts traditional production, it may face the risk of being exposed by the media. Assuming that the probability of media exposure is $z\,(0 \le z \le 1)$, then the media exposure will cause a negative impact on the enterprise and other reputation losses, which is recorded as zL. If the local government does not conduct regulation, it may face the risk of being exposed by the media. If the media is exposed, the reputation and credibility of the local government will be reduced, and the loss is recorded as zP. Assume $zP>E$. If the enterprise conducts traditional production and the local government does not regulate it, then the local government will be punished by the central government and recorded as zQ. Assume $E-H>zP+zQ$.

According to the model assumptions and the above set of benefits and costs of the model, the factor game of the evolution of local governments and enterprises is shown in Table 2.

Table 2 The factor game of the evolution of local governments and enterprises

Local government g	Enterprise i	
	Cleaner production $A(y)$	Traditional production B (1-y)
Regulation $I(x)$	$\underline{W-E}, R-C_1-C_2$	$-\theta F+H-E, R-zL-H$
Non-regulation NI(1-x)	$W-zP, R-C_1-C_2$	$\underline{-\theta F-zP-zQ}, \ R-zL$

Analyze the Nash equilibrium of the factor game in Table 2. If $C_1+C_2<zL$, there is a pure strategy Nash equilibrium{ regulation , cleaner production }. If $zL<C_1+C_2<zL+H$,There is pure strategy Nash equilibrium{ non-regulation , traditional production },

{ regulation , cleaner production }.If $zL+H<C_1+C_2$,there is a pure strategy Nash equilibrium { non-regulation，traditional production }.

The payoff matrixes of the local government and the enterprise are defined as K and V , respectively, which are given below:

$$K=\begin{pmatrix} W-E & -\theta F+H-E \\ W-zP & -\theta F-zP-zQ \end{pmatrix},\quad V=\begin{pmatrix} R-C_1-C_2 & R-zL-H \\ R-C_1-C_2 & R-zL \end{pmatrix} \tag{1}$$

Suppose that the proportion of local government *j* adopting regulation strategy *I* is *x*, the proportion of enterprise *i* adopting cleaner production strategy *A* is *y*, the expected payoff of local government and enterprise are respectively:

$$\begin{aligned} U_j &= \begin{pmatrix} x \\ 1-x \end{pmatrix}^{\mathrm{T}} K \begin{pmatrix} y \\ 1-y \end{pmatrix} = \begin{pmatrix} x & 1-x \end{pmatrix} \begin{pmatrix} W-E & -\theta F+H-E \\ W-zP & -\theta F-zP-zQ \end{pmatrix} \begin{pmatrix} y \\ 1-y \end{pmatrix} \\ &= x[y(-E+zP)+(1-y)(H-E+zP+zQ)]+y(W-zP)+(1-y)(-\theta F-zP-zQ) \end{aligned} \tag{2}$$

$$\begin{aligned} U_i &= \begin{pmatrix} y \\ 1-y \end{pmatrix}^{\mathrm{T}} V^{\mathrm{T}} \begin{pmatrix} x \\ 1-x \end{pmatrix} = \begin{pmatrix} y & 1-y \end{pmatrix} \begin{pmatrix} R-C_1-C_2 & R-C_1-C_2 \\ R-zL-H & R-zL \end{pmatrix} \begin{pmatrix} x \\ 1-x \end{pmatrix} \\ &= y(xH-C_1-C_2+zL)-xH+R-zL \end{aligned} \tag{3}$$

Let $\partial U_j/\partial x=0,\ \partial U_i/\partial y=0$, the mixed strategy Nash equilibrium can be obtained as:

$$\left(x^*,y^*\right)=\left(\frac{C_1+C_2-zL}{H},\ \frac{H-E+zP+zQ}{H+zQ}\right) \tag{4}$$

2.3 Evolutionary process and evolutionary equilibrium analysis

In the local government regulation of heavy chemical industry pollution incidents, the population behaviors of participants have the characteristics of mutual observation, imitation and learning, and there are population learning behaviors. Therefore, the replicator dynamic equation model is used to reflect the learning behavior of the parties:

$$\mathrm{d}\theta(t)/\mathrm{d}t=\theta(t)[u_t(s)-\overline{u}_t] \tag{5}$$

Among them, $\theta(t)$ is the proportion of the population that participants choose the strategy *s*, $\mathrm{d}\theta(t)/\mathrm{d}t$ is the growth rate of the proportion of the population that participants choose a certain strategy *s* at any moment *t*; $u_t(s)$ is the payoff of choosing the strategy *s*, and $\overline{u}_t$ is the average payoff.

According to the factort game of local governments and enterprises and the replicator dynamic equation (5), the replicator dynamic equation of local governments and enterprises can be obtained:

$$\begin{aligned} \mathrm{d}x/\mathrm{d}t &= x(1-x)[(1-y)(H+zQ)-E+zP] \\ \mathrm{d}y/\mathrm{d}t &= y(1-y)(xH+zL-C_1-C_2) \end{aligned} \tag{6}$$

According to Friedman's criterion of dynamic system stability, Judge the stability of equilibrium point.There are five equilibrium points $(0,0),(0,1),(1,0),(1,1),(x^*,y^*)$ in this system, among which $\left(x^*,y^*\right)=\left(\frac{C_1+C_2-zL}{H},\ \frac{H-E+zP+zQ}{H+zQ}\right)$. The Jacobian matrix of the evolution system (6) is:

$$\boldsymbol{J}=\begin{bmatrix} (1-2x)[(1-y)(H+zQ)-E+zP] & x(1-x)(-H-zQ) \\ y(1-y)H & (1-2y)(xH+zL-C_1-C_2) \end{bmatrix}_{\substack{x=x^* \\ y=y^*}} \tag{7}$$

Proposition 1: If the payoff satisfies condition $C_1+C_2<zL$, the evolutionary equilibrium of the game between the local government and the enterprise is {regulation, cleaner production}.

It can be seen from Proposition 1 that the cost of green technology innovation is lower, the cost of pollution control is lower, and the media exposure that the enterprise's pollution behavior suffers more reputational damage, enterprises tend to choose cleaner production strategy *A*. Therefore, enterprises can reduce pollution control costs through third-party governance. At the same time, local governments should provide subsidies to enterprises that carry out green technological innovation and control pollution, so as to reduce the cost of clean production of enterprises.

Proposition 2: If the payoff satisfies condition $zL<C_1+C_2<zL+H$, the evolutionary equilibrium of the game between the local government and the enterprise is { non-regulation, traditional production} and {regulation, cleaner production}.

It can be seen from Proposition 2 that the cost of clean production of enterprises, the probability of media exposure, and the punishment of polluting enterprises by local governments are the key factors that determine the production methods of enterprises. In rural remote and economically underdeveloped areas，local governments attach importance to GDP growth and ignore environmental protection. Environmental regulation is weak or even not implemented, and the news media has slower development and low exposure probability, leading to serious enterprise pollution. On the contrary, In developed urban areas, local governments attach importance to environmental protection, strictly implement environmental regulations and policies, and provide pollution control subsidies and environmental incentives to enterprises that conduct clean production. In addition, news The media industry is developing rapidly, and media supervision capabilities are strong. Once a enterprise's pollution is exposed by the media, it will seriously affect the enterprise's reputation, so as to achieve high-quality development.

Proposition 3: If the payoff satisfies condition $zL+H<C_1+C_2$, the evolutionary equilibrium of the game between the local government and the enterprise is { non-regulation, traditional production}.

local governments should increase penalties for polluting enterprises, deter polluting enterprises, and promote green and clean production.

3 Conclusions

Fighting the tough battle for pollution prevention and control and solving the prominent environmental problems that the people have strongly reported is not only

an urgent need to improve the environment and people's livelihood, but also an urgent task to strengthen the construction of ecological civilization. Although the central government has issued various environmental regulations and policies, in reality there are still phenomena that enterprises illegally discharge pollutants, and local governments do not strictly implement environmental regulations and policies, or even do not act. With the rapid development of news media, media supervision has played an increasingly important role in government actions and environmental issues. This paper conducts research from the perspective of media participation, and provides theoretical reference and reference for solving government environmental regulation problems.

This paper considers the role of media participation and constructs an evolutionary game model between local government and enterprises. Studies have shown that the greater the probability of media exposure, the greater the reputation loss caused by media exposure, the greater the intensity of local government environmental regulations, and the lower the cost of clean production for companies, which is conducive to green technology innovation and pollution control for companies to achieve high-quality development. The greater the loss of reputation and credibility caused by the media exposure of the local government's omissions, the greater the penalty imposed by the central government on the local government's omissions, which is conducive to the local government's environmental regulation. Therefore, we should give full attention to and play the role of news media supervision, increase media exposure, and strengthen media supervision over local governments and polluting enterprises. At the same time, local governments should increase environmental regulations to deter polluting enterprises. Provide pollution control subsidies and environmental protection incentives to reduce the cost of clean production of enterprises, promote green and clean production of enterprises, and achieve high-quality development.

The future research of this article can be extended. This article does not consider external stochastic factors. In future studies, external stochastic factors can be taken into consideration.

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