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Government Strategy for Environmental Pollution Prevention and Control Based on Evolutionary Game Theory

Rentao Sun and Wei Wan†
School of Management, Wuhan University of Technology, Wuhan, 430070, China
†Corresponding author: Wei Wan

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ABSTRACT

Controlling environmental pollution efficiently has become the common goal of the entire society. To explore whether the strategy of environmental pollution prevention and control formulated by the central government can effectively prevent the failure of traditional environmental regulation, the central and local governments were selected as the participants of a game model. The incentive mechanism was introduced into the constraints, the evolutionary game model of governments and enterprises was established, and the optimal regulation strategy of both sides was constructed from the effect of environmental pollution prevention and control. Results show that the key to preventing the failure of pollution control strategies is to introduce the constraints of the central government, allocate the cost of pollution control, and provide financial support for the prevention and control of environmental pollution. In addition, the central and local governments should adopt different prevention strategies. The optimal allocation strategy of the special funds for environmental pollution prevention and control at the central government level should be to correlate positively the amount of funds with the amount declared by the local government and show a marginal decreasing relationship. Local governments should not impose severe penalties on enterprises for excess discharge of pollutants. With the escalating discharge, imposing reasonable environmental taxes and reducing the marginal emission reduction costs of enterprises are better regulation means than increasing penalties.

INTRODUCTION

In recent years, China's environment has been polluted to varying degrees. The frequency of environmental pollution has increased continuously, affecting a large area and exhibiting regional characteristics. For example, in the economically developed regions of the Yangtze River Delta, Beijing-Tianjin-Hebei, and Pearl River Delta, haze pollution is severe, and the constant haze weather pollution has caused great risks to people's lives and social economy. Environmental pollution and public opinion also exert tremendous pressure on central and local governments. How to effectively regulate relevant enterprises has become a core concern of the government. The traditional pollution prevention and control of the government refers to the process wherein the government restricts and regulates the negative externalities of the environmental resource utilization mainly by enterprises (Zhao et al. 2009). The characteristics of the transregional transmission of environmental pollution sources and social acceptance of enterprise pollution indicate that the externality of environmental pollution is remarkable. When environmental pollution in a city is severe, the risk is likely to be transferred to other urban areas. Solving all types of environmental pollution problems solely with the resources of a city government is difficult (Pan et al. 2015). Pollution problems must be solved through regional cooperation. The high cost of defining environmental property rights determines the necessity of environmental regulation. Against the background of severe environmental pollution and the failure of traditional environmental regulation systems, the central government of China has reformed its regulation strategy and formulated a series of policies for environmental pollution control, including providing special funds for environmental pollution control, interviewing local leaders with weak governance, and returning funds. However, whether these policy changes are effective and can achieve good governance results are unclear. To this end, this study establishes an evolutionary game model to dynamically simulate the game process of environmental pollution control between central and local governments and analyse the factors affecting the regulatory effect. In doing so, this study can determine the reasons for the worsening environmental pollution and come up with effective prevention and control strategies.

PAST STUDIES

Environmental pollution not only has the attributes of environmental public goods and external reasons but is, more importantly, the result of the damage to environmental

resources caused by the comprehensive effect of external factors. Given these components, relevant scholars have studied the influencing factors of environmental pollution from the perspectives of economic growth, industrial structure, and technology. Among the existing studies, the environmental Kuznets curve (EKC) is the most representative in terms of describing the relationship between economic growth and environmental pollution. Grossman et al. (1995) summarized the data of air pollutants in 42 countries. They analysed the relationship between air quality and economic growth with comparative analysis method. The concentration of two pollutants (sulphur dioxide and smoke) is proportional to the GDP when the national income level is low (Grossman et al. 1995). However, an inverted U-shaped relationship is formed between the concentration of pollutants and economic growth as the GDP increases. Fodha et al. (2010) studied the relationship between economic growth and pollutant emissions in Tunisia from 1961 to 2004. Their results show that the relationship between income and pollution is a one-way causality, indicating that emission reduction policies and increased investment in pollution control will not affect economic growth. Bernard et al. (2015) proved that the EKC is realistic and emphasized the necessity of coordinating environment and economy, but he proposed that only 34 countries participating in the Organization for Economic Cooperation and Development conform to the inverted U-shaped curve. At the same time, industrial pollution restrains economic growth. Yang (2015) used the Copeland-Taylor method to analyse the impact of industrial agglomeration on environmental problems, and they concluded a clear relationship between the two with regard to threshold. When the level of industrial agglomeration is low, the improvement of the industrial agglomeration level will aggravate environmental pollution. When the level of industrial agglomeration breaks through the threshold, the industrial agglomeration is conducive to the governance of environmental pollution. Li (2015) obtained the ratio of the first output value to the second output value in China from 2004 to 2012, analysed the impact of industrial restructuring on the environment, and concluded that China's current industrial restructuring does not improve the environmental pollution situation. Fosten et al. (2012) studied the pollutant emission behaviour when the EKC is unbalanced. They concluded that the low actual emission of pollution in England is the result of strict environmental regulation and technological progress.

Government actions also directly or indirectly affect environmental pollution. Cai et al. (2008) believed that a local government's behaviour is the key to changing the mode of economic growth and implementing the energy saving and emission reduction policy. Before the EKC's turning point, the government took the initiative of changing the mode of economic growth and improving the EKC's turning point to cope with the increasing severity of environmental pollution. Li et al. (2017) used the system generalized moment estimation method to analyse the panel data of intergovernmental environmental expenditure of 31 provinces in China. The results showed that the competitive effect of intergovernmental environmental expenditure is significant. The fiscal decentralization system in China has a crowding-out effect on the environmental expenditure of local governments (Li et al. 2017). Jørgensen (2010) inspected the measures taken by local governments to control urban river pollution, including preventive measures (monitoring river pollution) and actions (removing accumulated substances from rivers). He believed that the degree of river pollution is negatively correlated with the degree of local governments' involvement in rivers. Farzanegan et al. (2012) analysed the Middle East and North Africa (two of the regions with the highest per capita of carbon dioxide emissions in the world) and showed that strengthening democratic development can help alleviate environmental problems and that democratic governments greatly influence local environmental problems. You et al. (2015) used the quantile regression method to study the determinants of carbon dioxide emissions, and they concluded that many democratic countries emit less carbon dioxide and that the degree of financial openness is not related to emissions.

China's environmental pollution control is mainly based on administrative divisions, that is, territorial governance under the responsibility of the central and local governments at all levels. However, pollution control cannot be accomplished independently by a local government because of the mobility of environmental pollution. To address this problem, China has begun to pay growing attention to the joint management of environmental pollution, and the need for effective mechanisms of joint prevention and control across regions has become urgent. Relevant scholars pointed out that cooperative governance between governments is necessary to resolve the increasingly serious environmental pollution. Zhang et al. (2011) constructed a tripartite game model to analyse the relationship among enterprises, local governments, and the central government with respect to environmental pollution control. They believed that the cost of central supervision can affect its intensity. Light punishment can lead to collusion between local governments and enterprises and the abandonment of pollution control by local governments. Pan et al. (2015) established an asymmetric evolutionary game model between central and local governments. The model considers the effect of the supervision cost of central government and the penalty

amount imposed by central government on local government on the evolutionary stabilization strategy of central and local governments. Cai et al. (2009) extended the multi-agent dynamic game in the evolutionary game model of pollution control. The model cannot achieve evolutionary stable equilibrium under the static penalty strategy of the central government. Only by adopting the dynamic penalty strategy can the stable point be found and the volatility of evolutionary game behaviour is reduced.

The above analysis shows that regulation policy constraints on environmental pollution greatly restrict participants' action strategies and governance effects. At present, the impact of regulatory policies specifically designed for environmental pollution on governance participants remains unclear. However, existing research lacks the modelling analysis under the constraints of the new environmental pollution governance system and discussion of relevant government regulation strategies. The central and local governments urgently need the theoretical guidance of action strategies to effectively carry out environmental pollution prevention and control. Formulation of action strategies for all parties can also substantially improve the effectiveness of governance. On this basis, this study establishes the game process among the central government, local governments, and enterprises under the restriction of the existing incentive mechanism of environmental regulation. The purpose is to formulate a balanced strategy of government regulation and provide theoretical guidance for the practice of environmental pollution control.

METHODOLOGY

Game Player

Environmental pollution prevention and control involves three main players- the central government, local governments, and enterprises. The central government formulates a series of environmental policies for environmental pollution control. To support regional environmental pollution control, the central finance also arranges special funds for environmental pollution prevention and control. Regarding specific environmental management, local governments possess a great degree of power and freedom. The central and local governments establish a decentralized environmental management system, which constitutes the main constraints of the game between governments and enterprises.

Model Hypothesis

Hypothesis 1: Participants include the central and local governments. Given that the central and local governments face different policy environment constraints, a bounded rational participant is formed. These constraints include regional development level, administrative function differences, information asymmetry, incomplete game information, government policy options, and limited decision-making ability. The utility of central and local governments is set as U_{gc} and U_{gl}, respectively.

Hypothesis 2: The relevant policies of environmental pollution prevention and control constitute the main content of the central government's constraints on local governments. Local governments declare emission reductions (x), central governments provide financial incentives (F), and local governments declare emission reductions as the weight of central government funds (θ). According to the actual planned emission reduction (y), local governments determine the intensity of supervision of the enterprises' pollutant discharge within its jurisdiction (α), forming a dynamic game of incomplete information.

Hypothesis 3: The actual emission reduction may differ from the declaration amount of local governments ($y<x$). In accordance with the relevant policies of environmental pollution prevention and control, the central government supervises the completion of local governments' emission reduction tasks (the intensity of supervision is denoted as β) and takes penalty measures against local governments with weak governance. These measures include deduction of special funds (represented by the loss of economic benefits function), suspension of approval of environmental impact assessment documents for all new environmental pollution emission construction projects within the jurisdiction, and interviews with key government leaders (represented by the political cost function).

Hypothesis 4: The economic benefit loss function (fund return) and the political cost function of local governments are the functions of their excess discharge ($\Delta=x-y$) and the supervision intensity of the central government (β), which are $\beta F(x-y)$ and $\beta G(x-y)$, respectively. Local governments adopt the environmental tax system to regulate enterprises' sewage discharge behaviour. The tax rate is t, the initial discharge of enterprise is Y, and the environmental tax revenue collected is $t(Y-y)$.

Hypothesis 5: The emission reduction of exhaust gas represents the effect of environmental pollution control. The social welfare function represents the total utility of the central government, including the cost of capital, the cost of supervision, the refund of funds from local governments who have not completed the governance tasks, and the improvement of social welfare by environmental pollution control. The local government utility consists of capital gains, supervision costs, refund of funds under incomplete governance tasks, political costs, and environmental tax benefits.

Hypothesis 6: The central government utility is negatively correlated with the cost of capital and supervision and positively correlated with the return of funds and the improvement of social welfare by environmental pollution control. The local government utility is positively related to the collection of funds for environmental pollution control and the benefit of environmental taxation, but negatively related to the cost of supervision, the refund of funds, and the political cost under the incomplete governance tasks.

RESULT ANALYSIS

Regulation strategy of central government: The central government's special fund for pollution control is F(θx), which constitutes the cost of pollution control. The central government can increase the social welfare level by promoting local governments to reduce emissions and improve air quality. The improvement of welfare level is a function of the actual emission reduction, and it is denoted as $H(x)$. The central government determines local governments' super-emission behaviour with a specific probability (β). The refund obtained is a function of super emission, which is denoted as $\beta F(x\text{-}y)$. The cost of supervision is a function of discovery probability β, and it is denoted as $S(\beta)$.

Accordingly, the total objective utility function of the central government is

$$\max U_{gc} = -F(\theta y) + H(x) + \beta F(x-y) - \mathrm{S}(\beta)$$
$$\frac{\partial x}{\partial F} > 0, \quad \frac{\partial y}{\partial H} > 0, \quad \frac{\partial \beta}{\partial S} > 0 \qquad ...(1)$$
$$0 < \theta < 1, \quad 0 < \beta < 1, \quad 0 < y < x$$

The optimal planning solution of the central government is expressed as follows:

$$\frac{\partial U_{gc}}{\partial y} = HX_{y}^{'}(\mathrm{y}) - \beta F_{\Delta}^{'}(\mathrm{x}-\mathrm{y}) = 0 \qquad ...(2)$$

$$\frac{\partial U_{gl}}{\partial x} = -\theta F_{x}^{'}(\theta x) + \beta F_{\Delta}^{'}(\mathrm{x}-\mathrm{y}) = 0 \qquad ...(3)$$

The result of optimal planning is the maximum emission reduction that the central government can obtain.

$$y_1^{*} = \left\{ y \middle| H_{y}^{'}(y) - \theta F_{x}^{'}(\theta x) = 0 \right\} \qquad ...(4)$$

Formula (4) indicates that the maximum emission reduction that the central government can obtain is related to the reported emission reduction by the local government y, the special fund budget F, the weight of emission reduction θ and the improvement of social welfare level H, but not to the intensity of supervision β. Therefore, the key to increasing emission reduction is allocating emission reduction and providing supporting funds in the early stage. The supervision and punishment in the latter stage is only the process of redistribution of special funds, which cannot improve the effect of environmental pollution prevention and control. For the expression of y^{*}_{1}, the derivatives of θ and x are obtained.

$$\frac{\partial y_1^{*}}{\partial y} = \frac{F_{x}^{'}(\theta x) + \theta x F_{x\theta}^{''}(x\theta)}{H_{yy}^{''}(\mathrm{y})} \qquad ...(5)$$

$$\frac{\partial y_1^{*}}{\partial x} = \frac{\theta^2 F_{xx}^{''}(x\theta)}{H_{yy}^{'}(\mathrm{y})} \qquad ...(6)$$

Formula (5) shows that the relationship between θ and y_1^{*} is complex. Based on the above analysis, no clear positive or negative relationship exists between $H_{yy}^{''}(\mathrm{y}) < 0$ and y_1^{*}, and between $F_{x}^{'}(\theta x) > 0$ and y_1^{*}.

Formula (6) indicates a relationship between x and y_1^{*}. Based on the hypothesis, $0 < \theta < 1$ is $\theta^2 > 0$. With the environment as a public product, the law of diminishing marginal utility is applicable to environmental pollution control. That is, $H_{y}^{'}(\mathrm{y})$ decreases, and $H(y)$ convex function is formed, resulting in $H_{yy}^{''}(\mathrm{y}) < 0$. Subsequently, when the increment of marginal capital brought by x increases, forms a concave function on x and , x is negatively correlated with . When the decrease in marginal capital brought by x increases, $F(x\theta)$ forms a convex function on x and $F_{xx}^{''}(x\theta) > 0$, x is positively correlated with y_1^{*}. The consequence of increasing the marginal capital increment caused by x is excessive fiscal incentives, which will not only increase the financial burden of the central government but also prevent or even reverse the improvement of the regulatory effect. Therefore, the optimal strategy for the central government to allocate funds should be to correlate positively the amount of funds F with x and show a marginal decreasing relationship. Doing so ensures that the increase of declaration improves the effectiveness of governance and promotes the efficient use of funds for environmental pollution control.

Regulation strategy of local governments: Local governments' emission reduction plan is y, the initial emission is Y, and enterprises' actual emission is y_3. When local governments discover the excessive behaviour of enterprises, the amount of supplementary taxation is t(y_3-Y-y), the number of fines is αf(y_3-Y+y), and other assumptions are the same as in Hypothesis 1. On this basis, the utility function of local governments can be obtained as follows:

$$U_{gl} = F(\theta x) - S(\alpha) + t(Y-y) + \alpha[t(y_3 - Y + y) + f(y_3 - Y + y)] -$$
$$\beta H_1(x-y) - \beta F(x-y) \qquad ...(7)$$

Similarly, the optimal planning method is used to obtain the optimal regulatory effect of local governments.

$$y_0^* = \left\{ y \middle| -t + \beta H_{1y}^{'}(x-y) - \beta F_y^{'}(x-y) = 0 \right\} \quad ...(8)$$

Formula (8) indicates that the illegal and concealed actions of enterprises do not affect the regulation effect of local governments. The intensity of supervision α, the excessive fines f and the payment of environmental taxes $t(y-y_3)$ cannot change the regulation effect of local governments. The existing incentive policies of local governments for enterprises are invalid, leading to regulation failure. Formula (8) also shows that the supervision intensity of the central government and negative incentives, such as the return of funds to local governments, can improve the regulatory effect of local governments.

CONCLUSIONS

1. The central government is the key to preventing the failure of environmental pollution control. In the absence of constraints from the central government, the positive and negative externalities of environmental governance cannot be internalized. The key to preventing environmental governance failure is to introduce the constraints of the central government, allocate governance costs, and provide financial support. Financial support for local government environmental governance is an important part of the central government's environmental governance strategy. The law of diminishing the marginal social utility of environmental governance indicates that the central government's financial support for local governments' environmental governance should be diminished marginally to avoid the dilemma that local governments cannot improve the regulatory effect despite improving the emission reduction target.
2. The central government's incentive to local governments' environmental governance, whether at the level of central or local governments, has no major impact on the regulatory effect of environmental governance. The incentive is only relevant in reducing the cost of the central government's supervision. The financial support of the central government is the key factor to determining the governance effect. The existing negative incentive system must be optimized urgently.
3. The strategy of local governments to regulate enterprises' behaviour warrants attention. Under the condition of inhibiting environmental pollution behaviours, such as concealment and illegal discharge, the central government's supervision will improve the governance effect of local governments. By contrast, the effect of local governments' supervision on environmental governance is not obvious.

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