Research on Game Behavior of Enterprise Pollution Discharge and Government Regulation

Jianguo Cai[a], Zhaoan Han[b,*]

School of Economics and Management, Northwestern University, Xi'an, Shaanxi, China

[a] 453967392@qq.com, [b] 790833409@qq.com

*corresponding author

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Abstract: The Game Analysis of environmental pollution control based on the relationship between enterprise sewage discharge and local government supervision shows that whether enterprises sewage discharge and local government supervision depends on the expected income of enterprises when they do not sewage discharge and sewage discharge, the cost of reputation of enterprises, the cost of law enforcement of local government for environmental protection supervision and the size of penalties for enterprise sewage discharge. The smaller the local government's punishment on enterprises' pollutant discharge, the higher the cost of law enforcement for environmental protection supervision by local government, the bigger the expected revenue and reputation cost when discharging pollutants, the more inclined enterprises are to discharging pollutants.

1. Introduction

From the point of view of market failure, environmental pollution is caused by the characteristics of environmental public resources. Environment is also an important input factor for enterprises to engage in production. However, due to weak supervision, environmental costs are often not regarded as explicit costs (accounting costs) of enterprises. The environmental costs caused by enterprises engaged in production activities are often borne by the public, thus enabling enterprises to engage in production activities. Private production costs of environmental pollution enterprises are not equal to their social costs. As a public resource, the environment has been put into the production of enterprises. This part of the cost is difficult to measure and the characteristics of its own public resources, which leads to the over-use of environmental resources in the production and life process, resulting in environmental pollution.

2. Basic assumptions of game analysis

To simplify the analysis, it is assumed that there are n rational participants in a particular regional environment who are engaged in product production according to the principle of maximum benefit. These rational participants themselves are also the "owners" of environmental resources, so when they discharge pollutants into the environment in the production process, considering the sustainability of future production, these rational participants will also take into account the governance of environmental pollution, that is, the need to invest a certain cost of environmental pollution control for production activities, but because environmental resources do not have clear property rights, I You can see how the "public tragedy" of the environment happened [1].

(1)Assume that each participant is free to use environmental resources, and that these n participants use the same technology to produce homogeneous products;

(2)Suppose that the level of pollutant discharge of the first participant is $x_i, x_i > 0$, and the total amount of pollutant discharge of the environment is $\mathrm{X} = \sum_{i=1}^{n} x_i$, $\mathrm{i} = 1,2,3 \cdots \mathrm{n}$;

(3)Participants bring benefits to themselves by using environmental resources to engage in production activities. Assuming that such benefits are related to the amount of pollutants they emit,

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the more pollution they emit, the more private benefits they receive. Assuming that the average income per unit of emissions is V and V is related to X, that is, V is a function of X, i.e. v = V (X), but when the total environmental pollution in this area is not large, the impact on the average income V can be neglected with the increase of pollutant discharge from participants, but when the total pollutant discharge is large, with the increase of pollutant discharge from participants, the negative impact of pollution on income will appear. Increasing the unit discharge will lead to a decrease in the average revenue v [2].

$$\frac{\partial v}{\partial X} < 0$$

(4)Sewage discharge also has negative effects on production, such as the health of employees caused by environmental pollution, the efficiency of production, or the deterioration of the environment caused by environmental pollution, and the need for reprocessing of raw materials that do not meet the standards. These negative effects will increase the production costs of participants, assuming that the average new production cost per unit is C [3].

(5)Assuming that the environmental pollution load in this area is limited, if the pollution exceeds this limit, it will affect the continuation of production and even the survival of the participants will be threatened. Assuming that the maximum pollution carrying capacity of the environment in this area is X_{maz}, it is obvious that the condition for production to continue is the total emission of the environment $X < X_{maz}$; if $X \geq X_{maz}$, production cannot continue, resulting in v(X)=0.

3. Game Analysis of Pollution Control between Enterprise Pollution Discharge and Government Regulation

In the game of environmental pollution, enterprises and local governments are very important participants. As producers, enterprises emit various pollutants to the environment while producing products. Because of the nature of environmental public resources, enterprises, as rational environmental participants, tend to discharge production wastes freely and directly to the environment without disposing of them for the purpose of maximizing profits. If the government does not regulate the system, the environmental pollution caused by the excessive use of the environment will be inevitable.

3.1. Prisoner's Dilemma in Environmental Pollution Control

For the convenience of analysis, we assume that the government does not regulate the discharge of pollutants by enterprises. We assume that there are only two enterprises in the environment: A and B. The scale and level of production of A and B are equal, the products produced are homogeneous, and A and B are two competing enterprises in the market. Both enterprises have two strategies in the production process: discharge of pollutants or non-discharge of pollutants; in the absence of external control, if both enterprises discharge pollutants, the environmental deterioration will exceed the optimal discharge limit. The polluted environmental quality will affect the earnings of the two enterprises, assuming that the earnings of each enterprise is a. On the contrary, if both enterprises do not discharge pollutants, the better environmental quality will reduce the production cost of the enterprise and improve the earnings of the enterprise, assuming that the earnings of each enterprise is b; and if the environment quality is not polluted, the earnings of each enterprise will be b. If one enterprise discharges pollutants and another does not, the income of the enterprise discharging pollutants will be greater than that of the enterprise discharging pollutants [4]. It is assumed that the income of the enterprise discharging pollutants is c and that of the enterprise discharging pollutants is d. Assuming d < a < b < c, the payment matrix of the above game is as follows:

		Enterprise B	
		Sewage disposal	No pollution discharge
Enterprise A	Sewage disposal	(a,a)	(c,d)
	No pollution discharge	(d,c)	(b,b)

In this game, it is assumed that enterprises A and B fully understand each other's choice strategies and the information is completely symmetrical. Then when enterprise A chooses to discharge pollutants, enterprise B must choose to discharge pollutants, because for enterprise B, if it chooses to discharge pollutants, it will get a benefit of a, if it chooses not to discharge pollutants, it will get a benefit of d, and d < a; conversely, if it chooses not to discharge pollutants, enterprise B will also choose to discharge pollutants, because if enterprise B chooses to discharge pollutants, its income will be c, and it will choose not to discharge pollutants. Benefit is B. At this time, for B, the benefits of choosing the sewage discharge strategy are obviously greater than those of choosing the sewage discharge strategy, that is, c>d . (b, b) is not a Nash equilibrium because it does not satisfy individual rationality. In this case, the result of competition between A and B will form Nash equilibrium (a, a), and A and B will eventually get lower returns. This example only assumes that there are two enterprises, A and B. In reality, there are a large number of enterprises discharging pollution, assuming that there are n enterprises (polluters). In the absence of supervision, each enterprise has incentives to discharge pollutants. These enterprises form a game among themselves and eventually fall into a typical "prisoner's dilemma" [5].

3.2. Pure Strategic Game Model of Enterprise Pollution Discharge and Government Regulation

Suppose that in an economy, all polluters are abstracted as a business, and all local revenue comes from that business. The environmental protection department of the government exercises the responsibility of environmental pollution supervision on behalf of the government. In the actual environmental supervision, the government environmental protection supervision department can not achieve 100% of the inspection of polluting enterprises, more is the use of spot checks. In the game of environmental pollution control formed by government and enterprises, we assume that both enterprises and governments are rational economic men. They all pursue the maximization of their own utility in economic behavior, enterprises pursue the maximization of profits, and the government pursues the maximization of social welfare. As a game party, the enterprise's action strategy is: sewage discharge or non-sewage discharge; the government's action strategy is: supervision or non-regulation. In the game, both enterprises and governments choose their actions according to the principle of utility maximization. The goal of enterprises is to maximize economic benefits. Assuming that the size of revenue is R, the size of R is related to the quantity of products Q, that is, R = R (Q). It is assumed that if enterprises take the initiative to control pollution, the output of their products is Q_1, and the corresponding revenue is$R_1 = R_1(Q_1)$. Correspondingly, if enterprises do not carry out sewage treatment and direct sewage discharge leads to environmental pollution, then the output of their products isQ_2, and the income of enterprises is $R_2 = R_2(Q_2)$when sewage is discharged. Because enterprises carry out pollution treatment, their production costs will be increased, thus affecting the output of water. So $Q_2 > Q_1$and $R_2 > R_1$ are established. Enterprises actively carry out sewage treatment, although it may affect their current economic benefits, but it will help to shape a good corporate social image, in the long run, is conducive to the sustainable development of enterprises. On the contrary, if pollution control is not carried out, the current economic benefits will be improved, but the negative effects of environmental pollution, such as the threat to the ecological environment and the impact on the life and health of the public, will inevitably lead to greater resistance or negative evaluation of the polluting enterprises by the public, and the social image of the enterprises will be greatly discounted.

This subjective negative evaluation of the polluting enterprises We assume that it can be measured by numerical value, that is, the cost of reputation of an enterprise, which is recorded as H. Obviously, h is related to the amount of sewage discharged by enterprises. If the reputation cost of the polluting enterprise is taken into account, the economic benefit of the polluting enterprise is$R_2 - h$. The direct revenue of the government comes from the tax T = T (Q) paid by enterprises. That is to say, the government tax is related to the output of enterprises. The more the output is, the more tax the government receives. If the enterprise discharges sewage without treatment, the government's tax $T_2 > T_1$. In addition, government supervision needs cost. Assuming that the cost of law enforcement of government environmental protection supervision is C, once enterprises are investigated and punished, they will be punished by fines. Assuming that the amount of fines is F, the government's fines for enterprises will also form the revenue of the government. Of course, if the government only pursues tax benefits and leaves enterprises to their own devices, the living environment of the people will deteriorate dramatically, which will lead to people's distrust of the government. That is to say, the government's neglect of environmental governance will also lead to people's dissatisfaction with the government (negative evaluation). Similarly, we assume that this negative evaluation can also be measured by numerical value, which is H, H. It can also be seen as the cost of government reputation.

		Government	
		Supervise	Non regulation
Enterprise	Sewage disposal	$R_2 - h - F, T_2 - H + F - C$	$R_2 - h, T_2 - h$
	No pollution discharge	$R_1, T_1 - C$	R_1, T_1

The game shows that:

(1) When the fines imposed by the government on polluting enterprises are less than the cost of government environmental supervision and enforcement, i.e. F < C, the optimal strategy chosen by the government is not to supervise.

(2) If $R_2 - h - F < R_1$, whether regulated by the government or not, the profits from pollution are always greater than those from non-pollution, then the optimal strategy of enterprises is pollution.

(3) Without considering (1) and (2), that is, in the case of F>C,$R_2 - h - F > R_1$, there are two Nash equilibria in the game between enterprise sewage discharge and government regulation, that is, if the government chooses to regulate, the enterprise chooses not to discharge sewage; otherwise, if the government chooses not to regulate, the enterprise must choose the strategy of sewage discharge.

3.3. Mixed Strategy Game Model of Enterprise Pollution Discharge and Government Regulation

In real life, due to the limitation of human, material and financial resources invested in environmental protection supervision, the government often fails to supervise all enterprises or enterprises in the jurisdiction for 100% of all environmental pollution behavior. The information between the government and the enterprise is asymmetric. Because the government and the enterprise can not judge each other's strategy beforehand, the actual game between the two sides is closer to the mixed strategy game. It is an incomplete information game, that is, both sides choose a certain strategy with a certain probability to achieve the mixed strategy game. In this case, no matter which side of the two sides changes. Action strategies will not add any benefits to themselves. Next, we will analyze the Nash equilibrium in the mixed strategy game.

Assuming that the probability of government regulation is p, the probability of non-regulation is 1-p; the probability of enterprises choosing to discharge pollutants is q, the probability of choosing not to discharge pollutants is 1-q; the payment matrix of mixed strategy game is as follows:

		Government	
		Supervise(p)	Non regulation(1-p)
Enterprise	Sewage disposal(q)	$R_2 - h - F, T_2 - H + F - C$	$R_2 - h, T_2 - h$
	No pollution discharge(1-q)	$R_1, T_1 - C$	R_1, T_1

Assuming that the expected earnings of enterprises under the emission and non-emission strategies are U_1^R, U_2^R R respectively, and that of the government under the supervision and non-regulation strategies are U_1^g, U_2^g respectively, the calculation of the expected earnings is as follows:

$$U_1^R = p(R_2 - h - F) + (1 - p)(R_2 - h)$$

$$U_2^R = pR_1 + (1 - p)R_1 = R_1$$

$$U_1^g = q(T_2 - H + F - C) + (1 - q)(T_1 - C)$$

$$U_2^g = q(T_1 - C) + (1 - q)T_1$$

When Nash equilibrium of mixed strategy is realized, the expected revenue of enterprises choosing sewage and non-sewage is equal, and the expected revenue of government choosing supervisory and non-supervisory strategies is equal. So there are:

$$U_1^R = U_2^R, U_1^g = U_2^g$$

That is to say, the following two forms are established:

$$p(R_2 - h - F) + (1 - p)(R_2 - h) = R_1$$

$$q(T_2 - H + F - C) + (1 - q)(T_1 - C) = q(T_1 - C) + (1 - q)T_1$$

Available:

$$\mathrm{p} = (R_2 - R_1 - \mathrm{h})/\mathrm{F}$$

$$\mathrm{q} = \mathrm{C}/\mathrm{F}$$

Thus we can get that when the probability of enterprise pollution and government environmental protection supervision is equal to p=$(R_2 - R_1 - \mathrm{h})/\mathrm{F}$ and q=C/F respectively, the mixed strategy game of enterprise and government environmental protection supervision achieves Nash equilibrium. For the convenience of analysis, we record the probability of realizing Nash equilibrium of mixed strategy as p^*=$(R_2 - R_1 - \mathrm{h})/\mathrm{F}$ and q^*= C/F, respectively.

From the p^* and q^* values of Nash equilibrium state of mixed strategy, we can also find out whether enterprises choose to discharge pollutants or not and whether the government chooses to regulate or not.

If p <p^*, the optimal strategy for enterprises is to discharge pollution.

If p > p^*, the optimal strategy for enterprises is not to emit pollution.

If q < q^*, the government's best choice is not to supervise.

If q > q^*, the best choice for the government is supervision.

Obviously, when the government punishes the enterprises less severely and the cost of law enforcement for environmental protection supervision is higher, the enterprises tend to choose sewage discharge. Similarly, when the expected benefits of non-pollutant discharge are smaller, the expected benefits of pollutant discharge are larger, the reputation cost of enterprises due to pollutant discharge is smaller, and the punishment of the government is smaller, the enterprises will also tend to discharge more pollutants.

4. Conclusion

In the treatment of environmental pollution, the market which uses price mechanism as the means of resource allocation has the phenomenon of failure. Therefore, it is necessary for the government to effectively supervise the environmental pollution in the environmental pollution control. Based on the relationship between sewage discharge enterprises and local government regulation, a game model between enterprise sewage discharge and local government regulation is established. It is analyzed that in environmental pollution control, whether the government chooses to supervise or not or whether the enterprise chooses to discharge sewage mainly depends on the expected income of the enterprise when it does not discharge sewage (or carries out pollution control), the reputation cost of the enterprise, and the government's use in environmental protection supervision. The cost of law enforcement and the size of the penalties imposed on enterprises for sewage discharge. Obviously, when the government punishes the enterprises less severely and the cost of law enforcement for environmental protection supervision is higher, the enterprises tend to choose sewage discharge. Similarly, when the benefits of non-pollutant discharge (or pollution control) are smaller, the benefits of pollutant discharge are larger, the reputation cost of enterprises due to pollutant discharge is smaller, and the punishment of the government is smaller, the enterprises will also tend to discharge more pollutants.

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