Analysis on Environmental Pollution and Control in China Based on Game Theory

Jiatian Li[1, *]

[1]Beijing No. 80 High school, Beijing 100102, China

*Corresponding author email: 2021000452@poers.edu.pl

Abstract. This paper analyzes the problem of environmental pollution control in China based on game theory. The two main participants in the game are the pollutant discharge enterprises and the government, of which government is divided into central government and local government. In this passage, three different game analysis is made. First, a game between enterprises is analyzed. Then, there is a game model made between government and pollutant discharge enterprises. Companies will decide whether to control pollution or not in their own interests, and their decisions will change due to the existence of supervision. Since local governments have the right of independent management, and control part of the administrative and financial power, tax revenue need not be handed over completely to the central government. Therefore, local governments might collude with the local enterprises to evade the supervision of the central government. As a result, a third game model of enterprises, local governments, and the central government is made. Results show that when there is no government supervision, enterprises will always choose to have no pollution control. When the local governments supervise, companies will choose to control pollution. The collusion between local governments and enterprises depends on the number of fines and the cost of collusion. When fines are greater, the two parties will not collude. When costs are higher, the two parties will choose to collude.

Keywords: game theory, environmental pollution, pollution regulation, mixed strategy

1 Introduction

Game theory is a mathematical theory and method to study phenomena with struggling or competition. It considers the predicted and actual behavior of individuals in the game and studies their optimized strategies. Game theory is widely used in finance, securities, biology, economics, international relations, computer science, political science, military strategy and many other disciplines, and has become one of the standard analytical tools of economics. Game can be divided into cooperative game and non-cooperative game. The difference lies in whether there is a binding agreement between the parties interacting with each other. A game includes players, strategy, payoff, information set,

H. Mallick et al. (Eds.): ICEMCI 2022, AEBMR 231, pp. 1417–1427, 2023.
https://doi.org/10.2991/978-94-6463-098-5_161

and equilibrium. Players are the ones who participate in the game and make their decisions. Strategy is an action a player would take in the given circumstances. Payoff is the payout a player receives from choosing a strategy. Information set is the information available at a given point in the game. Equilibrium is the point in the game where all players have decided, and the outcome is reached. In most cases, over time, Nash equilibrium will be reached. When Nash equilibrium is reached, no player can increase their payoff by changing their strategies, and players will have no regrets considering their outcomes. Since game theory can analyze and predict actions in interaction between two different players, it is appropriate to use game theory to analyze actions of firms and governments in environment protection.

China's ecological situation is not optimistic. With the continuous development of economy, environmental pollution is increasingly serious. Chemical pharmaceutical industry, printing and dyeing leather industry, wine food industry, livestock breeding, and other industries caused a certain degree of pollution to the environment. More than 70 percent of 47 major cities in China fail to meet China's second-level standards for air quality. The annual production of municipal solid waste in China is 140 million tons, less than 10% of which meets the requirements of harmless treatment. White pollution caused by plastic packaging and agricultural film has spread across the country. Water pollution is more serious, and China is one of the countries lacking freshwater resources. The population base is large, so that the insufficient water resources have become more precious. Industrial wastewater is directly discharged into water body, resulting in water pollution; Many pesticides are used in agricultural production, such as organophosphorus pesticides and organochlorine pesticides, which are directly thrown into river channels and ditches. According to the statistics, in 1996, the amount of fertilizer applied in China was 38 million tons, ranking first in the world [1]. Pesticide residues on crops penetrate underground water under the action of precipitation, resulting in water pollution. In China, 36 percent of urban river reaches fifth level poor water quality and are out of use. To this end, the government has also set up relevant regulations to supervise enterprises that discharge pollutants, strengthened law enforcement on environmental protection, resolutely punished all kinds of illegal discharge of pollutants, and launched a campaign to clean up and rectify enterprises that discharge pollutants illegally and ensure the health and environmental protection of the people.

However, the policies and regulations issued by the state to control the discharge of pollutants by enterprises have not achieved the expected results. The existing environmental protection laws are not specific enough to the environmental protection work, lack of unified regulations as the basis of administrative law enforcement [2]. There are many problems in the process of control that led to poor results. If the enterprises have limited operating capacity, they may lose money because they cannot afford the cost of cleaning up pollutants. The enterprises might give up follow the rules and protect the environment in order to protect their profits. Besides, benefits such as political achievements can also affect governments' actions. Therefore, they may be reluctant governing the enterprises. These two reasons led to the poor performance of pollution control.

Due to this issue about pollution control, this passage will focus on the decisions of polluting enterprises, local governments, and the central government with different conditions. Game theory can best show the conditions and results of these players, and thus

find the reasons of the decisions and give more useful suggestions. Therefore, this passage will explain strategies of enterprises and governments in different conditions and give conclusions and suggestions for pollution control regulations.

2 Method

2.1 Game Theory

Game theory studies the interaction of decision making among participants. It is a theory which extracts the key information of a situation and use relevant theories and methods to analyze and solve the problem. Recently, game theory has been widely used in various fields. There are two types of games—cooperative game and non-cooperative game. Cooperative game theory deal with groups of players, or coalitions, in one game where the payoffs are known. Non-cooperative game theory deals with how "rational" individuals make decisions in a game [3]. In a game, when solutions are optimized, it reaches Nash equilibrium. Under Nash equilibrium, a player cannot gain anything if they change their original strategy and when other players don't change their decisions. A game may include no Nash equilibrium or more than one of them. In the following article, game theory and Nash equilibrium will be explained using a specific game: The Prisoner's Dilemma.

The Prisoner's Dilemma is a classic game and is the most well-known case of game theory. In this example, two criminals are arrested, and they were asked whether to admit their crime. The two criminals will be in two different cells and are questioned separately, meaning that they cannot communicate during the whole process. The prisoners were given choices. If both of them confessed, they will each stay in prison for five years; If one of them confessed, the person who confessed could go immediately, and the other person will get a ten-year sentence; If both of them deny, they will both receive a one-year sentence, like shown in Table 1 [4].

Table 1. The Prisoner's Dilemma

		Suspect 2	
		Deny	Confess
Suspect 1	Deny	-1, -1	-10, 0
	Confess	0, -10	-5, -5

In this game, if suspect 1 choose to deny, suspect 2 should confess, since 0 is larger than -1, and if suspect 1 choose to confess, suspect should also choose to confess, since -5 is larger than -10. Thus, suspect 2 should choose to confess no matter what suspect 1 chooses. Likewise, suspect 1 should choose to confess no matter what suspect 2 chooses. In this game, the optimal decisions for both players are to confess and get the shorter sentences. Therefore, "confess, confess" is the Nash equilibrium. When both suspects confess, they will benefit the most no matter what the other person choose to do.

2.2 Participants in Environmental Pollution Control

The control of environmental pollution in China mainly includes local governments' control, the central governments' supervision, and the pollutant discharge enterprises' cooperation. The relationship among these main participants in pollution control is shown in Figure 1 [5].

Fig. 1. Participants' relationships of environmental pollution control in China.

2.2.1 Central government.

In controlling pollution, the central government is mainly responsible for making laws and regulations, coordinate the governance activities of various departments, and supervise local governments' actions. In addition to doing their best to clean the environment and keep the soil, water and air uncontaminated, the central government need to consider political and economic factors, keeping the economy developing and controlling the cost of managing the environment.

2.2.2 Local governments.

Local governments are responsible for implementing environmental protection work in their regions, and they follow all instructions of the central government. Local governments produce their own regulations of reducing pollution, provide environment public goods and services, and monitor local environment conditions. When local pollutant discharge enterprises do not cooperate and protect the environment, the local governments would give punishments to them.

2.2.3 Polluting enterprises.

The behavior of polluting enterprises is highly related to the public property of environmental resources and the profits of enterprises. In China, the pollution control of enterprises is to deal with their own pollutants, and to prevent pollutants from entering the natural environment, preventing the aggravation of the already formed soil pollution and damage. Companies are mostly rational, and their decisions are geared towards maximizing profits. Chinese enterprises tend to overuse environmental resources or discharge pollutants into the natural environment, which can cause environmental pollution.

2.3 Model descriptions

In this paper, three game models are made: game between enterprises, game between enterprises and local governments, game between enterprises, local governments, and the central government.

2.3.1 Game between enterprises.

Hypothesis 1: There are only two enterprises in the environment: Enterprise 1 and Enterprise 2. They compete and produce the same quality products on the same scale and at the same level of pollution. Both enterprises have two choices: to discharge the pollutant after treatment or reduce the pollution emission amount (Pollution Control), or to ignore the regulations and do not give any treatment (No Pollution Control).

Hypothesis 2: If the government does not take supervision, enterprises choose whether to discharge pollution for the principle of maximizing profits.

Hypothesis 3: Environmental change will affect enterprises' output and quality. The output and quality of enterprises is reduced when the environment is polluted, and the production cost of enterprises decreases, and the income increases when the environmental quality is improved.

2.3.2 Game between enterprises and local governments.

Data shows that the costs of controlling the pollution, especially industrial pollution, have been increasing almost every year, making the probability for governments to put effort into controlling pollution and the probability for enterprises to control their pollution decrease, as shown in figure 2.

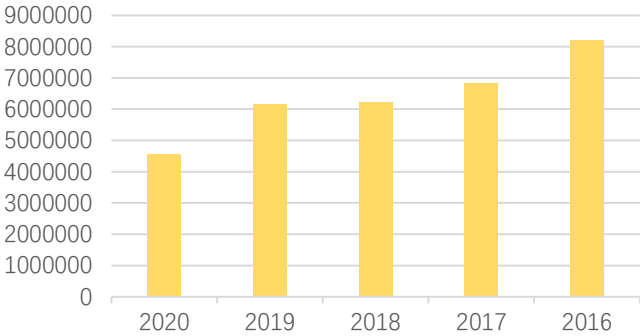

Fig. 2. Investment in environmental pollution control (100million yuan) (Data sourced from https://data.stats.gov.cn/)

Hypothesis 1: There are only one potential polluting enterprise in the environment, and the local government is responsible for supervising this enterprise and keep it from polluting [6].

Hypothesis 2: The output and quality of the enterprise will change when the environment is affected. When the enterprise does not control their pollution, they will be fined by the local government.

Hypothesis 3: The discharge of pollutants by the enterprise will affect the surrounding residents and cause their reputation to suffer. Governments that fail to regulate or collude with companies are similarly discredited. In this paper, it is assumed that the reputation cost is small and negligible.

Hypothesis 4: The local government's tax revenue is closely related to the enterprise's output and profit. When the enterprise's profit is high, the government will earn more money, and when the enterprise's profit is low, the government will earn less. When the enterprise pollutes the environment, their output and profit will be affected, so the government's revenue will be affected.

Hypothesis 5: The revenue that the local government get when the enterprise control pollution is T_1, and the revenue that the local government get when the enterprise does not control pollution is T_2 [7]. The enterprise will earn R_1 when they control pollution and will earn R_2 when they do not control pollution. $T_2 > T_1$, $R_2 > R_1$. The cost of local government's supervision is X, and the cost of the enterprise's pollution control is Y. Suppose the fine is F if the enterprise is found to have discharged pollutants. $F > X$, and $F > Y$.

2.3.3 Game between enterprises, local governments, and the central government.

Hypothesis 1: The three players in the game are all rational and aim to maximize their profits. The central government makes policies for pollution control [8].

Hypothesis 2: Confronted with the central government's environmental pollution supervision, there is a possibility of collusion between the local governments and enterprises in order to maximize their profits and increase the GDP in their area.

Hypothesis 3: The central government will not collude with any party. They are protecting the environment with a long-term view to maximize social welfare and achieve sustainable development [9].

Hypothesis 4: If the enterprise follows all the regulations and control the pollution, they will get a payoff of R_0, and the local government will get a payoff of T_0. When the firm colludes with the local government, they will get additional profit of G, and the local government will get additional profit of I.

Hypothesis 5: Environmental protection agencies pay a price for their choice of supervising, but the cost can be compensated by increasing the investment or reward of the relevant government departments to the environmental protection sector [10]. Assume the central government's cost of supervising collusion is Z. When collusion is found, the enterprise will receive a fine of F, and the local government will receive a fine of C.

3 Results and discussion

3.1 Game between enterprises

This model shows the payoffs of two different potential polluting enterprises competing in one environment. The game is shown in Table 2.

Table 2. Payoff matrix of enterprise-enterprise game.

		Enterprise 2	
		Pollution Control	No Pollution Control
Enterprise 1	Pollution Control	R, R	A, B
	No Pollution Control	B, A	N, N

When both enterprises control pollution, they both receive a payoff of R, otherwise, they will both receive a payoff of N. If one of the enterprises pollute, and the other do not, the enterprise which pollute will receive a payoff of A and the other gets a payoff of B, as shown in Table 1. $B > R > N > A$.

In this game, no matter what enterprise 2 choose to do, enterprise will always choose to have no pollution control. Similarly, enterprise 1 will always choose to pollute. In this game, the Nash equilibrium is (No Pollution Control, No Pollution Control). Therefore, when there is no central government regulation or local government supervision, the enterprises will all choose to pollute without control, and the environment will become worse and worse. When entrepreneurs act as "rational people", they will choose to emit pollution. When the total emissions exceed the maximum carrying capacity of the environment, the environment will be unable to voluntarily mitigate the pollution, and it will eventually cause severe environmental damage.

3.2 Game between enterprises and local governments

This model shows the game between the local government and the only enterprise that they are monitoring in their area. The payoff matrix is shown in Table 3.

Table 3. Payoff matrix of enterprise-local government game.

		Local Government	
		Supervise	Not Supervise
Enterprise	Pollution Control	R_1-Y, T_1-X	R_1-Y, T_1
	No Pollution Control	R_2-F, T_2-X+F	R_2, T_2

When the enterprise controls their pollution, they will earn a revenue of R_1, but they need to pay Y for controlling the environment. When the enterprise controls their pollution while the local government supervises them, the local government will lose X for supervision cost and get T_1 for their revenue. When the enterprise controls their pollution and the local government does not supervise, the local government will receive T_1 of revenue and no expenditure. When the polluting enterprise does not have pollution control, they will receive a revenue of R_2 and a fine of F when the local government supervises them, and a revenue of R_2 and no fine when the local government

does not supervise. The local government will receive a revenue of T_2, a fine of F, and will spend X supervising the enterprise. They will receive only a revenue of T_2 if they don't supervise.

It can be seen from the payoff matrix that, when the local government choose to supervise, the enterprise chooses to control pollution; when the local government choose not to supervise, the enterprise chooses not to control pollution. Thus, this is a mixed strategy game.

Assume the probability for the local government to supervise is p, and the probability of not supervising is $1-p$. Assume the probability of the enterprise controlling the pollution is q, and the probability of not controlling the pollution is $1-q$. The equations are as follows:

$$p(R_1 - Y) + (1-p)(R_1 - Y) = p(R_2 - F) + (1-p)R_2 \tag{1}$$

$$q(T_1 - X) + (1-q)(T_2 - X + F) = qT_1 + (1-q)T_2 \tag{2}$$

From the equations, we get $p = (R_2 - R_1 + Y)/F$, $q = (F - X)/F$. Assume, the probability of the local government supervision is p_0, and the probability of the enterprise controlling pollution is q_0. When $p_0 > p$, the enterprise will choose not to control pollution, and when $q_0 > q$, the local government will choose not to supervise. Therefore, the probability of controlling pollution or supervision depends on R_2, R_1, Y, F, and X. The greater the profit of enterprises is when they do not control pollutions, the smaller the profit is when they control pollutions. The larger the governance cost of enterprises is, the smaller the government's punishment is, or the larger the supervision cost is, the higher probability for the enterprises to discharge pollutants without regulation.

3.3 Game between enterprises, local governments, and the central government

This model shows the game between three players, the local government, the central government, and the polluting enterprise. The payoff matrix is shown in Table 4.

When the enterprise colludes with the local government, they will receive a revenue of R_0, and an additional profit of G. On this basis, if the central government supervises them and successes, the company will have to pay a fine of F. When the enterprise does not collude with the local government, they will get a payoff of R_0 regardless of the central government supervision. For the local government, if they collude with the enterprise, they will get $T_0 + I$, and if they do not collude, they will get T_0. However, when the central government successfully supervised and found the collusion, the local government will lose C. For the central government, if they do not supervise for collusion, they will have no gain and no loss, and if they supervise, it will cost them Z. When they success at supervising, they will gain C and F, the fine of the local government and the enterprise, and if they do not success, they will gain nothing.

Table 4. Payoff matrix of game between local government, central government, and enterprises.

		The Central Government		
		Supervise		Not Supervise
		Success	Fail	
Enterprise and Local Government	Collude	R_0+G-F, T_0+I-C, C+F-Z	R_0+G, T_0+I, -Z	R_0+G, T_0+I, 0
	Not Collude	R_0, T_0, -Z	R_0, T_0, -Z	R_0, T_0, 0

From the payoff matrix, it can be inferred that the central government would supervise collusion only if $C + F$ is larger than I. For enterprises and local governments, if the additional benefits brought by collusions are greater than the number of fines, then enterprises and local governments will collude.

Assume the probability for the central government to supervise collusion is r, and the probability of not to supervise collusion is $1 - r$. Assume the probability of successful supervision is k, and the probability of failing is $1 - k$. The probability of the enterprise and local government colluding is m, the probability of not colluding is $1 - m$. The equations are as follows:

$$rk(R_0 + G - F) + r(1 - k)(R_0 + G) + (1 - r)(R_0 + G) = rkR_0 + r(1 - k)R_0 + (1 - r)R_0 \quad (3)$$

$$rk(T_0 + I - C) + r(1 - k)(T_0 + I) + (1 - r)(T_0 + I) = rkT_0 + r(1 - k)T_0 + (1 - r)T_0 \quad (4)$$

$$mk(C + F - Z) + m(1 - k)(-Z) + (1 - m)k(-Z) + (1 - m)(1 - k)(-Z) = 0 \quad (5)$$

From these equations, we can get $r_{interprise} = G/Fk$, $r_{local\ government} = I/Ck$, $m = Z/(C + F + 2Z)k$. Assume the real probability of the central government supervising is r_0, the real probability of the enterprises and local government colluding is m_0. When $r_0 > r_{interprise}$, the enterprise will choose to collude with the local government. When $r_0 > r_{local\ government}$, the local government will choose to collude with the enterprise. When r_0 is larger than the maximum value of $r_{interprise}$ or $r_{local\ government}$, the central government will choose to supervise collusion. The probability of collusion or supervision is closely related to F, G, I, C, and Z. When C, F is smaller, the enterprise will more likely collude with the local government.

4 Conclusion

The environment is common resource. In order to maintain a good environment for long-term use, the enterprises' reckless discharge of pollutants in disregard of regulations must be corrected. The government should specify a more scientific and reasonable system to coordinate the conflicts of interests of all parties, to truly make the system practical and achieve the due effect.

As can be seen from the games, in the absence of supervision, all enterprises will choose not to control pollution and cause damage to the environment. Therefore, the

supervision system of local governments should be stricter, and some additional conditions can be added to restrain the regulators. They will have a greater possibility to choose to supervise enterprises' pollution discharge activities voluntarily.

Similarly, it can be seen from the games that the interests of local and central governments do not always coincide. In order to increase local GDP, many local governments may choose to cooperate with enterprises to lower pollution emission control standards in order to increase their production and income and maximize the benefits of both sides. In terms of this issue, more efforts should be made to try to bring the costs of central government regulation to the level of probability of regulation. As the probability of supervision increases, complicity declines to a certain extent. At the same time, the criteria for judging performance of different regions' governments could be changed. The proportion of GDP in the criteria could be reduced, making it less likely that local governments would want to collude with enterprises. Changing the policy based on these ideas, can effectively improve the unity of the goals of local governments and the central government, improve the adverse competition, control pollution effectively, and improve the level of environmental quality.

References

1. X. Zhang, Current situation of rural environmental pollution in China and its protection countermeasures, Rural Economy, 2004
2. J.P. Feng, H.S. Wu, F. Zhao, A Recollection and Prospect of the Water Pollution, South-to North Water Transfers and Water Science & Technology, Vol. 2, 2004
3. Y. Zhang, The Game Analysis on Environmental Pollution and Control, Shandong University Master's Thesis, 2010
4. J.Z. Guo, The Application of Game Theory in Environmental pollution, Shandong University Master's Thesis, 2008
5. Q.Q. Gu, H. Lei, S.R. Sun, Behavioral Game Theory Model in Pollution Control with Additional Supervision, MDPI, 2022
6. C. Zhu, Game Analysis of Environmental Pollution Control. Consume Guide · Technology Forum. 2009, pp. 204
7. G.H. Zhou, Game Theory-Based Analysis of Local Governments' Behavioral Dissimilation in the Third-Party Soil Pollution Control under Chinese-Style Fiscal Decentralization, MDPI, 2021
8. R.T. Sun, W. Wan, Government Strategy for Environmental Pollution Prevention and Control Based on Evolutionary Game Theory, Nature Environment and Pollution Technology, Vol. 18, 2019, pp. 563-567
9. B. Jiang, X.T. Tong, J.X. Guo, The game analysis of government, enterprise and public in environmental pollution in China, 2013
10. F.Y. Lu, Evolutionary Game Analysis on Environmental Pollution Problem. Zhengzhou University, 9, 2007, pp.148–152