A Game Theory Approach to Address Profit Conflicts in Environmental Regulation of Shale Gas Development in Chongqing of China

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Abstract—The shale gas industry is growing very fast in China. Its potential environmental risks cause disputes among different stake holders. This paper used a game theory to study the choice behaviors and their impact factors of environmental regulators and production companies. The proposed model was applied to a shale gas project in Chongqing, China for demonstrating a case study in fast developing regions. It turns out that the pressure of environmental regulators is high; local residents may have the tendency to neglect the environmental risk because of economic benefits. We propose the environmental management pays more attention on heavy regulations to over-standard discharge companies and strengthen public participation by opening up more ways to participate.

Index Terms—Environmental regulators, game theory, production company, shale gas.

I. INTRODUCTION

With the rapid economic development, the demand for energy is growing quickly. Shale gas, as an emerging unconventional gas with huge reserves, has challenged the dominant position of the energy structure. Development of shale gas industry will not only promote local economic development and employment, but also accelerate the adjustment of energy consumption structure and guarantee the security of energy supply [1]. But the hydraulic fracturing can lead to a large amount of water resources consumption, drilling fluid leakage, water pollution, air pollution, intensifying the greenhouse effect and even causing geological hazards [2]-[8].

According to latest results of national shale gas resource evaluation from China, the terrestrial shale gas geological resource potential is a total of 134.42×10^4 billion m^3. The recoverable resource potential is 25.08×10^4 billion m^3 (do not include the Tibetan region) and the accumulated proven reserve is 7364×10^4 billion m^3. The shale gas industry is growing very fast in China. Its potential environmental risks cause disputes among different stakeholders [4]-[6]. For example, there are conflicts of interest between companies and environmental regulators: Companies prefer to spend less money on investments for environmental protection; oppositely, regulators want companies to spend more budgets on pollutants treatment. This scenario leads to an interaction between two decision-makers with differently and potentially conflicting objectives. We need to focus on behaviours of production companies and environmental regulators, and put forward practical environmental regulation strategies. But most of the conducted researches about environmental managements on shale gas development are mainly focused on the environmental risk analysis [7]-[9]. Few researches focus on the interest conflicts among the stake holders. The aim of this paper was to use a game theory to address profit conflicts in environmental regulation of shale gas development in Chongqing of China, which demonstrated a case study in fast developing regions.

II. CONSTRUCTIONS OF GAME MODEL

A. Assumptions

The study is based on the hypothesis that there are only two participants -- environmental regulators and shale gas development companies and they both are rational economic people. Social image and welfare are the payoff of environmental regulators, and economic profits are the payoff of development companies.

B. Payoff Matrix

TABLE I: PARAMETERS IN THE MODEL

Symbols	Notes
I_e	Profit of the company's over-standard emission without treatments
C_e	Extra cost of disposing pollutants for the production company
I_g	Original payoff of the environmental supervision department
C_g	Special environmental regulatory fees of shale gas production project
F	Fine for the companies' over-standard emission found by regulators
A	Subsidies from environmental regulators to companies of under-standard emission
R	Bonus from higher authorities to regulators to improve their regulatory motivation
D	Penalty from higher authorities to regulators for their regulatory misconduct
J_g	Public evaluation towards environmental regulators' activities
J_e	Public evaluation towards production companies' activities
p	Probability of environmental regulators taking monitoring strategy
q	Probability of the production company achieving discharge standard

In this study, these two players' strategies are "monitor or not to monitor" and "under- standard emission or over-standard emission". The payoff matrix and definitions of relevant parameters in the model are shown in table 1 and table 2. Payoff functions are constructed as Eqs. (1) and (2) respectively. In the Eqs. Ve, indicates the payoffs of the production company, while Vg, indicates the payoffs of the environmental regulators. Then according to the theory of profit-maximization, $(p*, q*)$ is obtained, as shown in Eqs. (3).

TABLE II: GAME PAYOFF MATRIX

Environmental regulators (Player 2)	The shale gas production company (Player 1)	
	Under-standard emission(q)	Over-standard emission(1-q)
Monitor(p)	$(I_g - C_g + R + J_g, I_e - C_e + A + J_e)$	$(I_g - C_g + F + R + J_g, I_e - F - J_e)$
Not to monitor (1-p)	$(I_g - J_g - D, I_e - C_e + J_e)$	$(I_g - J_g - D, I_e - J_e)$

$$Ve = p\left[q\left(I_e - C_e + A + J_e\right) + \left(1 - q\right)\left(I_e - F - J_e\right)\right] \\ + \left(1 - p\right)\left[q\left(I_e - C_e + J_e\right) + \left(1 - q\right)\left(I_e - J_e\right)\right] \quad (1)$$

$$Vg = q\left[p\left(I_g - C_g + R + J_g\right) + \left(1 - p\right)\left(I_g - J_g - D\right)\right] \\ + \left(1 - p\right)\left[p\left(I_g - C_g + F + R + J_g\right) + \left(1 - p\right)\left(I_g - J_g - D\right)\right] \quad (2)$$

$$p* = \left(C_e - 2J_e\right)/\left(A + F\right), \\ q* = 1 - \left(C_g - R - D - 2J_g\right)/F \quad (3)$$

III. CASE ANALYSIS

A. Case Description

In this section, a shale gas project is presented to illustrate this proposed model, which is situated in Fuling Chongqing, China (the geographic location is shown in Fig. 1 and 2).

Fig. 1. The geographic position of Chongqing in China.

B. Data Sources

In this paper, study subjects include local residents, the production company (Petro China) and the environmental regulators (Chongqing Fuling District Environment Protection Bureau and the local government). We collected data by questionnaire, interview and searching online materials.

A questionnaire was designed aimed at the local residents and local workers from Petro China, including the subject's personal information, distance to the nearest shale gas well from his or her home, knowledge about this project and grades for the production company and the environmental protection department, mainly to investigate their opinions and evaluations about the shale gas development project. A hundred and twenty subjects were randomly selected, covering an area of about 2 kilometers radius from Jiaoshi Street to complete the questionnaire. 106 effective questionnaires were acquired.
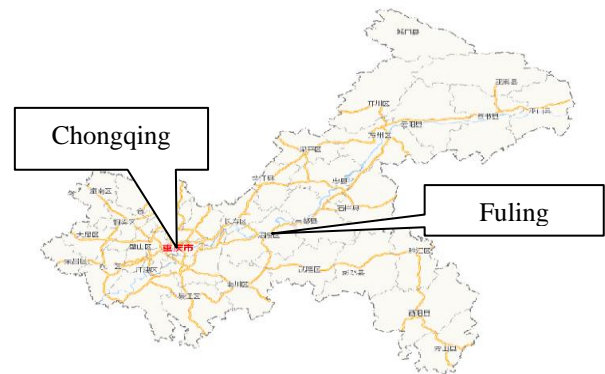

Fig. 2. The geographic position of Fuling in Chongqing.

We contacted and interviewed 13 technical or managerial staff from the production company (5) and the environmental protection department (8), to investigate some basic development and monitoring information of the shale gas project. (The production company: technical processes, pollutants and relevant treatments and cost of this development project; the environmental protection department: the frequency, measures, contents and cost of supervision, and the importance of public evaluation for both.)

We collected some supplementary material via internet to make up the data which we did not successfully acquired during the interview, due to confidentiality, namely, environmental cost, monitoring cost, monitoring contents, etc..

C. Observations and Results

1) Residents' investigation

Fig. 3 and 4 respectively show how subjects evaluate the production company and how education background influences their grades.

Fig. 3 shows that over 85% of subjects are clear what benefits the development has brought to them, namely promoting employment, increasing income, improving transport facilities etc.; about 47% of subjects may have a positive view, while nearly 19% of them oppositely; most subjects can point out the environmental problems of the shale gas project, including air pollution, noises, water pollution, soil contamination and others, and 9% of them have no ideas about the drawbacks.

Fig. 4 indicates that a well-educated subject is more likely to give a higher grade to companies. (In Fig. 4 and 6, the horizontal axis represents the distance to the nearest well from their home.) During the investigation, we found that

most poorly educated residents are illiterate or unemployed homemakers and farmers, most of whom may have no appropriate access to information. Oppositely, the information channel of better-educated subjects is wider, and they understand the project more thoroughly. Hence, if companies want to improve their social reputation, they need to adopt multi-form publicity to increase local people's knowledge about the shale gas project.
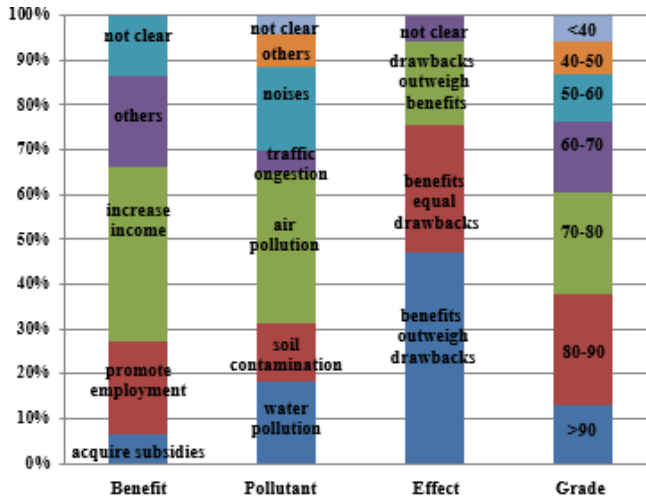

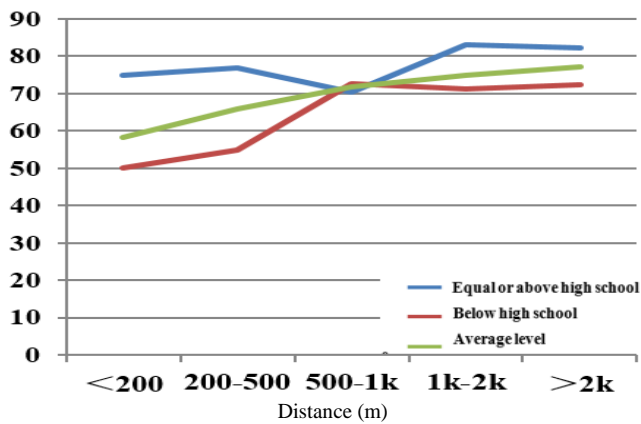Fig. 3. Residents' evaluations on Play 1.

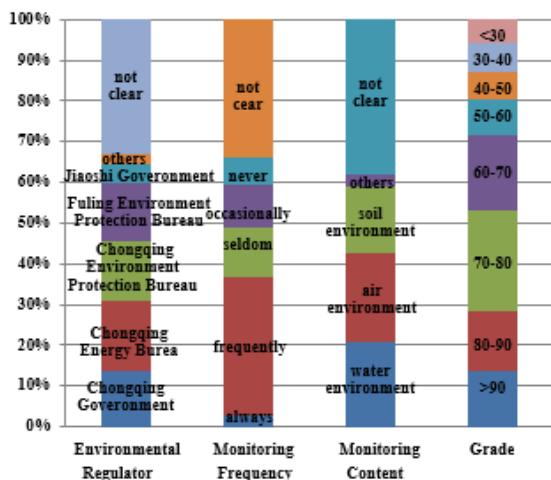Fig. 4. Distribution of grades on Player 1 based on education background.

Fig. 5. Residents' evaluations on Player 2.

Fig. 5 and 6 respectively show how subjects evaluate environmental regulators and how education background influences their grades.

Fig. 5 shows that only 18% of subjects may know the environmental regulator exactly; besides, over 30% of subjects may not know the monitoring frequency; nearly 40% of subjects are likely to be confused of monitoring contents.

In Fig. 6, grades on regulators have experienced a similar tendency like those on the company. Therefore, to improve social evaluation of environmental regulators, they may need to strengthen the communication with local residents, facilitate residents' understanding of their work, and make residents more involved in the environmental management.
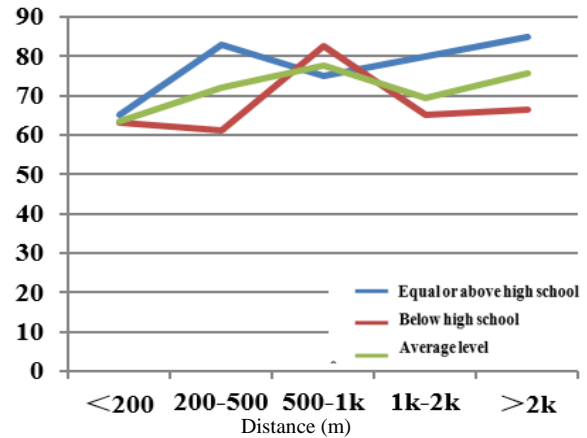

Fig. 6. Distribution of grades on Player 2based on education background.

Local residents may be very familiar with effects of the shale gas project. However, most residents know little about environmental regulators' work, and the possible reason may be that public participation is insufficient.

2) Interview analysis

Disposal methods of fracturing fluid include recycling and pollutant degradation, and at least 20% of flowback fluid needs to be degenerated based on the existing technology. The company agrees that public evaluation is important, but they are just willing to provide 34% of environmental cost to compensate surrounding residents. Interviews of regulators show that existing regulatory system is based on "in advance, in the course and afterwards", and the frequency is arranged by reality, usually several times a week. Regulators concern about public evaluation, willing to pay about 48% of their fiscal expenditures as public warfare.

3) Outputs of the model's parameters

Specific values of the parameters are summarized in Table III.

TABLE III: PARAMETERS AND ASSIGNMENTS OF THE MODEL

	The shale gas production company				The environmental regulator		
Parameters	Ce	Je	A	F	Cg	Jg	R	D
Amount (*10^4CNY)	88[10 1]	30 (34%)	0	5	65	31 (48%)	0	0

D. Game Results and Analysis

Then variables of p* and q* can be determined based on table 3. The detail calculation processes are expressed in Eqs. (4) and (5).

$$p^* = (Ce - 2Je)/(A + F) = (88 - 2*30)/5 = 5.6 \quad (4)$$

$$q^* = 1 - \left(Cg - R - D - 2Jg\right)/F$$
$$= 1 - \left(65 - 2 * 31\right)/5 = 0.4 \quad (5)$$

Hence, when the game is balanced, the probability that environmental regulators choose to monitor the company is about 5.6, which is far beyond 1, and the probability that the production company reaches the emission standard is only about 0.4. That may indicate that the regulatory pressure is high, and even if the company is supervised every day, the percentage of under-standard pollutant is lower than 50%.

Based on our site investigation, reasons that lead to this phenomenon may be that: Public evaluation may not play a role in companies' production activities adequately; the public cannot evaluate the shale gas project objectively, because of the lack of information and knowledge; besides, some local residents may overly focus on economic benefits rather than environment problems they cause, which may imply that local economic situation is backward, and the community's need is likely to stay on the basic physiological level; existing penalty of over-standard discharge may not have a deterrent effect on companies. Companies may be willing to accept the fine rather than increase investment in environmental measures, and these make environmental regulators suffer from heavy work pressure.

E. Analysis of Game Equilibrium Variation

From the aforementioned discussion, we may draw a conclusion that the practical supervision probability of environmental regulators does not reach the requirements when the game is balanced, and the over-discharge behavior of production companies is serious, which cannot guarantee local environmental quality. Hence, we will adjust values of parameters to convert the game equilibrium to maintain the environmental quality and reduce the pressure of environmental regulation.

1) Reduce the cost of pollutants treatment and environmental regulation.

To promote companies' under-standard emission probability (q) over 80%, Cg should be reduced to 31% of its original cost. For environmental regulators, it can be realized by cutting down environmental monitoring items, identifying and taking priority-monitoring items or applying for subsidy from Finance Ministry. However, to make monitoring probability down to 1, F should be reduced to 18% of its original value which is impossible.

2) Increase fines for over-standard polluters.

When fines is higher than $28*10^4$ CNY, $p**$ will be lower than 1 and the $q**$ will be higher than 0.89. Thus, increase F can help to improve companies' under-standard emission probability and protect local environmental quality.

3) Increase public participation of companies' production activities, in order to improve the importance of public evaluation for companies.

As long as the importance of public evaluation (Je) rising to 47%, $p**$ can be reduced to less than 1 and the regulatory pressure can be reduce significantly.

4) Increase the public participation of environmental

regulators, to improve the importance and objectivity of public evaluation.

According to questionnaires, the importance of public evaluation is 48%. If it can be raised to 60%, $q**$ can be raised to 3.6 and there is no impact on p, which can increase companies' under-standard emission significantly.

It is difficult to achieve the ideal game equilibrium by changing a single parameter, so here we reassign several parameters. For companies, decrease Ce to 90% of its original value, increase the importance of public evaluation to 45% and increase F to $10*10^4$ CNY. For environmental regulators, decrease Cg to 90% of its original value, increase the importance of public evaluation to 50%, and increase the bonus and penalty to 1000 CNY/month respectively as their work assessment system. The reassignments of parameters are summarized in Table IV.

TABLE IV: PARAMETERS AND REASSIGNMENTS OF THE MODEL

Parameters	The shale gas production company				The environmental regulator			
	Ce	Je	A	F	Cg	Jg	R	D
Amount ($*10^4$CNY)	79	36 (45%)	0	10	58	29 (50%)	0.6	0.6

Then a new game equilibrium can be acquired.

$$p** = \left(Ce - 2Je\right)/\left(A + F\right) = \left(79 - 2 * 36\right)/10 = 0.72$$
$$q** = 1 - \left(Cg - R - D - 2Jg\right)/F \quad (6)$$
$$= 1 - \left(58 - 0.6 - 0.6 - 2 * 29\right)/10 = 1.12$$

According to the new game results, the probability of environmental monitoring is 0.72 and the probability of companies' under-standard emission is 1.12, which indicates that environmental regulators' pressure could be decreased significantly, and development companies' under-standard emission behaviors could be enhanced remarkably. Therefore in the game between environmental regulators and shale gas companies, it needs multi-parameters' synergistic effect to facilitate the equilibrium variation.

IV. ENVIRONMENT MANAGEMENT SUGGESTIONS

A. Heavy Regulations on Over-Standard Discharge Companies

The amount of fine can be increased. When F is higher than 282 thousand CNY, $p**$ is less than 1, while $q**$ is higher than 0.88. Thus, it may help realize the aim of protecting the environment. Besides, subsidies can be given to companies of reaching the standard only. China implements the subsidy policy for the shale gas industry. If we take this measure, $p**$ decreases significantly, which means that the regulation pressure can be reduced.

B. Strengthening Public Participation and Opening up More Ways for Public to Participate

For companies, if the importance of public participation is raised to 48%, $p**$ decreases below 1, which may reduce regulatory pressure. Likewise, if the importance of public participation is raised to 60%, Jg and $q**$ reach to 387

thousand CNY and 3.6 respectively, which indicates that the rate of under-standard discharge of companies would be improved greatly. Therefore, diversified forms should be adopted to strengthen the local public participation. Environmental regulators should force companies to public the quantity and composition of fracturing fluid and make a list of forbidden additives that may cause environmental problems and risks in fracturing fluid.

C. Implementation of Key Regulations on Water Environment

Currently, the technology of hydraulic fracturing has been extensively used in the development of shale gas, while this method has some neglected adverse problems, for instance, dissipation of water resources, surface water pollution, groundwater pollution, causing geological disasters. Given the reality that most of shale gas fields is located in remote mountainous areas, which intensifies the difficulty and pressure of environmental supervision, the strategy of key regulations surrounding the water environment should be adopted, as according to American experience, the most important impact of shale gas development activities lies in the water environment. This monitoring tactic can not only control the major risk sources, but also can save cost of environmental regulation and reduce work pressure of monitoring department.

V. CONCLUSION

In this paper, we construct a specific game reflecting the decision-making believers of companies and regulators based on an instance. In order to alleviate the pressure of regulation, several measures have been put forward. Future work should consider more parameters, for instance, the pressure of local government and economic development. Besides, the specific quantitative analysis methods of public evaluation and public participation need to support this study. Finally, the sample capacity of questionnaire should be increased.

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