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CASE REPORT

Game Analysis of International Marine Petroleum Cooperation's Environmental Governance: The Bohai Gulf Oil Spill

Lin Zhu[1], Sha He[2,*], Xiantao Liu[2], Qingxiang Sun[2] and Huangsu Li[3]

[1]*School of Civil and Architecture Engineering, Southwest Petroleum University, China*
[2]*School of Economics and Management, Southwest Petroleum University, China*
[3]*Deyang Branch of China's State Grid Corp, China*

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Abstract: In this paper, we discuss the economic reasons for overexploitation that led to the Bohai Gulf oil spill, using game theory. Based on the Bohai Gulf incident, we present the causes of ocean international petroleum cooperation, reveal the connection between the interests of Chinese local oil companies and that of a foreign oil company, analyze both sides of the benefit equilibrium between ConocoPhillips China Inc. and the government, and examine the three sides of the dynamic asymmetric game equilibrium among ConocoPhillips China Inc., the government, and societal opinion. The study makes the following conclusions. First, Chinese offshore international petroleum cooperation is inevitable due to China's limited development level in science and technology. Second, Chinese local oil companies and foreign oil companies have formed a community of interests. Third, the two-side dynamic game analysis shows that the punishment for offshore environment pollution is rather low in China. Fourth, the asymmetric evolutionary game model shows that public opinions enhance government supervision, improve punishment for offshore pollution, and significantly increase the cost of excessive development. In addition, our analytical framework can be applied beneficially to the development of other resources, which will provide strategic support for government legislation and international resource management.

Keywords: Bohai gulf oil spill, Economic game, Evolution model, Game analysis, International petroleum cooperation.

1. INTRODUCTION

As an artery of the national economy and strategic resources industry, the Chinese oil industry is entering a new historical stage in which mining costs are higher and mining risks are greater. Oil and gas resources are relatively poor in China, and the country's geographical environment is rather complex. Consequently, the difficulty and cost of mining is very high. Most onshore oil fields are moving into middle and later development periods. The Chinese continental shelf is rich in petroleum and gas. Accordingly, marine petroleum exploitation has become inevitable. China's offshore oil development technology, however, is relatively backward, and it cannot satisfy the need for mining; consequently, international ocean petroleum cooperation has become an inevitable choice for China. In recent years, China's offshore oil development has been successful, but the frequency of problem incidents is increasing in the field of international petroleum cooperation. For example, in May 2010, an oil spill accident occurred on a drilling platform called ONE NUMBER of South China Sea, which is a platform belonging to CNOOC (the China National Offshore Oil Corporation), Tianjin branch; the tilting accident of the Shengli oil field drilling platform happened in September 2010, and the oil leak of COPC (ConocoPhillips China) in Bohai Bay happened in June 2011. The increase in the number of these emergencies seriously threatens people's health, life, and property security, and causes huge economic loss and environmental harm. Effective analysis of the internal mechanism of those incidents, which cause marine environmental

* Address correspondence to this author at the School of Economics and Management, Southwest Petroleum University, China; Tel: 8615002871918; Fax: 02883032092; E-mail: hesha28@sina.com

pollution problems, may provide a better solution or new insights into international ocean petroleum cooperation. In addition, research results may provide intellectual support for environmental protection in China and an analytical framework for similar incidents. In summary, the COPC Bohai Gulf oil spill is a very typical ocean contaminative event for international petroleum cooperation and, using that event as the research object, we adopt an economic game theory point of view, analyze the deep reasons for excessive development, and provide a basis for marine environmental legislation and management.

2. LITERATURE REVIEW

The international petroleum cooperation marine environmental pollution issue is considered to be a branch of emergency management. Emergency management is an active research field and many researchers have made numerous contributions in this area. Graham T. Allison published *Essence of Decision*, which brought emergency management and scientific decision making into the management discipline, and provided a theoretical basis for emergency management research [1]. Haddow, G., Bullock, J., and Coppola, D.P. summarized the historical context and the present-day trend of emergency management, and provided significant practical, real-world experiences through documented case studies [2]. Van De Walle, B., Turoff, M., and Hiltz, S.R. described the developed process of the combination of information systems and emergency management, and presented several typical case analyses and practical technologies [3]. Comfort, L.K., Waugh, W.L., and Cigler, B.A. reviewed the changeable process of research and practice in emergency management in the public administration field and its impact [4]. Handmer, J. and Dovers, S. provided a policy and institutional framework for emergencies and disasters [5]. Seppänen, H., *et al.* discussed the critical information needs for cooperation, a method for describing communication, and the components of system trust in emergency operations [6]. Owen, C., *et al.* developed a four phases' teamwork model for complex multi–team coordination in emergency management [7]. Liu, L., *et al.* presented a risk-based framework for dynamic decision making for emergency management [8]. Those researchers made many research contributions. Additionally, many researchers have applied emergency management to different fields (*e.g.*, medical science [9], city management [8], educational management, and other areas [10]).

Some scholars have provided in-depth research regarding the emergency management of marine environmental pollution. Groner, M.L., *et al.* emphasized the necessity of surveillance for marine diseases and proposed several pieces of advice for marine disease emergencies [11]. Yoo, B., Oh, K., and Baek, J. studied emergency response systems and recovery apparatuses for oil spill accidents in marine environments and provided a developed oil diffusion apparatus to minimize casualties [12]. Kirby, M.F., Gioia, R., and Law, R.J. described eight principles of effective post-spill monitoring programs in marine environments [13]. Kristiansen, S. summarized classic analysis approaches and technologies to monitor marine pollution and predict resulting loss [14]. Although many researchers have produced numerous studies, marine environmental pollution is developing rapidly, and we need to continue recording experiences of marine pollution incidents and perfecting the theory of emergency management.

The research of game theory presents a strategy question; participants select a strategy when they confront, compete, or face the same situation. A game requires at least four elements: game participants, the collection of all strategies that are selected by participants, the sequence of the game, and the benefit of the game. Game theory entered the mainstream of economic research in the 1980s. The Nash equilibrium expanded game theory from cooperative to noncooperative, and the evolutionary game is an important branch of game theory from the 1970s. Game theory was gradually perfected from the 1980s to the 1990s and it became an important and core analysis method. Game theory is used in all aspects of economic theory (*e.g.*, dynamic noncooperative game [15] and Bayes-Nash equilibria [16]).

3. EVOLUTIONARY ANALYSIS OF GAME MODEL

3.1. Background

In June 2011, a CNOOC oil field encountered an oil spill accident in the Bohai Gulf. This oil field is a cooperative project between CNOOC and COPC. On July 5, 2011, CNOS (the Chinese National Ocean Service) reported the primary result of the oil spill accident in the Bohai Gulf and published related oil spill pictures of the Penglai 19-3 oil field [17]. In August 2011, the North Sea branch of CNOS gave a notice to the COPC, which is the responsible party, demanding that COPC submit a self-assessment report on schedule, apologize for the nonfeasance of the oil contamination, and be fined 200 thousand RMB, pursuant to Chinese environmental protection law [18]. In August 2013, ACEF (the All-China Environment Federation), a public environmental protection organization, questioned the two corrective reply and environmental impact reports provided by CNOS, and commenced administrative litigation in the first intermediate people's court in Peking. At the same time, social opinion condemned the accident. CCTV (China Central Television) 13 broadcast the accident. In April 2012, COPC and CNOOC paid a compensation claim of 3.03 billion RMB; COPC paid 2.3 billion and CNOOC paid 0.73 billion. Of this compensation, 1 billion will be used to address fishing damage and 2 billion will be used for marine ecology [19].

3.2. Evolutionary Analysis

3.2.1. The Game of CNOOC and COPC

From the CNOOC's perspective, the Bohai Gulf is rich in oil from geology, but the sea state is complex. CNOOC lacks the technologies for marine oil exploration, and, at the same time, China's rapidly developing economy shows a soaring petroleum demand, marine oil exploration has huge commercial interest, so cooperation with a stronger company is the inevitable choice.

COPC overdevelopment's benefit is P_{kf}, CNOOC's benefit is P_{as}=1.04P_{k*}, and this equation is based on the production share contract. Once CNOOC demands that the oil field be developed moderately, the total revenue of the oil field will reduce a; once COPC demands that the oil field develop moderately, its revenue will reduce b,and $a, b>0$. Thus, we can construct the CNOOC and COPC two dimension payoff table model, as shown in Table **1**.

Table 1. CNOOC and COPC benefit matrix.

Strategic Matrix		CNOOC	
		Overdevelopment	**Moderate development**
COPC	Overdevelopment	(P_{kf}, P_{zs})	(P_{kf}-a, P_{zs})
	Moderate development	(P_{kf}-b, P_{zs})	(P_{kf}-a, P_{zs})

According to the Nash equilibrium's definition and Table **1**, we can easily determine that (P_{kf},P_{zs}) is the Nash equilibrium solution. In a production share contract, CNOOC and COPC conspire to produce oil field revenue. In this situation, overdevelopment of the oil field is the inevitable choice in the Bohai Gulf. Thus, for Table **1**, we can conclude that COPC should make an overdeveloped decision in marine oil production.

3.2.2. Government and COPC Two-side Game Analysis

To reflect reality better, we bring government into the model. Because the CNOOC's revenue is the positive function of the COPC, the CNOOC will be omitted in the model.

We assume the cost of government supervising the production action is C_{gm}, the revenue of government from fines for COPC's overdevelopment is F_g, the governance cost for the government is C_{ge}, which is used to eliminate environmental pollution, the rate of government supervision of COPC is Z, the rate of COPC overdevelopment is Y, and the rate of finding overdevelopment is P_d. Thus, we construct COPC, and the government two-dimension payoff table is shown in Table **2**.

Table 2. COPC and government benefit matrix.

Strategic Matrix		Government	
		Supervision	**No supervision**
COPC	Overdevelopment	(P_{kf}-F_g*P_d, -C_{gm}+F_g*P_d-C_{ge})	(P_{kf}, - C_{ge})
	Overdevelopment	(P_{kf}-b, -C_{gm})	(P_{kf}-b, 0)

From Table **2**, we can find the revenue of COPC.

$$\pi_k = Y[Z * (P_{kf} - F_g * P_d) + (1 - Z)P_{kf}] + (1 - Y)[Z(P_{kf} - b) + (1 - Z)(P_{kf} - b)] \quad (1)$$

We can simplify the equation to arrive at equation (2).

$$\pi_k = -ZYF_gP_d + P_{kf} - b + Yb \quad (2)$$

The government's revenue is listed below.

$$\pi_g = Z[Y*(-C_{gm} - F_g * P_d - C_{ge}) + (1-Y)(-C_{gm})] + (1-Z)[Y*(-C_{ge}) + (1-Y)*0] \quad (3)$$

We can simplify the equation to arrive at equation (4).

$$\pi_g = ZYF_gP_d - ZC_{gm} - YC_{ge} \quad (4)$$

We take the partial derivatives of equations (2) and (4). We then arrive at equations (5) and (6).

$$\frac{\partial \pi_k}{\partial Y} = -ZF_gP_d + b \quad (5)$$

$$\frac{\partial \pi_g}{\partial Z} = ZC_{gp}P_d - C_{gm} \quad (6)$$

We compute the balance point, and thereby set equations (5) and (6) equal to 0, subsequently arriving at equations (7) and (8).

$$Z = \frac{b}{F_gP_d} \quad (7)$$

$$Y = \frac{C_{gm}}{F_gP_d} \quad (8)$$

Based on equations (7) and (8), their revenues are shown in equations (9) and (10).

$$\pi_k^* = \frac{2bC_{gm}}{F_gP_d} + P_{kf} - b, \quad (9)$$

$$\pi_g^* = \frac{C_{gm}C_{ge}}{F_gP_d}. \quad (10)$$

3.2.3. Government, COPC, and Societal Opinion form a Three-Side Asymmetric Evolutionary Game Analysis

Starting with the government and COPC two-dimensional model, we add society to the model. Society has two strategies; one is supervision and the other is no supervision. The probability of society supervising the COPC is *X*, and 1-*X* is the probability of not supervising. Under supervision, the revenue of society is N_p, and the probability of finding the COPC's overdevelopment is P_{dn}. Under the no supervision state, the revenue of society is 0, the loss of COPC for social opinion is $L_{kn}P_{dn}$, and the loss of government's nonfeasance for social opinion is L_{gn}; thus, the probability of being found for overdevelopment is $P_d \cup P_{dn}$, and we set it as P_{cd}. Therefore, COPC, government, and society will produce eight kinds of combinations: (overdevelopment, supervision, supervision), (overdevelopment, supervision, no supervision), (overdevelopment, no supervision, supervision), (overdevelopment, no supervision, no supervision), (moderate development, supervision, supervision), (moderate development, supervision, no supervision), (moderate development, no supervision, no supervision), and (moderate development, no supervision, supervision). The revenue of the first kind of strategy is $(P_{kf} - F_gP_{cd} - L_{kn}P_{cd}, -C_{gm} + F_gP_{cd} - C_{ge}, N_p)$, $(P_{kf} - F_gP_{cd}, -C_{gm} + F_gP_{cd} - C_{ge}, 0)$, $(P_{kf} - L_{kn}P_{cd}, -C_{ge} - L_{gn}, N_p)$, $(P_{kf}, -C_{ge}, 0)$, $(P_{kf} - b, -C_{gm}, N_p)$, $(P_{kf} - b, -C_{gm}, 0)$, $(P_{kf} - b, -L_{gn}, N_p)$, $(P_{kf} - b, 0, 0)$.

Thus, the revenue of COPC's overdevelopment is:

$$\pi_{k1} = (P_{kf} - F_g P_{cd} - L_{kn} P_{cd})XZ + (P_{kf} - F_g P_{cd})Z(1 - X) + (P_{kf} - L_{kn} P_{cd})(1 - Z)X + P_{kf}(1 - Z)(1 - X) \quad (11)$$

The average revenue of COPC is:

$$\overline{\pi_k} = (P_{kf} - F_g P_{cd} - L_{kn} P_{cd})XYZ + (P_{kf} - F_g P_{cd})ZY(1 - X) + (P_{kf} - L_{kn} P_{cd})(1 - Z)XY + P_{kf}(1 - Z)(1 - X)Y + (P_{kf} - b)XZ(1 - Y) + (P_{kf} - b)(1 - X)Z(1 - Y) + (P_{kf} - b)X(1 - Z)(1 - Y) + (P_{kf} - b)(1 - X)(1 - Z)(1 - Y) \quad (12)$$

Thus, the replicated dynamic equation for COPC which adopts the overdevelopment strategy is

$$F(Y) = \frac{dY}{dt} = Y(\pi_{k1} - \overline{\pi_k}) = Y[1 - Y][-ZF_g P_{cd} - XL_{kn} P_{cd} + b] \quad (13)$$

If $-ZF_gP_{cd}-XL_{kn}P_{cd} + b=0$, thus set $F(Y)\equiv 0$, which means that the balance is at all levels (*i.e.*, regardless of whether COPC adopts any strategy for oil and gas development, it will tend to equilibrium, and the result does not change as time varies).

If $-ZF_gP_{cd}-XL_{kn}P_{cd} + b\neq 0$, then set $F(Y)=0$, so $Y=0$ and $Y=1$ is its balance point, so the replicated dynamic equation has two stable states (*i.e.*, regardless of whether COPC adopts any strategy, the selection will go to the 0 and 1 points).

If we calculate the differential of $F(Y)$, according to the stability theorem, we get $\frac{dF(Y)}{d(Y)} = (1 - 2Y)(-ZF_g P_{cd} - XL_{kn} P_{cd} + b) < 0$, and if we make an analysis of each parameter, it reveals the results below.

When $Y=0$,if $Y = 0$, if $\left.\frac{dF(Y)}{d(Y)}\right|_{Y=0} < 0$, $Z > \frac{b - XL_{kn}P_{cd}}{F_g P_{cd}}$, we simplify this equation to get $Z > \frac{b}{F_g P_{cd}} - X\frac{L_{kn}}{F_g}$ 。.

When $Y=1$,if $Y = 1$, if $\left.\frac{dF(Y)}{d(Y)}\right|_{Y=1} < 0$, $Z < \frac{b - XL_{kn}P_{cd}}{F_g P_{cd}}$, we simplify this equation to get $Z < \frac{b}{F_g P_{cd}} - X\frac{L_{kn}}{F_g}$ 。.

From the analysis, we can obtain a relation curve; this curve shows a replace relationship, as is shown in Fig. (**1**).

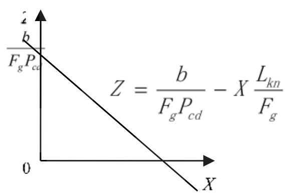

Fig. (1). Tripartite balance under the model decomposition function curve.

4. APPLICATION

If the production of the oil fields is 10,000 barrels, the price of one barrel is 100$, the average cost is 10$, so that the revenue is 90$ for one barrel, and the exchange of dollars into RMB is 6.22, F_g is 200 thousand RMB, new F_g is 3 billion RMB, C_{ge} is 120 billion RMB (which is determined based on the oil spill in the Gulf of Mexico), C_{gm} is 20,000 thousand RMB, L_{gn} is 20,000 thousand RMB, L_{kn} is 40,000 thousand RMB, P_d is one third, b is 2000 barrel, X is one third, $L_{kn}P_{dn}$ is 0.1 billion RMB, and Z is one third.

According to the above value, the optimal result from the two dimensions is $Y = \frac{C_{gm}}{F_g P_d}$. From equation (8), COPC revenue, government revenue, the probability of government finding the overdevelopment, and the cost of government have a functional relation. If, according to current Chinese environmental law, 200,000 RMB is the maximum fine for environmental pollution, the probability that COPC has an intention to make the overdevelopment decision is 300. If the maximum fine is 3 billion, the probability for overdevelopment is 2%, so a high fine can effectively prevent overdevelopment. Because the optimal point is influenced by three parameters, we can make a sensitivity analysis for them. As shown in Fig. (**2**), C_{gm} has a positive relationship with Y, and F_g, and P_d has a negative relationship with Y. When other parameters do not change, F_g must improve to 2 billion fines, which can significantly prevent overdevelopment. When other parameters do not change, P_d is 1, and the action of over-development will have a 100 percent chance of occurring. Through sensitivity analysis of the model's parameters, we find that improving F_g sharply is the simple and direct method to prevent oil companies from overdeveloping.

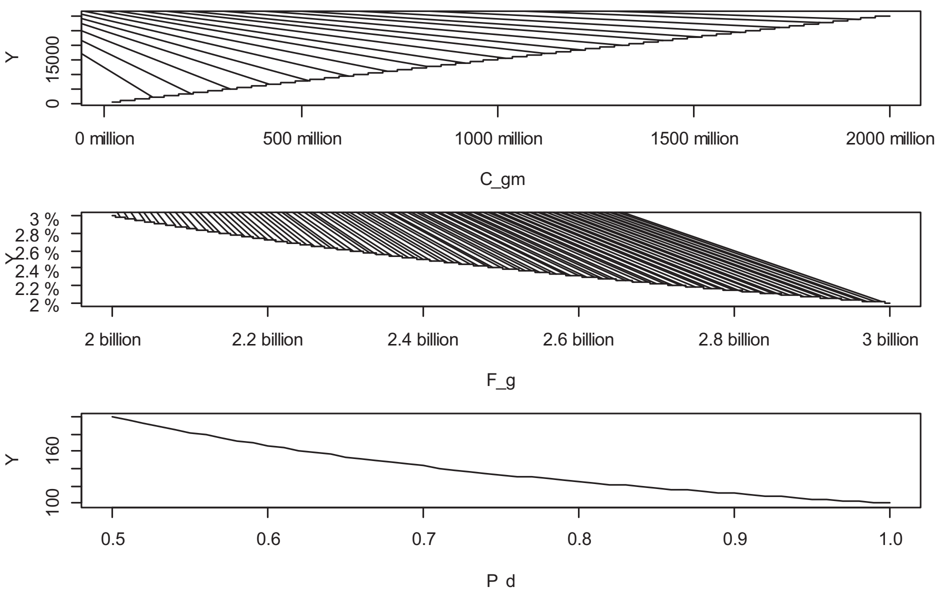

Fig. (2). The sensitivity analysis of three parameters of $Y = \frac{C_{gm}}{F_g P_d}$.

From the three-dimensional model, COPC production action will have two extreme points; one is absolute overdevelopment and the other is absolute moderate development, as shown in Fig. (**3**). From the above analysis, we can assume COPC is at the state of making the overdevelopment choice, Y is 1, and if we want to make the point unstable, the evolutionary strategy should satisfy $Z < \frac{b - XL_{kn}P_{cd}}{F_g P_{cd}}$; in that situation, we can transform the equation, $ZF_g + XL_{kn} > \frac{b}{P_{cd}}$. If the fine is 200 thousand RMB, then $\frac{1}{3} * 20 + \frac{1}{3} * 10000 > \frac{4.08654}{1/3}$ is false, so if we want COPC to make the moderate development choice, the fine should be 3.66 billion. This fine can make the overdevelopment points unstable, and a high fine will force COPC managers to make the moderate development decision.

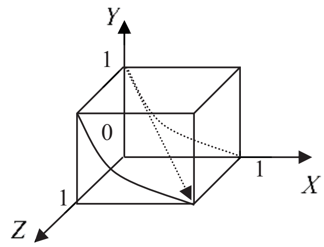

Fig. (3). ConocoPhillips balance transfer trajectory under punishment constraints.

CONCLUSION

The oil spill in the Bohai Gulf occurred as the necessary result of China's current international petroleum cooperation, and as the result of a multi-player game. The overdevelopment strategy of COPC will cause oil spilling, and it is the wise selection for COPC. From the above analysis result, enhancing the international petroleum cooperation contracts' selection, setting reasonable fines for overdevelopment and pollution, strengthening supervision of societal opinion for international petroleum cooperation, setting the industry credit admittance mechanism, and constructing an impartial, transparent, and efficient mechanism will reduce the overdevelopment and pollution of Chinese international petroleum cooperation. These research results can help industry superintendents handle and prevent a similar event.

We recommend strengthening the international petroleum cooperation's contracts' selection, and breaking the value chain of the local petroleum company and the international petroleum company. At the oil leak in Bohai Bay, the local petroleum company and the international petroleum company formed a community of interests through production share contracts; they behaved similarly in the subsequent accident process. Generally speaking, local petroleum companies should supervise international petroleum companies, but in this contract, it is easy to neglect this important responsibility, thereby harming the international marine environment. Contracts, like risk service contracts and pure service contracts, that can mitigate the risk, should be adopted.

We recommend increasing the fines for overdevelopment and pollution to add to the petroleum enterprises' costs for unlawful behavior. Currently, China's Environmental Protection Law specifies a maximum fine of 3 to 20 thousand RMB; this law cannot satisfy the needs of reality. From the analysis of two dimension game between COPC and government, we can see that whether COPC makes the overdevelopment decision depends on the government's fine, the probability of the government discovering the overdevelopment, and the cost of the government's supervision. From the analysis, we find that, if the fine is more than 0.6 billion, it can effectively suppress the trend of overdevelopment decisions by COPC. When societal opinion is added, the fine will be raised to 3.66 billion RMB. From this analysis, we can see that three-dimensional game analysis is better than two-dimensional game analysis.

We recommend strengthening the effect of societal opinion in supervising international petroleum cooperation. Installing industry credit admittance mechanisms and constructing impartial, transparent, and effective accountability mechanisms will be effective methods of preventing pollution and enhancing social responsibility. From the analysis, we see that government can improve the efficiency of supervision with the help of societal opinion. Especially today, societal opinions can decrease the asymmetry of government supervision, so that government must provide an avenue for societal opinions (*e.g.*, credit industry credit admittance mechanisms and impartial, transparent, and effective accountability mechanisms, which will give societal opinions a greater role in protecting our environment).

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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