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A game theory approach for corporate environmental risk mitigation

Yue Gao[a], Zhiwei Li[b], Fangming Wang[a], Fang Wang[a,c,*], Raymond R. Tan[d], Jun Bi[e], Xiaoping Jia[a,*]

[a] School of Environment and Safety Engineering, Qingdao University of Science and Technology, Qingdao 266042, China
[b] School of Chemical and Metallurgical Engineering, University of the Witwatersrand, 1 Jan Smuts Ave, Johannesburg 2001, South Africa
[c] Sino-German Engineering College, Qingdao University of Science and Technology, Qingdao 266061, China
[d] Chemical Engineering Department/Center for Engineering and Sustainable Development Research, De La Salle University, 2401 Taft Avenue, 0922 Manila, Philippines
[e] School of Environment, Nanjing University, Nanjing 210023, China

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ABSTRACT

Manufacturing companies face many environmental risk problems in their production process. Demands of safe production processes and strict environmental regulations drive companies to balance capital planning problems with minimization of risk constraints. Environmental pollution liability insurance (EPLI) could be a useful tool to mitigate these risks. Manufacturing companies generally prefer to spend less money on investments for risk minimization; on the other hand, insurance providers prefer to provide more alternatives to satisfy the needs of manufacturing companies and obtain as much benefit as possible. The interaction between a manufacturing company and a company providing EPLI may be modeled as a game between two players. This paper proposes a game theory approach for corporate environmental risk mitigation via EPLI. Parameters of the game theoretic model can be calibrated to achieve a desirable equilibrium. A pharmaceutical company case study is used to demonstrate the application of the proposed approach.

1. Introduction

Safety and environmental risk issues are important considerations in the chemical industry. The aim of environmental risk management is to determine an effective balance between the costs and benefits of a given course of action, and allow managers to choose an appropriate risk management plan. General risk management is based on the three fundamental questions proposed by Haimes (1991), namely:

- What can be done, and what options are available?
- What are the tradeoffs in terms of costs, benefits and risks?
- What are the impacts of current decisions on future options?

Environmental risk management is critical for normal production of manufacturing companies. Manufacturing companies are not only required to consider the obvious risks in production, but also they should pay attention to managing the potential risks that will occur in the future under budget constraints. Thus, the rational allocation of costs to prevent such obvious risks is an important management consideration (Wang et al., 2017). Other than the allocation of funds to ensure the normal operation of the company, another way of controlling risk is to minimize the potential risks via insurance, which can be provided by an insurance provider. Such a strategy is also an important means of environmental risk management.

Environmental liability insurance (also called pollution liability insurance) includes several major types of policies that can protect insurers from the burden of shouldering the cost of adverse environmental events by themselves. Like all other types of insurance, environmental liability policies aim to mitigate the risk posed by catastrophic events (Forrest and Wesley, 2008). Environmental pollution liability insurance (EPLI) is a kind of insurance, covering the violation of government environmental regulations that leads to legal liability for the polluter EPLI is based on the damage caused by a company's pollution accident to society, which can be regarded as the company's compensation liability (Zhao, 2015). Although in many emerging countries EPLI is still in its infancy, EPLI is already regarded as a mature strategy in solving problems of compensation for environmental pollution in developed countries. There are two main types of pollution insurance in developed countries: compulsory pollution insurance and voluntary pollution insurance. The former is widely implemented in the USA and Germany, where companies have been compelled to buy pollution insurance through law and government

* Corresponding authors.
E-mail addresses: Chgaoyue@126.com (Y. Gao), cnlizhiwei@126.com (Z. Li), wangf@qust.edu.cn (F. Wang), raymond.tan@dlsu.edu.ph (R.R. Tan), jbi@nju.edu.cn (J. Bi), jiaxp@qust.edu.cn (X. Jia).

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regulations. The latter allows companies to choose whether or not to buy pollution insurance; the practice has been adopted in some countries, such as France (Feng et al., 2014b).

In 2006, the Chinese government tried to promote environmental insurance development, and in 2008 the Chinese government started the trial application of EPLI in several cities and provinces, but progress has been slow. In recent years, because the new tort liability law has been in effect, more policies have been proposed to promote the implementation of EPLI. It provides a more favorable opportunity and a big market for the development of environmental liability insurance (Zhang and Xu, 2011). However, it is also predictable that China will face many challenges in applying this new policy tool. This is because it is clear that the preconditions for developing pollution insurance in China differ significantly from the experience of other countries. In China, there is a big gap between the level of economic development and the level or readiness of the environment insurance system (Shi, 2009). In order to construct a demonstration of implementing national pollution insurance policy, comparative case studies were carried out on voluntary (Chongqing City) and compulsory (Wuxi, Jiangsu Province) pollution insurance in 2015 (Feng et al., 2014a). In order to adjust to the change of actual demand, a new insurance product (safety and environmental pollution liability insurance) has been developed as a supplement to the existing system for environmental risk management (Yang et al., 2017). In the past three decades, China has experienced rapid economic growth and also witnessed dramatic growth in environmental problems related to the abuse of natural resources and poor control of pollution. Hence, EPLI, as a new market-based approach, will play an important role in protecting the environment and ensure the normal operation of manufacturing companies.

In production processes, many factors can lead to industrial accidents of different levels of severity. Furthermore, it is often difficult to analyze and quantify these risks. Manufacturing companies prefer to spend less money on the investments for obvious risk prevention. As a result, only the bare minimum fund is prepared for compliance to prevent these obvious risks and the company usually ignores potential risks in the production. Finally, it results in that the manufacturing companies tend to spend fewer budgets on the precaution of risks to achieve the minimum risk as possible. On the other hand, insurance providers prefer to provide more alternatives to satisfy the manufacturing companies based on the results of risk assessment and attain as much benefit as possible to minimize its probabilities to pay the loss and compensation costs of manufacturing companies. There is a conflict between the investment budget of manufacturing companies and the compensation cost paid by the insurance provider. This scenario leads to an interaction between two decision-makers with different and potentially conflicting objectives. Game theory can thus be used to investigate the behaviors of these players. Game theory provides a framework to analyze the interaction of these players for purposes of environmental risk management. It can balance the payment of manufacturing companies, benefits of insurance providers and the probabilities of risks.

Game theory is a powerful framework for the analysis of decision-making by multiple agents whose decisions will affect each other (Von Neumann and Morgenstern, 1944). It has been widely used in environmental risk management. For example, Franckx (2005) established a game model between multiple polluting companies and environmental enforcement agency. Tapiero (2005) proposed a game theory framework to determine an endogenous pollution probability and an environmental control policy. Dong et al. (2010) presented a game theory model to analyze the conflicts between a local government and a company causing pollution. Jin and Mei (2012) developed a game between the government and suppliers to seek optimal mixed strategies of the government and suppliers under equilibrium conditions. Zhao et al. (2013) showed how game theory could be applied to better assess the various strategies available to the government and manufacturers, so as to promote more environmentally friendly products through cleaner production. Zhao et al. (2016) proposed an evolutionary game model to investigate the potential responses of companies to incentives for the implementation of a carbon reduction labeling scheme. Jafari et al. (2017) established the game-theoretic models among the waste recycling process and obtained the equilibrium strategies for different power structures. Zhao et al. (2012) proposed game theory approach in the context of green supply chain management. Whalen et al. (2017) explored how learning about circular economy may be facilitated through the use of the serious game in the loop.

In addition to the applications listed above, game theory has also been widely used in economics. A game theoretic model consists of a set of players, a set of strategies and a set of payoffs (one for each player as a function of decisions made by the players) (Limaei, 2010). Industry and environment are often modeled as two players interacting within a policy framework. For example, in energy management, decision-making in industry have been evaluated in a game theoretic model (Aplak and Sogut, 2013). Game theory was used to examine the decision-making process in the context of environmental assessment (Bond et al., 2016). A waste management bargaining game was proposed as a decision support framework, within which future models can be embedded (Karmperis et al., 2013). Game theory has been applied in various fields, with different combinations of players or decision-makers. For example, Zhu and Dou (2007) developed an evolutionary game model to investigate the interaction between governments and companies in green supply chains. A similar study was done by Chen and Sheu (2009), who proposed a differential game model to design environmental regulation pricing strategies. Dong et al. (2010) presented a framework for analyzing the conflicts between a local government and a potentially polluting company using game theory.

In this work, a game theory approach is proposed to analyze the interaction between the production company and an insurance provider, considering both environmental risks and corresponding costs. The purpose of the analysis is to help these two players to balance reasonable capital investment and the insurance provider's income, and to achieve optimal allocation of funds to ensure environmental protection. The rest of the paper is organized as follows. Section 2 explains the methodology of this work. Section 3 demonstrates the application of proposed methodology for a pharmaceutical company. Finally, Section 4 concludes this work and suggests prospects for further research.

2. Methodology

2.1. Assumptions

Game theory is a mathematical framework for the analysis of the decision-making of multiple self-interested agents, whose choices will lead to mutual effects on each other's payoffs. It thus provides a basis for analyzing how policies affect the decision-making of the players. In this work, two players are involved in the analysis, i.e., a production company and an insurance provider. The proposed models are based on the following assumptions:

(1) The concept of environmental risk in this work is focused on the potential for causing environmental pollution. However, it does not include the risk of accidents. The aim of this work is to analyze how to encourage companies to buy EPLI under current conditions.
(2) In practice, the policy of a production company could affect the decision situation of neighbor companies. However, this work aims to analyze the interaction of the production company and the insurance provider only. The model does not consider the interaction of adjacent companies.
(3) In the model, it is assumed that the government does not give subsidies to the production company for EPLI. Although the local government may provide favorable policies to promote EPLI in order to construct a pollution insurance system, such measures are beyond the scope of this work.

Table 1
Game payoff matrix.

Production company's strategy (Player 1)	Insurance provider's strategy (Player 2)			
	1	2	—	n
1	(a_{11},b_{11})	(a_{12}, b_{12})	—	(a_{1n},b_{1n})
2	(a_{21},b_{21})	$(a_{22}b_{22})$	—	(a_{2n},b_{2n})
⋮	⋮	⋮		⋮
m	(a_{m1},b_{m1})	(a_{m2},b_{m2})	—	(a_{mn},b_{mn})

(4) When the production company plans to buy the EPLI, the insuance provider will make an assessment of the current risk based on the results of a third party. It is assumed there is no interest conflict between the production company and the third party. Extreme disruptions are not considered in this model, either (e.g., earthquake, war, etc.).

2.2. Payoff matrix

In this work, the economic benefits are the payoff of the production company (player 1) and the insurance provider (player 2). The possible actions/reactions of the game players are referred as "strategies". Based on the aforementioned assumptions, the payoff matrix ($m \times n$) is constructed, as shown in Table 1.

(1) There are two players in this model. Player 1 represents the production company. Player 2 is the insurance provider;
(2) The production company chooses 1 of m discrete strategies, while the insurance provider chooses 1 of n strategies.
(3) If the production company chooses its i^{th} strategy and the insurance provider choose its j^{th} strategy, the production company receives a payoff of a_{ij} and the insurance provider receives a payoff of b_{ij}. Thus, for a given combination of decisions, the combination of payoff is denoted as (a_{ij}, b_{ij}).

The definition of variables and parameters are illustrated in Table 2. For a particular industry, all input parameters are fixed. The EPLI provider can adjust the variables to influence the selection of alternatives for risk mitigation.

Different the production companies are subject to different levels of risk. For the insurance provider, the insured amount depends on the level of current risk of the production company. In order to develop a general product of EPLI, the insurance provider can provide alternatives for the production company to choose from. For example, the insurance provider could provide three alternatives (i.e., A, B, and C) based on potential risk. A, B, and C represent low, moderate and high level of risks, respectively. Each level is also associated with a different probability.

The payoffs of the production company and the insurance provider are given by Eqs. (1) and (2) respectively. The production company has the choice of buying insurance or not. However, the insurance provider does not have the option of providing no insurance service to the production company. But the insurance provider can provide a few alternatives to persuade the production company to buy EPLI, while getting as much benefit as possible based on the current risk profile of the production company. The payoff functions are shown in Table 3.

Table 2
Policy variables and input parameters in the model.

	Symbols	Notes
Parameters	L	The expected value of losses arising from multiple probabilistic adverse events.
	M	The insurance premium paid by the production company to the insurance provider
	N	The insured amount that the insurance provider is willing to bear
Variables	P	The probability of an event for a given risk level

Table 3
Game strategies matrix.

Players and strategies		Insurance provider Risk Level I
Production company	Buy insurance	(M+ L − N,N − M)
	Not to buy insurance	(L,0)

$$W_1 = M + L - N \tag{1}$$

$$W_2 = N - M \tag{2}$$

In the strategy matrix above, I indicates the set of risk levels. For example, in the illustrative example the insurance provider provides three alternatives for the production company (I = A,B,C). In general, the insurance provider can give more than three alternatives for the production company to choose from. The number of alternatives becomes case-specific and it depends on actual situation of the production company and the insurance provider.

In practice, the interaction of these two players is more complex. For example, the insurance provider cannot coverall of the losses if an adverse event happens; the compensation has a predetermined maximum value based on the insurance policy. In such cases, the difference of actual loss and maximum amount will be borne by the production company. If the adverse event probability is smaller (i.e., the actual loss of the production company does not exceed the maximum amount covered by the insurance policy), the insurance provider will only pay the actual loss.

In practice, the payoffs of these two players depend on the probabilities of risk. The payoff of the production company is expressed by Eqs. (3) and (4).

$$y = M\ (0 \le L \le N_{max}) \tag{3}$$

$$y = M + kP - N_{max}(N_{max} \le L) \tag{4}$$

The payoff of the insurance provider is given by Eqs. (5) and (6).

$$Y = -M + kP(0 \le L \le N_{max}) \tag{5}$$

$$Y = N_{max,}\ (N_{max} \le L) \tag{6}$$

Scenario 1: If the loss of the production company does not exceed the maximum amount paid by the insurance provider ($0 \le L \le N_{max}$), all the loss can be covered by the insurance provider, i.e., L = N. The payoff results are shown in Table 4.

Scenario 2: The loss of the production company exceeds the maximum amount paid by the insurance provider ($N_{max} \le L$), the insurance provider will only pay the predefined maximum amount, i.e., $N = N_{max}$. The deficient amount of cost is borne by the production company. The payoff results are shown in Table 5.

Where P is the probability of potential risk with a range between 0 and 1. P_A, P_B, and P_C are the probabilities of adverse events at Risk Levels A, B, and C, respectively; k_A, k_B, and k_C are the coefficients of specific risk level, representing the relationship between probability and loss for the risk level.

3. Illustrative example

3.1. Case description

In this section, a pharmaceutical company is presented to demonstrate the proposed methodology. The production process is described as follows. β-benzyl alcohol, the raw material, is fed into the reactor with sodium hydroxide and methyl ethyl benzene. The temperature is

Table 4
The game results of Scenario 1.

Players and strategies		Insurance provider		
		Risk Level A	Risk Level B	Risk Level C
Production company	Buy insurance	$(M_A, -M_A + k_AP_A)$	$(M_B, -M_B + k_BP_B)$	$(M_C, -M_C + k_CP_C)$
	Not to buy insurance	$(L_A,0)$	$(L_B,0)$	$(L_C,0)$

first raised to 95 °C. Afterwards, the reactor is then cooled to 57–59 °C and ethyl ether is discharged for subsequent distillation. During the nitration reaction stage, the temperature is reduced further to 0 °C, and the stream is filtered after the reaction to obtain the nitro compound. During the reduction reaction stage, the ethyl ether is dried using anhydrous sodium sulfate, yielding various amino compounds. Finally, at the hydrolysis reaction stage, the ethyl ether is removed through drying at 0 °C and pyrocatechol monoethyl ether is obtained by distillation and separation operation. According to site investigation of the production company, the countermeasure cost and criticality of each sub-event at different cost intervals are shown in Table 6 (Wang et al., 2017).

3.2. Game strategies

If the production company applies for insurance products, EPLI provider will ask a third party to assess the current risk profile of the production company. The insurance provider could classify the potential risks into many types, such as legal emergency rescue, personal injury, property loss, and cleaning (repair) cost. The share of different types of risks in the payment paid by the insurance provider is shown in Fig. 1. Based on the proportional distribution, the risk points are classified into different grades according to the degree (criticality) of risk. The concept of criticality signifies the extent to which a sub-event contributes to a major disaster (Ishizaka and Labib, 2014). And the calculation process and results are reported in another paper (Wang et al., 2017). The results are presented in Fig. 1.

From the insurance provider's point of view, it will redistribute all the risk points of the production company according to the capital distribution. The classification results of risk points in four sections are as follows:

a Legal emergency rescue;

Lack of reserve facilities for environmental emergency supplies (C1)

- Personal injury;

Lack of signs marking escape route, messy warning signs (A1)
Inadequate personal protective equipmen (A3)
Lack of safety awareness and flaws in security management structure (B1)
Lack of safety warning signs and protective equipment (B3)

- Property loss;

A number of damaged roads (A2)
No water level detection device (A4)
No intermediate tank storage (C2)

- Cleaning (repair) cost;

Accident emergency pool pumps are seriously eroded (A5)
No-organized emission source (B2)
Inadequate warehouse area for hazardous waste storage (C3)

Based on the data summarized in Table 6 and the redistribution of all the risk points, the criticality of the risk points at different grades are then reconfiguration. The insurance provider needs calculate the expenses it will incur. In other words, according to the capital distribution in four parts of the insurance provider, we calculate the payment of the insurance provider to the production company that is N. In this example, three risk levels A, B and C are considered. Risk Level A includes the points A_1, A_3, A_5, B_1, C_3. Risk Level B includes the points A_2, A_4, B_2, B_3, C_1, C_2. Risk Level C includes the points A_1, A_2, A_3, A_4, A_5, B_1, B_2, B_3, C_1, C_2, C_3.

The production company has the option of buying insurance or not from the insurance provider. The payoff matrix for the game is presented in Table 7.

3.3. Impact of risk probability

Now the payment from the specific company and the insurance provider are put into the game. Based on Table 6, the probability of different risk levels can be determined. The detail calculation process of the probability of different risk levels is expressed by Eqs. (7)–(9).

$$P_A = (P_{A1} + P_{A3} + P_{A5} + P_{B1} + P_{C3})/3 = 0.232 \tag{7}$$

$$P_B = (P_{A2} + P_{A4} + P_{B2} + P_{B3} + P_{C1} + P_{C2})/3 = 0.769 \tag{8}$$

$$P_C = (P_{A1} + P_{A2} + P_{A3} + P_{A4} + P_{A5} + P_{B1} + P_{B2} + P_{B3} + P_{C1} + P_{C2} + P_{C3})/3 = 1 \tag{9}$$

Based on Fig. 1, the insurance provider will distribute the insured amount according to the risk level. The calculations are as follows:

When the result of risk is located in Risk Level A, the payoff to the EPLI provider is:

$$N_A = (P_{A1} + P_{A3} + P_{B1})/(P_{A1} + P_{A3} + P_{B1} + P_{B3}) \times 500 \times 18\% + (P_{A5} + P_{C3})/(P_{A5} + P_{B2} + P_{C3}) \times 500 \times 37\% = 119$$

In Risk Level B, it is expressed as follows:

$$N_B = 500 \times 25\% + P_{B3}/(P_{A1} + P_{A3} + P_{B1} + P_{B3}) \times 500 \times 20\% + P_{B2}/(P_{A5} + P_{B2} + P_{C3}) \times 500 \times 37\% = 445.8$$

In Risk Level C, it is determined as follows:

Table 5
The game results of Scenario 2.

Players and strategies		Insurance provider		
		Risk Level A	Risk Level B	Risk Level C
Production company	Buy insurance	$(M_A + k_AP_A - N_{Amax}, N_{Amax})$	$(M_B + k_BP_B - N_{Bmax}, N_{Bmax})$	$(M_C + k_CP_C - N_{Cmax}, N_{Cmax})$
	Not to buy insurance	$(L_A,0)$	$(L_B,0)$	$(L_C,0)$

Table 6
The countermeasure cost and its criticality for each sub-event.

Cost interval	Sub-events	Countermeasure cost (CNY10,000)[a]	Criticality
Low	Lack of signs marking escape route, messy warning signs (A1)	0.2	0.125
	a number of damaged roads (A2)	2	0.332
	Inadequate personal protective equipmen (A3)	1	0.079
	No water level detection device (A4)	4	0.272
	Accident emergency pool pumps are seriously eroded (A5)	6	0.19
Medium	Lack of safety awareness and flaws in security management structure flaws (B1)	11	0.137
	No-organized emission source (B2)	56	0.623
	Lack of safety warning signs and protective equipment (B3)	79.8	0.24
High	Lack of reserve facilities for environmental emergency supplies (C1)	120	0.539
	No intermediate tank storage (C2)	184	0.297
	Inadequate warehouse area for hazardous waste storage (C3)	336	0.164

[a] CNY10,000 = US$ 1510.5740.

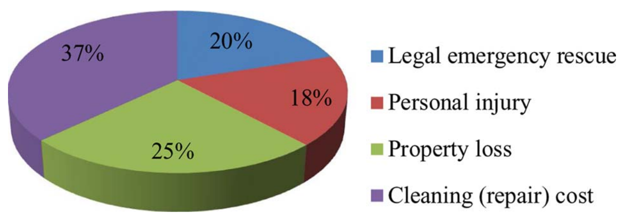

Fig. 1. The capital distribution of the insurance provider.

Table 7
Game strategies for the example.

Partners and strategies		Insurance provider		
		Risk Level A	Risk Level B	Risk Level C
Production company	Buy insurance	$(M_A + L_A - N_A, N_A - M_A)$	$(M_B + L_B - N_B, N_B - M_B)$	$(M_C + L_C - N_C, N_C - M_C)$
	Not to buy insurance	$(L_A, 0)$	$(L_B, 0)$	$(L_C, 0)$

$N_C = 500$

The list of payoff is as shown Table 8.

It is assumed that the production company's insured amount is CNY 50,000. Based on the different risk levels and the criticality of risk points, the insured amounts for different risk levels of the production company are CNY 12,000, CNY 38,000, and CNY 50,000, respectively.

3.4. Sensitivity analysis

Based on Tables 4 and 5, the payoffs of both players can be obtained for these two scenarios, as shown in Tables 9 and 10. The payoffs of both players are dependent on the probability of risk at corresponding risk level. As can be seen from Tables 9 and 10, if the production company is chosen the option of not to buy insurance, the payoff of the insurance provider is zero in these two scenarios. It does not need to pay for the loss of the production company and also has no benefit, whereas for the production company it suffers from the loss and pay for it by itself if the risks occur. In this case the loss of the production company is zero only if the probability is zero. If the production company chooses to buy the insurance product, it has different payoff in different scenarios. In scenario 1, the production company is required to pay the fixed cost to the insurance provider. The specific cost is related to the risk level. For the insurance provider the payoff is a function of the probability of specific risk level. On contrast, the payoffs of both players are reversed in Scenario 2. The payoff of the production company is relevant to probability of risks of corresponding risk level, while for the insurance provider it is a fixed amount.

Table 8
Summary of payoffs.

Unit of expense	Payoffs (CNY10,000)		
	Risk Level A	Risk Level B	Risk Level C
The expected value of losses arising from multiple probabilistic adverse events (L)	354.2	445.8	800
The cost of production company paid to the insurance provider (M)	1.2	3.8	5
The insurance provider expenditure (N)	119	381	500

Based on the results of Tables 9 and 10, the relationship of payoff and risk probability is presented with risk probability as the X-axis and the payoff (representing expenditure on both sides) as the Y-axis. For Risk Levels A, B, and C, the impact of risk probability on payoffs of both players are shown in Figs. 2–4.

For Risk Level A, the maximum payment provided by the insurance provider is identified as CNY 1,190,000 and the corresponding probability of risk is determined as 0.078. In Scenario 1, the payoff for the production company is constant, while for the insurance provider it increases gradually. The high cost means that the player have a high expenditure. As shown in Fig. 2, when P_A is less than 0.000786, the payoff is negative, indicating the insurance provider make net profit without any risks if the production company has bought the EPLI. When P_A is more than 0.000786 and less than 0.078, the insurance provider should pay for the loss of the production company with a varied probability. However, the payment is less than insurance product premium. Therefore, if the result of risk assessment recommended by the third party is between 0 and 0.000786, the optimal strategies for the insurance provider is provide the insurance product to the production company and try to persuade the production company to buy EPLI as possible. On the other hand, for the production company the loss is dependent on the probability of risk and is less than CNY 12,000, which is the payment of the insurance product. The actual loss is less than the payment for the insurance provider. The optimal strategy for the production company is not to buy the insurance product. If the results of risk profile are in the range of 0.000786–0.078, the same analysis procedure is repeated. In this interval, the preferential strategy for the production company is to buy the insurance product to mitigate the risks. For the insurance provider the payment is less than the predefined maximum payment with a low probability. Indeed, in this case it explained the significance of buying EPLI, spending fewer budgets but preventing serious consequence. Therefore, this interval is satisfied with both players. Because the production company can use the budget to mitigate the risks, while for the insurance provider the payment is less than predefined maximum amount and it has a low probability.

In the case of scenario 2, when the result of risk probability is between 0.078 and 0.232, the payoff for the insurance provider equals to the maximum payment (CNY 1,190,000). For the production company,

Table 9
The game results of Scenario 1 of illustrative example.

Partners and strategies		Insurance provider		
		Risk Level A	Risk Level B	Risk Level C
Production company	Buy insurance	$(1.2, -1.2 + 1526.7P_A)1526{\cdot}7P_A)$	$(3.8, -3.8 + 579.7P_B)579{\cdot}7P_B)$	$(5, -5 + 800P_C)$
	Not to buy insurance	$(1526.7P_A,0)$	$(579.7P_B,0)$	$(800P_C,0)$

the payoff has a gradual growth due to the loss caused by adverse events. When P_A is between 0.078 and 0.155, the payoff curve of the production company is below the insurance provider, it implies the compensate cost of the insurance provider is more than the actual loss of the production company. For the insurance provider it cannot do anything to reduce the loss caused by potential risk once the production company has bought the EPLI. When P_A is greater than 0.155, the payoff curve of the production company is above that of the insurance provider. It indicates that the actual loss of the production company is more than the maximum payment of the insurance provider. Therefore, in the range of 0.078–0.232, the strategy for the production company is to buy another EPLI with more compensate payment, while for the insurance provider it should provide an alternative with more compensate payment to attract this customer.

For Risk Level B, the maximum payment provided by the insurance provider is identified as CNY 3,810,000 and the corresponding probability of risk is determined as 0.657. The same procedure described in previous Risk Level A is repeated to analyze the optimal strategy of both players. In Scenario 1, when P_B is less than 0.006555, the insurance provider can make net benefit without any risks if the production company buys the EPLI. Therefore, in the range of 0–0.006555, the optimal strategy for the insurance provider is to persuade the production company to buy the EPLI as possible. However, for the production company the actual loss is less than the payment of the insurance product. It is not recommended for the production company to buy insurance. In the situation of $0.006555 < P_B < 0.657$, the insurance provider should pay for the loss of the production company which is dependent on the probability of adverse events. As shown in Fig. 3, the payoff curve of the insurance provider is above the production company. The payment of EPLI is greater than the expenditure of the production company. Therefore, in the range of 0.006555–0.657, it can satisfy both players. The reason is that the production company can use the low budget to mitigate the risks, while for the insurance provider the payment is less than predefined maximum amount. However, the upper bound of probability is 0.657. Therefore, the preferential strategy for the production company is to buy the insurance product. Meanwhile, for the insurance provider the best strategy is to provide an alternative product with higher insurance premium.

In scenario 2, when the result of risks is in the range of 0.657–0.769, the payoff for the insurance provider is the maximum payment CNY 3,810,000. For the production company the payoff is gradually increasing. The loss of adverse events occurred in the production company has exceeded the maximum payment of the insurance provider. But the total payment of the production company is less than the expenditure of the insurance provider. Although it can help the production company mitigates the risks, the insurance provider pays the loss at a high risk. Therefore, the strategy for the production company is to buy another EPLI to mitigate the risks, while the insurance provider should choose to provide a reduced compensate payment to decrease the expenditure.

For Risk Level C, the maximum payment and the corresponding probability of risk are identified as CNY 5,000,000 and 0.625, respectively. In Scenario 1, when P_C is less than 0.00625, the payoff for the production company is insurance product premium, while the insurance provider has a gradual increase of expenditure, but it is below the payoff curve of the production company. Furthermore, the insurance provider has a negative payoff, indicating it can make net benefit without any risks if the production company buys the EPLI. The optimal strategy for the insurance provider should try its best to persuade the production company to buy insurance product. However, for the production company the loss is dependent on the probability of risk and is less than CNY 50,000, the insurance product premium. The best strategy for the production company is not to buy the EPLI. Moreover, when the result of risk assessment is between 0.00625 and 0.625, the production company spends less money on EPLI but prevent the serious loss caused by adverse events. The result is similar to Risk Level B.

In the case of scenario 2, when the results of risk are in the range of 0.625–1, the payoff for the insurance provider is the maximum payment, CNY 5,000,000. The production company has a gradual growth trajectory of expenditure. The strategy for the production company is to buy another EPLI with more compensate payment to mitigate the risks, while the insurance provider should choose to provide a EPLI with a lower compensate payment and higher premium to decrease the expenditure.

The results of these three risk levels are presented in Fig. 5. We can see that the maximum expended value of losses of the production company's adverse events and the maximum payment of the insurance provider. At Risk Level A, it has a low probability and low expenditure. It also has the biggest difference between the maximum amount of compensation and the production company's maximum loss. It is advantageous to the insurance provider. Furthermore, at the interval (0.000786–0.078) of Risk Level A, the insurance provider has a low probability to pay for the loss, while the production company prefers to buy EPLI. Therefore, the insurance provider should provide EPLI at Risk Level A to the production company. For Risk Levels B and C, although there is a big gap between the maximum payment of the insurance provider and the expected maximum loss, it has a high probability to pay these costs.

In the case of Risk Level B, the production company has the smallest loss and the largest amount of compensation. The insurance provider's maximum amount of compensation and the production company's maximum loss have the minimum gap. The game results are most beneficial to the production company. So if the production company chooses to insurance the higher risk points (insure CNY 38,000), the

Table 10
The game results of Scenario 2 of illustrative example.

Partners and strategies		Insurance provider		
		Risk Level A	Risk Level B	Risk Level C
Production company	Buy insurance	$(1526.7P_A$ - $117.8, 119)$	$(579.7P_B - 377.2, 381)$	$(800P_C - 495, 500)$
	Not to buy insurance	$(1526.7P_A,0)$	$(579.7P_B,0)$	$(800P_C,0)$

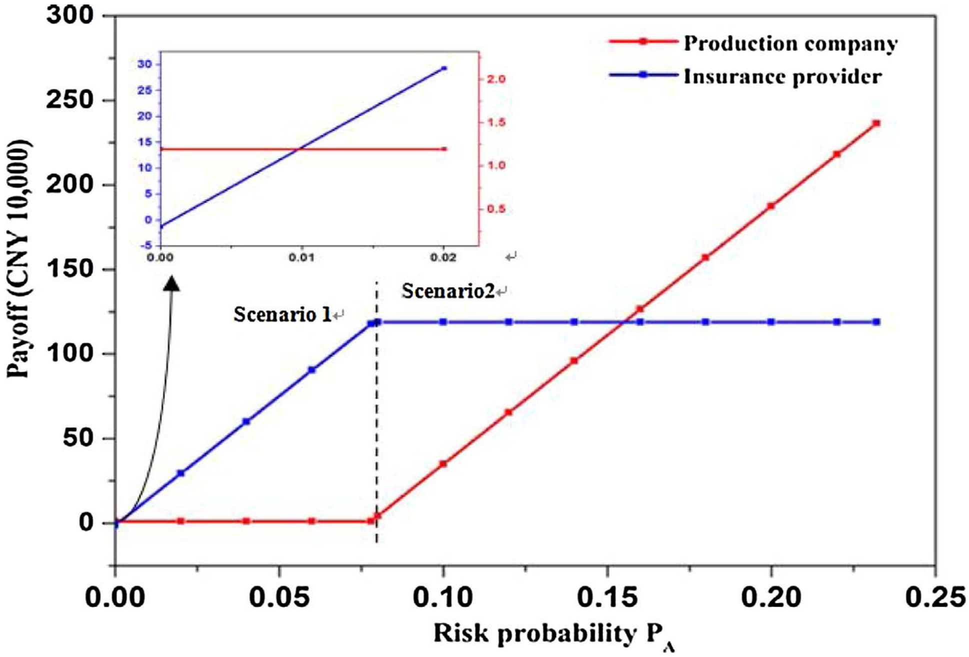

Fig. 2. Impact of risk probability on payoff to players at Risk Level A.

payment is most satisfactory. In the case of Risk Level C, the optimal situation on both sides of the game is achieved. The result suggests that the production company should subscribe to full insurance (insure CNY 50,000). It can ensure that the maximum operational safety of production companies make the insurance provider to obtain a reasonable amount of insurance.

4. Conclusions

As an important market-based approach for managing environmental risks, EPLI helps companies with high risk to prevent pollution and ensure compensation for victims when they fail. Due to the existence of various uncertainties in the pollution insurance market, the identification of the optimal allocation of financial costs within the production company for EPLI is difficult. In this paper, we considered a specific environmental risk game reflecting the decision making behaviors for two players (i.e. the production company and the insurance provider). A game payoff matrix is constructed and solved under different risk levels. From the game results, it can be seen that there are various game choices under different risk levels. This method can be used to analyze general interactions between production companies and insurance providers. In view of the advantages for both players at different risk levels, the two players of the game can choose the appropriate level of insurance. The impact of the risk probabilities on costs provided a set of potential EPLI policies to mitigate environmental risks.

Future work will consider the effects of interaction of adjacent companies on the manufacturing company. Also, the dynamic probability of each policy for each player will need to be taken into account. Finally, more factors should be considered in future work, such as government policies, the managerial preferences, etc.

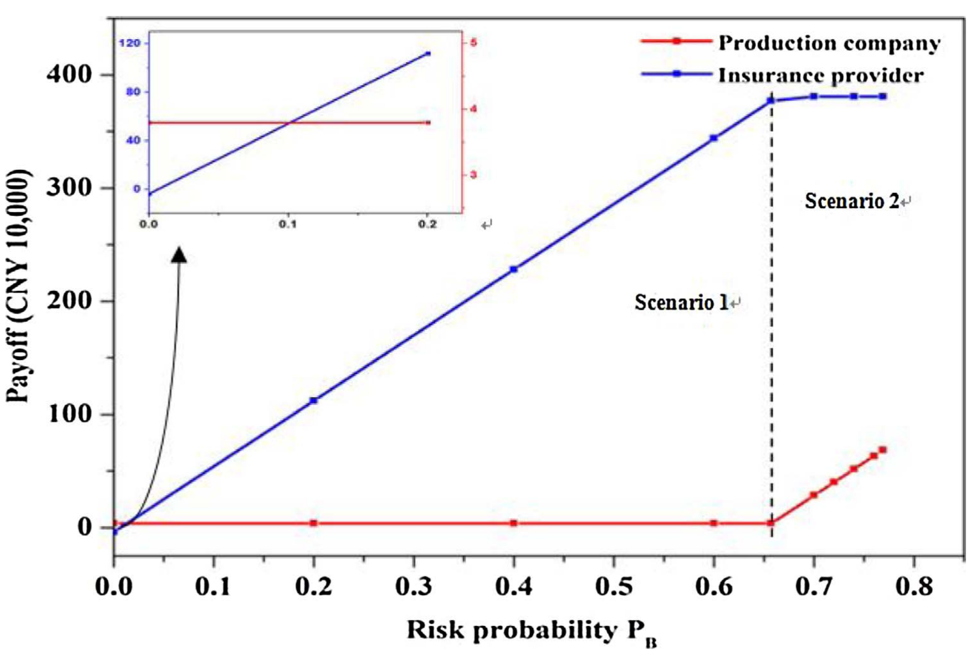

Fig. 3. Impact of risk probability on payoff to players at Risk Level B.

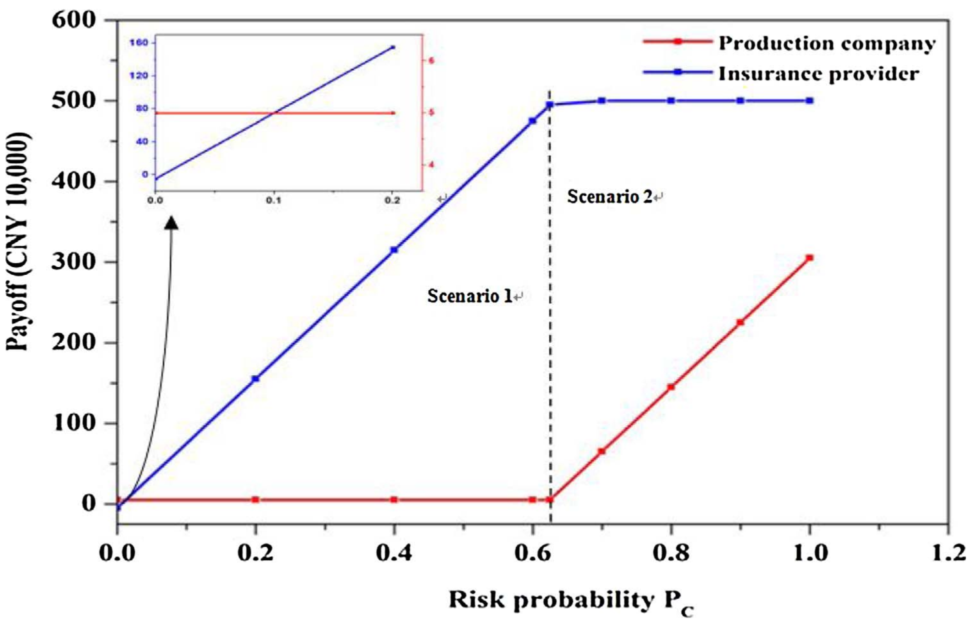

Fig. 4. Impact of risk probability on payoff to players at Risk Level C.

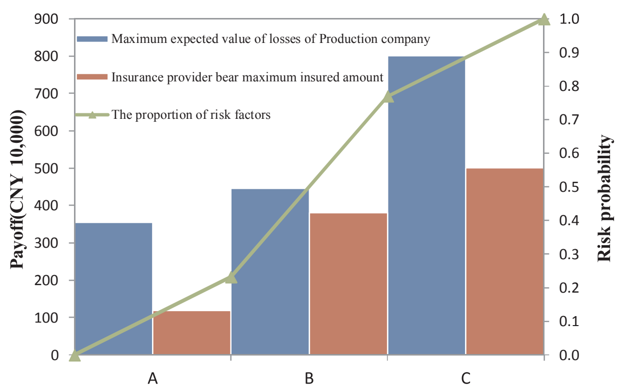

Fig. 5. The sensitivity analysis results of the game between the players.

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