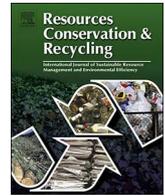




Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

A game theory approach for corporate environmental risk mitigation

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ARTICLE INFO

Keywords:

Environmental pollution liability insurance

Game theory

Environmental risk management

Risk mitigation

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

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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.

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