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Historical evolution and benefit–cost explanation of periodical fluctuation in coal mine safety supervision: An evolutionary game analysis framework

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ABSTRACT

The periodical fluctuation phenomenon appears in coal mine and other fields of government safety supervision. The paper provides a theoretical explanation by building an evolutionary game model between coal mine industry and governmental supervision institutions. Moreover, the paper provides a numerical example to demonstrate how the initial state and the costs (or gains) influence the fluctuation amplitude and the equilibrium position. We find that the initial state and the payoffs of different strategies are the two main determinants of periodical fluctuation phenomenon. The successful experience of coal mine safety supervision in China shows the importance of highly efficient government safety governance in developing countries.

1. Introduction

China is one of the biggest countries both in coal production and coal consumption. In the same time, it is also a country with a large number of coal mine accidents. The production safety problem is one of the hot topics most frequently discussed in the National People's Congress and Chinese People's Political Consultative Congress in recent years. According to one China Daily report, there were 1201 coal mine accidents killing 1973 people in 2011 in China. The mortality rate of per million ton coal production is 0.564 (Shi, 2012), which is the best record of coal mine safety production in the Chinese history. However, in the other major coal-producing countries in the world, for example, the United States, France, India, and South Africa, the occupational fatalities among coal miners have been significantly reduced through continuous efforts. At the beginning of the 21st century, the mortality rate producing one million tons of coal in the world ranged between 0.05 and 0.46. Moreover, in some developed countries, such as Canada, Germany, Britain, and Norway, the target of zero death coal mining has been achieved. The United States is the world's second largest coal-producing country. After the Mine Safety and Health Administration (MSHA) began to operate under the new Mine Safety and Health Act of 1977, safety in America's coal mining industry made significant progress, where only 20 miners died in coal mine accidents and the mortality rate producing one million tons of coal was only 0.025 in 2012.

In most of the developed countries, because coal mine tragedies leading to safety problems have been resolved satisfactorily, it is no longer a hot academic research topic. On the one hand, some literature reviewed the influences of coal mining injury in the United States (Komljenovic, Groves, & Kecojevic, 2008; Margolis, 2010), transnational comparative analysis (Chen, Feng, Long, & Qi, 2013), statistical analysis or some specific applications of coal mine safety technologies (Alpern & Lidbetter, 2013). On the other hand, in recent years, researchers are paying more attention to the other types of more challenging safety problems, such as earthquakes (Liu, Xu, Li, Zhang, & Wang, 2011), epidemics (Mamani, Chick, & Simchi-Levi, 2013), hurricanes (Zhuang & Bier, 2007), fire (Smith & Trenholme, 2009) and other natural disasters (He, Xu, Yang, & Liao, 2014), traffic accidents (Jalali & Noroozi, 2009), nuclear accidents (Wang, Chen, & Xu, 2013), medical assistance (Dobson, Hasija, & Pinker, 2011) and other engineering accidents (Bagchi & Paul, 2014); terrorism (Bakshi & Gans, 2010; Kaplan, Kress, & Szechtman, 2010), collective actions (Liu, 2010), and other social crises. Among them, game theory is one of the most frequently used methods, which can be used to investigate government rescues, crowd evacuations, material

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distribution and other decision-making problems during the disaster cycle of mitigation, preparedness, response, and recovery.

Due to the repeated effort of reorganization, basically the coal mine accidents in China have been curbed in the 2000s. However, the situation of safe production of the coal mine industry still faces a "grim" situation, and the problem of coal mine safety raised both the theoretical and practical interests in academic research. Being a powerful research tool of coal mine security supervision, game theory is widely used in analyzing the interactions among the central government supervision department, local government, coal mine operators and the miners (Hu & Liu, 2008; Li, Wang, & Liu, 2013). The basic assumption in those literatures is perfect information. However, in reality the actual asymmetric information often results in the rent seeking of local government officials in the process of establishing and reinforcing the safety regulations. Considering the asymmetric information between regulators and coal mine operators, Xiao and Zhao (2009) built a principle-agent model of coal mine safety regulations in China, and then analyzed the collusion behavior of the local government. Incomplete information games, and in particular information economics, focus on the efficiency loss problem derived from asymmetric information and the information disclosure problems. However, whether complete information or incomplete information games, the basic behavior hypothesis is still perfect rationality. When the safety supervision problem is analyzed in the paradigm of perfectly rational games, some important issues about time and institution could not be explained clearly, for example, the evolution of the regulatory system, the historical path dependence of a developing country, the stockholders' learning ability from coal mine disasters, and so on. Evolutionary games derived from the field of population biology in the 1980s provide a new analytical paradigm for the evolution of time-tested institutions (Anastasopoulos, 2012; Cai & Kock, 2009; Dutta, Sarmah, & Goyal, 2010; Xiao & Chen, 2009). The factor of time, which is more often referred to as the historical initial state and the corresponding "path dependence" phenomenon, and the institute that can be taken as exogenous given game rule or endogenous game equilibrium, are much more emphasized in the evolutionary game theory than in the traditional game theory (Friedman, 1998).

The periodical fluctuation of coal mine supervision is an interesting phenomenon in China, which has aroused the attention of many scholars. Xiao, Chen, and Qi (2011) examined the asymmetric effects of safety regulation fluctuations on coal production with a non-linear Smooth Transition Regression (STR) model based on the data of coal fatalities from 2001 to 2010. Nie, Jiang, and Wang (2013) tested how political cycles affect coal mine fatality based on a fixed effects panel data model that includes 2000–2010 monthly data of coal fatalities of 18 provinces in China. Although the periodical fluctuation of coal mine safety regulation has been verified by several empirical studies, there still lacks of an appropriate mathematical model to investigate the specific mechanism among the interactive decision-making of coal mine enterprises, government safety regulation, and the historical path dependence. Therefore there is a need to explain the periodical fluctuation of coal mine supervision theoretically. The paper provides a theoretical framework together with a numerical example to explain the phenomenon by establishing an evolutionary game model between the supervision institutions and coal mine operators. The relationship of the model with other existing models in the literature can be seen in Fig. 1.

The rest of the paper is organized as follows. In Section 2 we empirically analyze the periodical fluctuation of coal mine safety supervision in China. Section 3 proposes an evolutionary game model to explain the periodical fluctuation of coal mine safety supervision, where the analytical solution and numerical solution of stable equilibrium are obtained, respectively. Section 4 discusses two important determining factors in the periodical fluctuation of coal mine supervision, which are the historical initial state and benefit–cost of different strategies. Finally, Section 5 concludes with policy implications and suggestions.

2. Empirical analysis of periodical fluctuation of coal mine safety supervision

Being a major coal mine accident country, the Chinese government took severe measures continuously to shut down and reorganize a large number of small coal mines. As a result, the rising trend of coal mine accidents was curbed effectively during the years in the 2000s. However, the situation of coal production safety in China still faces complex situations due to the following reasons. First, as Wang (2006) pointed out that there have been certain unique features in the history of coal production in China. During the 1980s and the 1990s, the central government adopted a policy to promote coal production by all possible ways. When suddenly tens of thousands of legal or illegal small coal mines mushroomed all over China, the government then found that it was extremely difficult to regulate them, because the number and rate of fatalities of small coal mines were seven times higher than larger state coal mines. Second, regarding the quality of coal miners, the presence of a large number of untrained seasonal or migrant workers, the prevailing contract system, and unstable employment, have all contributed to safety problems in both the state mines and the small mines mostly owned by the private sectors. Third, when an excess supply of coal drives down the coal price in the mid-1990s, the state coal mines which already suffered heavy losses were desperate to reduce their costs by whatever means. As a result, one of the possible choices was to reduce safety investment. In small private-owned mines, there is an even stronger temptation for the owners to

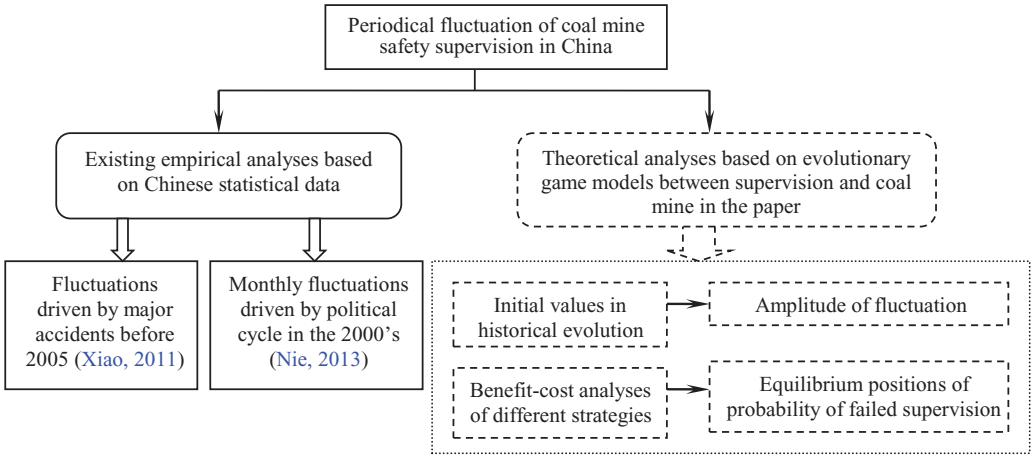

Fig. 1. Comparison of the existing literature and the paper.