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Evaluation of relative technological innovation capability: Model and case study for China's coal mine

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ABSTRACT

After decades of development, China has become both the largest producer and the consumer of coal in the world. The coal mine output has continued to increase, and the production capacity is expanding at an unprecedented rate. However, this level of the output had been accompanied by poor geological mining conditions, low efficiency, high pollution, and high fatality rates. Thus, in order to have healthy development in the future, it is necessary to establish a safe, efficient, and sustainable coal industry in China. This paper examines four key conceptual dimensions for relative technological innovation of China's coal mine: research and development, resource exploitation, organizational management, and financial management. We established groups of indicators reflecting the performance of coal mine's technological innovation activities in each dimension. After reviewing major approaches to increase capacity for innovation, we developed an index system based on Data Envelopment Analysis(DEA) to audit the progress of innovation and development. We performed a case study of twenty certified green coal mines, the result demonstrates that this index system and model can effectively evaluate coal mine's relative technological innovation capability and get the input gap towards safety, efficiency and sustainability.

1. Introduction

Technological innovation is playing an increasingly critical role in today's coal mine in China. The Chinese government has implemented a series of reform measures to guide the Chinese coal industry to move from an extensive mode of development to a kind of green development. Extensive development is the mode of growth in which industries expend inputs to increase output with high material consumption, high energy consumption and high pollution but with little consideration of the damage to the eco-environment (Liu, 2012). However, green development is characterized by the intensive growth mode. In the intensive growth mode, the industries increase their output by leveraging advances in science and technology and the improvement of labor quality, as well as implementation of modernization and scientific management. The American coal industry has crossed the extensive development (Michael et al., 2015). However, the Chinese coal mine industry needs to wisely manage development, since the mineral resources per capita are relatively insufficient; mineral quality conditions are not good; and lots of coal mines are difficult to exploit due to the natural environment.

In order to address these challenges, in 2010, the China Ministry of Land and Resources established the *Basic Requirements for National Level Green Coal Mines* (China Ministry of Land and Resources, 2010). According to these standards, a national green coal mine should meet requirements based upon nine different criteria including: compliance with legal standards, standardized management practices, rational use of resources, technological innovation resulting in energy savings and emissions reduction, environment protection, land reuse, maintenance of community harmony, and quality of enterprise culture. Technology innovation is one of the key requirements for green development in the coal industry. A national level coal mine should actively carry out technological innovation activities, continuously improve and optimize production processes, with strong emphasis on scientific and technological progress in order to develop a balanced economy.

In order to establish a modernized coal industry that is safe, efficient, and clean, China has to seek new ways of development through changing the traditional modes of production that are characterized as “high production, high damage, low safety, and low efficiency”. Technological innovation is a key factor in the successful transformation of a coal mine to the green mode (Darmstadter, Kropp, 1997). In recent years, the coal industry has seen many improvements in mining technology and equipment. These technological innovations are

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promising for improving production rates while reducing mortality rates and pollution levels. Still, when compared to other industries, such as electronic industry, the level of technological innovation in the coal industry lags far behind (Hou et al., 2006). Research based resource allocation, production efficiency, and a fundamental commitment to the improvement of workplace safety and environmental protection in coal industry are still at a low level. In order to develop the conceptual framework to evaluate progress towards developing the capacity to transform China's mining industry from its current state into a healthy sustainable industry, it is important to define the meaning of technological innovation capability and its components, as well as to establish a quantitative evaluation index system to help Chinese coal mines improve innovation activities and develop their capacity for innovation in a systematic way.

Evaluating industrial competitiveness is very important for any enterprise operating in the global market and influences the formulation of its R&D strategy, design process flow, and marketing (Oral, 1986; Oral and Reisman, 1988; Oral, 1993; Porter, 1980; Porter, 1981; Pun et al., 2004). Many researchers have been studying technological innovation capability in the past decades. In the early 1960s, Kuznets (1962) observed that the largest obstacle for understanding the economic effects of innovative activities was people's limited knowledge of how to define and measure it. Panda and Ramanathan (1996) classify technological capability into four areas; research and development capability, strategic capability, supplementary capability, and tactical capability. They believe research and development capability is the core of technological innovation capability, which helps to activate innovation in an enterprise. They also point out that technological innovation capability should be a set of comprehensive features that support enterprise development strategy, including the use and allocation of resources, ability to understand the development of the industry, the ability to understand technology development, structural and cultural conditions, and strategic management capabilities. Christensen (1995) pointed out human resources is the key to activating an enterprise's technological innovation capability. Based on this viewpoint, the impacts of technical staff, senior technicians' skills, technology systems, and management ability, as well as the influence of employee values on technological innovation capability should be emphasized. The mutual interaction among these capabilities determines the final technological innovation capabilities that an enterprise will possess. Riyanto et al. (2009) believes enterprise's capability for technological innovation is an integrated system of capabilities that is constituted by a number of factors. Innovation is a process that integrates research and development, design and industrialization, procurement, supply, and manufacturing, sales, and general management. He defined innovation as the development and successful implementation of new or improved product.

Data envelopment analysis (DEA) uses a mathematical programming model to estimate best-practice frontiers without a priori underlying functional form assumption through computing multi-input/multi-output values (Guan et al., 2006a, b). After Charnes et al. (1978) developed the first CCR DEA model in 1978 many different DEA models appeared in the literature (Cooper et al., 2000; Cui et al., 2015; Seiford and Zhu, 1998; Wu et al., 2013; Zhu, 2003). The DEA model can be used to optimize the performance measure of each decision making unit (DMU). DEA computes the performance measurement in the maximum range for each DMU. DEA has been widely used in different industrial sectors in the area of industrial management for performance evaluation and benchmarking studies. For example, Zhu (2000) employed DEA to explore the multi-dimensional financial performance of Fortune 500 companies. In this paper, we focus on figuring out the relative technological innovation capability and the improving direction for China's coal mines. We want to get the capability scale through analyzing the output with respect to the input of each coal mine. So the DEA, a non-parametric model, is suitable in this case.

Thus, it is full of significance to measure the multi-factor competitive performance of a coal mine enterprise with DEA, if a similar framework of analysis is adopted. This paper, based on the analysis of industry-specific features of the technological innovation process, develops a methodology to evaluate technological innovation capability of the coal mine, which in turn, may help coal mine strengthen innovation management and to advance its relations with the production sector. This methodology enables identification of indicators that clearly define the capabilities needed to stimulate successful innovation. Innovation capability indicators and competitiveness indicators will be taken respectively as inputs and outputs of the DEA model. Conceptually speaking, coal mining technological innovation capabilities are built on the perspective of resources and capabilities. These are dynamic capabilities that operate within the framework of the enterprise development strategy. The data envelopment analysis (DEA) model was developed to analyze the data collected from 20 coal mines in China. The results show that this index system can effectively evaluate coal mine technological innovation capability and provide a reference point for future studies.

2. Methodology

2.1. Configuration of technological innovation capability of coal mine

As mentioned previously, the elements of technological innovation capability of coal mine are best analyzed from multiple conceptual viewpoints. We analyzed all the main factors related to technological innovation capability with system dynamic model in the research program sponsored by China's Ministry of Land and resources(Grant No. 201211003). Based on the outcome of system dynamic model, this study divides technological innovation capability into four parts: R&D capability, resource capability, organizational management capability, and financial capability. As this study focuses on evaluation model and case study, we missed the system dynamic model.

R&D capability: The inputs and configuration of technology resources indicate the R&D capability which includes basic research and applied research. Basic research is a kind of experimental or theoretical work that is used to acquire new knowledge of basic principles regarding to mine safety and efficiency. Basic research, by definition is not for any special or specific application or usage, neither for any business purpose. Rather, it is a kind of exploratory research that may results in longer term discoveries that gradually lead to the advancement of technology. Applied research in coal mining and processing is a kind of creative inquiry that is engaged in finding solutions to specific problems. Thus applied research is targeted at improving results which are, in turn connected to increase competitiveness and profits. Applied research is the systematic work that builds upon knowledge (often produced by basic research) to develop new products or improve processing technology and services. It is useful to evaluate the R&D capability of coal mine by measuring the capabilities of both basic research and applied research. In this study, main evaluation indices are created in five categories, including the number of R&D platforms, the number of science and technology awards, the number patents and peer-reviewed academic contributions, and finally by technology export earnings.

Resource exploitation capability: Resource exploitation capability is the ability of transforming the research result into practice resulting in safe, efficient, clean, and sustainable mining. It includes mining efficiency capability, safe and clean production capability, and supporting capability. The evaluation indices are the mortality per million tons (safety), energy consumption level (efficiency), and green coverage ratio (clean and sustainability).

Organizational management capability: The organizational management capability of coal mine is the strategic ability to arrange and organize technological innovation activities to achieve positive outcomes. A coal mine with strong organizational management capability has enthusiasm for promoting innovation activities, coordinating different departments, and reducing the risks and uncertainties involved with