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Green total factor productivity of China's mining and quarrying industry: A global data envelopment analysis

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ABSTRACT

China's mining and quarrying industry is characterized by "high pollution, high energy consumption, and high emissions." Improving this sector's green total factor productivity (TFP) is of great importance for furthering the sustainable development of China's economy. Using a global data envelopment analysis (DEA), this paper analyzes the green TFP of China's mining and quarrying industry for the period of 1991–2014 with regard to technology, scale, and management. The following results are found. First, during the sample period, the green TFP of China's mining and quarrying industry increased by 71.7%. Technological progress was the most important contributor, and the decline in scale efficiency and management efficiency were two inhibitors. Fortunately, in recent years, management efficiency has gradually improved and become a new impetus for green TFP growth. Second, the characteristics of the green TFPs in the sub-industries vary considerably. During the sample period, the green TFPs of the mining and processing of ferrous metal ores (MPFMO), the mining and processing of non-ferrous metal ores (MPNFMO), and the mining and processing of nonmetal ores (MPNO) grew rapidly and became the benchmarks, whereas those of the mining and washing of coal (MWC) and the extraction of petroleum and natural gas (EPNG) remained very low. Third, the returns to scale of the sub-industries also varied. EPNG, MPNFMO, MPNO were in the stage of increasing returns to scale or constant returns to scale during the entire period, whereas MWC and MPFMO have recently entered the stage of decreasing returns to scale.

1. Introduction

Energy and minerals are vital factors for social and economic development, especially in the context of China's urbanization and industrialization. However, the depletion of resources and severe environmental problems call for a greener development mode in all walks of life, especially in the mining and quarrying industry, which is the fundamental sector of China's industrial economy. As shown in Fig. 1, the mining and quarrying industry took up an increasing share of both industrial output and China's gross domestic product (GDP) from 1991 to 2014, and in Fig. 2, it can be seen that the final energy consumption of the mining and quarrying industry rose by 4.77% annually from 1991 to 2014, with an annual growth of 4.35% in CO_2 emissions. In addition, according to the China Statistical Yearbook 2015, energy intensity in the mining and quarrying industry was 0.19 t of standard coal equivalent per ten thousand yuan at current prices in 2014, which was far beyond the nation's average level. To some extent, the above facts indicate that the rapid development of China's mining and quarrying industry is driven by an extensive mode.

Thus, the aim of this paper is to investigate the characteristics of green total factor productivity (TFP) using global data envelopment analysis (DEA). This paper's main contributions are as follows. First, it establishes slacks-based global DEA models to calculate the green TFP of the mining and quarrying industry. These models can help identify the features and the changing trends of the mining and quarrying industry's green TFP from 1991 to 2014. Second, this paper decomposes changes in green TFP by using the global Malmquist (GM) index. This decomposition can help identify the key factors responsible for green TFP changes in the mining and quarrying industry. Third, this paper reveals the returns to scale, the input redundancy, the output insufficiency, and the over-emissions of the sub-industries of the mining and quarrying industry. This information is meaningful for determining the path to improving the green TFP in China's mining and quarrying industry.

The rest of this paper's framework is organized as follows. Section 2 is a review of the available literature. Section 3 illustrates the methods used in this paper. The slacks-based global DEA models used to calculate the green TFP are introduced in 3.2, and a decomposition of the

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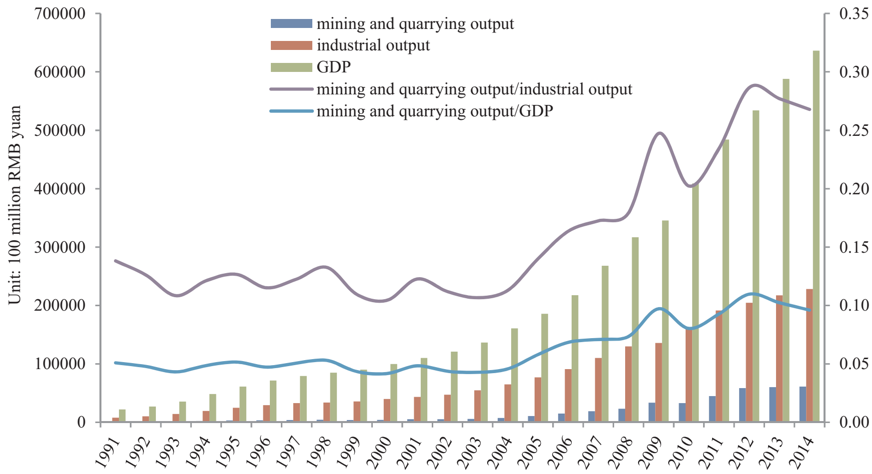

Fig. 1. Changing trends in the proportion of China's mining and quarrying output as a share of industry output and GDP. Data resource: the China Statistical Yearbook (1992–2015).

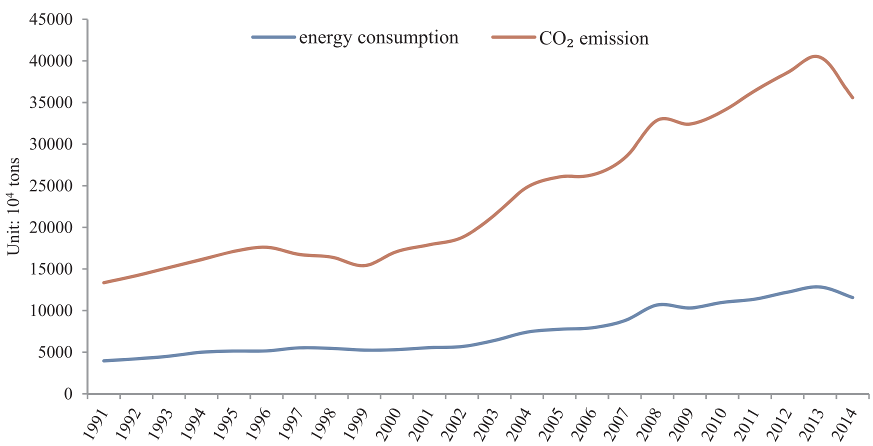

Fig. 2. Energy consumption and CO_2 emissions of China's mining and quarrying industry from 1991 to 2014. Data resource: the China Statistical Yearbook (1992–2015).

green TFP by using the GM index is described in 3.3. In Section 4, variable selection and data resources of the empirical study in this paper are described in detail. Section 5 presents and discusses the empirical results. Conclusions and corresponding policy implications are provided in Section 6.

2. Literature review

Total factor productivity (TFP) is a useful tool for measuring economic sustainability (Krugman, 1994; Prescott, 1998; Hulten, 2001). Numerous scholars have explored sustainability-related issues in countries or industries based on TFP. The literature divides the methods for measuring TFP into two categories: parametric methods and nonparametric methods. Parametric methods mainly consist of the estimation of classical or stochastic cost and production functions (Aigner et al., 1977; Lin and Wang, 2014; Shabanzadeh-Khoshrody et al., 2016), whereas nonparametric methods mainly refer to DEA. Superior to parametric methods, DEA methods do not require setting the functional form of the model in advance and can take various inputs and outputs into consideration (Johnes, 2006). Thus, an increasing number of scholars have applied DEA to measure productivity and efficiency (Zhou et al., 2008).

For example, using DEA, Krüger (2003) measured the TFP of 83 countries from 1960 to 1990, and the results showed that the TFP of most of the country groups (except Asia) decreased after 1973. Barros and Alves (2004) applied DEA to analyze the TFP of Portugal's publicly owned hotel chain for the period 1999–2001 and found that few hotels achieved TFP improvement during that period. Coelli and Rao (2005) examined the agricultural TFP in 93 developed and developing countries from 1980 to 2000 based on DEA and found that Asia was the leading performer, with 2.9% annual TFP growth, whereas Africa was the worst performer, with only 0.6% annual TFP growth. Abbott (2006) estimated the TFP of the Australian electricity supply industry through the DEA Malmquist approach, and the results indicated that the TFP of the industry had been increasing since the mid-1980s. Lin and Liu (2012) calculated China's TFP using an output-oriented DEA and then decomposed the TFP of each year into technological progress and efficiency change. Other TFP-based studies have also been summarized by Beveren (2012).

One common feature of the above studies is that they simply ignored byproducts/undesirable outputs (e.g., CO_2 emissions). Thus, their estimations may be biased (Jaffe et al., 2005; Kumar, 2006; Li and Lin, 2015). To overcome this defect, an increasing number of scholars have attempted to incorporate byproducts/undesirable outputs into the total factor framework. For instance, treating SO_2 emissions as the undesirable output, Yaisawarng and Klein (1994) measured the green TFP and explored the effects of SO_2 controls on the change in the productivity of the American electric power industry. Cao (2007) treated environmental damage as the undesirable output to measure the green TFP growth of China's manufacturing sectors. Incorporating CO_2 emissions

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