Resources Policy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Resources Policy

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

Analysis of green total-factor productivity in China's regional metal industry: A meta-frontier approach

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ARTICLE INFO

Keywords:
Meta-frontier
DEA
Technology gap
Green total-factor productivity
Metal industry
China

ABSTRACT

Nowadays, the metal industry has become an important source of China's energy consumption and environmental pollution. With the tightening of resources and environmental constraints and the calls for green development, transforming the development mode and improving green total-factor productivity (TFP) of China's metal industry become the only way to help China get out of the dual dilemmas of resources depletion and environmental degradation. By applying a meta-frontier approach, this paper investigates the sources of green TFP changes and its inefficiency of China's metal industry during 2000–2015, from regional and provincial perspectives. The results show that: (1) green TFP in China's metal industry increased by 11.52% annually. Technological progress is the most critical driving factor and the reduction of regional technology gap plays a certain role in promoting green TFP growth, while declines in scale efficiency and pure technical efficiency are two inhibitors; (2) the current green TFP of China's metal industry is relatively low and green TFP inefficiency mainly comes from three aspects, i.e., technology gap, scale inefficiency, and pure technical inefficiency; (3) Because the sources of green TFP inefficiency in metal industry and the potential for green TFP gains show distinct spatial characteristics, this paper takes a further step to formulate specific strategies for metal industries in each of China's provinces to improve their green TFPs, from three aspects of bridging the technology gap, adjusting industrial scale, and upgrading management level.

1. Introduction

Since the reform and opening up, the great development of China's metal industry has supported the rapid development of urbanization and industrialization in China, but it has also paid great resources and environmental costs (Wang and Feng, 2018). In the extensive mode, the mining and processing, the smelting and pressing, and the manufacture of metal mineral resources on one hand consume a large amount of energy resources, and on the other hand, they also bring serious air, water and soil pollution. According to NBSC (2017), in 2015 China's metal industrial (including mining, smelting and manufacture) output value accounts for 14.87% of the whole industrial output value. However, its energy consumption accounts for 36.65% of the total industry and its discharges of waste gas, wastewater, and solid waste respectively accounts for 32.69%, 12.17% and 50.12% of the whole industry. Undoubtedly, the metal industry in China is labeled by “high energy consumption and high emissions”. The resources and environmental problems caused by this extensive development mode have constituted serious threat to the further sustainable development of China's metal industry, as well as the nation's metal resources security and ecological security. In this context, transforming the development mode and improving green total-factor productivity (TFP) become the only way to help China's metal industry get out of the dual dilemmas of resources depletion and environmental degradation.

This paper tries to answer the following questions: what are the “gains” and “losses” of China's metal industry in promoting green TFP in the past few years? What is the current status of green TFP and its inefficiency in China's metal industry? And how can we further improve green TFP and promote the sustainable development of China's metal industry? For this purpose, this paper applied a meta-frontier data envelopment analysis (DEA) to investigate the driving factors of green TFP changes and the sources of green TFP inefficiency in China's metal industry for the period of 2000–2015. The study's main contributions can be summarized as follows: (i) its analysis of the driving factors for green TFPs in China's regional metal industry during 2000–2015, from four aspects of technological progress, technology gap, scale efficiency, and pure technical efficiency. The analysis could help us clarify the “gains” and “losses” of China's metal industry in promoting green TFP;

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https://doi.org/10.1016/j.resourpol.2018.05.008
Received 5 March 2018; Received in revised form 21 April 2018; Accepted 14 May 2018

(ii) its reveal of the sources and the spatial characteristics of green TFP inefficiency in China's regional metal industry. This could help us grasp the current status and features of green TFP and its inefficiency in China's regional metal industry; (iii) its formulation of specific strategies for metal industries in each of China's provinces to improve their green TFPs, from three aspects of bridging the technology gap, adjusting industrial scale, and upgrading management level.

The remainder of the study is as follows: Section 2 is the literature reviews. Section 3 introduces the meta-frontier DEA measure for green TFP and the global meta-frontier Malmquist index for decomposing its changes. Section 4 details the panel data (including its sources and processing process) for China's provincial metal industry during 2000–2015. The empirical results of the study are presented and discussed in Section 5. And the main conclusions and corresponding policy implications are given in Section 6.

2. Literature review

Nowadays, TFP has been widely used for investigating the sources of economic growth and the sustainability-related issues of economy and society. In the existing TFP studies, there are two main TFP indicators: the traditional TFP indicator and green TFP indicator. In the early traditional TFP indicator based studies, scholars only take traditional inputs (e.g., capital and labor) and desirable outputs (e.g., gross output) into consideration. For example, Nishimizu and Page (1982), Wen (1993), Färe et al. (1994), Wu (2000, 2003), Coelli and Rao (2005), and Chen et al. (2008) examined sustainability-related issues of various economies based on traditional TFP indicators. That's to say, they all ignored the importance of resources inputs and the environmental impacts. Because resource conservation and emissions reduction should be two main connotations of sustainability and green development, the neglect of them could mislead the true sustainability of an economy (Chen and Golley, 2014).

In response, increasing number of scholars tried to incorporate resources inputs and the environmental impacts into TFP framework to obtain green TFP (Zhou et al., 2008; Song et al., 2012; Sueyoshi et al., 2017; Emrouznejad and Yang, 2018). For example, by taking energy inputs and several environmental pollutants (e.g., chemical oxygen demand) into consideration, Chung et al. (1997) and Hailu and Veeman (2001) respectively estimated the green TFP of Swedish and Canadian pulp and paper industries; Kumar (2006) explored green TFP of 41 developing and developed countries during 1971–1992 by incorporating energy input and CO_2 emissions into TFP framework; Zhang et al. (2011) applied the DEA-based Malmquist–Luenberger index for green TFP measure of China's provinces during 1989–2008 by incorporating an integrated environmental factor as an undesirable output; Mahlberg et al. (2011) investigated the driving forces of green TFP changes in 14 EU countries by taking greenhouse gas into account; Chen and Golley (2014), Li and Lin (2015), and Yang et al. (2017a, 2017b) measured the green TFP of China's industrial sectors; Wang and Feng (2015), Li and Lin (2016), and Song et al. (2017) examined green TFP of China's regional economies; Tian and Lin (2017) investigated the green TFP of China's industrial exports.

Considering the importance of metal industry in China's economic development, issues on TFP of this sector have attracted attentions from more and more scholars in recent years. The research objects of the existing studies can be roughly divided into three categories, i.e., regional, industrial, and enterprise levels. At enterprise level, Ma et al. (2002) investigated the TFP changes of China's 88 iron and steel enterprises during 1989–1997 by taking gross output as output and labor, energy, and capital as inputs; Wei et al. (2013) chose total assets, operating expenses, and the number of employees as inputs, the total revenue, asset turnover ratio, and return on equity as outputs for TFP measurement of China's 42 nonferrous metal enterprises. The results show that pure technical inefficiency is the main sources of nonferrous metal enterprises' TFP inefficiency; He et al. (2013) incorporating wastes (waste water, gas, and solid) as the undesirable outputs for measurement of green TFP of China's 50 steel enterprises and found that technological progress is the key driving force of green TFP growth of China's 50 steel enterprises for the period of 2001–2008; Wu et al. (2017) built a two-stage network DEA for measuring efficiency of steelmaking stage and water treatment stage of China's 30 steel mills and found that the inefficiencies of steel mills come mainly from the steelmaking stage.

In addition to the above studies on TFP of China's metal industry at the enterprise level, there are also studies on that of China's metal industry at the industrial and regional levels. For example, Shao et al. (2016) applied global DEA and Malmquist index for TFP analysis of China's nonferrous metal sectors and found that technological progress is the main driver for TFP growth of China's nonferrous metal industry; based on time series data, Yu et al. (2017) calculated green TFP of China's ferrous metal industry for 1980–2013 and found that green TFP of this sector has been improved significantly in the past thirty years; Yang et al. (2017a, 2017b) studied TFP of China's regional iron and steel industry using a bootstrap network DEA and found that there are significant differences in TFP among regions; Wang and Zhao (2017) investigated regional energy and environmental efficiency of non-ferrous metals industry in China for the period of 2006–2011; Shao (2017) analyzed energy-saving potentials of China's nonferrous metals industry for the period of 2003–2009 by using a directional distance function DEA approach; Feng et al. (2018a) examined energy efficiency of China's iron and steel industry for the period of 2000–2014 by using a meta-frontier DEA approach; Zhu et al. (2018) studied the green TFP of mining and quarrying industry in China using a global DEA approach. Here, it should be noted that there are also studies focused on the sustainability of mining zones (e.g., Yu et al., 2005, 2008; Zeng et al., 2016; Li and Dewan, 2017)

To the best of our knowledge, none of the existing literature studied green TFP of China's regional metal industry. What's more, as reviewed above, none of the existing literature examined China's metal industry from regional perspective by taking regional heterogeneities into consideration. It is known that China covers a large territory and metal industry spread across the country. Due to factors of economy, geography, politics, history, etc., there should be heterogeneities among regions and neglecting the facts would lead to biased estimations (Wang et al., 2013; Zhang and Choi, 2013b). The purpose of this study is to fill the research gap by investigating regional green TFP of metal industry of China during 2000–2015, from regional perspective. In addition, a meta-frontier approach will be introduced to take regional heterogeneities into consideration.

Actually, there are two types of methods that can be used for green TFP measurement, i.e., the parametric ones (e.g., stochastic frontier analysis) and non-parametric ones (e.g., DEA). Compared to the parametric methods, DEA need not set functional form in advance, it is therefore more suitable for TFP or efficiency measure of decision-making units (DMUs) with multiple inputs and outputs (Coelli et al., 2005). For this consideration, a meta-frontier DEA will be built for green TFP measurement of this study. It can decompose green TFP changes into four parts, i.e., changes in technology, changes in technology gap, and changes in scale efficiency and pure technical efficiencies. In addition, it also can decompose green TFP inefficiency into three parts, i.e., the one attributes to technology gap, the one attributes to scale inefficiency, and the one attributes to pure technical inefficiency.

3. Methodologies

The purpose of this study is to investigate regional green TFP of metal industry of China by taking into account the undesirable outputs and regional/technology heterogeneities. In order to incorporate the undesirable outputs and heterogeneities into our TFP framework, the concepts of environmental technology and meta-frontier production