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Environmental efficiency of land transportation in China: A parallel slack-based measure for regional and temporal analysis

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ABSTRACT

As the second largest economic entity in the world, China plays an important role in controlling global carbon dioxide (CO_2) emissions. The land transportation sector (including railway transportation and road transportation) has been the most important source of emissions in China and the average CO_2 emissions of land transportation were 529.31 million tons during the period 2009–2012. In this study, a parallel Slack-Based Measure Data Envelopment Analysis model is proposed, which is used for evaluating the overall efficiency of the land transportation sector and individual efficiencies of the railway transportation and highway transportation subsectors at the same time, considering CO_2 emissions. The empirical results lead to three conclusions: (a) only Anhui province is efficient each year during 2009–2012. (b) The environmental efficiency of the Eastern area in China is the best, followed by the Central area, with the Western area being the worst. (c) The performance of railway transportation is better than that of highway transportation. These three conclusions lead to policy suggestions to promote highway transportation technological innovation and narrow the regional imbalances in land transportation. This paper makes two main contributions: the model advances improvements to methods used in the Data Envelopment Analysis technique, and also provides governments with a practical and yet easy-to-adopt perspective to implement land transportation performance measurement that aids in decision making.

1. Introduction

Since mankind entered the industrial age, the transportation industry has been developing rapidly all over the world (Wu et al., 2015a). This industry includes subsectors of highway transportation, railway transportation, water transportation, air transportation, and pipeline transportation. The rapid development of the Chinese economy over the past 30 years has resulted in the kilometers of both High-Speed Railway and Highway ranking the first in the world, reaching 16 thousand kilometers and 111.9 thousand kilometers respectively in 2014 (Ministry of Transport of the People's Republic of China (MTPRC), 2015).

Among all industries in China, the transportation industry acts as a more and more important role of regional economic development when it meets the augmented transportation needs induced by the growth of investment (Liu and Wu, 2015). Within the whole transportation industry, land transportation (including railway transportation and highway transportation) has been the most important sector and the most important source of carbon dioxide (CO_2) emissions. The passenger volume and freight volume of land transportation reached 21.44 billion people and 37.14 billion tons in 2014, accounting for 97.04% and 86.11% of the whole transportation industry (MTPRC, 2015). Furthermore, the average annual CO_2 emissions of land transportation were 529.31 million tons in 2009–2012 (Chang et al., 2013; Bi et al., 2014a,b), and the average growth rate of CO_2 emissions was 8.18%. From these statistics it can be seen that it is most meaningful and interesting to focus on land transportation rather than other sectors of the whole transportation industry.

Accordingly, land transportation is an active and important factor to actualize economic and environmental development. Despite and because of its importance, the transportation industry has one of the highest levels of energy consumption and pollution among industries worldwide (Ibanez and McCalley,

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2011; Motasemi et al., 2014). The transportation industry proportion of total energy consumption is 25% or more in developed countries, and land transportation constitutes more than 80% of that (Nian, 2014). More seriously, air pollution in China has also become more of a problem in recent years, and one reason for this is that exhaust emissions from the transportation industry have been increasing. The transportation industry is the second-largest source of emissions of air pollutants, accounting for 25% of global CO_2 emissions in 2014 according to the World Energy Outlook published by the International Energy Agency. Almost 75% of these emissions is caused by land transportation (Song et al., 2015). Regarding China's land transportation in particular, its energy consumption is overwhelmingly dominated by fossil fuels, which can produce large quantities of undesirable gases like CO_2. On the basis of the huge transportation demand, the emissions of undesirable gases such as CO_2 should receive more attention (Wu et al., 2015b, 2016). In fact, the CO_2 emissions and environmental pollution are currently hindering the sustainability of China's economic growth. In 2007, China surpassed the USA and became the world's largest contributor of CO_2 emissions (Wang et al., 2013). To address this issue, China's 12th five-year plan (2011–2015) sought to establish a “green, low-carbon, development concept.” (State Council of the People's Republic of China (SCPRC), 2011). For 2015, China planned to increase the proportion of non-fossil fuels in energy generation to 11.4%, and reduce CO_2 emissions per unit of GDP by 17% from the 2010 levels (Bi et al., 2014a,b).

Thus, both the public and academia should pay great attention to the CO_2 emissions problem of the transportation industry. Environmental problems, such as air pollution caused by large amounts of energy consumption, should also be taken seriously enough. It is very important for scholars to do research on resource utilization efficiency and environmental pollution problems related to the transportation industry.

It has been widely advocated that technology efficiencies and environmental efficiencies of all economic activities, including the transportation industry, should be measured to provide quantitative data to be used in analyzing and developing environmental policies (Avadí et al., 2014; Baležentis et al., 2016). The data envelopment analysis (DEA) model, which is commonly used for measuring technology efficiency and environmental efficiency, was developed by Charnes et al. (1978). It has been widely investigated and popularly applied to many fields such as universities (Beasley, 1995; Kao and Lin, 2012), health services (Tsai and Molinero, 2002), economic sectors (Baležentis et al., 2013; Miao et al., 2016), and banks (Cook et al., 2000). DEA is a nonparametric approach that measures the relative efficiency of decision-making units (DMUs) by comparing multiple inputs and multiple outputs. DEA is used to identify best practices within a set of comparable DMUs, leading to the identification of an “efficient frontier”. In this paper, a modified DEA method is applied to evaluate the resource utilization and environmental efficiency of China's land transportation sector.

In terms of environmental efficiency, Hu and Wang (2006) adopted the traditional Charnes-Cooper-Rhodes (CCR) model to analyze energy efficiencies of 29 administrative regions in China using data from 1995 to 2002. Furthermore, Zhang et al. (2008) analyzed the industrial sector eco-efficiency of 30 administrative regions in China by employing a DEA model and found that most Chinese regions with higher levels of GDP per capita have higher eco-efficiency. Zhou et al. (2008) proposed pure measures under different situations and a mixed measure under the variant returns to scale for evaluating the CO_2 emissions performance of eight different regions in the world using DEA techniques. Shi et al. (2010) used three extended DEA models to evaluate the environmental overall technical efficiency, pure technical efficiency, and scale efficiency of different regions of China from 2000 to 2006, with the undesirable output of industrial waste gas being treated as an input in the environmental efficiency analysis. Similarly, Chen and Jia (2016) also evaluated the environmental efficiency of China's regional industry based on a DEA approach. Song et al. (2013) utilized a Super-SBM model to measure and calculate the energy efficiency of the group of nations called BRICS (Brazil, Russia, India, China, and South Africa), and then analyzed each member country's present status and development trend. Song and Wang (2014) calculated China's regional environmental efficiency performance based on technological progress and government regulation by applying a DEA method, in which study the concept of DEA decomposition is proposed with a search algorithm approach. Xie et al. (2014) evaluated the environmental efficiency of electric power industries in Brazil, Russia, India, and China by using the Malmquist index method based on DEA. Baležentis and Baležentis (2011) applied energy use (which has been neglected in the present study) as an input to assess the efficiency of the Lithuanian transport sector, on the basis of which Baležentis et al. (2016) estimated the environmental performance by employing DEA. All of these studies investigated the environmental efficiency from various perspectives with different models, which contributes much to both the theory and the practice of environmental efficiency evaluation.

Besides evaluation of environmental efficiency, DEA models are also applied to transportation efficiency evaluation. Most of the current studies on transportation efficiency assessment mainly focus on two research perspectives: technology efficiency without considering undesirable outputs, and environmental efficiency taking undesirable outputs into account. Without considering undesirable outputs, Hayuth (1993) applied DEA mathematical programming techniques to assess the efficiency of 20 seaports and Tongzon (2001) applied DEA to provide an efficiency measurement of four Australian and twelve other international container ports. Analogously, Yoshida and Fujimoto (2004) and Barros and Dieke (2008) employed DEA models to evaluate the technology efficiency of air transportation in Japan and Italy respectively. While there are other studies on transportation efficiency evaluation (such as Frans et al. (2010) and Lu et al. (2012)), they ignore the environmental factor which has attracted more and more attention.

In order to strengthen the research by considering both technology and environmental factors, Vedantham and Oppenheimer (1998) investigated the CO_2 emissions of the air transportation sector and provided some suggestions for governments. Mazzarino (2000) studied the influence of transportation on the environment in Italy. Along this research direction, González and Marrero (2012) and Okada (2012) investigated the CO_2 emissions of the highway transportation sectors in various countries; and Rentziou et al. (2012) studied the CO_2 emissions of passenger transportation and freight transportation. Some studies have investigated the CO_2 emissions of different national transportation industries, such as Pongthanaisawan and Sorapipatana (2013) who analyzed the CO_2 emissions and emissions reduction policy of Thailand's transportation industry; and Lipscy and Schipper (2013) who discussed the relationship between the energy utilization efficiency and CO_2 emissions. In terms of environmental efficiency of transportation in China, Qu et al. (2010) and Wang et al. (2012) used the system optimization method to forecast the CO_2 emissions of the Chinese transportation industry in various contexts; Loo and Li (2012) and Wang et al. (2012) estimated carbon emissions from road freight transport through the method provided by the Intergovernmental Panel on Climate Change (IPCC);

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