ARTICLE IN PRESS

Transportation Research Part D xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Transportation Research Part D

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

Environmental efficiency assessment of U.S. transport sector: A slack-based data envelopment analysis approach

Yong Shin Park [a,*], Siew Hoon Lim [b], Gokhan Egilmez [c], Joseph Szmerekovsky [d]

[a] Transportation and Logistics Program, North Dakota State University, 1320 Albrecht Blvd, Fargo, ND 58105, USA

[b] Department of Agribusiness and Applied Economics, North Dakota State University, NDSU Dept. 7610, PO Box 6050, Fargo, ND 58108, USA

[c] Department of Civil, Mechanical and Environmental Engineering, University of New Haven, 300 Boston Post Road, Buckman Hall 223F, West Haven, CT 06516, USA

[d] Department of Management and Marketing, North Dakota State University, NDSU Department 2420, PO Box 6050, Fargo, ND 58108, USA

ARTICLE INFO

Article history:
Received 8 October 2015
Revised 31 May 2016
Accepted 13 September 2016
Available online xxxx

ABSTRACT

Sustainable transportation in the U.S. is essential for long-term economic growth and mobility, and environmental preservation. Using a non-radial slack-based measurement data envelopment analysis (SBM-DEA) model and state-level data, this study assesses the environmental efficiency of the transportation sector in the U.S. from years 2004 to 2012. In addition to environmental efficiency, carbon efficiency and potential carbon reduction were estimated for the 50 U.S. states. The findings of this study reveal that U. S. transportation sector was environmentally inefficient; U.S. states had an average transportation environmental efficiency score below 0.64. Therefore the states could substantially reduce carbon emissions to improve the environmental efficiency of their transportation sectors.

1. Introduction

Transportation has great influence on the economy of the United States (U.S.). However, one of the most serious issues arising from transportation and economic growth is the environmental impacts across the country, especially increased transportation carbon emissions (Chang, 2013). In recent years, there has been increasing global interest in environmentally sustainability issues. "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, Chapter 2, Section IV). Transportation consumes a high amount of energy (Zhou et al., 2014), and sustainable transportation hinges on the ability to maximize transportation environmental performance and to minimize the associated adverse impacts (Hendrickson et al., 2006).

The transportation sector accounted for approximately 10% of the U.S. Gross Domestic Product (GDP) in 2014 (RITA, 2014). The same sector was found to be the second largest source of greenhouse gas (GHG) emissions accounting for 27% of total U.S. GHG emissions, following the power generation industry (US EPA, 2014). An additional critical environmental concern is that energy consumption by the transportation sector is expected to increase dramatically in the next quarter century (Frey and Kuo, 2007). In this context, President Barack Obama initiated a climate action plan that seeks to reduce 17% of total carbon dioxide (CO_2) by 2020 (Leggett, 2014).

* Corresponding author.

E-mail addresses: Yong.Park@ndsu.edu (Y.S. Park), Siew.Lim@ndsu.edu (S.H. Lim), GEgilmez@newhaven.edu (G. Egilmez), joseph.szmerekovsky@ndsu.edu (J. Szmerekovsky).

http://dx.doi.org/10.1016/j.trd.2016.09.009

Please cite this article in press as: Park, Y.S., et al. Environmental efficiency assessment of U.S. transport sector: A slack-based data envelopment analysis approach. Transport. Res. Part D (2016), http://dx.doi.org/10.1016/j.trd.2016.09.009

Increasing concerns over the recent environmental issues related to transportation activities have led to sustainable development initiatives becoming a central element of public policy (Egilmez and Park, 2014), and transporting goods and services in a more sustainable way has become an essential topic of discussion. These discussions and projects are expected to contribute to the overall objective of sustainable development (Benjaafar and Savelsbergh, 2014; Choi et al., 2015). Therefore, it is essential to study the environmental performance of transportation activities from a holistic viewpoint to facilitate sustainable development in the transportation sector of a country or a region (Goldman and Gorham, 2006). Recognizing the importance of reducing GHG emissions and energy consumption, a number of studies have evaluated the environmental efficiency of U.S. industries, but they have focused on the environmental efficiency of the industrial sector (Egilmez et al., 2013), freight transportation from a manufacturing perspective (Egilmez and Park, 2014; Park et al., 2015), cross-country comparison (Zhou et al., 2006; Simsek, 2014), and the electricity sector (Barba-Gutiérrez, 2009). No study in the literature has been conducted on the overall environmental performance of the U.S.'s transportation sector.

Given this context, the main objective of this study is to analyze U.S. transportation environmental efficiency over a 9-year period (2004–2012) using a slack-based non-radial data envelopment analysis (SBM-DEA), and to estimate the potential reduction of transportation CO_2 emission. We first measure the environmental efficiency of the transportation sectors in all 50 U.S. states through the SBM-DEA model by incorporating CO_2 as an undesirable output (Chang et al., 2013). More specifically, we estimate carbon efficiency (CE), potential carbon reduction (PCR), excess of inputs and shortfall of output of the U.S. transportation sector. The paper is organized as follows: Section 2 reviews the literature; Section 3 provides the methodology of this study and data description; Section 4 presents the results of the analysis and discussion. Finally, Section 5 provides the conclusion, a discussion on policy implications, and suggests the direction for future research.

2. Literature

Various approaches for measuring environmental efficiency have been proposed in the literature. First of all, one can consider the presence of undesirable outputs using an index number approach. For example, Pittman (1983) extended the study by Caves et al. (1982) incorporating undesirable outputs into a multilateral productivity index. The drawback of this method is the difficulty of measuring the shadow price of undesirable outputs for the productivity index (Chang, 2013; Zhou et al., 2007). Another widely used approach is Data Envelopment Analysis (DEA). DEA has become one of the most used approaches in measuring environmental efficiency due to its robustness in finding optimal efficiency scores for different problems and datasets (Chang, 2013).

As the primary approach, Charnes et al. (1978) proposed the constant returns to scale DEA (CCR-DEA). DEA is a non-parametric approach for estimating the relative efficiency of decision making units (DMUs) by comparing multiple inputs with outputs in the framework of frontier analysis (Cooper et al., 2007). Banker et al. (1984) extended the basic CCR-DEA model to variable returns to scale DEA (BCC-DEA). Since then, DEA has been a popular benchmarking approach commonly used to identify best management practice within a set of DMUs.

In an output-oriented DEA model, an inefficient DMU could expand all its outputs simultaneously and equal-proportionally without increasing its input use. While in an input-oriented model, an inefficient DMU could reduce all its inputs simultaneously and equal-proportionally without sacrificing or reducing its outputs. Hence, the conventional DEA models provide a radial efficiency measure that is either output- or input-oriented (Charnes et al., 1992, 1996; Cook and Seiford, 2009). However, when an environmental pollutant is present in the model, the efficiency assessment becomes a challenging task (Chang, 2013), especially since an environmental pollutant need not increase or decrease equal-proportionally with outputs or inputs (Cooper et al., 2007).

Various methods for modeling undesirable outputs in DEA have been proposed in the literature. One treatment is to consider the pollutant as a free disposable input variable (Hailu and Veeman, 2001), but this concept was challenged by Färe and Grosskopf (2003) who viewed undesirable byproducts as weakly disposable outputs. The concepts of weak disposability and strong disposability of undesirable outputs were proposed by Färe et al. (1989). Under the weak disposability property, a reduction in undesirable outputs will result in a reduction of desirable outputs, while strong disposability also means free disposability, and it assumes that it is possible to reduce the desirable output without reducing the undesirable outputs (Färe et al., 1989). Another approach involves the use of translated input and output data in the traditional BCC-DEA model, and the resulting efficiency classifications remain invariant to data transformation (Seiford and Zhu, 2002; Rousseau and Semple, 1995). In addition to the abovementioned radial approaches, a non-radial DEA model can be used to handle undesirable outputs (Zhou et al., 2007), and a slack-based measurement model proposed by Tone (2001) has also been used to account for the presence of undesirable outputs (Hu and Wang, 2006; Lozano and Gutiérrez, 2011; Chang, 2013; Li et al., 2013).

The slack-based measure (SBM) of efficiency was first proposed by Tone (2001). One main advantage of SBM over the aforementioned radial DEA models is that SBM captures input excesses and output shortfalls of the DMUs while conventional CCR-DEA and BCC-DEA models deal with a proportional reduction or expansion of inputs and outputs (Chang, 2013). Based on the principle of a non-radial model, the primary purpose of the SBM is to locate the DMUs on the efficient frontier, and the objective function of the SBM is to be minimized by finding the maximum slacks (Tone, 2001). Non-radial efficiency SBM-DEA is found to be more appropriate compared to traditional DEA models when it comes to modeling