Transportation Research Part D 50 (2017) 505–519

Contents lists available at ScienceDirect

Transportation Research Part D

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

Efficiency evaluation of bus transit firms with and without consideration of environmental air-pollution emissions

Chao-Chung Kang [a,*], Haider A. Khan [b], Cheng-Min Feng [c], Chin-Chia Wu [d]

[a] Department of Business Administration, Providence University, 200, Chung-Chi, Rd., Shalu, Taichung 433, Taiwan
[b] Department of Economics and Josef Korbel School of International Studies, University of Denver, 2201 South Gaylord Street, Denver, CO 80208, USA
[c] Department of Transportation and Logistics Management, National Chiao Tung University., 114, 4F, Sec. 1, Chung Hsiao W. Rd., Taipei 100, Taiwan
[d] Department of Statistics, Feng Chia University, 100 Wenhua Road, Taichung, Taiwan

A R T I C L E I N F O

Article history:
Available online 21 December 2016

Keywords:
Externalities
Undesirable output
Technical efficiency
Bus transits
Environmental emissions
SBM model

A B S T R A C T

This study examines the technical efficiency and environmental efficiency of bus transit firms using the slack-based measures (SBM) and non-separable slack-based measures (NSSBM) models with and without considerations of desirable and undesirable outputs. A case study based on data from 12 bus transit firms for the years 2007 to 2011 was conducted. Empirical results show that technical efficiency was affected by environmental pollution constraints from 2007 to 2011. The study has more general theoretical implications for the externalities literature as well.

1. Introduction

Bus transit is a mode of public transportation that can support sustainable development in urban areas and surrounding regions. Many promotion strategies for improving the operational performance of bus transit systems have been proposed by government agencies and international organizations. These include enhancements of mass transportation programs, privatization policies, public-private partnerships, toll regulation, mergers between bus transit firms, and subsidy strategies for upgrading service levels. From the perspective of bus operators, operational performance assessments have allowed operators to reexamine or adjust bus routes, timetables, frequencies, and the scope of service (Sheth et al., 2007). From the perspective of government agencies, performance evaluations can be used to assess the effects of subsidies, mergers, or other policy measures (Sampaio et al., 2008; Karlaftis, 2008; Tsamboulas, 2006). Thus, numerous studies have tried to assess the operational performance of transportation systems using a wide array of diverse methodologies (De Borger and Kerstens, 2008; Yu, 2008).

Many terms such as efficiency, effectiveness, or productivity can be used to describe the performance outcomes of bus transit firms (Karlaftis, 2004; De Borger and Kerstens, 2008; Barros and Peypoch, 2010). In the literature, prior studies have focused mainly on firms' measurable desirable outputs (i.e., marketable outputs), such as "vehicle-miles", passengers, "passenger-miles", or operating revenue (Barros and Peypoch, 2010, p. 297; De Borger and Kerstens, 2008). The impacts of measurable undesirable externalities such as air-pollution emissions (which are inherent in the provision of bus services to passengers), however, have largely been ignored (Kerstens, 1996; Karlaftis, 2004; Odeck and Alkadi, 2001; Odeck, 2008).

* Corresponding author.
E-mail addresses: cckang@pu.edu.tw (C.-C. Kang), Haider.Khan@du.edu (H.A. Khan), cmfeng@mail.nctu.edu.tw (C.-M. Feng), cchwu@fcu.edu.tw (C.-C. Wu).

http://dx.doi.org/10.1016/j.trd.2016.10.012
1361-9209/

The earlier performance measurements are therefore inaccurate because these external effects were not considered (Nijkamp, 1994). Recently, many studies have advocated that factors such as safety, fairness, and environmental protection should also be considered when government agencies assess the efficiency of bus transit systems for the purposes of formulating transportation policies (McMullen and Noh, 2007; Lin and Lan, 2009; Lin et al., 2010). For instance, Lin et al. (2010) employed a stochastic frontier analysis (SFA) model taking into consideration the effects of traffic accidents in order to assess the impact of operational efficiency changes within the Taipei Municipal Bus transit system. In addition, Chen et al. (2012) proposed an "integer-valued" data envelopment analysis (DEA) model with accidents included for measuring the relative efficiency of the Kaohsiung Municipal Bus Company. Weber and Weber (2004) incorporated accidents (regarded as an undesirable output) into their model to investigate the impact on productivity in the transportation industry. Moreover, Heng et al. (2012) introduced the factor of toxic air pollutants, such as nitrogen oxides (NO_x), carbon monoxide (CO), particulate matter of less than 10 μm (PM_{10}), and volatile organic compounds (VOC), into the Malmquist index for evaluating productivity changes in the trucking industry.

The above-mentioned studies suggest that performance evaluations, whether or not they take into consideration undesirable outputs or external factors, have demonstrated significant impacts on efficiency and/or productivity changes for bus transit systems and other transportation industries.[1] As shown by Zhou et al. (2008) in their review of a survey of analyses of energy and environmental efficiency (mainly using data from electrical utilities), not much effort has been devoted to environmental efficiency assessments within the transportation industry.

Therefore, from the literature on this subject, it can be shown that few studies have accounted for the effects of environmental emissions in assessing the operational efficiency of bus transit systems (Heng et al., 2012; McMullen and Noh, 2007; Zhou et al., 2008; Lin et al., 2010). The objective of our study is to investigate the technical efficiency and environmental efficiency of bus transit, taking into consideration air-pollution emissions, and to compare the efficiency changes with and without air pollution emissions. The remainder of this study is organized as follows: Section 2 contains the literature review; and Section 3 describes the methodology. Results of a case study are presented in detail in Section 4, with conclusions and implications presented in the final section.

2. Literature review

Numerous researchers have proposed or developed appropriate methodologies to assess the efficiency, effectiveness, or productivity for bus transit systems. A comprehensive survey of bus transit performance studies has been compiled by De Borgerand and Kerstens (2008). A brief review of these studies is presented below.

As pointed out by De Borger and Kerstens (2008), past studies have investigated the relative efficiency or productivity of bus transit firms using various methodologies; the issues covered include the exploration of the differences in relative efficiency between private and public firms (Barros and Peypoch, 2010), discussion of the effects of privatization, subsidies, and regulation on bus transit systems (Tsamboulas, 2006; Fan, 2004; Odeck, 2008; Kerstens, 1996; Karlaftis, 2008), and investigating the efficiency or effectiveness of bus transit firms (Barros and Peypoch, 2010; Boame, 2004; Karlaftis, 2004). For example, Kerstens (1996) investigated the technical efficiency of French urban transit companies using DEA and Free Disposal Hull (FDH) approaches. He also used a Tobit regression model to explain the effects of policy debates on the network structure. In addition, Viton (1997) utilized input-oriented and output-oriented DEA models to investigate technical efficiency for multimode bus transit systems in the U.S.; he found that 80% of the bus transit systems were technically efficient, and that there was no difference in overall efficiency between the public and private sectors. Moreover, Viton (1998) employed DEA and Malmquist index models to evaluate the technical efficiency and productivity of both motor-bus (MB) and demand-responsive (DR) bus transit systems in the U.S. The analysis revealed a slight improvement in bus transit efficiency over the years 1988–1992. Other studies used different types of DEA model to evaluate firm efficiency; for example, Odeck and Alkadi (2001) used the input-oriented BCC model proposed by Banker et al. (1984) to assess efficiency for a sample of 47 Norwegian bus companies. Factors such as company ownership and area of operation were incorporated into the model in order to assess their influence on efficiency changes. In addition, Odeck (2008) also used the DEA and Malmquist models to examine the effects of mergers between bus transit firms by measuring changes in efficiency and productivity before and after the merger of Norwegian bus firms. Boame (2004) used a bootstrap DEA approach to assess the relative technical efficiency of Canadian urban transit systems from 1990 to 1998.

In the productivity analysis literature, Translog cost or production functions[2] and the Malmquist productivity index have widely been employed to analyze changes in productivity for bus transits systems (De Borger and Kerstens, 2008; Cho and Fan, 2007). For instance, Chang (2006) employed the Malmquist productivity index to investigate productivity changes for 14 bus firms in Taipei city. Cho and Fan (2007) also used the Malmquist total factor productivity index (MPI) to assess productivity for other bus companies. In addition, Wu (2009) investigated productivity changes in Taipei bus transit firms between 2004 and 2007. Results show that, on average, the mean pure technical efficiency change (PUEFCH) and mean scale efficiency change

[1] Khan and Judzik (2015) present a general model of vector valued production functions with multiple desirable and undesirable input and output variables on the RHS and LHS, respectively, and concrete examples satisfying the standard axioms for such models. The specific studies cited above are examples of applications of such a general multivariate production function for both desirable and undesirable inputs and outputs.

[2] For an early application of translog production function to the case of South Korean energy and environment model, see Khan (1985). See also Khan (1997) book-length discussion.