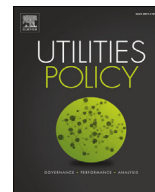




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Efficiency and productive slacks in urban transportation modes: A two-stage SDEA-Beta Regression approach

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ABSTRACT

The performance of urban transportation modes is a critical issue for people's mobility. This research analyses various transportation modes in 285 cities across the world from 2009 to 2012, exploring efficiency levels with a focus on productive capacity slacks. The idea is to better apprehend the resilience of different transport modes in terms of absorbing demand shocks, shedding some light not only in terms of the intrinsic characteristics of each mode but also on the demographic context. A novel approach derived from a two-stage combination of Stochastic Data Envelopment Analysis (SDEA) and Beta Regression was used to support the findings, which indicate the concentration of productive slacks on heavy metro and the need of specific solutions for mid-sized cities. Policy implications are then derived.

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1. Introduction

It is widely held belief that all nations should invest in infrastructure and urban transportation services to develop their economies (Hoel et al., 2008). According to Unacila (2013), well-functioning transportation networks are a key functional element for cities and towns across the globe and a precondition for economic activity and access to basic services. Indeed, urban transportation plays a major role in the life of all city dwellers (Hadas and Ranjitkar, 2012). Therefore, both policy and investment decisions should focus on strategies that include urban planning to support transport, traffic demand management, mass rapid transit, light rapid transit, bus rapid transit, informal non-motorized transit (such as walking and bicycling), low-emission vehicles and alternative fuels, and freight planning.

This paper analyzes urban transportation efficiency in different cities of the world. Mobility in metropolitan areas is often supported by multiple transit modes (Barnum et al., 2011). In today's urban structure, the development of transport systems that can respond to people's demands to travel more comfortably and faster is essential (Vitosoglou et al., 2014). Transit efficiency has long been

a critical policy concern and has recently become even more important (Barnum et al., 2011).

A wide variety of data and methodologies have been used to estimate transit system performance (Karlaftis, 2004). According to Isabello et al. (2014), several methods to evaluate the efficiency and effectiveness of transport lines or networks are based on DEA or similar approaches, such as the ones proposed by Button and Costa (1998) and Yu (2008). For instance, Lao and Liu (2009) suggested a method that integrates DEA and geographic information systems (GIS), as also used by Macharis and Pekin (2009). Indeed, since the 1990s, DEA has been used to study urban transportation in combination with other analytical techniques (Stochastic Frontier Analysis or Free Disposal Hull) in order to crosscheck results (Fancello et al., 2014). DEA is often used not only to assess the efficiency of transport modes but also the impact of regulations on efficiency (Piacenza, 2006) or for evaluation of other particular policies (Gagnepain and Ivaldi, 2002). The actual measurement of performance differs substantially depending on the methodology and the output specification used in various studies (Karlaftis, 2004).

This paper innovates in this context, first by undertaking a review of urban transportation efficiency and second by adopting as a research tool SDEA combined with Beta Regression in a two-stage approach. In this research, contextual variables are used as explanatory variables in Beta Regression models in order to assess

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their impact on efficiency levels and productive slacks calculated from SDEA. The motivations for the present research are twofold. First, this paper innovates in relation to urban transportation by evaluating the relative efficiency of various transportation modes in different countries. Efficiency is the relative position of a given transport mode in the frontier of best practices, which is defined by the group of modes analyzed. Second, the present analysis enables the assessment of the productive slacks of each transportation mode, while controlling for the impact of different contextual variables related to population size and city location on efficiency levels.

The purpose of this study is to assess the determinants of urban transport efficiency globally based on the inputs, outputs, and contextual variables commonly found in the literature. In order to achieve this objective, an efficiency analysis is developed using a two-stage approach - SDEA followed by Beta Regression. The remainder of this paper is structured as follows. The literature survey is presented in Section 2, followed by an overview of the methodology in Section 3. Section 4 presents the data, followed by the discussion of the results in Section 5.

2. Literature review

A number of papers on urban transport efficiency in the literature have used DEA as a basic analytical tool. These papers focus on several aspects of policy-making in urban transportation, ranging from the impact of privatization and types of corporate governance on transportation efficiency to the need for segmentation of the different modes. Unfortunately, most published, urban transport DEA articles deal only with one transportation mode, which is almost always motorbuses (Barnum et al., 2011). The earliest transit DEA articles to consider multiple modes were published in 1997 and 1998, involving fixed-route, fixed-schedule motorbuses, and demand-responsive operations (Viton, 1997, 1998). The next set of transit DEA articles that considered multiple modes were published in 2006 and 2008, and involved organizations that operated both highway and urban bus lines (Yu and Fan, 2006; Yu, 2008).

The importance of analyzing multiple modes simultaneously stems from the fact that urban rail transit systems are regarded as the backbone of sustainable urban development (Jain et al., 2008), and in the public transport systems of large cities, consist of sub-urban railway, subway and light-rail lines. The lower-capacity public

transport modes, such as bus, trolleybus, and minibus, serve to feed these main lines. Rail systems play a vital role in meeting transportation demands in large cities due to their desirable characteristics, such as high capacity, speed, safety, and comfort (Vitosoglou et al., 2014). However, because of the comfort and speed they afford, the demand for rail systems in urban public transport is increasing (Vitosoglou et al., 2014). Characterized by high capital investment, sizable operating costs, and substantial economies of scale, the majority of urban rail transport systems have historically been built, financed, and operated by public authorities (Qin et al., 2014). These systems have evolved considerably since the first underground rail system opened in London in 1863. Subsequently, owing to the rapid rate of growth in motorization and changes in political structures, urban rail transit systems have undergone many structural and operational changes.

Karlaftis (2004) used DEA and globally efficient frontier production functions to investigate two important issues in transit operations: first, the relationship between the two basic dimensions of performance (namely efficiency and effectiveness); and second, the relationship between performance and scale economies. Using data from 256 US transit systems over a five-year period, the results indicated that efficiency and effectiveness are

positively related. The findings further imply that the magnitude of scale economies depends on the output specification. Boame (2004) used a bootstrap DEA method to estimate technical efficiency scores for Canadian urban transit systems from 1990 to 1998. Bias and confidence intervals were estimated for the efficiency scores. A Tobit regression was used to analyze the sources of efficiency change. The analysis found that the original efficiency scores were biased. The bootstrap results indicated that the average technical efficiency of transit systems in Canada is about 78%. Jain et al. (2008) analyzed the relationship between ownership structure and technical efficiency through the application of DEA in urban rail transport systems. A comparative analysis of 15 urban rail transport systems revealed that among the different available governance models, privatization has a direct and positive bearing on efficiency. Granham (2008) formulated and compared parametric productivity estimates and non-parametric efficiency scores for urban rail operators using DEA. Despite the lack of easily available comparative information, the study was able to identify benchmark groups of urban transportation firms for which relative performance could be compared. The results pointed to the need for segmentation in urban transportation analysis. Barnum et al. (2011) developed and illustrated a DEA-based procedure for estimating (a) overall efficiency of an area's public transportation; (b) technical efficiencies of the individual transit types; (c) effect of each type on overall efficiency; and (d) efficiency of the allocation of resources among types and an algorithm for its improvement. The paper concluded that the overall efficiency of an urban area's public transportation can be validly estimated only if the technical efficiency of each major transport type and the efficiency in allocating resources among them are taken into consideration. Li et al. (2013) presented a method for evaluating the performance of bus routes within a public transportation system using a revised DEA method and sensitivity analysis of indexes. Fancello et al. (2014) compared the performances of different urban networks using non-parametric linear programming techniques such as DEA in order to provide technical support for policymakers to assist them in choosing among options for actions to make urban road systems efficient. Qin et al. (2014) applied a proposed SM-NDEA model and found (a) that the average overall efficiency of Chinese urban rail transport systems is relatively low, and that (b) efficiency is influenced more by financial and construction inefficiencies than by production and consumption inefficiencies.

Based on the literature review, it appears that, thus far, no prior research has adopted either SDEA or Beta Regression. Furthermore, no prior analysis has considered several cities around the globe, which is an additional innovation of our study.

3. Methodology

Before proceeding, we provide some background on the two-stage approaches usually applied in efficiency analysis as well as the advantages of the SDEA-bootstrap Beta Regression approach adopted in this research.

Methods for treating DEA estimates obtained in the first stage using regression or statistical models in the second stage have evolved over the years (e.g. Banker, 1993; Simar and Wilson, 2007; Cooper et al., 2007). This reflects the use of two-stage approaches to acknowledge the impact of contextual variables on efficiency (Fried et al., 2002). Although some early two-stage studies employ Tobit regression in a second stage or other non-parametric tests (e.g. Turner et al., 2004), Simar and Wilson (2007, 2011) showed that truncated regression combined with bootstrapping as a resampling technique best overcomes the unknown serial correlation complicating the two-stage analysis. This bias may help in explaining why the literature review reveals that the inefficiencies found in transit

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