

Public road transport efficiency: a literature review via the classification scheme

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Abstract The paper provides a literature review of public road transport efficiency. We classified 24 articles published between 2000 and 2011, based on journals, date of publication, the nature of the papers', the context of the study, the adopted approach by which efficiency is measured, the adopted outputs and inputs and empirical findings. Results are presented, discussed and future directions are generated. The classification scheme technique shows that the application of the mixed approach of Data Envelopment Analysis and Stochastic Frontier Analysis (DEA-SFA), with operators of different nationalities, is more robust for analysis of public transport efficiency, and for identifying sources inefficiency. Financial variables are important inputs and outputs for efficiency studies. However, although the frontier literature has substantially contributed to the knowledge of public transport technologies and the determinants of performance, it has been found that many important issues remain unresolved.

Keywords Public road transport · Efficiency and performance · Classification scheme · Data Envelopment Analysis · Stochastic Frontier Analysis

JEL Classification C14 · C67 · C83 · D24 · L92 · N70 · R40

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1 Introduction

Public transport by bus is the mainstay of the transportation system in an economy (Agarwal et al. 2011). Although modes of travel in most developed countries are increasingly dependent on the car (see Banister and Berechman 2000), causing a downward trend in demand for transport in most industrial economies, public transport by bus remains an important mode of transportation. Bus transport services are provided by public, private or mixed corporations in a highly regulated environment. In addition, important constituents of the transport infrastructure are essentially (semi-) public goods. Therefore, there are economic reasons for a significant degree of state intervention in this area, mainly based on the recognition of a variety of market failures (e.g., Kerstens 1996). Over the last two decades, serious concerns about possible regulatory failures have resulted in a reassessment of the role of government in organising this sector (Glaister et al. 1990).

In view of these concerns, it is of great interest to investigate whether public transport operators work in a technically efficient manner (e.g., achieve economic goals such as minimising costs or maximising output). An effective and solid measure of efficiency can make a significant contribution to the discussion of the relative merits of the supply of public and private transport services.

Since the early 1980s, various techniques for estimating frontier have been developed to determine the best practices in any industry. Frontier methods are used to distinguish between efficient and inefficient production and to estimate the degree of (in) efficiency. Not surprisingly, frontier methods have found their way into the transport sector, and studies on the productivity and efficiency of almost all transport modes are now available in the literature. A comprehensive study of parametric and non-parametric frontier methods and empirical findings for urban public transport has been published by De Borger et al. (2002). Our study presented below attempts to fill a gap in the available literature. While an overview of the pioneering studies on public transport operators has recently appeared (e.g., von Hirschhausen and Cullmann 2010), a thorough investigation of frontier methods and empirical results for public transport of the 2000s is not yet available.

This paper is complementary to De Borger, with a different classification technique and study period. This last study is an overview of studies published during the 1990s. Moreover, it is an analysis of frontier studies. This paper research is based on work published during the 2000s'. We use criteria to select, classify and analyse the studies in this research. In this paper, we use the classification scheme technique to study the papers selected. Thus, is the De Borger et al. (2002) has an influence on the later studies of public transport efficiency?

The objective of this paper is to provide a comprehensive literature review of public transport efficiency and describe the different adopted approaches and methods. It also evaluates the contributions of frontier analysis as a way to understand performance of public transport.

The rest of paper is organised as follows: the next section aims to define central concepts and details the methodologies of performance and technical efficiency analysis. Section 3 deals with the methodological approach and discussion of research procedures of the literature. As well, it introduces the classification scheme

technique. In this section, we describe criteria's and classification methods used. In Sect. 4, the results and interpretations of the classification of papers are presented, and we identify the determinants that may explain the differentiation of the efficiency results that are reported in the literature. Finally, Sect. 5 closes the paper by offering conclusions and attempts to provide some perspectives on future research.

2 Concepts and methodologies

Performance serves to compare the behaviour of organisations across space, over time, or both. Moreover, productivity is a concept which evaluates the outputs of an organisation in relation to inputs used in the production process. This concept obtains its meaning for the economic comparisons over time between different organisations. For example, increased productivity over time indicates that, compared to the inputs used, organisations have managed to produce more output.

Thus, performance measurement can be made by means of comparative analyses in one sector or across sectors, either at the national or international level. Above all, we must specify the objectives of the organisations assessed. In principle, public sector activities (such as public transport) may serve as a set of objectives, making the evaluation of their performance a difficult exercise (De Borger et al. 2002). Indeed, from a welfare economic viewpoint, the public sector attends to four main goals: efficiency, equity, financial balance and macroeconomic stabilisation (Marchand et al. 1984 and Rees 1984).

However, despite the existence of multiple objectives, the focus in many empirical studies (e.g. Barnum et al. 2011) in the transport industry is on issues of productivity and efficiency. There are at least two reasons for this occurrence. First, a transparent framework for productivity and efficiency measurement has been developed, unlike for the other objectives. Second, it has been forcefully argued that, independently of the other objectives, a first and indispensable demand for all public sector activities is to operate in an efficient manner (Marchand et al. 1984; Pestieau and Tulkens 1993). Therefore, in the remainder of this section, we review the most relevant efficiency notions and explain how to make them operational.

2.1 Efficiency

Farrell (1957) is the founder of frontiers and efficiency measure, which provided definitions and a framework for calculating the technical and allocative (in) efficiency. Based on his, efficiency measurement and estimation of frontiers has had an explosive development over the past decades. Literature documents the existence of several types of efficiency, of which the three most commonly used are: technical efficiency, allocative efficiency and scale efficiency.

First, technical efficiency relates the outputs (products or results) to the real inputs (the resources consumed). This is the frontier of all production possibilities. This set summarises all the technological possibilities of transforming inputs into outputs. A producer is technically inefficient, if their production is below the production possibility frontier. Technical efficiency indicates, for a given level of production, how a producer uses its resources in an optimal way (see Coelli et al. 1998).

Second, allocative efficiency requires the specification of a behavioural goal and is defined by a point on the boundary of the production possibility set that satisfies this objective, given certain constraints on prices and quantities (De Borger et al. 2002). Most often organisations are thought to be minimising costs. In such a case, a technically efficient producer is allocatively inefficient if there is a divergence between observed and optimal costs.

Finally, scale efficiency indicates the optimal size of an organisation. It relates to a possible divergence between actual and ideal production size. The ideal situation coincides with the long-term competitive equilibrium, where production is characterised by constant returns to scale. A producer is scale efficient if its choice of inputs and outputs is situated on a constant return to scale frontier (see De Borger et al. 2002). However, there may be increasing or decreasing returns to scale. With increasing returns to scale the variation in the output is greater than the variation of the used inputs. So, if the production of an additional unit is accompanied by a decrease in unit cost, it is an economy of scale. The decreasing returns to scale is when the variation output is lower than the variation of used inputs. Therefore, the marginal cost increases, while the production of an additional unit is expensive and is accompanied by an increase in unit cost. This is a diseconomy of scale.

In the studies of public transport, we can distinguish between the effectiveness and efficiency. Efficiency is the ratio between output and input. The Effectiveness is the service offered over promised service, for example, punctuality of buses, the number of bus travel. In this study, we focus on the studies of public transport efficiency.

2.2 Efficiency measure

In the literature, we can find different methods for measuring efficiency and performance of the public road transport sector. Based on the work of Farrell (1957), the efficiency measurement and estimation of frontiers have experienced an explosive development over the past decades. Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) are the two most important alternative approaches in this regard and have been extensively studied methodologies in their own right and ubiquitously applied to an eclectic range of industrial and organisational contexts.

In this paper, we focus on two approaches that seem most used in this area: “stochastic frontier analysis” and “data envelopment analysis”. DEA can be defined as a nonparametric method to measure the efficiency of the decision-making unit (DMU) with multiple inputs and multiple outputs. SFA, as an alternative approach to DEA, supposes a parametric function between the inputs and outputs. In the following, we give a brief description of each approach.

2.2.1 Data envelopment analysis

DEA modelling, initially proposed by Charnes et al. (1978), provides a relative measure of efficiency that is increasingly used in evaluating the performance of the public service industry (Ganley and Cubbin 1992). Efficiency measures are the distances at the empirical production frontier, and the values are calculated on the basis of the Pareto efficiency norm. No assumptions are made about the functional form to the production frontier.

Generally, the DEA can be defined as a nonparametric method to measure the efficiency of a decision making unit (DMU) with multiple inputs and multiple outputs. This is achieved by constructing a single virtual output to the virtual input one without predefining a production function. Among the DEA models, the two models that are most widely used are named DEA-CCR (Charnes, Cooper and Rhodes) and DEA-BCC models (Banker, Charnes and Cooper).

In the DEA-CCR model, the frontier is generated by the linear combination of units in the data set. The efficiency scores obtained from this model are known as technical efficiency (TE). These scores reflect the radial distance from the frontier estimated at the unit concerned. A lower score of the unit amounts to inefficiency in the unit. When the unit has an efficiency score less than 1, then there must be at least one unit in the data set that is efficient. All these units are called the reference set or the reference group for the inefficient unit. In order to obtain efficiency; we must seek a way to minimise inputs while satisfying not less than the given level of outputs. This model is called “input-oriented”. Another way is to maximise outputs without increasing inputs observed. This model is called “output-oriented”. The DEA-CCR model is based on the assumption of constant returns to scale (CRS).

In the DEA-BCC model, the frontier is generated by the convex board of the units in the dataset. The frontier of this model has linear characteristics and is concave. Efficiency scores of this model are known as pure technical efficiency (PTE). It is based on the assumption of variable returns to scale (VRS). In both models, the unit is efficient; it is possible to reduce any input without increasing other inputs and achieve the same levels of output or it is possible to increase an output without reducing any other outputs and use the same levels of inputs. The ratio of technical efficiency to pure technical efficiency (TE/PTE) is called the return to scale of this unit. The influence of the DEA-CCR paper is reflected in the fact that in 1999 it was cited over 700 times (Forsund and Sarafoglou 2002).¹ The DEA-CCR model assumes constant returns to scale so that all observed production combinations can be proportionally enlarged or reduced. Moreover, the DEA-BCC model assumes variable returns to scale and is graphically represented by a linear frontier convex section.

The early literature often used deterministic parametric frontier methods. However, given that they combine the most restrictive assumptions (deterministic and parametric), they are no longer very popular (Lovell 1993). This approach argues that all organisations share the same mode of production and their respective efficiencies are compared to the same frontier of the entire production. Moreover, the observed divergence over the frontier is explained by inefficiency. This deterministic frontier approach ignores the possibility that the efficiency of an organisation may be affected by many factors beyond its control, such as scarcity of inputs, poor performance tools or climatic hazards. The flaws in this approach are the cause of the development of the stochastic approach or the composite error.

¹The increasingly popular empirical use of linear programming techniques for calculating efficiency scores is due to the *DEA model* introduced to the general research public in CCR.

2.2.2 Stochastic Frontier Analysis

Simultaneously introduced by Aigner et al. (1977) and Meeusen and Broeck (1977), it assumes that the SFA is a parametric function existing between the inputs and outputs. As an alternative approach to the DEA, the great advantage of SFA is that it can measure not only technical inefficiency, but also recognises the fact that random shocks, beyond the control of producers, can affect production.

For this reason, the essential idea of SFA is that the error term is composed of two parts: one unilateral component that captures the effects of the relative inefficiency of the stochastic frontier, and a symmetric component that allows a random variation of the frontier between companies and includes the effects of measurement error, other statistical noise, and random error outside the control of the company. Thus, the main attraction of the stochastic frontier approach, in contrast to deterministic approaches such as the DEA, that isolates the influence of factors to the inefficient behaviour, thus correcting possible upward bias of the inefficiency of deterministic methods. A stochastic frontier model can be expressed as an equation, where the technical efficiency of firm K is " U_{it} " and must be positive, while the statistical noise component " V_{it} " can be either positive or negative.

$$Y_{it} = \exp(x_{it}\beta + V_{it} - U_{it})$$

Where Y_{it} is the output produced by the i -th firm ($i = 1, 2, \dots, N$) and at the t -th period ($t = 1, 2, \dots, T$); x_{it} is the inputs vector of the i -th firm at the t -th period, β is the parameters vector to be estimated.

The first step in solving a stochastic frontier model is to specify a functional form, with the most common solutions based on the maximum likelihood estimation. The SFA approach has the advantage of allowing for random error and measurement errors. Another advantage of the SFA approach is that it makes it possible to analyse the structure, and investigate the determinants of inefficiency. Therefore, it has a more solid grounding in economic theory (Battese and Coelli 1995).

Comparing the non-parametric approach with the stochastic parametric frontier approach, DEA has advantages when it comes to measuring the relative efficiency of public transport operators. First, DEA is a non-parametric frontier approach and does not require, rigid assumptions regarding production technology and specific statistical distribution of the error terms. Second, DEA is amenable for small sample studies. Third, as a non-parametric frontier technique, DEA identifies the inefficiency in a particular firm by comparing it to similar firms regarded as efficient. Other DEA advantages are (Banker and Morey 1986): easy to interpret efficiency score; independent measurement units (giving great flexibility in selecting outputs/inputs); and manipulation of uncontrollable and environmental factors, e.g. competition. However, the DEA model does not allow for measurement random error. Instead, all these factors are attributed to inefficiency, a characteristic that inevitably leads to potential estimation errors.

With DEA, all deviations from the frontier are attributed to inefficiency. The DEA does explicitly account for stochastic events such as measurement error in the data. DEA does not yield estimates that can be easily validated with conventional statistical procedures. Sensitivity to outliers has been another criticism of DEA (Coelli et al.

1998; Thompson et al. 1990; Burgess and Wilson 1993). Sensitivity to outliers may also pose problems for estimating the SPF or any regression relationship. As such, the sensitivity issue is probably over-exaggerated. A mixed approach may be an adequate solution to solve the problems of these approaches.

3 Methodology

Three basic approaches exist in the investigation of the state of knowledge in a field or subject (see Li and Gavusgil 1995). The first one is the Delphi technique by which experts who are familiar with the area are surveyed. The meta-analysis is the second approach, where empirical studies on the specific subject are gathered and statistically analysed. Finally, the third approach is content analysis, which is the one applied in this paper.

Content analysis is a research method for systematic, qualitative and quantitative description of the manifest content of the literature in an area (Marasco 2008). Following Li and Gavusgil (1995) and Seuring et al. (2005), to conduct an investigation by content analysis, we should centre on two major steps: first, it is needed to define the sources and procedures for searching the articles to be analysed; then, categories must be defined for the classification of the collected articles.

3.1 Literature search procedure

This survey was based on a study of journals. Hence, we exclude conference proceedings papers, Masters' theses, doctoral dissertations, textbooks, and unpublished working papers. According to Nord et al. (1995), academics and practitioners usually use journals most often for acquiring information and disseminating new findings, and so, journal articles represent the highest level of research.

Certain selection criteria were used to choose and accept the papers in this study. If the paper did not meet the selection criteria, then it had to be excluded. The search procedure takes two steps. In the first step, papers were found by electronic search topics on the field. We used different terms when searching the paper to be considered. Specifically, we searched for the terms: efficiency analysis, or efficiency measurement, and efficiency frontier, Stochastic Frontier Analysis (SFA), Data Envelopment Analysis (DEA), and technical efficiency.

The first term is utilised in order to generate all the papers that treat the efficiency of the public transport sector, including papers referring to this subject via the deferent's methods and techniques used. The second term aims to find all papers related to the efficiency frontier of the public transport. This is an attempt to delimit papers that relate to the efficiency of public road transport sector. Finally, the last two terms are adopted to generate all papers analysing the efficiency of the public transport sector via the "Stochastic frontier analysis" approach and the "data envelopment analysis" approach. These two approaches are those most known and adopted in the analysis of efficiency frontier, and in analysing the efficiency of the transport sector.

As was previously mentioned, papers that are included in this literature review are limited to published works obtained from electronic sources. Our search cover

literature obtained from different electronic sources. More precisely, we explore Science Direct, Springer Link, JSTOR, Wiley Interscience, Inderscience databases and Ingenta Connect databases. To obtain additional sources of information, we examine references cited in each relevant literature source.

The research covers a period of more than ten years between 2000 and 2011. The choice of the starting date is governed by the publication of the first comprehensive study of the literature on production frontiers for public transport operators generated by De Borger et al. (2002) and published in Transport Reviews. They have established a general survey of articles published during the 1990s. Our research is based on work published in the 2000s' and 2010s'. In the second step, we exclude all papers that are not related to the efficiency of public road transport sector or by bus. This means that we analysed each item based on the title of the manuscript, abstract, keywords that. Following that, we decided to keep or exclude each of them. Finally, the papers were fully analysed and we included the papers that were only in the core of the field analysed in this study. After executing the search procedure papers, 24 papers were obtained that met all selection criteria.

3.2 Classification method

The classification framework is based on the literature review and research in the field of transport sector efficiency. According to the classification scheme technique, the papers will be classified into six major categories: (i) nature of the paper, (ii) context of study, (iii) approach adapted to measure efficiency, (iv) nature of the data, (v) inputs and outputs adopted, and (vi) empirical findings. We will discuss each category in the following.

3.2.1 *The nature of papers*

According to this criterion, papers will be classified into two categories: a theoretical paper or an empirical one. We mean here by theoretical paper all papers that treat the problem of efficiency of public transport without an empirical analysis, as well as empirical papers that measure the efficiency of public transport sector in a specific context and specify the inefficiency sources.

3.2.2 *Countries of the study*

Under this criterion, the papers will be classified according to the countries of the study. In this part two main questions are answered: what are the countries for the study of the efficiency of the public road transport sector of each paper and are there any papers that have treated this problem at multi-international contexts (between countries).

3.2.3 *The adopted approach to measure efficiency*

According to this criterion, studies will be classified into two approaches: a non parametric studies or parametric one. We mean here by parametric studies all papers that

treat the problem of efficiency of public transport with a stochastic frontier analysis method, as well as non parametric studies that use the Data Envelopment Analysis for evaluates the efficiency of public transport sector. In this paper, we focus on two approaches that seem most used in this area, which are defined previously.

3.2.4 *Nature of the data*

Under this criterion, the papers will be classified according to the nature of the data used to measure the efficiency of public transport operators. Thus, according to this criterion, we seek to use any nature of data (cross section, time series or panel data, etc.) that are the most used and equitable for the measurement of efficiency in public transportation.

3.2.5 *Outputs and inputs*

In contrast to manufacturing industries where output is a clearly identifiable entity, the output of a transport operator can be quantified in different ways. The fundamental reason for this difference is that the output of a transport system is a service that cannot be stored for future use. Cullinane et al. (2004) have provided a comprehensive discussion of the used variables. Thus, the variables input and output should reflect the objectives and the actual service production process of the transport system as accurately as possible. Under this criterion, articles will be classified according to the inputs and outputs used.

3.2.6 *Empirical findings*

According to this criterion, the papers will be classified according to the efficiency scores of each study. We will rely on the minimum, maximum and average efficiency scores in each study to classify the papers. This criteria helps assess the empirical approach and study context, answering two questions: what is the approach that accurately measures the efficiency of public transport?

4 Results

4.1 Classification of papers by types of paper and study contexts

In this section we focus on the types and study contexts of papers. Table 1 shows the papers selected. It shows that studies of the frontier are still an affair of interest to this day: several studies have been published during the 2000s.

An advantage of the technique of classification scheme is to make some observations, such as a high concentration of the literature on a specific date, journal or study context. Figure 1 shows that a study of the efficiency of public transport is even a relatively recent issue. The majority of papers have been published in the last five years. In the articles references, the majority of work refers to the study of De Borger et al. (2002) since it provides an overview of studies of the frontier in the public transport

Table 1 Papers on public transport efficiency

Author(s)	Period	Nature of paper	Context of the study	Sample size	Inputs	Outputs	Approach	Empirical findings
Karlaftis (2004)	1990–1994	Empirical	USA	259 systems (private/public)	Number of employees; total annual amount of fuel used; total number of vehicles operated by the system	Vehicle-miles; total annual ridership	DEA	Average TE per group of operators: between 61.8 % and 89.3 %. When returns to scale estimates are based on effectiveness, appear to be operating under decreasing returns.
Boame (2004)	1990–1999	Empirical	Canada	30 transit systems	Number of buses in the active fleet; litres of fuel/energy; total number of paid employee hours	Revenue, vehicle-km	DEA	The average technical efficiency of Canadian transit systems is 78 %, implying an inefficiency level of 22 %. Also, most transit systems (56 %) experience increasing returns (IRS), while 29 % experience decreasing returns (DRS) to scale.
Barnum and Gleason (2007)	2005	Empirical	USA	16 lots	Number of parking spaces; mean daily operating costs	Mean number of cars parked in the lot during the workday; mean daily revenue	SFA	Low efficiency scores make it easy to identify those lots that need thorough examination. Uncorrectable factors or other justifiable reasons account for the low scores. Low scores may identify lots that can and should be improved.

Table 1 (Continued)

Author(s)	Period	Nature of paper	Context of the study	Sample size	Inputs	Outputs	Approach	Empirical findings
Cowie (2002)	1990–1997	Empirical	Brittany	58 companies (private/public)	Number of staff employed; fleet size	Vehicle-km;	DEA	Efficiency improvements have not occurred per se due to scale economies, but are a result of improved internal company efficiency. This may be from a number of sources such as improved working practices, better management of operations, increased investment or rationalisations arising from the eradication of duplicate administrative/maintenance functions.
Agarwal et al. (2011)	2004–2005	Empirical	India	35 (private) state transport undertakings (STUs)	Fleet size (number of buses in hundreds); total staff (total number of employees working in an STU); fuel consumption; accident per km	Bus utilisation; passenger-km; load factor;	DEA	The results indicate that out of 35 STUs, 14 STUs (40 %) are relatively efficient (efficiency score = 1) while remaining 21 STUs are relatively inefficient (efficiency score < 1). The overall mean TE of the STUs is 83.26 %, indicating that on average 16.74 % of the technical potential of the STUs is not in use.
De Borger et al. (2002)	1986–2000	Theoretical	AI research context	22 papers (non parametric) 40 papers (parametric)	Diversity of inputs	Diversity of outputs	DEA; SFA; FDH;	Discuss efficiency and productivity results, returns to scale and scope, the relation between efficiency and effectiveness, the impact of ownership, subsidies and contracts, and the role of environmental variables and network characteristics.

Table 1 (Continued)

Author(s)	Period	Nature of paper	Context of the study	Sample size	Inputs	Outputs	Approach	Empirical findings
Odeck and Alkadi (2001)	1994	Empirical	Norway	47 companies	Total number of seats; fuel consumption in litres; equipment; effective driving hours; total number of staff employed	Seat-km	DEA	The average bus company exhibits increasing return to scale in production of its services. The extent of such returns however varies, with size and is more prevalent among smaller companies. The average bus company is found to have a considerable input saving potential of about 28 percent. Neither economies of scope nor company ownership are found to have an influence on company performance.
Farsi et al. (2006)	1986–1997	Empirical	Switzerland	94 operators	Total number of employees; network length; total number of bus-km; passenger-km	Number of seat-km	SFA	This study suggests that an econometric specification that includes separate stochastic terms for firm-specific effects and inefficiency can improve the estimations regarding both inefficiencies and scopes. The inefficiency estimates are sensitive to the adopted model.

Table 1 (Continued)

Author(s)	Period	Nature of paper	Context of the study	Sample size	Inputs	Outputs	Approach	Empirical findings
Barnum et al. (2011)	2002–2006	Empirical	USA	52 (private) transit agencies	Total operating expenses	Estimated seat-hours	DEA	Identify the individual technical efficiencies of each type of transit employed in an urban area, to identify allocation and technical efficiency in the DEA aggregated score, to estimate the effect of changes in each type of transit's efficiency on the overall public transportation efficiency; to offer a method for reallocating resources in order to improve efficiency.
Karlaftis (2003)	1990–1994	Empirical	USA	259 systems (private/public)	Total of buses, total of employees, fuel	Vehicle-miles	DEA	The largest systems operate under decreasing returns to scale, it must be noted that while the use of vehicle-miles as the measure of output captures economies of scale sufficiently from the supply side of the transit industry, this study concentrates strictly on the supply side of the transit industry.
Kumar (2011)	2006–2007	Empirical	India	31 (private) state road transport undertakings	Fleet size, total number of staff, fuel and lubricants	Revenue bus-day, passenger-km	DEA	Five SRTUs define the efficient frontier, and the remaining 26 inefficient undertakings have a scope of inputs reduction, the extent of average overall technical inefficiency (OTIE) in these SRTUs is to the tune of 22.8 percent, operation in the zone of increasing returns-to-scale is a common feature for most of the undertakings.

Table 1 (Continued)

Author(s)	Period	Nature of paper	Context of the study	Sample size	Inputs	Outputs	Approach	Empirical findings
P. Saxena and R. Saxena (2011)	2002–2005	Empirical	India	25 (public) transport undertakings	Fleet size; total staff; fuel consumption	Passenger-km; seat-km	DEA	The potential for the average company to improve their outputs is 22 %. The potential for the least efficient company is 28.5 %. The average of the scores is different from the scores of the average unit.
Holvad et al. (2004)	1991	Empirical	Norway	154 bus companies (public/private)	Fuel costs, driver costs and other costs	Seat-km	DEA, MEA	DEA underestimates the reduction potential, as 69 % of the companies have larger relative excesses in Multi-directional Efficiency Analysis (MEA) than in DEA with a maximal difference of 27 %. A closer inspection of the total relative excesses demonstrates that 52 % of the companies differ less than 1 % in the relative potential saving between MEA and DEA.
Yu and Fan (2009)	2001–2002	Empirical	Taiwan	23 firms (public)	Technical staff; sales staff;	Vehicle-km; passenger-km	DEA	The contributions of the paper to the literature are that a unified DEA framework is constructed for gauging production efficiency (PE), service effectiveness (SEV) and operational ineffectiveness (OEV) (Number of inefficient or ineffective scores per model: 20, 15, 22) simultaneously and dependently. The proposed model also deals with the situation where shared inputs are needed to allocate the activities and/or processes in the operation of a transit firm.

Table 1 (Continued)

Author(s)	Period	Nature of paper	Context of the study	Sample size	Inputs	Outputs	Approach	Empirical findings
Sheth et al. (2007)	2007	Empirical	Greece	60 bus companies	Headway, cost, service duration, number of intersections, and priority lanes	Average travelling time, vehicle-miles, schedule reliability, and passenger-miles	DEA	Actual transportation planners, managers of transportation agencies and traffic engineers could potentially be the users of the modelling framework proposed in this research. One would attempt to include these decision makers as part of the modelling process.
Pestana Barros and Peypoch (2010)	1995–2008	Empirical	Portugal	11 public and private companies	Liquid assets; number of employees; fuel costs; vehicle capacity	Sales, number of passengers,	DEA	(i) Two companies where a nil change in technical efficiency co-exists with improvements in technological change. (ii) One company, in which nil technical efficiency change co-exists with nil change in technological change. (iii) Companies in which negative technical efficiency change co-exists with positive technological change. (iv) One company in which nil technical efficiency co-exists with negative technological change. (v) One company in which negative technical efficiency co-exists with deterioration in technological change.

Table 1 (Continued)

Author(s)	Period	Nature of paper	Context of the study	Sample size	Inputs	Outputs	Approach	Empirical findings
Margari et al. (2007)	1993–1999	Empirical	Italy	42 public companies	Number of workers; total amount in litres of gasoline consumed each year; corresponding cost; total operating expenditure—the costs of labour and fuel	The yearly vehicle-km; the yearly seat-km	DEA, SFA	These preliminary unadjusted DEA scores indicate an average efficiency level of around 93 % for the urban firms and an average value of 85–86 % for the mixed and intercity local public transport systems. The authors separate inefficiency caused by exogenous factors like regulation and network from management skills, and conclude that pure managerial skills play a minor role.
Pina and Torres (2001)		Empirical	Spain	Public and private companies	Fuel/100 km; cost/km or cost/traveller; subsidy/traveller	Bus-km/employ; bus-km/bus, bus-km/inhabitant, accident rate population	DEA	Exogenous factors are not relevant and the private management of urban transport service is not more efficient than public management. Public companies more efficient, but not significantly. Economical sector focus, geographical extension, population density, no. of cars, income per capita, and population age without significant influence.
Sanchez (2009)	2008	Empirical	Spain	24 public and private companies	Staff, fuel consumption, number of operating buses	Hours seats, vehicles-km, passengers, frequency, accessibility, comfort, safety	DEA	The average index of technical efficiency was situated at 51.03 %, of pure technical efficiency at 94.91 %, and of scale efficiency at 52.02 %; the ownership does not in itself entail a higher attainment of levels of efficiency.

Table 1 (Continued)

Author(s)	Period	Nature of paper	Context of the study	Sample size	Inputs	Outputs	Approach	Empirical findings
Odeck (2008)	1995–2002	Empirical	Norway	27 bus operators	Total number of seats, fuel consumption, total number of hours worked	Seat-km	DEA	The potentials for efficiency in the sector ranged from 4 % to 11 % depending on the technology assumed. Efficiency increased more in the post-merger years compared to the pre-mergers.
Odeck and Alkadi (2003)	1994	Empirical	Norway	47 bus operators	Total number of seats, effective driving hours, total number of staff, fuel consumption	Seat-km	DEA	Rural operators on average have lower mean scale efficiency and a higher variance of scale efficiency. The scale efficiency shows that an average bus company is smaller than optimal. Substantial variation in efficiency scores across units in the bus industry.
Hirschhausen and Cullmann (2010)	1990–2004	Empirical	Germany	127 to 179 bus companies	Number of full-time and part-time workers; number of busses	Seat-km; bus-km		Increasing returns to scale for small- and medium-sized companies. Slight increase in technical efficiency over the years on average (42.0–46.0 %). Slight increase of average efficiency due to the additional constraint.

Table 1 (Continued)

Author(s)	Period	Nature of paper	Context of the study	Sample size	Inputs	Outputs	Approach	Empirical findings
Sampaio et al. (2008)	2001–2005	Empirical	Brazil, Spain, England, France, Germany, Holland, Greece, Lithuania.	19 systems	Total number of employees; number of vehicles; fuel (gallons per year)	Vehicles/distance travelled; number of passengers/distance travelled	DEA	Efficiency analysis comparing Brazilian and European transport systems may be very important to highlight aspects for service improvement. The DEA variable returns model used showed that only 14.3 % of the analysed Brazilian systems are efficient or 5.3 % of the total analysed systems. In contrast, only 2.5 % of European systems were inefficient.
De Borger et al. (2008)	1991	Empirical	Norway, France	154 (public/private) Norwegian, 55 French bus operators	Fuel costs, driver costs, other costs	Seat-km	DEA	The difference between the CRS and the VRS versions of the respective models amounts to almost 8 % for the cost efficiency ratio (mean efficiencies are 57 % and 65 %) and 9 % for the radial efficiency measure based on the production frontier (mean efficiencies are 63 % and 72 %, respectively). The cost efficiency ratios are—as expected—somewhat lower, since overall efficiency is a more demanding criterion. These rather low levels of relative efficiency indicate considerable heterogeneity with respect to the efficiency with which individual bus companies provide their services.

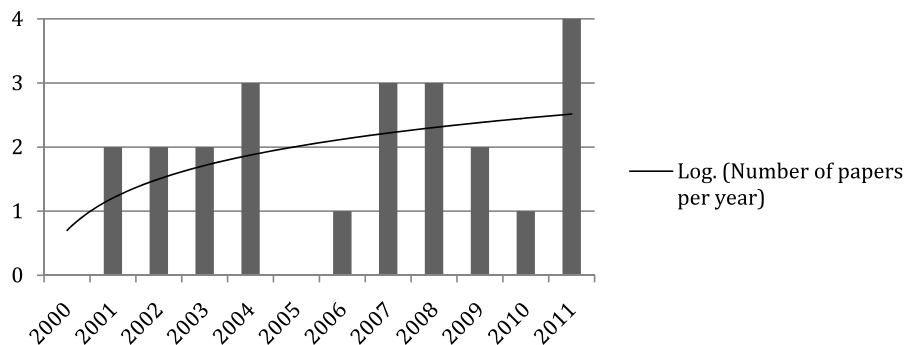


Fig. 1 Distribution of papers on public transport efficiency by date of publication

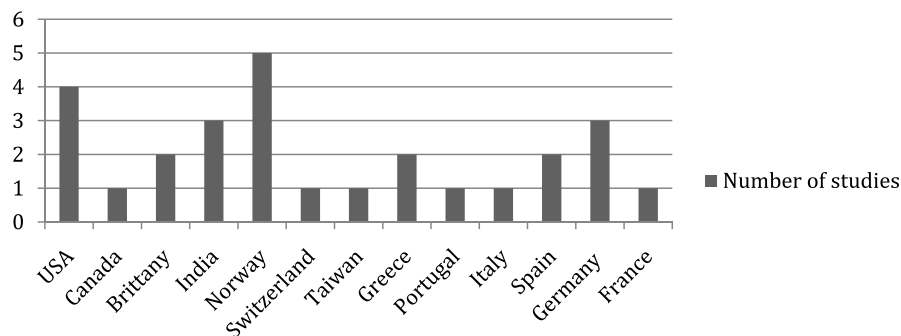


Fig. 2 Distribution of papers on public transport efficiency by countries of studies

sector and provides an overview of methods used to measure efficiency and determinants of inefficiency of public transport operators. Thus, the study by De Borger et al. (2002) contributes to the increasing number of published studies on this area, which, shows that the survey paper have a great interest in scientific research.

According to Fig. 2, the analysis of the efficiency of public transport is an interesting case in all different economies. According to the papers examined in this study, we find that the U.S. and Norwegian contexts are those most studied. However, other countries that have recently become interested in this field of research. For example, Agarwal et al. (2011) and Kumar (2011) propose an application in the Indian context. Yu and Fan (2009) used Taiwan data and Hirschhausen and Cullmann (2010) studied German data. Only Sampaio et al. (2008) and De Borger et al. (2008) adopted an international comparative perspective.

4.2 Classification by efficiency evaluation method

The classification scheme technique is a technique to understand literature in a specific area of research. Figure 3 illustrates the results of classification of articles based on the method adopted. It shows that the majority of studies have adopted the DEA method, but there are some studies that adopt the method SFA, and a very limited

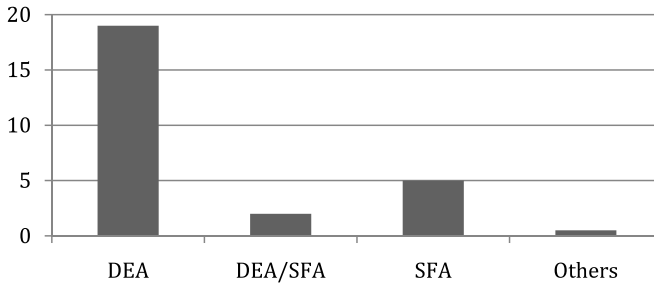


Fig. 3 Papers distribution by the adopted method

number of studies that adopt a comparative perspective, or mixed for two DEA and SFA method.

Sampaio et al. (2008) have justified their adoption of the DEA method. When units are found inefficient, the DEA method automatically generates target units. Thus, DEA identifies that a certain DMU is inefficient, the DMU of reference against which the DMU is inefficient. In most cases, the non-parametric analysis is preferable. But, generally, the particular choice of the DEA is incomplete. This is the reason a number of studies have adopted a comparative perspective, a mixed method or a double method for the study of frontier, for example, Holvad et al. (2004).

Stated simply, the problem is that dominated companies in the public transport can appear efficient, and a significant part of the studied are measured against these dominated reference units, which seems to call for the use of another method or type of efficiency index referring only to non-dominated reference units. Moreover, in contrast to the studies based on the DEA method, it is necessary to adopt another approach to study the efficiency of public transport operators. This is the case for the study of Margari et al. (2007) and Karlaftis and Tsamboulas (2012). They implement the DEA-SFA mixed approach proposed by Fried et al. (2002). This approach is based on the decomposition of the measurement of the DEA inefficiency into three components: exogenous effects, ineffective management and stochastic events.

4.3 Classification by nature of data

In our sample of papers examined, we conclude that the data used come in different natures. Thus, several studies are based on panel data: either cylindrical or non cylindrical panels, for example, Cowie (2002). Other studies used data such as cross section (for example, Karlaftis 2003, 2004 and Kumar 2011). However, Boame (2004) and Saxena and Saxena (2011) have used type data time series. In recent years, usually studies of the efficiency of public transport use panel data in their applications (e.g., Sheth et al. 2007; Odeck 2008; Yu and Fan 2009; Hirschhausen and Cullmann 2010; and Barros and Peypoch 2010). This establishes the reliability of such data for assessing the efficiency of public transport.

Panel data sets for economic research possess several major advantages over conventional cross-sectional or time series data sets (e.g., Hsiao 2003). Panel data usually give the researcher a large number of data points, increasing the degrees of

freedom and reducing the collinearity among explanatory variables, hence improving the efficiency of econometric estimates. More importantly, longitudinal data allow a researcher to analyse a number of important economic questions that cannot be addressed using cross-sectional or time-series data sets. Panel data also provide the possibility of generating more accurate predictions for individual outcomes than time-series data alone. If individual behaviours are similarly conditional on certain variables, panel data provide the possibility of learning an individual's behaviour by observing the behaviour of others in addition to the information on that individual's behaviour.

4.4 Classification by outputs and inputs adopted

Probably, the most notable inputs of Table 1 are those showing the high variability in the use of inputs and outputs in public transport operators' specification technology. Most studies use labour and capital as inputs (Yu and Fan 2009 has an application using labour as the only input). But not all of them include energy. For example, Cowie (2002) includes the number of staff employed and the size of park and Farsi et al. (2006) use the total number of employees, network length, the total number of bus/kilometres and passenger kilometres, energy has been eliminated for these studies. In contrast, Boame (2004) and Agarwal et al. (2011) include energy as a measure of inputs.

Some studies include environment variables to provide more details on inputs quality. For example, Sheth et al. (2007) include the length of service, the number of intersections and priority lanes as inputs. Agarwal et al. (2011) consider the size of the park, total staff, fuel consumption and accidents per kilometre. Barnum et al. (2011) include the total operating expenses; Barros and Peypoch (2010) include liquid assets, the number of employees, fuel costs, vehicle ability. A similar variety of numbers of indicators is observed with output. Moreover, the use of traditional inputs such as labour, energy and vehicles poses a substitution problem among inputs. For transport, this would mean that to produce a fixed level of output, a bus or transport operation adapted could substitute labour for vehicles, or substitute vehicles for energies. Thus, the elimination of nonsubstitutable inputs would usually result in some really inefficient firms being reported as efficient. Since, increasing the number of inputs and outputs results in higher efficiency scores. Further, for the reason of the random error component in all variables, the larger number of inputs and outputs, the more possible that a firm's efficiency scores will be high.

Some studies use supply-oriented indicators such as "vehicle-km" as output (e.g., Cowie 2002; Karlaftis 2003, 2004; Sheth et al. 2007; Yu and Fan 2009). However, more recent studies used supply-oriented indicators in their application, such as "seat-km" as an appropriate measure of output. Margari et al. (2007), De Borger et al. (2008), Odeck (2008) and Saxena and Saxena (2011) used "seat-km" as output measure in their studies. Hirschhausen and Cullmann (2010) used "vehicle-km" and "seat-km" in their application as an appropriate measure of output.

Indeed, the revenue and sales of their shares are used as measures of output in several studies, for example, Barros and Peypoch (2010) and Kumar (2011). In studies of the efficiency of public transport, there is a wide choice of output, although

the specifications of “vehicle-km” and “seat-km” are used frequently. Agarwal et al. (2011) have also considered “passenger-km”, which is a demand-oriented indicator. Some studies have used different natures of output.

The definition of outputs is more problematic. The early literature focused on the distinction between pure supply indicators (vehicle-km or seat-km) and output measures that at least to some extent reflect the demand for transport services (e.g. passenger-km and number of passengers). Arguments for and against either specification can be found in the literature.

Many authors have argued that demand-oriented output specifications are very relevant when evaluating the companies’ efficiency (Chu et al. 1992; Costa 1998; Tone and Sawada 1990), but demand-oriented output should be careful when the focus is on costs and productivity. The main arguments have been summarised by Berechman (1993). First, inputs do not vary systematically with demand-oriented output measures so that they do not allow an adequate description of transport technology. Second, supply-oriented output indicators are to a larger extent more under the control of transport companies than demand-oriented outputs. In unregulated environments, they really would be direct decision variables for the transport companies. Even if this is not the case due to government regulation of service levels, transport operators do have some control with the authorities via the negotiation process. Third, independently of the achievement of frontier aims defined in terms of passenger transport services really consumed, supplying the transport services in the least costly way may be considered a best requirement for transport operators. Therefore, the focus should be on pure supply indices when measuring productivity and efficiency. This is especially the case since it is unlikely that all parties involved can agree upon possible broader objectives. For instance, regulators may be interested in the efficient use of their funds, while operators may be inclined to stress efficiency in terms of the number of passengers, service availability, etc. However, the problem remains: there is no general consensus on the objective of transport operators.

This discussion on the use of supply-oriented or demand-oriented variables proposes an initiative to use financials variables. These variables are more robust since they reduce the problems reflected by the use of variable-oriented demand or supply. Financial variables are relatively related to the economic variables. Thus, the number of passenger and seat-km are variables similar to the variables “revenue”, “operating income” and “sales”. For example, Barros and Peypoch (2010) propose sales as an appropriate measure of output; while Kumar (2011) uses the revenue as measure of output. Regarding the inputs, Barnum et al. (2011) propose total operating expenses as an appropriate measure of inputs.

4.5 Classification by empirical findings

In the papers reviewed in Table 1, the authors discuss the efficiency, productivity and returns to scale of transport operators.

To some extent, the efficiency is determined by the approaches adopted. For example, the differences in underlying assumptions imply that the deterministic non-parametric and parametric stochastic approaches may generate relatively different efficiency scores. Thus, the application of different approaches (parametric and non-parametric) automatically results in different efficiency scores. However, one should

keep in mind that frontier methods are related only in efficiency, and efficiency scores are relative to the sample considered and are not based on absolute norms. So, it is impossible to make comparisons of efficiency levels between studies.

With these warnings, we turn to the main findings. First, in terms of technical efficiency, most studies indicate that inefficiency occurs substantially between transport operators in different countries (e.g. Karlaftis 2004; Boame 2004; Margari et al. 2007; Agarwal et al. 2011). Thus, if the evidence of substantial technical inefficiency between transport operators in different countries is confirmed, it is difficult to generalise these results to the efficiency in other sectors of the economy (De Borger et al. 2002). Second, comparative studies of the efficiency of transport operators in different countries (e.g. Sampaio et al. 2008; De Borger et al. 2008) indicate a great variability in technical inefficiency, both between and among countries. The observed variation captures differences in the regulatory environment, population density, quality management and operating environment (De Borger et al. 2008).

In our sample, most researches in transportation efficiency are directed to the study of the efficiency and returns to scale of public transport operators. Thus, Karlaftis (2004) has organised his sample to groups of operators. He remarked that the average technical efficiency groups were between 61.8 % and 89.3 %; this reflects the average efficiency of the sample, and is characterised by decreasing returns to scale. Thus, Boame (2004) has studied the efficiency of Canadian transport systems; he found that the average technical efficiency is 78 %. According to the comparative efficiency study of Sampaio et al. (2008), they proved only 14.3 % of Brazilian systems analysed are efficient, which is 5.3 % of all systems analysed. And only 25 % of European systems were inefficient; which reflects the average inefficiency of the sample. Moreover, most transport systems (56 %) have increasing returns to scale (IRS), while 29 % have decreasing returns to scale (DRS). In addition, five Indian state road transport undertakings (SRTUs) of all 31 define the efficient frontier, and the remaining 26 inefficient firms have a range reducing inputs. Operating in the zone increasing returns to scale is a common feature of most companies, Kumar (2011). Consequently, we find that when the study was founded on the efficiency of different contexts, the average operators' efficiency will be small. On the other hand, if the study is founded on a specific context, the average efficiency would be broad. We can conclude that the variety of study contexts contributes to the detection of inefficiency of transport operators.

Although the studies reviewed are not specifically designed to study the returns to scale and fields of application, they produce interesting results such as an automatic sub-result. Most of these studies have sustained that small operators usually experience increasing returns to scale, while average-sized operators are subject to increasing or constant returns to scale, and large systems are subject to decreasing returns to scale. However, these results are specific to a particular context.

The deregulation and privatisation are key factors in improving the efficiency of public transport. So, Cowie (2002) found that deregulation and privatisation have improved the efficiency of firms, and that productivity and efficiency are higher in the private than in the public sector. De Borger et al. (2002) argues that privatisation and regulation is a favourable solution to improve the efficiency of the transport sector. The public transport needs to be more efficient in private firms as it is considered to

be a revenue generating sector. As well, Pestana Barros and Peypoch (2010) indicate that public bus companies have similar efficiency to private bus companies. Not surprisingly, efficiency has played a prominent role in political and academic arguments guiding privatisation and deregulation policies (e.g. Mackie et al. 1995).

We note that the majority of the studies reviewed are interested in measuring the efficiency of transport operators in different contexts, with different approaches and methods of measurement, and different variables and indicators (inputs and outputs). Thus, we conclude that the results of these studies are interested only for the sector, the context, the operators studied. Then, the empirical implications of a study cannot be generalised. As well, studies of the same context, the same operators, can have different results and empirical implications, since they use different methods and measurement approaches, and different indicators and variables. Studies that evaluate the different contexts with different approaches and with a set of representative indicators of the objective function of transport operators are lacking. This type of study is very interesting to adequately assess the efficiency of transport operators.

After measuring the efficiency of public transport operators, it is interesting to explain the sources of inefficiency. The use of variables under the control of the firm is more robust to explain the determinants of inefficiency, such as the investment on new technologies and new equipments for the operating cycle, the operating income and the firm size. The technical efficiency can be affected by the financial resources availability; more exactly, once a firm cannot have access to external financial resources, then it has an incentive to improve its technical efficiency over time to guarantee positive profits and gains in productivity Sena (2006). Tariffs and benefits are fundamental to the public transport activities, because they are a major source of revenue (Paulley et al. 2006). In addition, Cowie (2002) affirmed that the improvement of company efficiency may be from a number of sources such as improved working practices, better management of operations and increased investment. Lun and Quaddus (2011) have examined the effect of firm size on the firm efficiency and performance. They have shown that the firm size has a relatively positive effect on efficiency and it is a determinant of output growth.

5 Conclusion and future research

This paper aims to survey literature on public transport efficiency. We introduce an approach based on classification scheme technique where research papers in this domain are collected, classified and results are interpreted. A classification scheme technique was adopted in order to make a comprehensive literature study. This study provides insights and future directions into the research of public transport efficiency. Based on the review, classification and analysis of the articles, some broad suggestions for future research can be advanced.

The classification by context highlights that research in this field is restrained into three contexts only: the European context (Germany and Norway), the American context (USA) and the Asian one (India). The transportation economy should depart from these contexts to study public transport efficiency in other European countries and in the African context. This is in order to generalise theoretical predictions and empirical findings and to neutralise the contexts' effect on the public transport operators'

efficiency study. It is primordial to assure that the efficiency is independent from the context of the study.

The classification scheme technique shows a concentration of studies on the use of supply and demand oriented inputs and outputs, notwithstanding these deficiencies. The potential for growth literature may be possible with the adoption of other types of inputs and outputs. We also show that financial variables are more robust, since they reduce the problems reflected by the use of demand or supply-oriented variables. They are relatively related and explanatory of the variables used initially. Thus, the “number of passenger” variable and the “seat-km” variables are consistent with “revenue” and “sales”. For example, Barros and Peypoch (2010) have proposed sales as appropriate measure of output, and Kumar (2011) used the revenue as a measure of output.

The use of traditional inputs such as labour, energy and vehicles poses a substitution problem among inputs. For transport, this would mean that to produce a fixed level of output, a bus or transport operation adapted could substitute labour for vehicles, or substitute vehicles for energies. Thus, the elimination of nonsubstitutable inputs would usually results in some really inefficient firms being reported as efficient. Since, increasing the number of inputs and outputs results in higher efficiency scores. Further, for the reason of the random error component in all variables, the larger number of inputs and outputs, the more possible that a firm's efficiency scores will be high. Therefore, operating expenses and the number of employees are an appropriate measure of inputs.

Public transport efficiency analyses have focused both on developing methods for assessing system performance and on using performance findings to make different policy recommendations. According to the criterion of classification scheme “adopted approach”, we found that most studies reviewed are based on the DEA approach or to a lower percentage the SFA approach. There is a lack of comparative studies that adopt a mixed approach (DEA and SFA), despite of the robustness of its results. The only exception is the study of Margari et al. (2007) and Karlaftis and Tsamboulas (2012), which implements the DEA-SFA mixed approach proposed by Fried et al. (2002). Thus, using a mixed approach (DEA-SFA) or the application of a comparative perspective to assess the efficiency of public transport is more robust.

After measuring the efficiency of public transport operators, it is interesting to explain the sources of inefficiency. They are under the control of the firm or outside of its control such as regulations of the authorities? The use of variables under the control of the firm is more robust to explain the determinants of inefficiency, such as the investment on new technologies and new equipments for the operating cycle, the operating income and the firm size. Tariffs and benefits are fundamental to the public transport activities, because they are a major source of revenue (Paulley et al. 2006). The technical efficiency can be affected by the financial resources availability; more exactly, once a firm cannot have access to external financial resources, then it has an incentive to improve its technical efficiency over time to guarantee positive profits and gains in productivity Sena (2006). Indeed, it is reasonable to think that the availability of resources can affect the efficiency of the productive process. Therefore, with the operating income, transport operators can improve the quality of services and indeed improvement of efficiency. The operating income constitutes an

internal financing source for the investments related in the productive activities for firm. The operating income can be considered a determinant of transport operators' inefficiency. Moreover, we can consider that the investment is an important source of efficiency (see Ahern and Anandarajah 2007). Cowie (2002) affirmed that the improvement of company efficiency may be from a number of sources such as improved working practices, better management of operations and increased investment. In addition, Lun and Quaddus (2011) have examined the effect of firm size on the firm efficiency and performance. They have shown that the firm size has a relatively positive effect on efficiency and it is a determinant of output growth.

Another interesting topic related to transport efficiency has been that of examining differences in efficiency and productivity for bus systems in periods before and after regulatory reform (usually this regulatory reform was privatisation), or the comparison of privately and publicly operated transport systems.

The literature review on the field of public transport highlights that there is no previous research paper that introduces the effect of CEOs' psychological bias on the explanation of efficiency. In the transport literature, the implications of the emergence of behavioural economics and behavioural finance are ignored. These areas consider the managerial psychological bias and especially the overconfidence or optimism as powerful factors that can explain many firms' decisions and policies. It will be an interesting way to initiate an open and original debate: can managerial optimism and others psychological and emotional bias affect the transport's operators' efficiency? If the answer will be positive, so it will be time to discuss the effect of corporate governance mechanisms' effect on the operators' efficiency. It will be an attractive approach to jointly analysis the impact of such variables in this field.

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