

Technical Efficiency Analysis of Bus Companies Based on Stochastic Frontier Analysis and Data Envelopment Analysis



Feras Tayeh and Shujun Ye

Abstract An efficiency evaluation is a leading tool of assessing transportation performance, seeking to examine the valued outcomes of transportation system in relation to the resources, thus having an extreme importance for policymakers. Technical efficiency evaluation of Istanbul bus companies is the ultimate objective for the sake of identification the passenger performance, and to identify how concern factors influence the technical efficiency. Additionally, to find out the influence of the competitive transportation modes and distance factors that each bus line connects. The present study employs Stochastic Frontier Analysis with production function; the results of the current study are compared to those obtained by Data Envelopment Analysis.

Keywords Technical efficiency • Stochastic frontier analysis • Production function • Data envelopment analysis • Trolley buses passenger

1 Introduction

Increasing concerns about fiscal sustainability transportation have brought the issue of transportation system efficiency to the forefront of policy discussions at both national and international level. Numerous highways have significantly lost business to other transportation modes efficiency, such as railways and air over the past decades. Development of passenger transport is dependent on the economic play a critical role in transport planning authority's decision in policy development and resource allocation. In Turkey, road transportation is the main mode of passenger transportation and has one of the most developed road networks in its region, passengers transport increased by 4.36% which is reflected in the increase in the

F. Tayeh (✉) · S. Ye
School of Economics and Management, Beijing Jiao Tong University, Beijing, China
e-mail: elkbeer11@gmail.com

S. Ye
e-mail: shjye@bjtu.edu.cn

number of driver's licenses of over 24 million in 2018. Istanbul is a big city with more than 15 million inhabitants. Undoubtedly, in Istanbul of these extents, the travel is one of the major troubles. Most of the transportation networks modes on land in Istanbul consist of trolley buses, private cars and taxis, which generate a big stress on the passenger's movement intercity and traveling to other cities. According to Turkish State Railways Annual Statistics in 2018 Istanbul had 20 trolley bus lines to connect main cities in turkey, which covered more than 6800 km, the fleet consisted of 3059 trolley buses, more than 28 million travelers use trolley buses and approximately 2800 employees yearly. For that, evaluating gaps and efficiency trolley buses is critical issue to the decision makers in transport sector.

Technical efficiency evaluation of Istanbul bus companies is the ultimate objective for the sake of identification the passenger performance in 2018, and to identify how concern factors influence the technical efficiency. The present study employs Stochastic Frontier Analysis with the production function. Monthly survey of twenty lines with 240 surveys, one output is passenger-kilometers as dependent variable, and three inputs are labor, vehicle-kilometers, and vehicles trolley and coaches number, of each line as independent variables. Additionally, the power of other factors on the competitive transport modes and distance that each line connects is conducted. The results of the current study are compared to those obtained (DEA-CCR).

2 Literature Review

The significance of evaluating transport modes concurrently stems from the fact that transport networks are considered as the pillar of sustainable metropolitan improvement, Stamos report on south east Europe explores its contribution to the rail transport enhancement [1]. Using the populated areas to study the urban rail networks system with currently travel positions and the circumstances such as London underground and British rail, an additional model to integrate and identify safety level was carried out by [2]. Although, there is a number of publications on DEA to evaluate efficiency within the various fields of transport [3]. Loizides presented the cost structure of 10 European countries based on the general index of technical change Between 1970 and 1992, and made the following rankings of the most productive countries; Germany, United Kingdom, Belgium, France, Italy, Netherlands, Greece, Denmark, Luxembourg, and Portugal [4]. Suarez quantified the efficiency level of European railway companies, examined key indicators (passengers, freight, kilometers of lines, the percentage of electrification and the percentage of kilometers of double line) and indicates that the most highly developed railway companies are found in Austria, Italy and Germany [5].

Pedro in some European countries such as Sweden, Britain, Italy, France and Germany, they observed the revenue from rail passenger market and public subsidies; and improvements in rail technology are a key driver of productivity growth in

the railway transport sector [6]. Other studies examined a detailed analysis of previous empirical researches on data envelopment analysis (DEA) which uses as a tool to measure and a technique of linear programming to analysis the comparative efficiency of other decision-making units, with efficiency levels lie between (0–1) for the most efficient alternative [7]. This method of Data Envelopment Analysis and its extension are skilled to deal different variables of inputs and outputs; and discover other dealings that may be concluded with other approaches but assuming that all variables of input and output data are precisely recognized [8]. As a useful method for analyzing the relative performance within a group of organizations, Data Envelopment Analysis method discovered practical association between competition framework and productive effectiveness of decision-making units by designing construct efficiency scores and regressing these scores against variables. Bojović affirmed that DEA analysis provide indications for measuring and monitoring efficiency while improving the performance and ability to reach the efficiency frontier [9]. To determine efficiency using data envelopment analysis method and Tobit regression [10], examined 31 transport firms between 2000 to 2009 that offers passenger and other services in world, the results show that some transport companies in France, Japan, Luxemburg, and Spain in Western Europe operate effectively using six input variables. Bråthen identified that tool of measurement is used to evaluate and compare the relationships different road networks to discover the performance and comparing with other positions for technical support and help the policymakers to enable them take essential actions to make highway system efficient [11].

3 Research Methodology

Several methodologies have been used to estimate and analysis efficiency within the various fields of transport: The method needs a practical shape to determine the production function with contaminated data and evaluation errors and other noise [12, 13].

3.1 Stochastic Frontier Analysis (SFA)

Farrell recognized the explanation of technical efficiency, the empirical function was comparatively limited [13]. Aigner, Lovell, and Schmidt introduced the stochastic frontier production function [14], Meeusen and van Den Broeck offered the Cobb-Douglas production function with a composed multiplicative disturbance term [15], they presented as:

$$y = f(x, \beta) \exp(\varepsilon), (\varepsilon) = (v - \mu), \mu > 0 \tag{1}$$

- y : the observed output quantity.
- f : the deterministic part of the frontier production.
- β : vector of the input quantities.
- x : vector of parameters to be estimated.
- v : symmetrical random error.
- μ : One-sided non-negative random error

Technical efficiency is calculated:

$$TE = y/[f(x) \exp(v)] = \exp(-u) \tag{2}$$

Where TE has a value between 0 and 1, with 1 defining a technically efficient firm. More specifically, from Eq. (1) is written as:

$$\ln(y) = \ln[f(x)] + v - u \tag{2a}$$

$$\ln(y) = -u + \ln[f(x)] + (v - u + \mu) \tag{2b}$$

$$\mu = E(u) > 0$$

Estimation of (2) by OLS gives the residuals $e_i, i = 1, 2, \dots, n$.

The second and third central moments of the residuals, $m_2(e), m_3(e)$ respectively, are considered, as follows:

$$m_2(e) = \left[\frac{1}{N - K} \right] * \sum e_i^2 \tag{3a}$$

$$m_3(e) = \left[\frac{1}{N - K} \right] * \sum e_i^3 \tag{3b}$$

N : number of observations. k : number of regressors. Then, we estimate σ_u^2 and σ_v^2 by using the formula.

$$\sigma_u^2 = [(\pi/2)[\pi/(\pi - 4)] m_2(e)]^{2/3} \tag{4}$$

$$\sigma_v^2 = m_2(e) - [(\pi - 2)/(\pi)] \sigma_u^2 \tag{5}$$

The point measure of technical efficiency is

$$TE_i = E(\exp\{-u_i\}/\varepsilon_i) = [1 - F[\sigma - (M_i^*/\sigma)]]/[1 - F(-M_i^*/\sigma)] \exp[-M_i^* + (\sigma^2/2)] \tag{6}$$

$$M_i^* = (-\sigma_u^2 \varepsilon_i)(\sigma_u^2 + \sigma_v^2) - 1 \tag{6a}$$

$$\sigma^2 = \sigma_u^2 \sigma_v^2 (\sigma_u^2 + \sigma_v^2) - 1 \tag{6b}$$

3.2 The DEA Input Oriented Model

With the most fundamental DEA method is DEA-CCR [16]. This method is very important because it process with constant returns to scale (CRS) to find that the observed DMUs work at the large amount efficient scale size [17]. The mathematical function of DEA-CCR method is offered with number of Decision Making Units can be measured. Each DMU has inputs, and different outputs [18]: v_i ($i = 1, 2, \dots, n$) as input and u_r ($r = 1, 2, \dots, q$) as output

$$\max \sum_{r=1}^q u_r y_{rk} \tag{7}$$

$$s.t. \sum_{r=1}^q u_r y_{rk} - \sum_{i=1}^m v_i x_{ij} \leq 0 \tag{7a}$$

$$\sum_{i=1}^m v_i x_{ik} = 1 \tag{7b}$$

$$i = 1, 2, \dots, m; r = 1, 2, \dots, q; j = 1, 2, \dots, n$$

To examine the weak efficiency, dual model of (7) is formulated as:

$$\min \theta \tag{8}$$

$$s.t. \sum_{j=1}^n \lambda_j x_{ij} \leq \theta x_{ik} \tag{8a}$$

$$\sum_{j=1}^n \lambda_j y_{rj} \geq \lambda_{rk} \tag{8b}$$

$$\lambda \geq 0 \tag{8c}$$

the panel data set consists of 240 monthly buses movement observations of the 20 buses network of Istanbul bus companies in 2018, which cover a large surface from Istanbul to the other cities in Turkey Table 1.

Table 2 shows inputs and outputs variables used in the study, dataset consists of following variables. One output is passenger-kilometers as dependent variable. The inputs are labor vehicle-kilometers and vehicles trolley buses number of each line as independent variables. Every one of these inputs expresses the practical conditions of each line of Istanbul. Moreover, to evaluate the probability impact of some other factors, two dummy variables were presented in Table 3.

Table 1 Trolley bus lines

Line	DMU
Line 1	Istanbul - Adapazari
Line 2	Istanbul - Afyonkarahisar
Line 3	Istanbul - Alanya
Line 4	Istanbul - Antalya
Line 5	Istanbul - Aydin
Line 6	Istanbul - Balikesir
Line 7	Istanbul - Bodrum
Line 8	Istanbul - Bolu
Line 9	Istanbul - Burdur
Line 10	Istanbul - Düzce
Line 11	Istanbul - Eskişehir
Line 12	Istanbul - Gebze
Line 13	Istanbul - Izmir
Line 14	Istanbul - Izmit
Line 15	Istanbul - Kütahya
Line 16	Istanbul - Manavgat
Line 17	Istanbul - Manisa
Line 18	Istanbul - Ordu
Line 19	Istanbul - Samsun
Line 20	Istanbul - Serik

Table 2 Input - outputs used to evaluate technical efficiency

Inputs	Outputs
Labor	Total passenger-kilometers
Vehicle-kilometers	–
Vehicles trolley buses number	–

The influence of the competitive transportation modes and distance factors that each bus line connects such as railway influence in passengers movements decision provides other options to be chosen, these options are conducted in this study as dummy variables, the influence of Istanbul railway, passengers prefer to use Istanbul railway, in this framework, we make the supposition that the lines that serve areas directly connected with the railway are negatively affected, where the dummy variables take two values (0, 1), other dummy variable is the impact of the distance.

Table 3 Dummy variables used in the analysis

DMU	Route	Dummy 1	Dummy 2
Line 1	Istanbul - Adapazari	1	1
Line 2	Istanbul - Afyonkarahisar	1	1
Line 3	Istanbul - Alanya	1	1
Line 4	Istanbul - Antalya	1	1
Line 5	Istanbul - Aydin	1	0
Line 6	Istanbul - Balikesir	1	0
Line 7	Istanbul - Bodrum	1	0
Line 8	Istanbul - Bolu	1	1
Line 9	Istanbul - Burdur	1	1
Line 10	Istanbul - Düzce	1	1
Line 11	Istanbul - Eskişehir	1	1
Line 12	Istanbul - Gebze	0	0
Line 13	Istanbul - Izmir	1	0
Line 14	Istanbul - Izmit	0	0
Line 15	Istanbul - Kütahya	1	1
Line 16	Istanbul - Manavgat	1	1
Line 17	Istanbul - Manisa	1	0
Line 18	Istanbul - Ordu	1	1
Line 19	Istanbul - Samsun	1	0
Line 20	Istanbul - Serik	1	1

4 Results and Discussion

The production function to convert the inputs into outputs can be showed by log-linear Cobb-Douglas measurement, the logarithmic stochastic functions presented as

$$lny_{it} = \beta_0 + \sum_{i=1..N} \beta_n lnx_{nit} + v_{it} - u_i$$

y_{it} and x_{it} are observed output and inputs of the i^{th} unit in year t .
 u_i : Non-negative time-invariant random variables.

$$lny_{it} = \beta_0 + \beta_1 lnx_{1it} + \beta_3 lnx_{3it} + v - u$$

v_{it} Random variables of i^{th} unit in year t.

From (1), the fitted functional form is:

$$\ln y_{it} = \beta_0 + \beta_1 \ln x_{1it} + \beta_2 \ln x_{2it} + \beta_3 \ln x_{3it} + \beta_4 d_1 + \beta_5 d_2 + v - u$$

y: dependent variable and donate to output

x_1 : inputs of labor

x_2 : vehicle-kilometers

x_3 : trolley bus and Coaches number

d_1 : dummy variable donates to the influence of other mode in transportation such as Istanbul railway, and d_2 : the influence of the distance and covered areas.

4.1 Descriptive Statistics and Correlation in Dataset

Table 4 presents the descriptive statistics of variables used in the study and contains the descriptive statistics of the variables used in the study. They include the sample mean, median, standard deviation, minimum and maximum value for each of the variables.

Table 5 shows the variables which have influence on Passengers movement are vehicle-kilometers, total labor, available vehicles, and influence of dummy variables, that each line has impact significant coefficients. Vehicle-kilometers variable is statistically significant. With an increase by 1% of Vehicle-kilometers value, passengers will decrease by 1.02% on average. The total labor is highly statistically

Table 4 The descriptive statistics

Characteristics	y	x_1	x_2	x_3	d_1	d_2
Mean	112990.0	340.1	141.1	2824.7	0.7	0.75
Median	77900.0	291.1	97.12	1947.5	1	1
Maximum	456000.0	753.1	570	11400	1	1
Minimum	14400.0	45.4	18	360	0	0
Std. Dev.	98792.8	199.9	123.5	2469.8	0.4	0.44
Skewness	2.14925	0.47	2.40	2.14	-0.8	-1.1
Kutosis	7.40526	2.1	7.40	7.40	1.7	2.34
Jarque-Bera	378.834	17.57	379.30	378.8	46	57.8
Probability	0	0	0	0	0	0
Sum	271176	8162	3388	6779	168	180
Sum Sq. Dev.	2.33E+9	9557885	364476	1.46E+9	50	45
Observations	240	240	240	240	240	240

Table 5 Analysis of variance

Variable	Coefficient	Std. error	t-Statistic	Prob
C	12118072	4428893	2.736140	0.0067
ln_x ₁	-27906.38	3137.751	-8.893752	0.0000
ln_x ₂	4255228	1477585	2.879853	0.0043
ln_x ₃	-4136840	1477597	-2.799709	0.0055
d ₁	15962.28	5633.912	2.833250	0.0050
d ₂	-24473.16	6258.46	-3.910409	0.0001
R-squared	0.886364			
Adjusted R-squared	0.883936			
F-statistic	365.0414			
Prob (F-statistic)	0.000000			

Table 6 Correlation in the dataset

Independent variable	Parameters	Estimate	t-Statistic	P-Value
C	β_0	1.96E+13	2.736140	0.0067
x ₁	β_1	-1.02E+09	-8.893752	0.0000
x ₂	β_2	6.54E+12	2.879853	0.0043
x ₃	β_3	-6.54E+12	-2.2799709	0.0055
d ₁	β_4	-2.11E+09	2.736140	0.0050
d ₂	β_5	3.45E+08	-3910409	0.0001

significant with an increase by 1% of the total labor; passengers will increase by 6.54% on average. The available vehicles variable is also highly statistically significant Table 6.

4.2 Technical Efficiency Scores and Lines Ranking

According to The Stochastic Frontier Analysis (SFA) Table 7 presents technical efficiency scores (TE). The results lie between 0.83 and 0.94, with an average equal to 0.9055, lines of Istanbul - Aydin, Istanbul - Manavgat, Istanbul - Alanya, Istanbul - Burdur, and Istanbul - Ordu are the highest technical efficiency scores, while Istanbul - Afyonkarahisar line is the lowest technical efficiency scores one, lines of Istanbul and Istanbul - Izmit, which are subjective by the operation of the Istanbul railway, are not found to be between the highest technical efficiency scores.

Table 7 Technical efficiency scores and lines ranking

Line	Line	Technical efficiency	Ranking	Line
Istanbul - Adapazari	Line 1	0.91	1	Istanbul - Aydin
Istanbul - Afyonkarahisar	Line 2	0.83	1	Istanbul - Manavgat
Istanbul - Alanya	Line 3	0.93	2	Istanbul - Alanya
Istanbul - Antalya	Line 4	0.92	2	Istanbul - Burdur
Istanbul - Aydin	Line 5	0.94	2	Istanbul - Ordu
Istanbul - Balikesir	Line 6	0.91	3	Istanbul - Antalya
Istanbul - Bodrum	Line 7	0.92	3	Istanbul - Bodrum
Istanbul - Bolu	Line 8	0.87	3	Istanbul - Izmir
Istanbul - Burdur	Line 9	0.93	3	Istanbul - Izmit
Istanbul - Düzce	Line 10	0.90	3	Istanbul - Samsun
Istanbul - Eskişehir	Line 11	0.88	4	Istanbul - Adapazari
Istanbul - Gebze	Line 12	0.84	4	Istanbul - Balikesir
Istanbul - Izmir	Line 13	0.92	5	Istanbul - Düzce
Istanbul - Izmit	Line 14	0.92	5	Istanbul - Kütahya
Istanbul - Kütahya	Line 15	0.90	5	Istanbul - Manisa
Istanbul - Manavgat	Line 16	0.94	5	Istanbul - Serik
Istanbul - Manisa	Line 17	0.90	6	Istanbul - Eskişehir
Istanbul - Ordu	Line 18	0.93	7	Istanbul - Bolu
Istanbul - Samsun	Line 19	0.92	8	Istanbul - Gebze
Istanbul - Serik	Line 20	0.90	9	Istanbul - Afyonkarahisar

4.3 Comparison with DEA

With an average equal to 0.879. The most inefficient line regarding the CRATE-DEA scores were line Istanbul - Serik and Istanbul - Afyonkarahisar lines Table 8.

To compare the results from the two methods (SFA and DEA), we rank the buses lines in both methods. The results are consistent; lines of Istanbul - Alanya, Istanbul - Antalya, Istanbul - Aydin, Istanbul - Burdur, Istanbul - Manavgat, and Istanbul-Ordu are among the most efficient lines. Furthermore, lines of Istanbul - Afyonkarahisar, Istanbul - Bolu, Istanbul - Gebze, and Istanbul are among the least efficient lines in both methods Table 9.

Table 8 Line ranking of DEA and SFA

Ranking	SFA	CCR (TE)
1	Istanbul - Aydin	Istanbul - Burdur
2	Istanbul - Manavgat	Istanbul - Manavgat
3	Istanbul - Alanya	Istanbul - Ordu
4	Istanbul - Burdur	Istanbul - Alanya
5	Istanbul - Ordu	Istanbul - Aydin
6	Istanbul - Antalya	Istanbul - Antalya
7	Istanbul - Bodrum	Istanbul - Izmit
8	Istanbul - Izmir	Istanbul - Samsun
9	Istanbul - Izmit	Istanbul - Kütahya
10	Istanbul - Samsun	Istanbul - Manisa
11	Istanbul - Adapazari	Istanbul - Adapazari
12	Istanbul - Balikesir	Istanbul - Eskişehir
13	Istanbul - Düzce	Istanbul - Balikesir
14	Istanbul - Kütahya	Istanbul - Düzce
15	Istanbul - Manisa	Istanbul - Bolu
16	Istanbul - Serik	Istanbul - Bodrum
17	Istanbul - Eskişehir	Istanbul - Izmir
18	Istanbul - Bolu	Istanbul - Gebze
19	Istanbul - Gebze	Istanbul - Afyonkarahisar
20	Istanbul - Afyonkarahisar	Istanbul - Serik

Table 9 Technical efficiency measures and line rankings

Line	Technical efficiency	Line	Ranking
Istanbul - Adapazari	0.90	Istanbul - Burdur	1
Istanbul - Afyonkarahisar	0.71	Istanbul - Manavgat	1
Istanbul - Alanya	0.98	Istanbul - Ordu	1
Istanbul - Antalya	0.96	Istanbul - Alanya	2
Istanbul - Aydin	0.98	Istanbul - Aydin	2
Istanbul - Balikesir	0.87	Istanbul - Antalya	3
Istanbul - Bodrum	0.79	Istanbul - Izmit	4
Istanbul - Bolu	0.82	Istanbul - Samsun	5
Istanbul - Burdur	1	Istanbul - Kütahya	6
Istanbul - Düzce	0.84	Istanbul - Manisa	6
Istanbul - Eskişehir	0.90	Istanbul - Adapazari	7
Istanbul - Gebze	0.71	Istanbul - Eskişehir	7
Istanbul - Izmir	0.75	Istanbul - Balikesir	8
Istanbul - Izmit	0.95	Istanbul - Düzce	9
Istanbul - Kütahya	0.91	Istanbul - Bolu	10

(continued)

Table 9 (continued)

Line	Technical efficiency	Line	Ranking
Istanbul - Manavgat	1	Istanbul - Bodrum	11
Istanbul - Manisa	0.91	Istanbul - Izmir	12
Istanbul - Ordu	1	Istanbul - Gebze	13
Istanbul - Samsun	0.93	Istanbul - Afyonkarahisar	13
Istanbul - Serik	0.67	Istanbul - Serik	14
Mean	0.879		

5 Conclusion and Recommendations

Technical efficiency evaluation of Istanbul bus companies is the ultimate objective for the sake of identification the passenger performance, for the sake of identification the passenger performance of Istanbul bus companies, and to identify how concern factors influence the technical efficiency. The present study employs Stochastic Frontier Analysis with the production function Twenty lines with 240 survey, one output is passenger-kilometers as dependent variable, and three inputs are labor, vehicle-kilometers, and vehicles trolley and Coaches number, of each line as independent variables. Additionally, the power of other factors on the competitive transport modes and distance that each line connects is conducted. The results of the current study are compared to those obtained (DEA-CCR). Panel data showed well fitted According to production function of Cobb-Douglas and the probability value of the inputs and output variables were significantly efficient. Moreover, the explanatory control of certain dummy factors of the competitive transport modes and distance also were confirmed with significant probability value. The scores of technical efficiencies were ranked and provided variety scale efficiency in high levels, with average technical efficiency equal to 0.9055 and 0.879 for the Stochastic Frontier Analysis and data envelopment analysis methods, respectively.

The differences between the technical efficiency of each line could be explained by a number of reasons. The first reason is the total vehicle-kilometers and the coverage level that each line connects. The Stochastic Frontier Analysis outcomes pointed that the total of vehicle-kilometers of each line has positively impacts on the technical efficiency. Lines of Istanbul - Alanya, Istanbul - Antalya, Istanbul - Aydin, Istanbul - Burdur, Istanbul - Manavgat, and Istanbul - Ordu are among the most efficient lines, Furthermore, lines Istanbul - Afyonkarahisar, Istanbul - Bolu, Istanbul - Gebze, and Istanbul are among the least efficient lines in both methods. The second reason is the competitive transport modes that the areas are covered by buses network are also covered by other modes, like Istanbul railway. The results pointed that Istanbul - Gebze line which is influenced by the operation of the Istanbul railway, and serves areas near Istanbul city is not found to be among the most efficient ones. This study confirmed the significant of these factors for the future of passenger's performance. Since the wide development and rapidly

expand of Istanbul railway a future strategic planning of the buses network would be appropriate, particularly minibuses, taxis and private automobiles also are available in Istanbul.

References

1. Stamos, I., Myrovali, G., & Aifadopoulos, G. (2016). Formulation of a roadmap towards the enhancement of international rail passenger transport – The South East Europe example. *Journal of Rail Transport Planning and Management*, 6(2), 89–98.
2. Evans, A. W., & Morrison, A. D. (1997). Incorporating accident risk and disruption in economic models of public transport. *Journal of Transport, Economics and Policy*, 2541, 46–55.
3. Lan, L. W., & Lin, E. T. J. (2006). Performance measurement for railway transport: Stochastic distance functions with inefficiency and ineffectiveness effects. *Journal of Transport, Economics and Policy*, 40, 383–408.
4. Munda, G. (2004). Social multi-criteria evaluation: Methodological foundations and operational consequences. *European Journal of Operational Research*, 158, 662–677.
5. Jorge, J., & Suarez, C. (2003). Has the efficiency of European railway companies been improved? *European Business Review*, 15, 213–220.
6. Cantos, P., & Maudos, J. (2001). Regulation and efficiency: The case of European railways. *Transportation Research Part A: Policy and Practice*, 35, 459–472.
7. Thanassoulis, E., Kortelainen, M., & Allen, R. (2012). Improving envelopment in Data Envelopment Analysis under variable returns to scale. *European Journal of Operational Research*, 218(1), 175–185.
8. O'Donnell, C. J. (2018). Stochastic frontier analysis. In *Productivity and Efficiency Analysis* (Vol. 63, pp. 991–1011).
9. Bogetoft P., & Otto L. (2011). Stochastic frontier analysis SFA. In *International Series in Operations Research and Management Science* (Vol. 5, p. 36).
10. Bauer, P. W. (1990). Recent developments in the econometric estimation of frontiers. *Journal Economic*, 46, 39–56.
11. Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society*, 120, 253–290.
12. Aigner, D., Lovell, C. A. K., & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal Economic*, 6, 21–37.
13. Meeusen, W., & van Den Broeck, J. (1977). Efficiency estimation from Cobb-Douglas production functions with composed error. *International Economic Review (Philadelphia)*, 18, 435–444.
14. Battese, G. E., & Coelli, T. J. (1988). Prediction of firm-level technical efficiencies with a generalized frontier production function and panel data. *Journal Economic*, 38, 387–399.
15. Coelli, T. J., Prasada Rao, D. S., O'Donnell, C. J., & Battese, G. E. (2005). *An introduction to efficiency and productivity analysis* (Vol. 7, pp. 11–37). Boston: Springer.
16. Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, 2, 429–444.
17. Markovits-Somogyi, R. (2011). Data envelopment analysis and its key variants utilized in the transport sector. *Periodica Polytechnica Transportation Engineering*, 39, 1366–1371.
18. Banker, R. D., Cooper, W. W., Seiford, L. M., & Zhu, J. (2004). Return to scale in DEA. In *Handbook on data envelopment analysis* (Vol. 154, pp. 345–362).