Journal of
Marine Science: Research & Development

Kammoun and Abdenadher, J Marine Sci Res Dev 2018, 8:6
DOI: 10.4172/2155-9910.1000261

Research Article Open Access

The Technical Efficiency of Tunisian Ports: Comparing Data Envelopment Analysis and Stochastic Frontier Analysis Scores

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Abstract

Maritime transportation for Tunisia plays an important role in trade exchange with other countries. Therefore, the objective of this paper is to measure the efficiency scores of 7 seaports in Tunisia by applying the Stochastic Frontier Analysis (SFA) with Cobb-Douglas production function and Data envelopment analysis (DEA) with CCR and BCC models. The annual data collected cover the 2007-2017 period for each port. Thus, the sample size for the analysis comprises a total of 77 observations. The empirical result shows that the total average scores of operating efficiency scores were DEA-BCC (0.746)>SFACD (0.536)>DEA-CCR (0.334) from 2007 to 2017. Given these results, the port of Gabes can be considered as the best efficient port in the 3 models (DEA-BCC, DEA-CCR and SFACD).

Keywords: Efficiency; Data Envelopment Analysis (DEA); Stochastic Frontier Analysis (SFA); Tunisian seaports

Introduction

Maritime transport is the backbone of the world globalization and trade because 80 per cent of the volume of international trade in goods is carried by sea [1]. The maritime transport provides efficient and low-cost means of transporting goods, which help create prosperity among nations and peoples and facilitates trade. The advantage of seaway is safety, speed, comfort, and the ability to manage heavy traffic of goods and passengers at relatively low prices.

Efficiency is the success with which a Decision Making Unit (DMU) uses its inputs to produce outputs. In simple terms, efficiency can be simply defined as the ratio of output to input.

Farell [2] proposed that the efficiency of a DMU consists of two components, technical efficiency, which reflects the ability and willingness of a firm to maximize its output from a given set of inputs and allocative efficiency which reflects the ability and willingness of the firm to use the inputs in optimal proportions for given factor prices. Economic efficiency or total efficiency is determined by the product of the technical and allocative efficiency.

A review of previous studies shows that the majority of the studies focused on the seaports in Europe [3-6] and Asia [7,8]. Nevertheless, none of these studies has focused on North Africa so far. Tunisia has 7 commercial ports (Bizerte, Goulette, Rades, Sousse, Sfax, Gabes and Zarzis). Their complementarity and exceptional location can accommodate various types of ships and treat all types of merchandise. Hence, it is important to study and evaluate the efficiency of the Tunisian ports as this country is witnessing significant development in port legislation and is setting many investment plans in port infrastructure like the new project of Enfidha port which is dedicated to receive panamax and post-panamax ships.

The objective of this paper is to investigate the technical efficiency of 7 ports in Tunisia by using two methodologies: the Data Envelopment Analysis (DEA) and the Stochastic Frontier Analysis (SFA). The analysis of technical efficiency in this research covers DEACCR [9], DEABCC [10] and SFACD (Cobb-Douglas function).

Moreover, we propose the input-oriented DEA model to minimize the inputs while the given current output remains the same if we look at the inefficiency in terms of excess inputs.

This study is organized as follows. In section 2, we present the of DEA and SFA methodologies. In section 3, we give a review of studies on measurement of port efficiency. We describe the data and present the results of empirical study in section 4. Finally, section 5 concludes this paper.

In the fast twenty years, a significant part of the literature on ports has focused on seaport efficiency. Most of the studies focused on seaports in Europe [3,5,11] and in Asia [7,8] but few dealt with the efficiency in the African and in the Middle East seaports. Thus, the majority of studies use both DEA and SFA methodologies to measure the efficiency of seaports.

Empirical port efficiency by using DEA

The first researchers who attempted to use the DEA to analyze the seaport efficiency are Hayuth and Roll [12]. They used cross-section data to estimate the efficiency of 20 seaports. Their work was limited to the application of the DEA-CCR, which is a standard DEA model.

Martinez et al. [11] classified 26 Spanish ports into three groups namely high, medium and low complexity ports. These authors examined the technical efficiency of these ports by using the DEA-CCR and DEA-BCC models. They conclude that high complexity seaports were associated with high efficiency.

Applying both DEA-CCR and DEA-additive models, Tongzon [13] estimated the technical efficiency of four Australian and twelve international ports for the year 1996. He concludes that Melbourne, Rotterdam, Yokohama and Osaka are the most inefficient ports in the sample.

By using a cross-sectional data for the year 1998, Valentine and Gray [14] applied the DEA-CCR model to determine the relationship between

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Received July 13, 2018; **Accepted** September 12, 2018; **Published** September 15, 2018

Citation: Kammoun R, Abdenadher C (2018) The Technical Efficiency of Tunisian Ports: Comparing Data Envelopment Analysis and Stochastic Frontier Analysis Scores. J Marine Sci Res Dev 8: 261. doi: 10.4172/2155-9910.1000261

port efficiency with a particular type of ownership and organizational structure of 31 container seaports among the world's top 100 container seaports in 1998.

Barros and Athanassiou [3] employed both DEA-CCR and DEA-BCC to estimate the efficiency of 4 Portuguese and 2 Greek seaports. The writers conclude that the majority of the seaports are efficient, with the sole exception of Thessaloniki.

By using DEA window analysis, Park [15] estimated the efficiency of 11 Korean container terminals for a period of three years 1999-2002. The data include the total quay length, the number of cranes, the size of yard areas, the size of the labour force, the size Lifts per Calls (LPC) storage, Net Berth Productivity (NBP) as inputs. The cargo throughput and the terminal capacity are used as outputs.

By using a cross-sectional data for the year 2002, Cullinane and Wang [4] applied the DEA-CCR and DEA-BCC models to estimate the efficiency of 69 container terminals with an annual throughput of over 10,000 TEUs in Europe. The general conclusion is that the terminals are inefficient.

Regarding the research applied to Africa and the Middle East, Al-Eraqi et al. [1] used the Standard Data Envelopment Analysis (DEA) and DEA Window Analysis to study the technical efficiency of seaports. Cross-sectional and panel data from 2000 to 2005 were collected for each of the twenty-two seaports in the Middle East and East African region. They reveal that the DEA-BCC model provides higher efficiency scores than the DEA-CCR model and they also conclude that the ports of Khor Fakkan and Djibouti are the most efficient.

Both DEA-CCR and DEA-CCR models were applied by Munisamy and Singh [7] to analyze the technical efficiency of 69 container ports in the Asian region. They concluded that most of the efficient ports in Asia are located in Bangladesh, Philippines, China, Cambodia, India and Singapore.

Rajasekar and Deo [8] have applied the Standard Data Envelopment Analysis (DEA) and DEA-Additive models to examine the technical efficiency of selected major ports in India for the period between 1993 and 2011. They concluded that the size is not a determinant factor for port efficiency i.e. bigger ports Jnpt, Mormugao and smaller ports Tuticorin and Ennore were proved to have efficient port operations all through. Table 1 below presents the studies conducted using the DEA method.

Recently, Zheng and Park [16] evaluated the efficiency of 30 seaports in 2014 with using the DEA-BCC and DEA-CCR models. They concluded that the efficiency of major terminals in Korea (DEA-CCR: 0.815, DEA-BCC: 0.886) showed similar efficiency with China's terminals (DEA-CCR: 0.817, DEA-BCC: 0.887).

Hasan Esmai [17] applied the Standard Data Envelopment Analysis (DEA) of nine seaport in Saudi Arabian. They used two output and three inputs to measure of port performance for the year 2014. The writer concluded that Jazan port is considered inefficient plus most of the ports are also inefficient.

Empirical port efficiency by using SFA

Among the applications of SFA to the port industry, Liu [18] used the technical efficiency with a translog production function to test the hypothesis which states that the public sector ports are less efficient than private ones. A set of panel data relating to the outputs and inputs of 28 British ports over the 1983-1990 period was used.

The translog cost function was used by Coto Millan et al. [19] to estimate the economic efficiency of 27 Spanish ports from 1985 to 1989. They concluded that smaller ports are more efficient. These authors claimed that this is not so much due to size, but to the level of autonomy: ports with smaller autonomy are considered to be highly efficient.

By using the cross-sectional and panel data versions, Cullinane and Song [20] applied the SFA with Cobb-Douglas cost function to access the privatization achievement of 5 Korean and UK container terminals. For inputs, they took the managerial service, the employees' salaries, the capital cost of terminal operations, the net book value of mobile and cargo and handling equipment. For outputs, they took the turnover derived from the provision of container terminal services, but excluded property sales.

Tongzon and Heng [21] used the Cobb-Douglas production to measure the efficiency levels of 25 container ports/terminals and examine the relationship between port efficiency and port specific characteristics. They concluded that the private sector participation in the port industry can to some extent improve the port operation efficiency, which will in turn increase port competitiveness.

By using the translog cost function, Barros [22] analyzed the extent of the technical change and technical efficiency in Portuguese seaport for the 1999-2000 period. His results showed an average score of inefficiency of 39.6%, denoting a high degree of waste in the management of seaports. The inputs include the price of labour and of capital. The outputs included the number of ships and the total cargo.

Applying the Cobb-Douglas production function, Sun et al. [23] estimated the efficiency of the container port production. Annual panel data from 1997 to 2005 have been collected for each of the eighty-three container terminal operators. Their inputs were the handling capacity between the ship and the quay, the handling capacity between the quay and the yard, the number of berths, the length of quay lines, the terminal area, the storage capacity of the port and the refers points while the cargo throughput was the output.

Using the cross-sectional data for 2002, Trujillo and Tovar [6] also used the Cobb-Douglas production function to analyze the technical efficiency of 22 European ports and estimate their legislation. They concluded that their analysis can't explain the factors that determine the level of port efficiency.

González and Trujillo [24] applied a translog production function with panel data for 9 Spanish ports from 1990 to 2002 to evaluate the technical efficiency evolution in transport infrastructure and analyze the impact of 90's port reforms. The results show that average technical efficiency has changed after the reforms.

By applying a panel data from 2002 to 2012, Barros et al. [25] analysed the impacts of cost and operational variables on major Chinese ports by means of a stochastic frontier model. Their inputs were the cost in Renminb, the price of labour, price of capital and price of intermediate consumption. The number of passengers and handled containers are output variables. The writers conclude that there is considerable heterogeneity in China's seaports, affecting their cost efficiency estimation. Table 2 below shows the applications made by using the SFA method.

Material and Methods

We adopt two alternative approaches, DEA and SFA to quantify operational efficiency. The main difference between the two is

Authors	Method	Units	Inputs	Outputs
Hayuth and Roll [12]	DEA-CCR model	Hypothetical numerical example of 20 ports	Manpower, capital, cargo uniformity	Cargo throughput, level service, consumer satisfaction, ship calls
Martinez et al. [11]	DEA-BCC model	26 Spanish ports, 1993-1997	Labour expenditure, depreciation charges, other expenses	Total cargo moved through docks, revenue obtained from rent of port facilities
Tongzon [13]	DEA-CCR additive model	4 Australian and 12 other international container ports for the 1996	Number of cranes, number of container berths, number of tugs, terminal area, delay time, labour,	Cargo throughput, ship working rate
Valentine and Gray [14]	DEA with CCR model	31 container ports out of the world's top 100 container ports for the year 1998	Total length of berth, And container berth length	Number of container, total tons throughput
Barros and Athanassiou [3]	DEA-CCR and BCC	2 Greek and 4 Portuguese	Number amount of workersand capital	Number of ships, movement of freight , cargo handled, container handled
Park [15]	DEA window	11 Korean container terminals, 1999-2002	Total length of quay, number of cranes, size of the yard areas, size of the labour force, LPC (lifts per calls), NBP(net berth productivity)	Cargo throughput, terminal capacity
Cullinane and Wang [4]	DEA-CCR and BCC	69 container terminals in Europe for the year 2002	The terminal length, size of the terminal area, equipment	Container throughput
Barros [5]	DEA-CCR and BCC	24 Italian seaports, 2002-2003	Number of personnel, the capital invested, value of the operational costs	Liquid bulk, solid bulk, number of containers, number of ships, total receipt
Al-Eraqi et al. [1]	Standard DEA and DEA window	Middle East and East Africa, 2000–2005	Berth length, storage area, handling equipment	Ship calls , cargo throughput
Munisamy and Singh [7]	DEA-CCR and BCC	69 container ports in the Asian region for the year 2007	Berth length, terminal area, total refers points, total quayside cranes, total yard equipment	Total throughput
Rajasekar and Deo [8]	Standard DEA and DEA-Additive	8 ports in India, 1993 -2011	The number of berths, berth length, number of equipments and number of employees	Container throughput in TEU, total traffic
Zheng and Park [16]	DEA-CCR and BCC	30 seaports for the year 2014	Berth length, yard area, number of quay cranes and number of yard cranes	Container throughput in TEU
Hanaa Abdelaty [17]	Standard DEA	9 seaport in Saudi Arabian for the year 2014	Ports imports, number of discharged vessels and number of berth	Number of loaded vessels and ports exports

Table 1: Literature review of DEA studies.

Authors	Method	Units	Inputs	Outputs
Liu [18]	Translog production function	28 British port authorities, 1983-1990	Labour, capital	Turnover
Coto-Millan, et al. [19]	Translog cost function	27 Spanish Ports, 1985-1989	Price of labour, price of capital, price of intermediate consumption	Aggregated single variable of goods, passengers and vehicles
Estache et al. [26]	Cobb-Douglas and Translog production function	11 Mexican port authorities 1996-1999	Number of workers, length of docks	Volume of merchandise handled
Cullinane and Song [20]	Cobb-Douglas cost function	5 container terminals, Korean and UK, different year of observations (65 observations)	Managerial service, employees' salaries, capital cost of terminal operations, net book value of mobile, cargo handling equipment	Turnover
Tongzon and Heng [21]	Cobb–Douglas production	25 container ports/terminals	The terminal quay length, the terminal surface, the number of quay cranes	Total throughput
Barros [22]	Translog cost function	10 Portuguese port authorities, 1990-2000	Price of labour, price of capital	Number of ships, total cargo
Sun, et al. [23]	Cobb-Douglas production function	83 container terminal operators 1997-2005	Handling capacity between ship and quay, handling capacity between quay and yard, number of berths, length of quay lines, terminal area, storage capacity of port, reefer points	Throughput
Trujillo and Tovar [6]	Cobb-Douglas production function	22 European port authorities 2002	Number of employees, surface area	Container traffic, other types of freight and passenger traffic
González and Trujillo [24]	Translog production function	9 Spanish port authorities, 1990-2002	Length of berth, surface area, labour	Container and passenger traffic,liquid bulk and other cargo
Barros et al. [25]	random and fixed-effect stochastic models	major Chinese ports 2002-2012	Cost in Renminb, the price of labour, price of capital, price of intermediate consumption	Number of passengers, handled containers

Table 2: Literature review of SFA studies.

that the former is a non-parametric technique and doesn't make accommodation for statistical noise, whereas the latter is a parametric technique and accounts for statistical noise. Both in the SFA and DEA analysis, a DMU's distance from the efficient frontier measures its relative inefficiency. The two approaches are presented in the next paragraphs.

Data envelopment analysis approach

Data Envelopment Analysis (DEA) was proposed by Charnes et al. [9] in 1978. The DEA is non-parametric technique for measuring the relative efficiencies on making units (DMUs) with multiple inputs and/or outputs. In case when there is no other DMU or a combination of DMUs which can produce at least the same amount of output with less of the same resources input and not more of any other resources, the DEA method states that a DMU is considered efficient. In general, a DMU is considered to be inefficient if it obtains a score of less than the unity where a score of unity implies that it is efficient.

Among the number of DEA models, we employ the two most used ones: DEA-CCR model [9] and DEA-BCC model [10]. The DEA-CCR model estimates constant returns to scale so that all the detected production combinations can be proportionally scaled up or down. Besides, the DEA-BCC model was developed by adding a convexity restriction to the DEA-CCR model envelope formulation, which leads to variable returns to scale. Besides, this model is an extreme point technique; noise (even symmetrical noise with zero mean) such as measurement error may cause significant problems [26].

In this study, we will adopt the input-oriented approach. Therefore, the dual mathematical formulation of the DEA-CCR model is:

$$\text{(DEA-CCR)}\begin{cases} \text{Min}_{\theta\lambda}\theta \\ \text{Subject to} \\ -Y_o + \lambda Y \geq 0 \\ \theta X_o - \lambda X \geq 0 \\ \lambda \geq 0 \end{cases} \quad (1)$$

Equation 1: Mathematical formulation of the DEA-CCR model [27].

Where:

θ: is a sought scalar (it represents the efficiency score of DMU_i), λ: vector of non-negative weights, Y: is the m × n matrix of outputs, X: is the k × n matrix of inputs.

Y_o's and X_o's are the observed output and input values, respectively, of the DMU_o, and the DMU to be evaluated.

θ* is the input-oriented efficiency score of DMU_o. If θ * is equal to the unity, then the current input levels cannot be reduced, indicating that DMU_o is efficient. However, if θ *<1, then DMU_o is technically inefficient.

The DEA-CCR problem (3) integrates an additional constraint, the convexity constraint N1′λ = 1, where N1 is the n × 1 vector of 1s.

$$\text{DEA-BCC)}\begin{cases} \text{Min}\,\theta,\lambda\theta \\ \text{Subject to} \\ -Y_o + \lambda Y \geq 0 \\ \theta X_o - \lambda X \geq 0 \\ N1'\lambda = 1 \\ \lambda \geq 0 \end{cases} \quad (2)$$

Equation 2: The DEA-CCR problem [27].

However, the DEA presents some drawbacks. The first drawbacks is that the DEA it ignores the statistical noise. So, one can apply the parametric Stochastic Frontier Approach (SFA) to resolve this problem.

Stochastic frontier approach

This approach was independently introduced by Aigner et al. [28] and Meeusen and van den Broeck [29]. In fact, this paper uses the SFA model of Cobb-Douglas production function to analyze the efficiency of 7 Tunisian ports. The estimation of this model is allowed by the access to a panel of data which covers a nine year period 2007-2017. The specific functional formal tested are the following:

$$\ln y_{it} = \beta_0 + \beta_1 \ln x_{1it} + \beta_2 \ln x_{2it} + \beta_3 \ln x_{3it} + V_{it} - U_{it}$$

$$U_{it} = (U_i \exp(-\eta(t-T)))$$

Equation 3: Specific functional formal test equation [30].

Where the variables are all deviations from the geometric mean and defined as i=1,2,...,7; t=1,2,…,T; t: is a time trend; y_{it}: is the volume of merchandise handled in port i during period t; x_{1it}: is the area stored in port i during period t; x_{2it}: is the number of stevedoring equipment used by port i in period t; x_{3it}: is the number of employees in port i in period t; β_k: is the unknown parameters to be estimated k=0,1,2,3; V_{it}: are random variables which are assumed to be i.i.d $N(0,\sigma_V^2)$, and independent of the U_{it}; U_{it}: are non-negative random variables representing technical inefficiency and are assumed to be i.i.d as half-normal distribution $N(0,\sigma_U^2)$; η: is a parameter to be estimated; σ_V: is the variance parameter of noise term; σ_U: is the variance parameter of inefficiency term.

Furthermore, we use the parameterization of Battese and Corra [30,31]. They substitute σ_V^2 and σ_U^2 with $\sigma^2 = \sigma V^2 + \sigma U^2$ and $\gamma = \sigma U^2 / (\sigma V^2 + \sigma U^2)$, respectively. The parameter γ is between 0 and 1. If γ is close to one, it shows that the deviations from the frontier are due principally to the technical inefficiency. However, if γ is close to zero, it shows that the deviations from the frontier are due principally to noise.

The method of likelihood ratio-test is proposed to examine the presence of inefficiency effect (u_{it}) under both the null and alternate assumptions. This method is defined as:

$$LR = -2\{\ln[L(H_0)] - \ln[L(H_1)]\}$$

Equation 4: Likelihood ratio-test [32].

Where $L(H_0)$ and $L(H_1)$ are the values of the likelihood function under the null hypothesis (H_0) and the alternative (H_1), respectively. In this case, if H_0=0 is true, this LR statistics, has an asymptotic distribution which is a mixture of chi-square distributions X^2.

Results

The available data are annual covering eleven years period, from 2007 to 2017, about 7 Tunisian ports (Bizerte, Goulette, Rades, Sousse, Sfax, Gabes and Zarzis). Thus, the sample of the analysis comprises a total of 77 observations.

The data were obtained from the Merchant Marine and Port Office (OMMP) and the Tunisian Stevedoring and Handling Company (STAM).

The measurement of the output is indicated for one element:

- Throughput: Movements of general cargo (dry, liquids and containers) unload and load (tons).

The measurement of the inputs is considered by the indicators:

- Number of stevedoring equipment: Total number of reach

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stackers, straddle carriers, number of quayside cranes, mobile cranes, quay gantry, mobile gantry and the ship shore container gantry,

• Number of employees: Total number of employees of the OMMP and of the STAM,

• Area stores: Total area stores (m^2).

Table 3 contains the descriptive statistics of the variables used in the study. They include the sample mean, the median, the standard deviation, the minimum and maximum value for each of the variables. Here, the largest traffic of throughput (i.e., 10319193 tons in 2017), the largest number of stevedoring equipment (i.e., 122 in 2014) and the largest number of employees (i.e., 709 in 2015) correspond to the port of Rades since it plays an important role in the national transport chain through its specialization in container traffic and rolling units (mainly trailer traffic). While the maximum Area stores (i.e., 35600 m^2 in 2014) correspond to the port of la Goulette.

On the other hand, the minimum values of the number of stevedoring equipment (i.e., 2 in 2007 and 2009) and of the area stores (i.e., 4000 m^2 from 2007 to 2015) are related to the port of Gabes. However, the minimum value of traffic of throughput (i.e., 650573 tons in 2007) corresponds to the port of Zarzis. Finally, the minimum number of employees (i.e., 6) is recorded in Gabes and Zarzis during 2007 and 2008, respectively.

To estimate the efficiency scores, we used balanced panel data on Tunisian seaport authorities for the years 2007 to 2017. This number of observations allows the estimation of DEA with CCR and BCC models and a stochastic frontier model based on Cobb-Douglass production function.

Discussion

Coelli [30] FRONTIER Version 4.1 computer software is adopted for the calculation of the frontier for SFA with Cobb-Douglas function for the half-normal distribution (SFA_{CD}). Table 4 summarizes the maximum-likelihood estimation results, the test value calculated and the corresponding critical value of the X^2 distribution at 5% of significance.

ariables	Output	Inputs		
	Throughput (Tons)	Stevedoring equipment (No)	Area stores (m^2)	Employees (No)
Mean	3672270,013	42,0259	15986,1558	168,2597
Median	4048751	31	13000	85
Std. Deviation	2556765,005	35,8755	11481,9591	205,0763
Maximum	10319193	122	35600	709
Minimum	650573	2	4000	6

Table 3: Summary; statistics for the period.

Variables	Coefficient	Standard-Error	T-Ratio
Constant	15.463	0.244	63.434
Inx_{1it}	-15.051	0.104×10^{-8}	-6.754
Inx_{2it}	0.041	0.05	0.592
Inx_{3it}	0.116×10^{-9}	0.924×10^{-10}	1.259
$^2=\sigma_{\varsigma}^2+\sigma_Y^2$	1.704	0.924	1.845
$=\sigma_Y^2/(\sigma_{\varsigma}^2+\sigma_Y^2)$	0.971	0.016	59.176
Log (likelihood)	-9.272		
LR =	165.777		
Observations	77		

Table 4: Maximum likelihood estimates of the SFA model.

The estimated value of the variance parameter $\gamma(0.971)$ is close to the unity, which suggests that deviations are due to technical inefficiency. The test refers to the evaluation of a Cobb-Douglas as a representation of production technology. The null hypothesis, $\beta1=\beta2=\beta3=0$ test the joint significance of input parameters. LR values of SFA_{CD} (165.77722) are larger than the critical values (7.81) of X^2 distribution. This test suggests that we cannot reject this hypothesis and therefore the Cobb-Douglas function can be considered a good model to represent the production technology of the Tunisian port sector.

Table 5 reports the technical efficiency of each port in Tunisia calculated by DEA_{CCR}, DEA_{BCC} and SFA_{CD} models within the observed period, between 2007 and 2017.

The scores raised by the application of the DEA models were calculated using the DEAP 2.1 program created by Coelli [27].

The input-oriented efficiency represents the degree to which a port could minimize its input use without altering its output. The DEA and SFA scores are between 0 and 1 DMUs with DEA and SFA scores equal to the unity are efficient. A DMU with a score of less than the unity is relatively inefficient.

Based on the DEA_{BCC} results, the ports of Rades, Gabes and Zarzis have achieved the best overall technical efficiency (score=1). However, the results for the port of Bizerte vary because it was inefficient in 2009.

Moreover, the results of DEA_{BCC} for the port of Sfax also vary in terms of efficiency as shown in Table 5. In fact, this port was inefficient along 2007, 2008, 2010, 2016 and 2017. On the other side, it was efficient during the rest of the study period.

When the DEA_{CCR} model captures the total technical efficiency and adequately discriminate the efficient DMUs. The results show that the port of Gabes was the only efficient port for this set of samples and showed efficiency scores of 1. This efficiency can be explained by its large production (this port is ranked second in Tunisia in terms of freight traffic) and by the optimal use of the infrastructure and the superstructure.

The results also showed that the ports of Bizerte, la Goulette, Rades, Sousse, Sfax and Zarzis were inefficient during the whole period of analysis. Those ports that invested from 2007 to 2017 found a general decline in efficiency scores, an element which could be explained by the time lag between the investment and the subsequent potential increase in container throughput.

Regarding the SFA_{CD} analysis, the results showed that none of the studied ports has high efficiency. However, the port of Rades can be considered as an efficient port during all the study period since its SFA_{CD} efficiency scores are always higher than 0.7193 while the SFA_{CD} scores for the other seaports are fluctuating.

The port of the La Goulette is the most inefficient; this inefficiency can be explained by its specilization in the passenger traffic and cruise. On the other hand, the port of Gabes is the most efficient by applying the 3 models. In 2016, this port represents 2 times of total traffic of port of Sousse and 3 times of total traffic of port of Zerzis.

We can conclude that the inefficiency of tunisian seaports is noticed in the decline of handling traffic, which corresponds to the results obtained by Pjevčević et al. [33] regarding the Serbian ports case.

Year	Scores	Port							
		Bizerte	La Goulette	Rades	Sousse	Sfax	Gabes	Zarzis	Average
2007	DEA_{CCR}	0.548	0.026	0.211	0.109	0.278	1.000	0.164	0.334
	DEA_{BCC}	1.000	0.112	1.000	0.308	0.801	1.000	1.000	0.746
	SFA_{CD}	0.840	0.141	0.999	0.201	0.793	0.965	0.139	0.582
2008	DEA_{CCR}	0.500	0.029	0.235	0.109	0.259	1.000	0.198	0.333
	DEA_{BCC}	1.000	0.112	1.000	0.308	0.951	1.000	1.000	0.767
	SFA_{CD}	0.998	0.365	0.738	0.245	0.326	0.856	0.886	0.631
2009	DEA_{CCR}	0.503	0.025	0.230	0.124	0.297	1.000	0.201	0.340
	DEA_{BCC}	0.889	0.112	1.000	0.328	1.000	1.000	1.000	0.761
	SFA_{CD}	0.691	0.995	0.803	0.260	1.000	0.728	0.499	0.711
2010	DEA_{CCR}	0.496	0.027	0.229	0.123	0.267	1.000	0.174	0.331
	DEA_{BCC}	1.000	0.112	1.000	0.321	0.859	1.000	1.000	0.756
	SFA_{CD}	0.935	0.927	0.918	0.919	0.934	0.926	0.914	0.925
2011	DEA_{CCR}	0.536	0.024	0.260	0.174	0.340	1.000	0.163	0.357
	DEA_{BCC}	1.000	0.112	1.000	0.351	1.000	1.000	1.000	0.781
	SFA_{CD}	0.385	0.139	0.924	0.655	0.722	0.999	0.128	0.565
2012	DEA_{CCR}	0.587	0.026	0.270	0.189	0.381	1.000	0.191	0.378
	DEA_{BCC}	1.000	0.112	1.000	0.333	1.000	1.000	1.000	0.778
	SFA_{CD}	0.437	0.125	0.996	0.626	0.454	0.759	0.203	0.514
2013	DEA_{CCR}	0.572	0.025	0.265	0.236	0.457	1.000	0.255	0.401
	DEA_{BCC}	1.000	0.151	1.000	0.526	1.000	1.000	1.000	0.811
	SFA_{CD}	0.999	0.100	0.831	0.259	0.917	0.554	0.121	0.540
2014	DEA_{CCR}	0.427	0.030	0.260	0.269	0.497	1.000	0.290	0.396
	DEA_{BCC}	0.509	0.175	1.000	0.560	1.000	1.000	1.000	0.749
	SFA_{CD}	0.326	0.216	0.781	0.831	0.658	1.000	0.160	0.567
2015	DEA_{CCR}	0.994	0.060	0.470	0.496	0.838	1.000	0.470	0.618
	DEA_{BCC}	1.000	0.178	1.000	0.565	1.000	1.000	1.000	0.820
	SFA_{CD}	0.962	0.889	0.719	0.926	0.966	0.771	0.830	0.866
2016	DEA_{CCR}	1.000	0.074	0.435	0.370	0.661	1.000	0.265	0.544
	DEA_{BCC}	1.000	0.178	1.000	0.565	0.728	1.000	1.000	0.782
	SFA_{CD}	0.383	0.342	0.807	0.836	0.916	1.000	0.459	0.678
2017	DEA_{CCR}	0.843	0.060	0.417	0.369	0.647	1.000	0.224	0.508
	DEA_{BCC}	1.000	0.178	1.000	0.565	0.894	1.000	1.000	0.805
	SFA_{CD}	0.935	0.917	0.925	0.930	0.914	0.927	0.915	0.924

Table 5: Efficiency scores for 7 Tunisian ports (2007-2017).

Conclusion

This study applies the two leading approaches to the efficiency measurement, DEA and SFA, on the same data set for the port industry in Tunisia and compares the efficiency derived from the two approaches.

The input data are composed of the storage area, the number of employees and the number of stevedoring equipment while the output data include the aggregated port throughput per year.

The analysis shows that the total average of operating efficiency scores of DEABCC (0.746)>SFACD (0.536)>DEACCR (0.334) between 2007 and 2017. Based on the DEABCC results, the ports of Rades, Gabes and Zarzis achieved the best overall technical efficiency of 1.0 over11 years of the observed periods. However, the port of Rades can be considered efficient during the whole period of analysis since its SFACD efficiency score has never fallen below 0.7193. Given these results, we can say that the port of Rades can be considered as the best efficient port in the 2 models (DEABCC, SFACD). Based on the DEACCR results, the port of Gabes is defined as the only efficient one for this set of samples, so we can conclude that the port of Gabes can be considered as the best efficient port by using the DEABCC, DEACCR and SFACD models.

We can conclude that there are two solutions to resolve the sources of inefficiencies. Firstly, all the most inefficient seaports are advised to increase the quantity of goods that can be transferred by attracting more clients. Secondly, these ports should rent their stevedoring equipment and storage area to other companies in order to reduce the use of considered inputs (number of stevedoring equipment, number of employees and storage area) in proportion to the achieved output (throughput) in these ports.

References

1. Al-Eraqi A, Adli M, Khader M, Barros CP (2008) Efficiency of Middle Eastern and East African Seaports: Application of DEA Using Window Analysis. Europ J Sci Res 23: 597-612.
2. Farrell MJ (1957) The measurement of productive efficiency. J Royal Stat Soc Series A (General) 120: 253.
3. Barros CP, Athanassiou M (2004) Efficiency in European Seaports with DEA: Evidence from Greece and Portugal. Maritime Econom Logist 6: 122-140.
4. Cullinane KPB, Wang TF (2006) The efficiency of European container ports: A cross-sectional data envelopment analysis. Int J Logist: Res Appl 9: 19-31.
5. Barros CP (2006) A benchmark analysis of Italian seaports using data envelopment analysis. Maritime Econom Logist 8: 347-365.
6. Trujillo L, Tovar B (2007) The European Port Industry: An Analysis of its Economic Efficiency. Maritime Econom Logist 9: 148-171.
7. Munisamy S, Singh G (2011) Benchmarking the efficiency of Asian container ports. African J Business Manag 5: 1397-1407.

8. Rajasekar T, Deo M (2013) Measuring the operational efficiency of selected Major Ports in India. MJOR 2: 29-34.
9. Charnes A, Cooper WW, Rhodes E (1978) Measuring the efficiency of decision making units. Europ J Operat Res 2: 429-444.
10. Banker RD, Charnes A, Cooper WW (1984) Some models for estimating technical and scale inefficiencies in data envelopment analysis. J Manage Sci 30: 1078-1092.
11. Martinez BE, Diaz AR, Navarro IM, Ravelo MT (1999) A Study of the Efficiency of Spanish Port Authorities Using Data Envelopment Analisys. Int J Transport Econ XXVI 2: 237-253.
12. Hayuth Y, Roll Y (1993) Port Performance Comparison Applying Data Envelopment Analysis (DEA). Maritime Policy Manage 20: 153-161.
13. Tongzon JL (2001) Efficiency Measurement of Selected Australian and Other International Ports Using Data Envelopment Analysis. Transport Res Part A: Policy Pract 35: 107-122.
14. Valentine VC, Gray R (2001) The Measurement of Port Efficiency Using Data Envelopment Analysis. Proc Ninth World Conference on Transportation Research, Seoul 22: 27.
15. Park BI (2005) An Efficiency Analysis for the Korea Container Terminals by the DEA/Simulation Approach. Korean Manag Sci Rev 22: 77-97.
16. Zheng XB, Park NK (2016) A study on the Efficiency of Container Terminals in Korea and China. The Asian J Shipping Logistics 32: 213-220.
17. Hanaa Abdelaty HE (2016) Efficiency Assessment of Jazan Port Based on Data Envelopment Analysis. Mediterranean J Soc Sci 7: 320-327.
18. Liu Z (1995) The comparative performance of public and private enterprises: The case of British ports. J Trans Econ Policy 29: 263-274.
19. Coto-Millan P, Banos-Pino J, Rodriguez-Alvarez A (2000) Economic Efficiency in Spanish ports: some empirical evidence. Maritime Policy Manage 27: 169-174.
20. Cullinane KPB, Song DW (2003) A stochastic frontier model of the productive efficiency of korean container terminals. Applied Economics 35: 251-267.
21. Tongzon J, Heng W (2005) Port privatization, efficiency and competitiveness: Some empirical evidence from container ports (terminals). Transport Res Part A: Policy Pract 39: 405-424.
22. Barros CP (2005) Decomposing Growth in Portuguese Seaports: A Frontier Cost Approach. Maritime Econ Log 7: 297-315.
23. Sun X, Yan Y, Liu J (2006) Econometric Analysis of Technical Efficiency of Global Container Operators. Proceedings of the 11th International Conference of Hong Kong Society for Transportation Studies: Sustainable Transportation 667-676.
24. González M, Trujillo L (2008) Reforms and Infrastructure Efficiency in Spain's Container Ports. Transportation Research Part A: Policy Pract 42: 243-257.
25. Barros CP, Chen Z, Wanke P (2015) Efficiency in Chinese seaports: 2002-2012. Maritime Economics & Logistics 18: 295-316.
26. Estache A, González M, Trujillo L (2002) Efficiency gains from port reform and the potential for yardstick competition: Lessons from Mexico. World Development 30: 545-560.
27. Coelli TJ (1996a) A guide to DEAP version 2.1: A Data Envelopment Analysis Computer Program. CEPA Working Paper 96/98. Armidale: CEPA , University of New England, Australia.
28. Aigner D, Lovell C, Schmidt P (1977) Formulation and estimation of stochastic frontier production function models. J Econ 6: 21-37.
29. Meeusen W, Van DBJ (1977) Efficiency estimation from Cobb-Douglas production functions with composed error. Int Econ Rev 18: 435-444.
30. Coelli TJ (1996b) A Guide to FRONTIER Version 4.1: A Computer Program for Stochastic Frontier Production and Cost Function Estimation, CEPA Working Paper No. 96/07, Centre for Efficiency and Productivity Analysis, University of New England, Armidale.
31. Battese GE, Corra GS (1977) Estimation of a production frontier model: With application to the pastoral zone of Eastern Australia. Australian J Agri Econom 21: 169-179.
32. Battese GE, Coelli TJ (1993) A stochastic frontier production function incorporating a model for technical inefficiency effects, working Papers in Econometrics and Applied Statistics No. 69, Dept. Econometrics, University of New England, Armidale.
33. Pjevcevic D, Radonjic A, Hrle Z, Colic V (2012) DEA window analysis for measuring port efficiencies in Serbia. Promet-Traffic & Transportation 24: 63-72.