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Efficiency Analysis with non parametric method: Illustration of the Tunisian ports

Arbia HLALI[1]
[1]University of Economics and Management science of Sfax, Tunisia.

Abstract—This paper applies a non-parametric method to provide level technical efficiency for 7 Tunisian ports during 18 years (1998-2015). These ports represent different data set. The use of the model of variable returns to scale (VRS) has led to interesting results. The results show that the most ports are characterized by low levels of technical efficiency, with the exception port of Rades. In addition, the result shows the variation of variable returns to scale and constant returns to scale of technical port's efficiency. Furthermore, we concluded that the panel data improves the efficiency estimates.

Key words: Technical efficiency, Tunisian ports, non parametric analysis

I. INTRODUCTION

The port efficiency is a significant indicator of economic development. Further, the most international trade is transported by sea. In addition, port efficiency, increase transport costs as examined by [30] which founded that port efficiency is a relevant determinant of maritime transport costs. Thus, in order to assist the ports to identify their own strengths, weakness and opportunities in a competitive environment, it is necessary to evaluate their efficiency.

Ports are complex organizations where operators engaged in diverse activities intersect, have different objectives and different subject of competition and regulation. Furthermore, it is appropriate to analyze the concrete activities of the seaport, which must be specified according to their characteristics. The most analyzed activities are the developed ones for the port authorities and for the terminuses of manipulation of load, fundamentally, those of containers [8].

Two main reasons lead us to favor the DEA (compared to the parametric approach) to estimate the port efficiency. The first concerns the difficulties of modeling the production process of port and the construction of a functional form appropriate with the port activities. The second concerns the multidimensional (multi-output) port.

In Tunisia 96% of foreign commercial trade is conducted by sea. At least 80% of maritime trade is processed through Rades port. The aim of this paper is to study port efficiency in Tunisia over the period 1998 to 2015, by estimating of the technical efficiency frontier. This research tries to process the technical efficiency by the application of the method (DEA). It used variable returns to scale model DEA-BCC [5]. An output-oriented model has been adopted because the key objective of ports is to maximize the numbers of containers and the containerized freight quantity every year. This paper is structured as follows. The first section represents an introduction with a literature review on the technical port efficiency. The second section explains the methodology. The third section discusses the empirical results. The last section treats the conclusion.

The first study treats the port efficiency sector was realized by Roll and Hayuth [29] which used DEA-CCR as mentioned by Charnes et al [9] to assess the efficiency of 20 ports. Actually, there is progress in studies analyzing port efficiency and port productivity.

The table 1 show that the most popular search emerged data envelopment analysis DEA with BCC model and used Panel data as [22]; [20]; [21]; [23]; [3]; [12]; [13]; [7]; [31]; [26]; [25]; [18]; [14] and [32]. Other studies have utilized cross-sectional data to assess the efficiency of ports or terminals such as [34]; [28]; [11]; [2]; [35], [1]; [16]; [36]; [19]; [24]; [27]; [4] and [17].

Table 1. literature review of technical port efficiency with DEA method

Author(s) (year)	Data type	Location
Martinez-Budria et al,[22]	Panel	26 Spanish ports (1993–1997)
Wang et al, [34]	Cross-sectional	57 international container ports
Rios and Maçada [28]	Cross-sectional	23 MERCOSUR container Terminals
Cullinane and Wang[11]	Cross-sectional	69 European container terminals(2002)
Kaisar et al, [20]	Panel	20 US container ports
Al-Eraqi et al [2]	Cross-sectional	22 ports in Middle East and East Africa
Liu et al, [21]	Panel	45 Chinese container terminals
Min and Park [23]	Panel	11 Korean terminals

Wu and Liang [35]	Cross-sectional	77 world container ports
Ab-Rosas and Ru Torres [1]	Cross-sectional	29 Mexican coastal ports
Al-Eraqi et al, [3]	Panel	22 ports in East Africa and Middle East
Cullinane and Wang[12]	Panel	25 leading container ports
Hung et al, [16]	Cross-sectional	31 container ports in Asia-Pacific region
Wu and Goh [36]	Cross-sectional	20 largest container ports in countries
Kamble et al, [19]	Cross-sectional	12 Indian ports
Munisamy and Singh [24]	Cross-sectional	69 major Asian Container ports
Niavis and Tsekeris [27]	Cross-sectional	30 Europe
Demirel et al,[13]	Panel data	16 Mediterranean
Bichou [7]	Panel data	420 International container terminals
Schøyen and Odeck [31]	Panel data	24 container ports in Norway, Nordic and UK
Mokhtar and Shah [26]	Panel data	6 Malaysien container terminals
Munisamy and Jun [25]	Panel data	30 Latin American
Infante and Gutiérrez [18]	Panel data	33 Asian Pacific region
Ding et al, (2015) [14]	Panel data	21 China ports
Almawsheki and Shah [4]	Cross sectional	19 Container terminals in the Middle Eastern region
Hyun at al, [17]	Cross sectional	21 Asian container ports
Tetteh et al, [32]	Panel data	Container port in china and 5 west Africa

Source: own elaboration

The cross-sectional data and the panel data are the most commonly used in the literature. Cross-sectional data is data collected from multiple ports at a single point in time. This type of data enables researchers to evaluate and compare the efficiency of different ports and to study the structure of the port industry at a single point in time. In contrast, panel data, that is, data collected from multiple ports over multiple time periods can be used to observe and study changes in efficiency, management, and the impact of regulation of container ports. Finally, the regional location is one of the most distinctive features of a port and therefore the selection of ports is important. Three types of sampling can be identified in the literature: international, regional, and national ports.

The interest of this study is to analyze the efficiency of the Tunisian ports, used panel data with several variables.

II. METHODOLOGY

According to[15] the technical efficiency is illustrated as the “fig.1” shows, the point P represents the inputs of the two factors, per unit of output, that the firm is observed to use. The isoquent SS’ represents the various combinations of the two factors that the efficient firm used to produce unit output. The Q represents an efficient firm using the two factors in the same ratio as P. It can be seen that it produces the same output as P using only a fraction OQ/OP as much of each factor. It could also be thought of as producing OP/OQ times as much output from the same inputs. It thus seems natural to define OQ/OP as the technical efficiency of the firm P. this ratio has the properties that a measure of efficiency obviously needs. It takes the value unity (or 100 percent) for a perfectly efficient firm, and will become indefinitely small if the amounts of input per unit output became indefinitely large. Moreover, so long as SS’ has a negative slope, an increase in the input per unit output of one factor will, imply lower. However, one also needs a measure of the extent to which a firm uses the various factors of production in the best proportions, in view of their prices. Thus, in figure1 if AA’ has a slope equal to the ration of the prices of the two factors, Q’ and not Q is the optimal method of production, for although both points represent 100 percent. Technical efficiency production at Q’ will only be a fraction OR/OQ of those at Q. Further, if the observed firm were to change the proportions of its inputs until they were the same as those represented by Q’, while keeping its technical efficiency constant, its costs would be reduced by a factors OR/OQ, so long as factor prices did not change. It is therefore reasonable to let this ratio measure the price efficiency of the observed firm P, too. This argument is not entirely conclusion, as it is impossible to say what they will happen to technical efficiency of a firm as it changes the proportions of its inputs, but, with this qualification, it seems the best measure available. It also has the desirable property of giving the same price efficiency to firms using the factors in the same proportions.

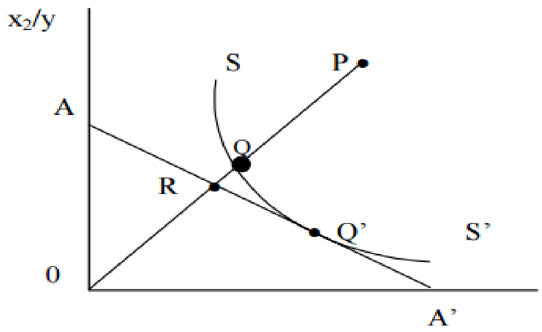

Figure 1: Technical and allocative efficiency.
Source: Farrell, 1957

If the observed firm were perfectly efficient, both technically and in respect of prices, its costs would be a fraction OR/OP of what they in fact are. It is convenient to call this ratio the overall efficiency of the firm, and one may note it is equal to the product of the technical and price efficiencies.

DEA is a non-parametric mathematical programming model used to evaluate the relative efficiency of a group of entities or decision-making units (DMUs) in their use of multiple inputs to produce multiple outputs. The DEA models can be classified according to the type of efficiency measure to provide technical, allocative, economic, etc. It can be also classified to the orientation of the model input-oriented, output-oriented or input-output oriented. In addition, it can be classified by the type of returns to scale that characterizes the production technology constant or variable scale.

The DEA approach uses a linear programming model to construct a hypothetical composite unit based on all units in the reference group. That is, the performance of each DMU is measured relative to the performance of all other DMUs. The unit being evaluated can be judged relatively inefficient if the composite unit requires less input to obtain the output achieved by the unit being evaluated, or judged relatively.

The constant return to scale (CRS) assumption is only appropriate when all the DMU's are operating at an optimal scale. Imperfect competition, constraints on finance, etc. may cause a DMU to be not operating at optimal scale. Banker, Charnes and Cooper [5] suggested an extension of the (CRS-DEA) model to account for variable returns to scale (VRS) situations. The use of the CRS specification when not all DMU's are operating at the optimal scale will result in measures of technical efficiency, which are confounded by scale efficiencies (SE). The use of VRS specification will permit the calculation of the TE devoid of these SE effects.

The technical efficiency was proposed by [5], it was decomposed overall technical efficiency, into pure technical efficiency and efficient technical scale. To do this it need to compute the two models: CRS and VRS on the same data, if there is a difference in the two measurements for a particular DMU, and then it means that the DMU has scale inefficiency and inefficiency value is the difference between CRS and VRS measurement. The Global Technical Efficiency (GTE) can be decomposed into Pure Technical Efficiency (PTE) and Scale Efficiency (SE), Therefore SE= $\theta CCR/\theta BCC$,Where, CCR= constant returns to scale; BBC = variables returns to scale.

The technical efficiency can be measured with output or input orientation, assuming to the goal of the researcher, in this paper the objective is to maximize the number of containers and the maximize the tonnage of fret containerized. The orientation is output orientation as “fig. 2” represents.

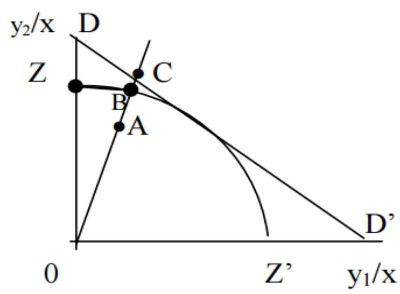

Figure 2: Output oriented efficiency measures.
Source: Farrell 1957

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As it is described by “fig.2,” the production frontier is represented by the isoquant ZZ’. The technical inefficiency of the firm defined by the point A can be measured by the distance AB. It corresponds to the output proportions that can be increased without changing the input level. The measurement of the technical efficiency oriented output is defined by the ratio ET=OA/OB.

To achieve the technical efficiency of Tunisian ports this paper adopts DEA-BCC model with output orientation. Each port is producing an output, y, using a set of k=1, K inputs. The formal output-oriented DEA model can be declared as follows in (1):

$$\begin{aligned} & \text{Max}_{\phi i\, \lambda j}\ \phi_i \\ & \sum_{j=1}^{n} \lambda j\, yj - \phi iyi - s = 0 \\ & \sum_{j=1}^{n} \lambda j\, xkj - xki + ek = 0 \\ & \sum_{j=1}^{n} \lambda j = 1 \end{aligned} \qquad (1)$$

Where j=1, n is the ports, the s and e are output and input slacks (both being ≥0), and ϕ_i measures the increase in output potential for each port. Hence, $\phi_i \geq 1$.The weights, λ, on outputs and inputs give rise to variable returns to scale (VRS) in production and are due to [5]. In this case, the underlying technology of production can be one of increasing, decreasing, or constant returns to scale. The more restrictive constant returns to scale (CRS) model originally developed by [9] eliminates the last equation. The technical efficiency with which each container port is based on its actual production accomplishment relative to its estimated production level for the frontier as in (2).

$$\text{TE}= y/\sum_{j=1}^{n} \lambda j\, yj = \frac{y}{\phi y} = \frac{1}{\phi} \qquad (2)$$

Technical efficiency, therefore, varies between 0 and 1; $0 \leq TE \leq 1$.

In this paper, the DEA methodology is adapted to measure the efficiency ports. The choice of DEA is based on the small number of ports which constitute the sample. The solution of econometric models with a few of observations may turn out to be inefficient and unstable, because of the problem of limited degrees of freedom which typically arises. As it described in table 2, the DEA method has some advantages and disadvantages.

Table 2. advantages and disadvantages of the DEA method.

	Advantages	Disavantages
DEA method	-no a priori structural assumption is placed on the production process	-non parametric and deterministic approach. -does not consider random noise and not allow statistical hypothesis to be contrasted. -does not include error term and not require specifying a functional form. -sensitive to the number of variable measurements.

Source: own elaboration

The inputs and output variables should reflect actual objectives and the process of container port production as accurately as possible [10]. In this paper, the main objective for the port is assumed to minimize the use of inputs to get the maximum outputs. Table 3 describes the variables collected for the 7 ports included in our study.

Four variables are selected, the ships traffic entry and exit port and Goods traffics as input variables then, the number of containers and the containerized freight quantity as output variables. Indeed, it wanted to test, the technical efficiency of each port to discover the resource of technical inefficiency.

Table 3. list of variables

List of variables		
Containers number (TEU) (number)	Y1	Outputs variables
containerized freight quantity (tons)	Y2	
ships traffic entry and exit (number)	X1	Inputs variables
Goods traffic (tons)	X2	

The data are obtained from the annual reports published by OMMP (merchant marine and ports office). It covers the period (1998-2015) and concern seven Tunisian ports, selected according to their size, type and availability of information.

"Fig.3" describes the average container number of each port in Tunisia over 1998-2015 period. It shows that the important number of containers is handled by the port of Rades more than (180.000) containers. The port of Sfax handled less than 10.000 containers and the other ports even less. This means that the port of Rades occupies an important place in the national transport chain in container traffic.

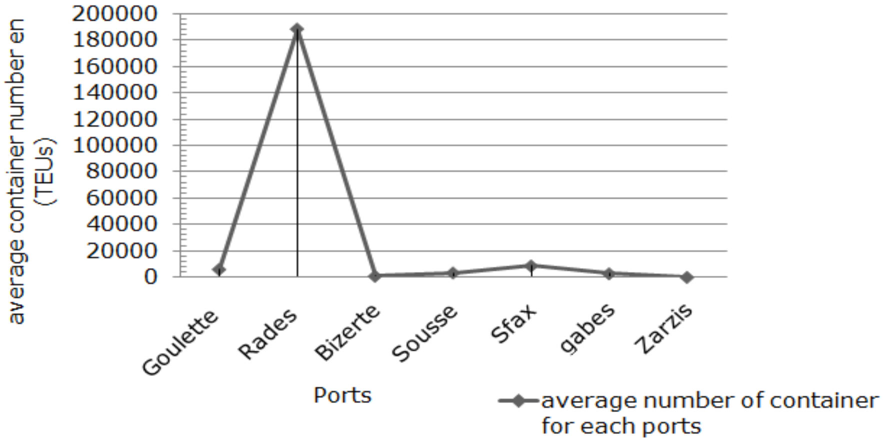

Figure 3: Average number of container en (TEUs) for each port.

III. RESULTS

This section presents and analyses the results of the overall technical efficiency of 7 Tunisian ports. Panel data for 1998-2015 was estimated by applying DEA-BCC model with output-orientation, therefore, the analysis of results used to supply different recommendations for each efficient (inefficient) port.

The efficiency scores of the ports by each year of observation, and by average are reported in Table 4. The scores are determined by deriving the VRS according to the DEA-BCC formulation. The use of the DEA-BCC gives the results of technical efficiency from constant returns to scale (crste) and technical efficiency from variable returns to scale (vrste) as described in table 4.

Table 4. average score efficiency results

	DEA-CCR	DEA-BCC	SE
Goulette	0.286	0.518	0.552
Rades	1.000	1.000	1.000
Bizerte	0.060	0.391	0.153
Sousse	0.167	0.475	0.351
Sfax	0.063	0.072	0.875
Gabes	0.047	0.160	0.293
Zarzis	0.022	0.944	0.023
Average	0.235	0.508	0.462

(SE) = crste/vrste

Table 4 shows that the average efficiency of Tunisian ports around to 0.235 with DEA-CCR model, 0.508 with the DEA-BCC and around to 0.462 for the SE. which means that the Tunisian port are not efficient en average. In addition, the analysis shows that only the port of Rades achieved score efficiency equal to 1. For the others, we find 3 ports present an average efficiency score between 0.5 and 0.8 and 3 ports between 0.05 and 0.4.

The important finding indicates that there is a score efficiency of 1 for the port of Rades and a score around to 0.875 for the port of Sfax. This result is explicated by the reason that the port of Rades is specialized in the traffic of containerization. However, the port of Sfax is the most multipurpose port in Tunisia, it handled more container traffic and arrived after the port of Rades.

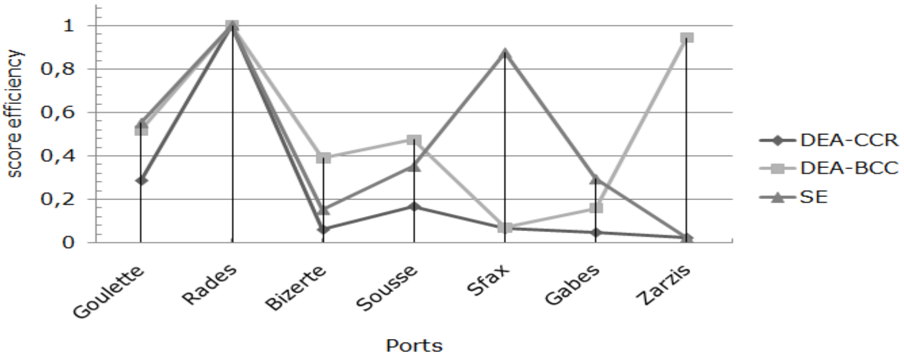

Figure 4:Average efficiency for each port.
Source: own elaboration

The "fig.4" represents the variation of the average efficiency for each port. It shows that only the port of Rades is efficient with the DEA-CCR model, also only Rades, Sfax and Goulette are efficient with the DEA-BCC. In addition, only Rades, Sfax and Goulette have score efficiency more than 0.5.

The port of Bizerte has a SE more than 0.50 from 1998 to 2008 and leave to be completely inefficient between 2009 to 2015 which make SE less than 0.05. The same conclusion it founded in the port of Gabes which achieved inefficiency scale in the last years. This result has two reasons, first that the inputs and outputs decrease in the last years.

There is little variation in efficiency scores obtained by the individual ports across the years of observation. This indicates that the relative position of the ports to the frontier is stable through the period studied. There are explanations for the variation in efficiency scores displayed by certain ports.

The variations of scores efficient are between 1 and 0.062 an average for Tunisian ports. These results are similar to the results of [31] that founded the variations of Norwegian ports efficiency scores which, are 1 for the efficient ports while, others score as low as 0.27. These results are also comparable with [33], where the technical efficiency of 22 European ports was estimated, and it was concluded that an average port could handle 0.40 more traffic with the some resources. However, as every port has its specific characteristics, including the hinterland transportation system, an optimal production achievable in one port is not necessarily achievable for other ports [34].

Moreover, according to this methodology we find that technical efficiency varies between ports in time. This variability is not the same for all ports. In other words, technical efficiency does not vary independently. In addition, we observe that it does not improve over the last years.

The returns to scales of Tunisian ports are increasing between 1998 and 2015. This is consistent with the descriptive statistics, which shows that approximately all Tunisian ports have a gradual evolution in terms of variables studied.

The scale inefficiency observed is due to ports that operate with increasing returns. This indicates that ports can increase their scale of operations to be more efficient. In the last years all Tunisian ports operate with increasing returns to scale. Indeed, Tunisian ports need to increase their operating scale in order to become scale efficient because it appears that they are specialized expect the port of Sfax which, is multipurpose port.

IV. CONCLUSION

The evaluation and measurement of efficiency take into account the specific nature of the study area and used several approaches: parametric and nonparametric. In this context, we used the implementation of the non-parametric DEA method to evaluate the technical efficiency of Tunisian ports. This study provides a previous idea about technical efficiency of Tunisian ports.

In view of other researchers measuring port efficiency is complicated for two main reasons: the first is the designation of the method because, the modeling of the port production functions is delicate. The second is the selection of inputs and output variables, because the port is a multidimensional sector.

Numerous conclusions can be drawn from this study, as follows. Among the 7 ports in Tunisia only the port of Rades is efficient, the port of Sfax achieved a value of 0.892 is considered efficient in comparison with the rest of the port that are inefficient. Zarzis port shows the lowest level of average efficiency with a score of 0.0062. All the inefficient ports show increasing returns to scale. Ports need to increase their operating scale in order to be efficient.

The result obtained shows that the efficiency scores are, on average lower, while the returns to scale growing in time. In addition, the empirical case, we conclude that the port of Sfax and Rades are the most technically efficient.

The model (DEA-BCC) produces only a partial evaluation of technical efficiency. Thus, their result cannot be interpreted as a specific measure of technical efficiency. Therefore, this study has several limitations that are caused by the port sector specificities and the available data, or the limits granted to the DEA models. On the other hand, the advantage of this research appears at the using of panel data approach which is more appropriate for capturing the dynamics of capacity optimization, efficiency changes over the years and the technical innovations that may eventually occur.

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AUTHORS

A. **Arbia. Hlali** is a doctors of economics science, university of Economics and Management science of Sfax; Laboratory URED, Airport road, km 4, POB: 1088, Postal code 3018 Sfax, Tunisia (e-mail: arbiaarbiahlali@yahoo.fr)

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