Comparison of the technical efficiency of ports Algeria-Quebec

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Abstract

The development and modernization of maritime ports has become one of the main concerns of port authorities. In order to better see the potential for improving port logistics, we plan to compare foreign and local technical efficiency. The idea is to compare technical efficiency more particularly technical efficiency, between terminals located in two different regions, a first region of Annaba Algeria and second region Quebec Canada. Based on Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) on a set of quality of service performance indicators, measured over a two-year period, it results that the terminals of the two ports Annaba and Quebec have average efficiency scores by the model (SFA) between 53% and 63% respectively and for the DEA model, we find that the model of constant scale (CRS) very close for the two ports of the order of 0,19 and the variable scale model (VRS) of 0.87 for Annaba and 0.98 for the Port of Quebec. The result is that both ports are inefficient, given the complexity of port activities and the irregularity of the transport market.

Keywords: Technical efficiency, stochastic analysis, non-parametric analysis, maritime ports, port terminals, SFA, DEA.

Introduction

Today, ports play a key role in global supply chains. The development and modernization of seaports have become a key concern for port authorities.

This development of international trade requires new strategies to create more favorable conditions than those offered by competitors in terms of port logistics. And to do this, the Algerian port authorities and especially the port of Annaba embarked on a quality approach (Quality Management System) based continuously on performance measures of the ratio quality price more advantageous.

It is in this sense that this work is part of an approach that can better see the potential for improving port logistics by analyzing foreign and local port performance. The idea is to compare performance, and more specifically technical efficiency, between terminals located in two different regions: the first in Annaba, Algeria, and the second in Quebec, Canada,

Based on SFA and DEA methods, we targeted seven terminals in Annaba and six terminals in Quebec to assess tonnage handled, loading time, number of ships handled and terminal length over a two-year period. In order to carry out our work, the document is composed of 4 main sections. A literature review to position the expected contribution. Secondly, an analysis of port efficiency applied and tested on terminals in Algeria and

Quebec. Thirdly, an illustrative case validates the contribution and discusses port efficiency. Fourthly, a brief conclusion is given and avenues for future research are proposed.

1. Literature review

The notion of performance extends to several dimensions; the word is recognized especially from the point of view of economic and financial evaluation. [1] The notions of effectiveness, efficiency and relevance are complementary in the notion of performance.

In the economic literature, the concept of efficiency is widely used to measure the performance of production units. Debreu (1951), Koopmans (1951), Shephard (1953) and Farrell (1957) were the first to take an interest in the concept of efficiency. Their work is considered the starting point for the construction of the concept. They proposed a formalization of technical efficiency that allows breaking down technical efficiency into scale efficiency and pure technical efficiency. Debreu (1951) was the first to measure it empirically, using resource use.

Technical efficiency is defined as the company's ability to make optimal use of resources. According to Ghali et al (2014), technical efficiency concerns the ability to operate and avoid waste through good management of available resources.In the same spirit, Djimasra (2009) describes it as the ability of a company to produce efficiently with the necessarily limited resources at its disposal. For Farrell (1957), a production unit is technically efficient when it is located at the frontier, i.e. it consists in producing the highest possible level of output for a given level of input (output orientation, output maximization), or it consists in using the lowest possible level of input for a given level of output (input orientation).

In terms of the range of efficiency estimation methods available, two main approaches have been adopted in the economic literature and are the most widely used for establishing a production frontier and estimating technical efficiency: one parametric, an econometric approach known as stochastic frontier analysis (SFA), and the other non-parametric, an approach based on mathematical programming and known as data envelopment analysis (DEA). The main distinguishing feature of these two approaches lies in the assumptions concerning, on the one hand, the inclusion of residuals (random factors) and, on the other hand, the functional or non-functional specification of the production function. Thus, each of these two methods is based on a different conception of the construction of this efficient frontier. Nevertheless, all these techniques have advantages as well as weaknesses, which limit the scope of their applications as efficiency assessment tools. These have been extensively described in the literature by several authors, such as Coelli et al, 1998; Amara et al, 2000. [2] The detailed study of parametric and non-parametric methods will be discussed in the following section.

The parametric SFA method is used to estimate production and cost functions. In our study, we will estimate the production function for the technical efficiency measure. In the SFA model, the error term is composed of technical inefficiency. Efficiency u and a white noise v. concerning the asymmetric term u, an assumption has to be made about its distribution, in order to be able to separate the two contributions to the deviation from the frontier. The problem is that there is no theoretical model for choosing a particular distribution a priori. Efficiency results are potentially sensitive to assumptions about the distribution of the asymmetric variable. The distribution frequently used distributions are the semi-normal distribution, the exponential distribution or a truncated normal distribution or gamma distribution. And the symmetrical v element allows for purely random variations, reflecting measurement errors, model specification errors (variations related to variables not taken into consideration in the model) and uncontrollable factors.

The origins of the DEA method can be found in the doctoral thesis of Rhodes (1978), who later contributed to the development of the Charnes, Cooper and Rhodes (CCR) model. The CCR model is an extension of the work of Farrell (1957), who initiated the measurement of technical efficiency in the case of a single input and a single output. Since the CCR model, the DEA method has been applied in the case of several inputs and outputs. [3] [4] The DEA method is used to evaluate the performance of organizations (called decision method) manufacturing units or (DMU) that transform resources (inputs) into services (outputs). It is adapted to private and public sector organizations.

2. Methodology

To compare the two ports, we have chosen the measurement approaches of Production Function Estimation (SFA) and Data Envelopment Analysis (DEA), as they are both widely used, and their current application is focused on a better assessment of technical efficiency.

2.1 The choice of input and output variables for the various studies

2.1.1 DEA model

In the DEA model, we chose one output (loading/unloading quantity) and three inputs (loading time, number of ships, terminal length).

2.1.2 SFA model

In this model, the same variables as in the DEA model, which we have called explanatory variables, and factors influencing technical efficiency, we have selected three criteria that are common to and of interest in both ports. These factors are "easy access" to the port, on a scale of 0 (difficult access) ,1 (moderately difficult access), 2 (easy access), "security" on a scale of 0 (absence of security) ,1 (presence of security), "draught" on a scale of 0 (low draught) ,1 (medium draught) 2 (adequate draught).

2.2 Model specification

2.2.1 The stochastic function method

Two stochastic functions are used in the literature, the production function and the stochastic cost function. Before estimating the production function (SFA) using Frontier 4.1 software, the following tests, which are preliminary to any measurement, were carried out using SPSS software.

A first test to verify the Independence of the error term (the Durbin-Watson test), a second test to verify the correlation between the input variables. Variance Inflation Factor (VIF), a third test to check the normality of residuals, the graphical test using SPSS software, a fourth test to check the linearity condition between dependent and independent variables, a fifth test to check homoscedasticity, homoscedasticity indicates that the variance of one variable is compatible with the variance of another variable.

After checking the five tests on our data to obtain the most reliable estimators, we specified the SFA model and tested its validity (SFA) through hypothesis testing to choose the best appropriate model. Empirical estimation of the production function was then carried out using FRONTIER4.1 software

2.2.1.1 Presentation of the selected model

Since our model was estimated using data from 26 terminals over the 2-year period (2022-2023), the translog stochastic production model used to measure the technical efficiency of each terminal in the two ports is written as follows:

$$\mathrm{Prod}_{it} = \beta_0 + \beta_1 \mathrm{time} + \beta_2 \mathrm{ships} + \beta_3 \mathrm{terminal} + \frac{1}{2}\beta_{11}\mathrm{time} * \mathrm{time} + \frac{1}{2}\beta_{22}\mathrm{ships} * \mathrm{ships} + \frac{1}{2}\beta_{33}\mathrm{terminal} * \mathrm{terminal} + \beta_{12}\mathrm{time} * \mathrm{ships} + \beta_{13}\mathrm{time} * \mathrm{terminal} + \beta_{23}\mathrm{ships} * \mathrm{terminal} + v_{it} - u_{it} \qquad (1)$$

The model for the inefficiency term is written as follows:

$$u_{it} = \delta_0 + \delta_1 \mathrm{access} + \delta_2 \mathrm{security} + \delta_3 \mathrm{draught} + w_{it} \qquad (2)$$

With:
Time: loading time;
Ships: number of ships handled;
Terminal: length of terminal;
Access: access to the port;
Security: security;
Draught: length of draught;
v_{it}: random error term;
u_{it}: inefficiency term of the i -th terminal in period t;
W_{it}: error term of the inefficiency term;
β: coefficients of the stochastic production frontier model;
δ: coefficients of the inefficiency model.

2.2.2 The Data Envelopment (DEA) model

The second methodology adopted to study the technical efficiency of each port terminals is the non-parametric approach, which uses linear programming to solve the model and determine each terminal's efficiency score.

This DEA method uses two models for efficiency estimation. The first model, CRS, assumes that all operators operate with constant returns to scale, while the second model, VRS, assumes that they operate with varying returns to scale. And scale efficiency is obtained by dividing the technical inefficiency score of the VRS model by CRS, to find out how much the scale efficiency can be improved so that operators operate at an optimum size.

1. CRS model, input orientation of port terminal k among 26 terminals

Dual equation

$$\text{Minimize } \theta_k - \epsilon S^{+}_{time} - \epsilon S^{-}_{ships} - \epsilon S^{-}_{terminal} - \epsilon S^{-}_{security} - \epsilon S^{-}_{draught} \quad (3)$$

$$y_{time,k} - \sum_{j=1}^{26} \lambda_j y_{time,j} + S^{+}_{time} = 0 \quad (4)$$

$$\theta_1 x_{time,k} - \sum_{j=1}^{26} \lambda_j x_{time,j} - S_{time} = 0 \quad (5)$$

$$\theta_1 x_{ships,k} - \sum_{j=1}^{26} \lambda_j x_{ships,j} - S_{ships} = 0 \quad (6)$$

$$\theta_1 x_{terminal,k} - \sum_{j=1}^{26} \lambda_j x_{terminal,j} - S_{terminal} = 0 \quad (7)$$

$$\lambda_j, s_r, s_i \geq 0 \quad \forall j = 1, \ldots, 26, \quad r = 1, \quad i = 1, \ldots, 3 \quad (8)$$

2. VRS model, input orientation of port terminal number k among 26 terminals

Dual equation

$$\text{Minimize } \theta_k - \epsilon S^{+}_{time} - \epsilon S^{-}_{ships} - \epsilon S^{-}_{terminal} - \epsilon S^{-}_{security} - \epsilon S^{-}_{draught} \quad (9)$$

$$y_{time,k} - \sum_{j=1}^{26} \lambda_j y_{time,j} + S^{+}_{time} = 0 \quad (10)$$

$$\theta_1 x_{ships,k} - \sum_{j=1}^{26} \lambda_j x_{ships,j} - S_{ships} = 0 \quad (11)$$

$$\theta_1 x_{terminal,k} - \sum_{j=1}^{26} \lambda_j x_{terminal,j} - S_{terminal} = 0 \quad (12)$$

$$\sum_{j=1}^{26} \lambda_j = 0 \quad (13)$$

$$\lambda_j, s_r, s_i \geq 0 \quad \forall j = 1, \ldots, 26, \quad r = 1, \quad i = 1, \ldots, 3 \quad (14)$$

3. Results and discussion

3.1 Sample descriptive statistics

The construction of the technical efficiency model is based on the prior determination of the most appropriate inputs and outputs for analyzing the technical efficiency of port terminals. Port efficiency at terminal level is based on three key indicators: tonnage handled number of ships and loading/unloading time.

Tableau 1: Liste des risques identifiés au sein de la chaine logistique de MFG.

Port	Characteristics	Tonnage	Unloading time	Number of vessels	Terminal length
Annaba, Algeria	Mean	436010	2759	23	508
	Standard deviation	556187	551	3	198
	Minimum	3554	1840	18	180
	Maximum	2468234	3700	28	950
	Observation	14	14	14	14
Québec, Canada	Mean	9911627	1408	72	1368
	Standard deviation	11655198	250	14	198
	Minimum	67132,08	858,67	51	1120
	Maximum	60980681	2066	98	1700
	Observation	12	12	12	12

Source: Calculations based on 2022-2023 data

Once the inputs and outputs are chosen, we can define a curve corresponding to the best output/input ratios, known as the “efficiency frontier.” This frontier can be used to identify and rank units with a high likelihood of inefficiency.

3.2 DEA port results

The analysis of port terminal efficiency scores is carried out for two ports: the Port of Annaba, Algeria, and the Port of Quebec, Canada. The unit of analysis adopted in our case is the port terminal. The Annaba region has seven port terminals, while the Quebec region has six.
The scale model is derived from the terminal efficiency analysis, which is based on the simultaneous use of two categories of model scales: the constant model scale (CRS) of Charnes, Cooper and Rhodes, and the variable model scale (VRS).

3.2.1 Annaba Algeria Port Area

The average efficiency score using technology (CRS) in Annaba Port (figure) is around 0.20. This apparently low value means that loading times, the number of vessels handled, and terminal length did not produce the expected results in terms of tonnage.

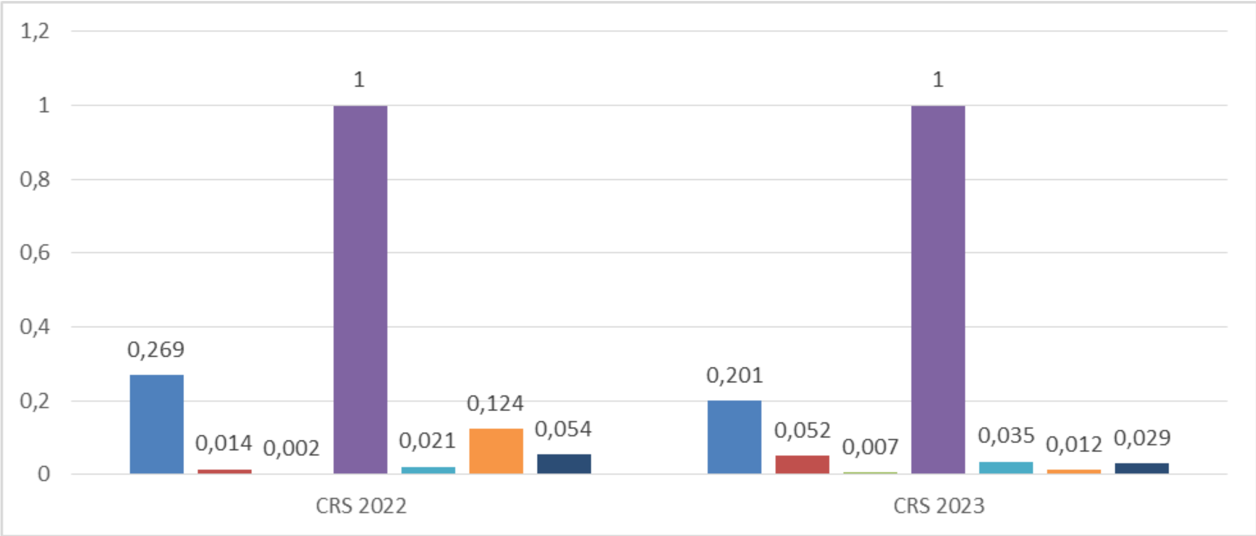

Figure 1: CRS, VRS and EE scores at Annaba port

Source: winDEAP results

About technology (VRS), the score obtained by Annaba port is 0.87, with two terminals having an optimum VRS of 1. With two terminals showing an optimum VRS of 1, this efficiency can be explained, according to data observed, by a rather efficient management of available resources. Scale efficiency showed a low score of 0.21. This inefficiency can be explained, according to data observed, by a rather inefficient management of available resources in general. The decomposition of efficiency of scale has enabled us to make other readings on the returns (constant, decreasing, and increasing) of terminals. For Annaba port, results show that terminals operate largely under increasing returns to scale and one terminal (over two periods, 2022–2023) under constant returns to scale (score equal to 1). Scale efficiency presents two situations: a first situation of constant returns to scale, i.e., the situation has reached its optimal size (or its efficient scale). A second situation is increasing returns to scale (IRS). An organization in this situation has not yet reached its optimum size. To improve its scale efficiency, it must increase its tonnage processing production at the terminals, i.e., a variation in output production of 1% implies a variation in input consumption of less than 1%.

3.2.2 Quebec Port Area

The average efficiency score using technology (CRS) in Quebec terminals is around 0.19. This apparently low value means that the operation and organization of port flows have not produced the expected results in terms of tonnage handled.

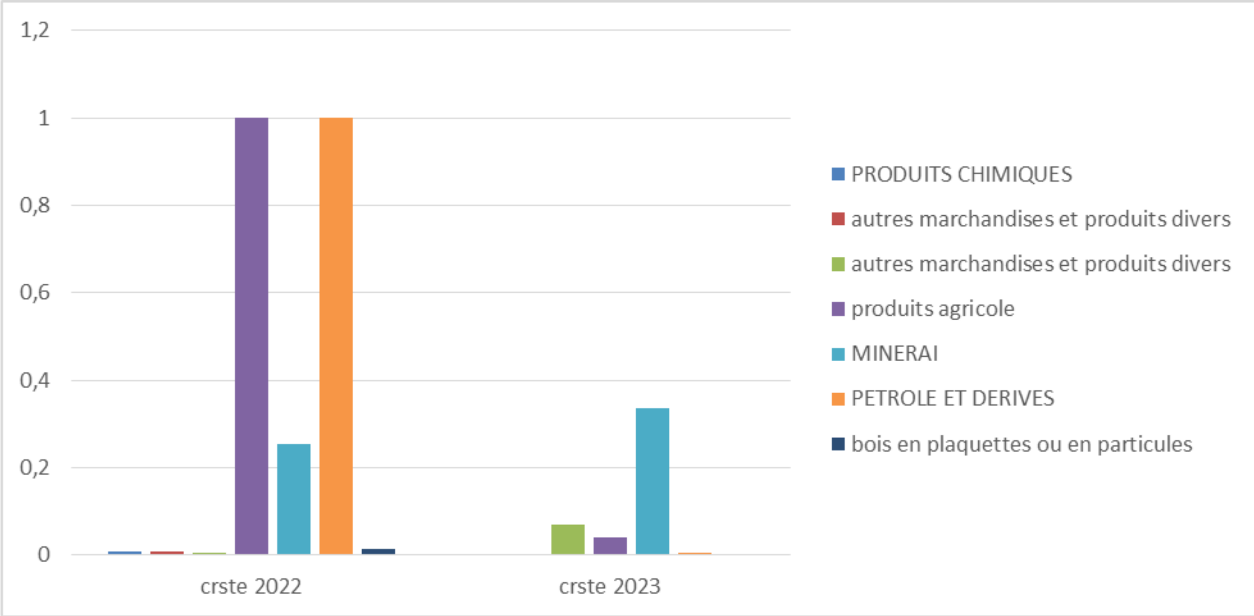

Figure 2 : Scores CRS at Quebec port

Source: winDEAP results

About technology (VRS), the score obtained by Quebec Port is 0.98. According to the data observed, this efficiency can be explained by the presence of resources and adequate organization at port level. Scale efficiency showed a low score of 0.19. This inefficiency can be explained, according to data observed, by a rather inefficient management of available resources in general. Results show that terminals operate largely under increasing returns to scale and one terminal under constant returns to scale (score equal to 1). An organization in this situation has not yet reached its optimal size. To improve its scale efficiency, it must increase its tonnage processing production at the terminal level, i.e., a variation in output production of 1% implies a variation in input consumption of less than 1%.

3.3 SFA port results

3.3.1 SFA model results at Port Annaba

Once the Frontier 4.1 program has run the input data, i.e., the four variables tonnage, loading time, terminal length, number of vessels handled, and three explanatory variables (security, easy access, draft),. Results from figure 4.10 show a gamma estimator value of 0.91, which is significant at the 1% threshold, indicating that the model is good. The gamma value illustrates “that the variation at the level of the units studied (terminals) in relation to the estimated frontier” is explained by the technical inefficiency at 91% of this variability. Therefore, 91% of data variation between terminals can be attributed to technical inefficiency, while the remaining 8% is pure “noise.” Additionally, the LR (Likelihood Ratio) statistic also shows a significant value at the 1% level, indicating the effects of the model’s technical inefficiency.

```
Output from the program FRONTIER (Version 4.1c)

instruction file = terminal
data file =          Annaba|.txt

 Tech. Eff. Effects Frontier (see B&C 1993)
 The model is a production function
 The dependent variable is logged

the ols estimates are :

                  coefficient     standard-error    t-ratio

  beta 0          -0.23962717E+02  0.11713193E+02 -0.20457887E+01
  beta 1          -0.29335782E-08  0.10859784E-08 -0.27013228E+01
  beta 2           0.20225215E+01  0.14291472E+01  0.14151947E+01
  beta 3           0.16325495E-08  0.19404353E-08  0.84133160E+00
  beta 4           0.16427044E+01  0.28701137E+01  0.57234819E+00
  beta 5           0.29006167E-08  0.30907351E-08  0.93848762E+00
  beta 6           0.25719000E+01  0.71717487E+00  0.35861547E+01
  beta 7          -0.38509246E-09  0.13003409E-08 -0.29614731E+00
  sigma-squared    0.94673112E+00
log likelihood function =  -0.13550873E+02
the estimates after the grid search were :

  beta 0          -0.23215216E+02
  beta 1          -0.29335782E-08
  beta 2           0.20225215E+01
  beta 3           0.16325495E-08
  beta 4           0.16427044E+01
  beta 5           0.29006167E-08
  beta 6           0.25719000E+01
  beta 7          -0.38509246E-09
  delta 0          0.00000000E+00
  delta 1          0.00000000E+00
  delta 2          0.00000000E+00
  delta 3          0.00000000E+00
  sigma-squared    0.96449982E+00
  gamma            0.91000000E+00
```

Figure 3: SFA results of Annaba port

Source: FRONTIER results

The negative sign (-) in the inefficiency model indicates that dominant variables represented by the characteristics “security, easy access, and draft” increase the technical efficiency of tonnage handling in the study region. Ultimately, a gamma value of 91% demonstrates that inefficiency is caused by factors that can be controlled by port operators, while 9% is due to uncontrollable random factors. Also, the (σ2) is estimated at 0.91, which is a significant value at the 1% level, showing that technical inefficiency was the cause of variation in tonnage handled at port.

3.3.2 SFA model results at Port Quebec

The results from the following figure 4.11 show a gamma estimator value of 0.78, i.e., 78% of variation in data between terminals can be attributed to technical inefficiency, while the remaining 22% is due to pure “noise.” The LR (Likelihood Ratio) statistic also shows a significant value at the 1% level, indicating the effects of the model’s technical inefficiency.

```
Output from the program FRONTIER (Version 4.1c)

instruction file = terminal
data file =        Quebec.txt

 Tech. Eff. Effects Frontier (see B&C 1993)
 The model is a production function
 The dependent variable is logged

the ols estimates are :

                  coefficient      standard-error     t-ratio

  beta 0          -0.51808536E+01  0.25813005E+02 -0.20070711E+00
  beta 1           0.33318282E-07  0.23229620E-07  0.14343016E+01
  beta 2          -0.28227497E+01  0.27363946E+01 -0.10315580E+01
  beta 3          -0.60241937E-08  0.40158967E-08 -0.15000868E+01
  beta 4           0.29943478E+01  0.26760109E+01  0.11189595E+01
  beta 5          -0.23478487E-08  0.37528520E-08 -0.62561718E+00
  beta 6           0.40895227E+01  0.10781031E+01  0.37932575E+01
  beta 7           0.16817127E-08  0.58489128E-08  0.28752569E+00
  sigma-squared    0.14690450E+01
log likelihood function =  -0.12743264E+02
the estimates after the grid search were :

  beta 0          -0.44858742E+01
  beta 1           0.33318282E-07
  beta 2          -0.28227497E+01
  beta 3          -0.60241937E-08
  beta 4           0.29943478E+01
  beta 5          -0.23478487E-08
  beta 6           0.40895227E+01
  beta 7           0.16817127E-08
  delta 0          0.00000000E+00
  delta 1          0.00000000E+00
  delta 2          0.00000000E+00
  delta 3          0.00000000E+00
  sigma-squared    0.97267803E+00
  gamma            0.78000000E+00
```

Figure 4: SFA results of Quebec port

Source: FRONTIER results

Positive (+) in the inefficiency model indicates that dominant variables represented by the characteristics "security, easy access, and draft" decrease the technical efficiency of tonnage handling in the study region. Ultimately, a gamma value of 78% demonstrates that inefficiency is caused by factors that can be controlled by port operators, while 22% are due to uncontrollable random factors. Also, the (σ^2) is estimated at 0.97, which is a significant value at the 1% level, showing that technical inefficiency was the cause of variation in tonnage handled at port.

4. Comparison of DEA and SFA technical efficiency results

To recap, the DEA method attributes any deviations from the frontier solely to inefficiencies. On the other hand, the parametric stochastic frontier approach considers these deviations as a combination of random error ("white noise") and inefficiency. Therefore, SFA not only statistically tests hypotheses but also constructs confidence intervals.

Using these two methods, this synthesis compares the two ports of Annaba and Quebec in terms of tonnages handled by the two DEA and SFA models. It can be concluded that the average technical efficiency over the two years calculated by the two methods is close, ranging from 83% to 88%.

The terminals of the two ports Annaba and Quebec obtained average efficiency scores using the SFA model of between 53% and 63% respectively, while for the DEA model we find a very close CRS for the two ports of around 0.19 and a VRS of 0.87 for Annaba and 0.98 for the port of Quebec.

A comparative analysis of the results of the two methods leads to a number of conclusions, summarized as follows:

It can be seen that in the SFA model, all 26 terminals are inefficient over the years 2022-2023, whereas in the DEA model, some terminals (two terminals) have a technical efficiency of 100% using either the CRS or VRS model. This difference can be explained by the fact that the SFA method breaks down the observed value in relation to the production frontier into two terms: inefficiency and random errors, whereas the DEA method, which is deterministic, considers any deviation from the frontier as inefficiency.

Each method has advantages over the other, we can say that SFA and DEA are complementary, for the DEA method it is a non-parametric method ie deterministic that does not take in consideration measurement errors but it has advantages , the first is the establishment of decision-making units presenting the reference for each inefficient terminal to which it must compare itself to review its resource management, and the second is to determine the shares of management problem size in the inefficiency calculation. The SFA is derived from the stochastic parametric boundary and the nonparametric deterministic boundary; it takes in consideration the error term and determines the explanatory variables of inefficiency on the basis of statistical tests.

The most common comparison is the one that considers the technical efficiency results obtained by SFA and those obtained by DEA CRS, as the latter takes in consideration the effect of terminal size.

Conclusion

In this study, we worked on a comparison of port terminals in two countries Algeria and Canada, we measured the technical efficiency by two different approaches a nonparametric represented by CRS and VRS as well as the efficiency of scale, and a second approach, stochastic parametric represented by the efficiency scores and the factors that influence it were estimated, and at the end a comparison was made between the two approaches DEA and SFA.

The results of the study show that the terminals of the two ports Annaba and Quebec obtained average efficiency scores by the model SFA between 53% and 63% respectively and for the model DEA we find a very close CRS for the two ports of the order of 0,19 and a VRS of 0.87 for Annaba and 0.98 for the Port of Québec. Thus the SFA model the 26 terminals are inefficient over the years 2022-2023, on the other hand for the DEA model some terminals (two terminals) have a technical efficiency of 100% either by the model CRS or VRS. This difference is explained by the fact that the SFA method breaks down the observed value by input at the production boundary in two terms: inefficiency and random errors, however, the DEA method, which is deterministic, considers any deviation from the border to be inefficient.

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