JOURNAL OF MARITIME RESEARCH

Vol XX. No. III (2023) pp 251–258

ISSN: 1697-4840, www.jmr.unican.es

Measuring Efficiency of Mediterranean Ports Using Data Envelopment Analysis (DEA) Method

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ARTICLE INFO

Article history:
Received 01 Aug 2023;
in revised from 20 Oct 2023;
accepted 27 Dec 2023.

Keywords:
efficiency, Mediterranean seaports, DEA-BCC, DEA-CCR.

ABSTRACT

The aim of this paper is to examine the efficiency of 37 Mediterranean seaports between 2005 and 2017 using the Data Envelopment Analysis (DEA) method. The results from two DEA models, DEA-BCC and DEA-CCR, indicate that ports like Genoa, Cagliari, Valencia, Tarragona, Port Said, Alexandria, and Tripoli demonstrate the highest efficiency scores. In contrast, Barcelona, Livorno, Arzew, Thessaloniki, and Latakia consistently exhibit inefficiency throughout the analysis period. The inefficiency in Mediterranean ports is attributed to overcapacity and trade fluctuations.

1. Introduction.

Maritime transport is a handling method that transports goods in large quantities over long distances, for small batches and short distances. A container terminal is divided into two main areas, each characterized by its own handling operations and equipment. Indeed, ships are loaded/unloaded by quay cranes. Meanwhile, the yard crane requires its own equipment, and another transport equipment ensures the connection between these two areas. To improve the efficiency of port operations, it is essential to identify and solve several optimization problems such as truck transport route planning, yard crane operations planning, quay crane operations planning, and container allocation in customs storage warehouses. In a container terminal, containers are stored in multiple levels called tiers. The position of a container in the yard is characterized by a specific address formed by block, bay, row, and tier. The maximum number of tiers depends on the handling equipment available in the terminal (Steenken et al., 2004). Moreover, according to the work of Chen and Langevin (2011), containers that are exported, loaded onto trucks, and structured on the quay are distributed and stored in a storage area. After a period, the containers are removed with yard cranes and transported by yard trucks to the retrieval quays using quay cranes and loaded onto ships.

Through the use of a container terminal system, several researchers have succeeded in improving the performance of ports and contributing to the reduction of congestion by planning, monitoring, and executing the movement of containers from one truck to another, from a truck to a boat, and from a boat to a truck (Hervás et al., 2019).

This work addresses a significant real-world problem related to the efficiency of major Mediterranean ports, based on the DEA method.

This work consists of 6 sections. In the second section, we provide a literature review on port performance. In the third section, we describe the DEA method. In the fourth section, we present the variables of efficiency for Mediterranean ports, then in the fifth section, we interpret the results obtained through the DEA method. Finally, in the sixth section, we provide a conclusion.

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2. Literature Review: Port Performance.

The performance of ports is a crucial determinant for evaluating their competitiveness. Measuring port performance is a vital exercise in strengthening its competitiveness, providing a benchmark against which the port can be assessed in comparison to others.

Roll and Hayuth (1993) likely represented the first work to promote the application of the Data Envelopment Analysis (DEA) technique to the context of ports. However, their work remains purely theoretical, rather than a practical application. After this initial exploratory study, only six years later, another document was published. Martinez-Budria et al. (1999) classified 26 ports into three groups based on high, medium, and low complexity. Using the DEA-BCC model, the authors examined the efficiency of ports and concluded that high-complexity ports are associated with greater efficiency compared to medium and low efficiency in other port groups.

The DEA-CCR model, according to Valentine and Gray (2001), was applied to 31 container ports in 1998. They used two inputs: total length of quay berths and length of container berths, total freight volume, and the number of containers. They concluded that group analysis is a reliable tool for identifying organizational structures, and the port sector exhibits three structural forms that seem to be related to estimated levels of efficiency.

Barros (2003) applied the DEA approach to ten Portuguese seaports for the period 1999-2000. The versatile nature of national ports was represented by measuring the production of various types of cargoes (general cargo, bulk cargo, containerized cargo, solid bulk, and liquid bulk). The number of ships was also considered an output, while the number of employees and the book value of assets were adopted as inputs.

According to Nguyen et al. (2015), classical Data Envelopment Analysis (DEA) tends to be sensitive to the number of variables in a chosen sample and does not account for their random nature. Standard DEA may present statistical inconsistencies, biased results, and a debatable inference process. Therefore, this study uses a method of efficiency evaluation to overcome these limitations, especially as no study on port efficiency has addressed this issue. This study applies bootstrapped DEA to a sample of the 43 largest Vietnamese ports and compares the results with those of Stochastic Frontier Analysis (SFA) and standard DEA. The results show that efficiency scores obtained through these methods provide useful and consistent information about port efficiency. Furthermore, while efficiency scores are already introduced by bootstrapped DEA, the variables remain consistent and insensitive to sample size, making DEA and SFA yields much larger than DEA alone. Additionally, bootstrapped DEA provides efficiency scores and allows hypothesis testing of port performance.

The research presented in this article, according to Nikolina et al. (2020), focuses on small ports that have not received much attention until now. The strategic position of the ports in the northern Mediterranean has gained importance with Chinese investment. In the first half of 2019, Croatia and Italy agreed to participate in a project aiming to shorten the route between China and Central Europe by redirecting maritime routes to the ports of the Adriatic Sea. This article examines the technical and scale efficiency of 25 ports in Croatia, Italy, and Slovenia, as a possible precondition for investments. The research uses returns of variables from Data Envelopment Analysis (DEA) to scale a results-oriented model on a panel data sheet for 25 ports in the period 2009-2018. This research suggests that the number of efficient ports, in this case, is not directly related to the size of the port or the country in which it is located. However, larger ports are more often efficient. For all inefficient ports, DEA provides examples of best practices to which these ports should aspire, highlighting the practical implications of the work.

According to Ezebunwa et al. (2020), performance evaluation is a regular check that every organization adapts to regulate the performance of its establishment. It shows the relationships between outputs and input variables in organizations. The study aims to examine the performance of six Nigerian seaports between the periods 2012-2017 by applying Data Envelopment Analysis (DEA) models, general linear models, and multivariate analysis. The collected data cover the periods (2012-2017) for each port. The empirical result shows that the seaports operated efficiently. The results from the regression model and multivariate analysis reject the null hypothesis and accept that at a significance level of 5%, there is a significant relationship between input and output variables for each port.

Li et al. (2021) use a super-efficiency Data Envelopment Analysis (SE-DEA) approach. The SE-DEA model is superior to the basic DEA model as it allows for a more accurate and comprehensive categorization and ranking of container terminals' efficiency. In the basic model, if different Decision Making Units (DMUs) are efficient, their efficiency value is "1." However, in the SE-DEA model, the most efficient DMU is greater than "1." Based on the container throughput level in 2018, the top 20 Chinese container terminal companies were selected. Various production quotas were chosen as inputs, while container throughput was considered an output. The results show that the Shanghai terminal was ranked first. This study contributes to providing information on the Chinese container terminal industry to increase efficiency. It also provides practical and policy implications (e.g., improved terminal operations) for container terminals.

Wang et al. (2021) use the DEA-Malmquist model, selecting freight throughput, operating profit, and net profit as output indicators, and quay berth length, number of quay berths, assets, and operating expenses as input indicators. They calculate and study changes in the total factor productivity of ten ports from 2007 to 2018 and analyze the impact of efficiency changes and technological changes on total factor productivity. The results show that: (1) The total factor productivity of the ten ports as a whole has shown a downward trend over the past 11 years, mainly due to technological changes. (2) The financial crisis reduced the overall total factor productivity in a short time. (3) The adoption of active economic policies and the reform of the management system can significantly promote improvement in efficiency changes and technological changes. Finally, combined with the results of the empirical analysis, some suggestions are put forward, such as increasing investments in scientific research, rational planning of scale, and deepening system reform, etc.

3. Methodology.

The DEA (Data Envelopment Analysis) technique, introduces concepts into a basic model. We find a CCR (1978) type model that evaluates overall efficiency and identifies sources of inefficiency, as well as the BCC (1984) model that distinguishes technical inefficiencies and scale inefficiencies to estimate technical efficiency at scale and identify variable or constant returns to scale. Finally, the model by Charnes, Cooper, Golany, Seiford, and Stutz (1985) attempted to connect DEA analysis to Charnes and Cooper's (1962) early analyses of inefficiency and, in this process, further link efficiency analyzed in Koopmans' (1951) research. The DEA method provides a comprehensive picture of an organization's performance and appears to be a particularly suitable tool for service organizations. Depending on the problem orientation (input orientation or output orientation), the DEA method has three extremely useful features (Charnes et al. (1995)):

- It is very useful in complex situations where there are multiple outputs and inputs asserted in different units of measurement.
- It characterizes each Decision Making Unit (DMU) by a single efficiency score.
- It indicates changes in inputs and outputs for the most efficient units.
- Charnes et al. (1995) provide an additional list of other advantages of the DEA method:
- By projecting inefficient units, it provides the improvement value for each DMU.
- It focuses on determining the frontier of the best unit. Each unit is compared to an efficient unit or a combination of efficient units.
- It does not require any restrictions on cost or production functions (inputs and outputs).

The advantages of the DEA method essentially rely on the fact that it is a non-parametric approach. In fact, these characteristics have made Data Envelopment Analysis a popular method in efficiency estimation.

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

$$\text{DEA-CCR}\begin{cases} Min_{\theta,\lambda}\ \theta \\ Subject\ to \\ -Y_0 + \lambda Y \geq 0 \\ \theta X_0 - \lambda X \geq 0 \\ \lambda \geq 0 \end{cases}$$

Equation 1: Mathematical formulation of the DEA-CCR model

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 output matrix,

X: is the k × n input matrix.

Y_0 and X_0 are the observed output and input values, respectively, of DMU_0 and the DMU to be evaluated.

θ^* is the efficiency score of DMU_0 focused on inputs. If θ^* is equal to unity, current input levels cannot be reduced, indicating that DMU_0 is efficient. However, if $\theta^* < 1$, then DMU_0 is technically inefficient.

The DEA-CCR problem (1) incorporates an additional constraint, the convexity constraint $N1'\lambda = 1$, where N1 is the n × 1 vector of 1s.

$$\text{DEA-BCC}\begin{cases} Min_{\theta,\lambda}\ \theta \\ Subject\ to \\ -Y_0 + \lambda Y \geq 0 \\ \theta X_0 - \lambda X \geq 0 \\ N1'\lambda = 1 \\ \lambda \geq 0 \end{cases}$$

Equation 2: Mathematical formulation of the DEA-BCC model.

4. Data Description.

The ports studied in this chapter are located in the Mediterranean region and are represented by twelve countries: France, Spain, Italy, Algeria, Morocco, Greece, Turkey, Cyprus, Syria, Lebanon, Egypt, and Libya. The container ports used in this research, therefore, have diverse policies, management structures, and characteristics.

Figure 1: Location of Container Ports in the Mediterranean Area.

Source: www.aquarius.geomar.de.

Not only do port regulations differ, but the size of ports also varies significantly. From the port throughput, we can observe the different sizes of ports that can be classified as small ports, as their throughput is less than 500000 EVP, while other ports are relatively large, with a throughput exceeding 2000000 EVP. The analysis, therefore, encompasses a wide range of port sizes in the Mediterranean basin.

In this study, the data consists of 481 annual observations. We use data from 37 Mediterranean seaports between 2005 and

2017. We use the database to calculate inputs, outputs, and efficiency explanatory variables. The choice of inputs and outputs depends primarily on the actual goal of the port authority and the sample size (for the DEA method to yield reasonable results, the sum of inputs and outputs should not exceed half the sample size) and the availability of data.

The container port's container throughput crucially depends on the efficient use of labor, land, and equipment. Therefore, the total number of quay berths, terminal area, number of quay cranes, and the number of workers are highly appropriate elements to be incorporated into the models as input variables.
Inputs:

- X1: Number of containers
- X2 : Number of passengers
- X3 : Number of ships
- X4: Surface area
- X5 : Depth
- X6: Number of cranes
- X 7: Petroleum products
- X 8 :Chemical products
- X 9: Solid bulk
- X 10: Liquid bulk
- X 11 : Dry products.

Outputs:

- Y: EVP: a unit of container measurement that includes both 20-foot and 40-foot containers.

Table 1: Descriptive statistics.

Factors	Obs	Mean	Std. Dev.	Min	Max
Y	481	1113035	1156637	1000	4832000
X1	481	2488349	5032531	1000	41100000
X2	481	1512235	1779857	1000	9028000
X3	481	2836.867	4900.668	1	29752
X4	481	80.31081	74.10905	2.3	431
X5	481	12.80811	3.352337	6	21.5
X6	481	13.0894	9.082854	1	53
X7	481	4033624	9837637	34000	64200000
X8	481	2663084	4552992	11000	25900000
X9	481	3851965	6281234	1000	36100000
X10	481	5323426	7726367	6000	28800000
X11	481	1816881	1457878	18000	11900000

Source: Authors.

5. Empirical Analysis of Port Efficiency.

The following interpretations can be derived: The DEA score, calculated under constant returns to scale (DEA-CCR), provides general measures of the technical efficiency of ports. The results indicate that the ports of Genoa, Cagliari, Valencia, Tarragona, Port Said, Alexandria, and Tripoli represent the set of efficient samples. Throughout the period from 2005 to 2017, the analysis demonstrates that the efficiency scores obtained by these ports are the highest (==1).

In contrast, the ports of Barcelona, Livorno, Arzew, Thessaloniki, and Latakia are consistently inefficient throughout the analysis period. The results show that the port of Bejaia was efficient during the analysis period with efficiency ranging between 0.162 and 0.78. It is also noteworthy that the results for the port of Annaba vary, as it was efficient in the years 2013, 2015, and 2016. However, during the rest of the analysis period, it was efficient with an efficiency score ranging between 0.468 and 0.780.

In 2005, 2006, and 2007, the ports of Algiers, Valencia, Tarragona, Genoa, Gioia Tauro, Cagliari, Skikda, Piraeus, Port Said, and Alexandria were efficient with a score of 1, while other ports had efficiency scores ranging between 0.08 and 0.918. The port of Sete is relatively the most inefficient with a score of 0.008.

In 2008, it is found that the port of Civitavecchia is inefficient with a score between 0.025.

In 2009, on the other hand, the port of Algiers is efficient with a score of 0.821. The port of Sete is the most inefficient with a score of 0.024.

It is observed in 2010 and 2011 that the port of Sete is more inefficient (0.003) than the port of Piraeus, which achieved an efficiency score of 0.956.

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Table 2: The CRS (Constant Returns to Scale) and VRS (Variable Returns to Scale) efficiency scores for the period 2005 to 2011.

Countries	PORT	2005			2006			2007			2008			2009			2010			2011		
		CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE
Spain	Algeciras	1	1	1	1	1	1	1	1	1	0.923	0.929	0.993	0.821	0.828	0.992	0.849	0.852	0.997	0.849	0.852	0.997
	Malaga	1	1	1	1	1	1	0.533	1	0.533	0.282	1	0.282	0.256	1	0.256	0.291	1	0.291	0.291	1	0.291
	Alicante	0.783	1	0.783	0.756	1	0.756	0.643	1	0.643	0.683	1	0.683	0.67	1	0.67	0.719	1	0.719	0.719	1	0.719
	Valencia	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Tarragona	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Barcelona	0.845	0.894	0.946	0.979	0.988	0.99	0.88	0.912	0.965	0.724	0.825	0.878	0.594	0.758	0.784	0.577	0.742	0.777	0.577	0.742	0.777
France	Sete	0.008	1	0.008	0.028	1	0.028	0.11	1	0.11	0.432	1	0.432	0.024	1	0.024	0.003	1	0.003	0.003	1	0.003
	Marseille	0.895	1	0.895	0.975	1	0.975	0.089	1	0.089	0.633	1	0.633	0.688	1	0.688	0.654	1	0.654	0.654	1	0.654
	Fos-sur-Mer	0.799	1	0.799	1	1	1	1	1	1	0.636	1	0.636	0.605	1	0.605	0.672	1	0.672	0.672	1	0.672
Italia	Genoa	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	La Spezia	1	1	1	0.77	1	0.77	0.798	1	0.798	0.766	1	0.766	1	1	1	1	1	1	1	1	1
	Livorno	0.397	0.881	0.451	0.387	0.717	0.539	0.519	0.935	0.555	0.3	0.654	0.459	0.511	1	0.511	0.396	0.911	0.435	0.396	0.911	0.435
	Civitavecchia	0.038	1	0.038	0.044	1	0.044	0.033	1	0.033	0.025	1	0.025	0.028	1	0.028	0.036	1	0.036	0.036	1	0.036
	Naples	0.465	1	0.465	0.478	1	0.478	0.496	1	0.496	0.274	0.995	0.275	1	1	1	0.308	0.888	0.347	0.308	0.888	0.347
	Gioia Tauro	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Salerno	0.456	1	0.456	0.419	1	0.419	0.384	1	0.384	0.777	1	0.777	0.516	1	0.516	0.348	1	0.348	0.348	1	0.348
	Cagliari	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Palermo	0.17	1	0.17	0.066	1	0.066	0.194	1	0.194	0.226	1	0.226	0.162	1	0.162	0.03	1	0.03	0.03	1	0.03
	Augusta	0.221	1	0.221	0.242	1	0.242	0.243	1	0.243	0.174	0.95	0.183	0.167	1	0.167	0.138	0.923	0.15	0.138	0.923	0.15
	Catania	0.028	1	0.028	0.054	1	0.054	0.045	1	0.045	0.704	1	0.704	0.117	1	0.117	0.135	1	0.135	0.135	1	0.135
Algeria	Algiers	0.918	1	0.918	1	1	1	0.542	1	0.542	0.593	1	0.593	1	1	1	1	1	1	1	1	1
	Annaba	0.603	1	0.603	0.608	0.997	0.609	0.534	0.991	0.54	0.468	0.902	0.519	0.508	0.956	0.531	0.744	0.983	0.757	0.744	0.983	0.757
	Arzew	0.112	0.714	0.157	0.126	0.714	0.176	0.105	0.714	0.147	0.112	0.714	0.157	0.106	0.714	0.149	0.089	0.73	0.122	0.089	0.73	0.122
	Bejaia	0.162	1	0.162	0.237	1	0.237	0.253	1	0.253	0.218	1	0.218	0.283	1	0.283	0.386	1	0.386	0.386	1	0.386
	Oran	0.684	1	0.684	0.497	0.874	0.569	0.41	0.976	0.42	0.523	0.963	0.543	0.259	0.803	0.323	0.811	1	0.811	0.811	1	0.811
Algeria	Skikda	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Marocco	Tangier	1	1	1	0.761	0.886	0.86	0.606	0.759	0.799	0.812	0.917	0.886	1	1	1	0.565	0.823	0.687	0.565	0.823	0.687
Greece	Piraeus	1	1	1	1	1	1	1	1	1	0.679	1	0.679	0.8	1	0.8	0.956	1	0.956	0.956	1	0.956
	Thessaloniki	0.383	0.789	0.485	0.194	0.77	0.251	0.188	0.763	0.247	0.093	0.758	0.123	0.145	0.757	0.191	0.136	0.752	0.18	0.136	0.752	0.18
Turkey	Izmir	0.859	1	0.859	0.865	1	0.865	0.766	1	0.766	0.761	1	0.761	0.647	1	0.647	0.558	1	0.558	0.558	1	0.558
	Antalya	0.08	1	0.08	0.275	1	0.275	0.318	1	0.318	0.316	1	0.316	0.379	1	0.379	0.177	1	0.177	0.177	1	0.177
Cyprus	Limassol	0.6	1	0.6	0.501	1	0.501	0.575	1	0.575	0.234	1	0.234	0.307	1	0.307	0.404	1	0.404	0.404	1	0.404
Syria	Latakia	0.248	0.798	0.31	0.37	0.778	0.476	0.32	0.764	0.418	0.195	0.641	0.304	0.293	0.688	0.425	0.203	0.58	0.351	0.203	0.58	0.351
Libanon	Beirut	0.814	1	0.814	0.716	1	0.716	1	1	1	0.411	0.776	0.529	0.466	0.779	0.598	0.549	0.932	0.589	0.549	0.932	0.589
Egypt	Port-Saïd	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Alexandria	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Lybia	Tripoli	1	1	1	1	1	1	0.978	1	0.978	1	1	1	1	1	1	1	1	1	1	1	1

Source: Authors.

Table 3: The CRS (Constant Returns to Scale) and VRS (Variable Returns to Scale) efficiency scores for the period 2012 to 2017.

Countries	PORT	2012			2013			2014			2015			2016			2017		
		CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE
Spain	Algeciras	0.939	1	0.939	1	1	1	0.949	1	0.949	0.937	1	0.937	0.943	1	0.943	0.781	0.89	0.877
	Malaga	0.143	1	0.143	1	1	1	0.227	1	0.227	1	1	1	0.257	1	0.257	1	1	1
	Alicante	0.681	1	0.681	0.855	1	0.855	0.771	1	0.771	0.655	1	0.655	0.609	1	0.609	0.609	1	0.609
	Valencia	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Tarragona	1	1	1	1	1	1	1	1	1	0.704	1	0.704	0.568	1	0.568	0.283	1	0.283
	Barcelona	0.463	0.689	0.672	0.427	0.667	0.639	0.455	0.655	0.694	0.456	0.656	0.696	0.506	0.659	0.769	0.647	0.732	0.884
France	Sète	0.03	1	0.03	0.037	1	0.037	0.005	0.944	0.005	0.006	1	0.006	0.008	1	0.008	0.39	1	0.39
	Marseille	0.712	1	0.712	0.989	1	0.989	0.943	1	0.943	0.911	1	0.911	0.803	1	0.803	0.816	1	0.816
	Fos-sur-Mer	1	1	1	1	1	1	0.741	1	0.741	0.7	1	0.7	0.731	1	0.731	0.643	1	0.643
Italia	Genoa	1	1	1	1	1	1	1	1	1	1	1	1	0.83	1	0.83	0.87	1	0.87
	La Spezia	1	1	1	1	1	1	0.716	1	0.716	1	1	1	0.655	1	0.655	0.895	1	0.895
	Livorno	0.266	0.841	0.316	0.276	0.801	0.345	0.245	0.813	0.302	0.312	0.958	0.326	0.278	1	0.278	0.146	0.954	0.153
	Civitavecchia	0.032	1	0.032	0.037	1	0.037	0.035	1	0.035	0.036	1	0.036	0.035	1	0.035	0.034	1	0.034
	Naples	0.439	1	0.439	0.457	0.921	0.496	0.245	1	0.245	0.253	1	0.253	0.206	0.929	0.222	0.379	1	0.379
	Gioia Tauro	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Salerno	0.266	1	0.266	0.419	1	0.419	0.522	1	0.522	0.735	1	0.735	0.649	1	0.649	0.821	1	0.821
	Cagliari	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Palermo	0.042	1	0.042	0.049	1	0.049	0.04	1	0.04	0.052	1	0.052	0.094	1	0.094	0.024	1	0.024
	Augusta	0.19	0.916	0.207	0.152	0.788	0.193	0.201	1	0.201	0.245	0.958	0.256	0.493	1	0.493	1	1	1
	Catania	0.656	1	0.656	0.283	1	0.283	1	1	1	0.737	1	0.737	0.755	1	0.755	0.588	1	0.588
Algeria	Algiers	0.742	1	0.742	1	1	1	0.975	1	0.975	1	1	1	1	1	1	1	1	1
	Annaba	0.794	1	0.794	1	1	1	0.78	0.997	0.782	1	1	1	1	1	1	0.798	1	0.798
	Arzew	0.068	0.714	0.095	0.057	0.714	0.08	0.037	0.714	0.052	0.071	0.714	0.099	0.058	0.714	0.081	0.077	0.714	0.108
	Bejaia	0.544	1	0.544	0.243	1	0.243	0.362	1	0.362	0.78	1	0.78	0.56	1	0.56	0.501	1	0.501
Countries	PORT	2012			2013			2014			2015			2016			2017		
		CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE	CCR	BCC	SE
Algeria	Oran	0.84	1	0.84	0.76	0.877	0.866	1	1	1	1	1	1	1	1	1	0.996	1	0.996
	Skikda	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Marocco	Tangier	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Greece	Piraeus	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Thessaloniki	0.294	0.773	0.381	0.177	0.756	0.234	0.126	0.756	0.166	0.114	0.769	0.149	0.109	0.745	0.146	0.119	0.752	0.158
Turkey	Izmir	0.56	1	0.56	0.489	1	0.489	0.356	1	0.356	0.46	1	0.46	0.621	1	0.621	0.742	1	0.742
	Antalya	0.239	1	0.239	0.25	1	0.25	0.21	1	0.21	0.255	1	0.255	0.252	1	0.252	0.237	1	0.237
Cyprus	Limassol	0.305	1	0.305	0.249	1	0.249	0.474	1	0.474	0.14	1	0.14	0.246	1	0.246	0.266	1	0.266
Syria	Latakia	0.076	0.548	0.139	0.24	0.521	0.46	0.097	0.813	0.119	0.382	0.777	0.491	0.228	0.679	0.335	0.216	0.632	0.341
Libanon	Beirut	0.69	0.899	0.767	0.859	1	0.859	0.548	0.795	0.69	0.514	0.839	0.612	0.32	0.818	0.391	0.44	0.936	0.471
Egypt	Port-Saïd	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Alexandria	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Lybia	Tripoli	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Source: Authors.

In 2008, it is found that the port of Civitavecchia is inefficient with a score between 0.025.

In 2009, on the other hand, the port of Algiers is efficient with a score of 0.821. The port of Sete is the most inefficient with a score of 0.024.

It is observed in 2010 and 2011 that the port of Sete is more inefficient (0.003) than the port of Piraeus, which achieved an efficiency score of 0.956.

Referring to the efficiency scores with the DEA-BCC model, we observe that the ports (Valencia, Gioia Tauro, Cagliari, Skikda, Tangier, Piraeus, Port Said, Alexandria, and Tripoli) are efficient throughout the analysis period [2012-2017]. It is also noted that the results for the port of Annaba vary as it was efficient during the period [2012-2017]. However, during the rest of the analysis period, it was efficient with an efficiency of 0.780.

We notice that among the 37 analyzed ports, only the following ports have an efficiency score equal to 1 over the entire period: Algiers in 2005-2007, Malaga in 2005-2006, Valencia in 2005-2017, Tarragona in 2005-2014, Fos-sur-mer in 2006-2007-2012-2013, Genoa in 2005-2015, La Spezia in 2005-2009-2010-2011-2012-2013-2015, Gioia Tauro in 2005-2017, Cagliari in 2005-2017, Oran in 2014-2016, Skikda in 2005-2017, Tangier in 2005 and 2009, 2012-2017, Piraeus in 2005-2007 and 2012-2017, Port Said in 2005-2017, Alexandria in 2005-2017, and Tripoli in 2005-2017.

We observe that seven ports are inefficient throughout all years of the study (Barcelona, Livorno, Augusta, Arzew, Thessaloniki, Latakia, and Beirut), while the other ports are efficient, having obtained efficiency scores equal to 1. The results provided by the DEAP program give us an idea of the efficiency scores in a general sense, and then the scores for each firm. This program suggests projected values for the inputs or outputs used. By using these values in new iterations, the scores of inefficient firms improve each time until reaching the value of 1 for both BCC and CCR models. Similarly, when using TEU as an output, the scores, as projected by the DEAP program, are equal to 1 for both inefficient and efficient ports.

The DEAP program offers a projection for inefficient units by reducing the values of inputs and increasing the value of the output. Thus, the projection of variables maintains the constancy of inputs by increasing the output. The value given by the program corrects only the score of the BCC model, which becomes 1 after the first iteration. To correct the score of the CCR model, we attempted several iterations to achieve the necessary output value to obtain a score equal to 1.

To assist the port administration in handling the new output variables to achieve efficient scores while using the same quantities of inputs, the port administration must seek solutions to accommodate more ships and cargo to increase the scores of inefficient ports.

The results of our study identify several variables to improve port efficiency. The significance attributed to the availability of loading and unloading equipment and the competence of operating personnel is explained by the fact that dysfunction at this level leads to increased waiting times for ships, raising port costs on one hand and penalizing the carrier on the other, increasing the overall cost of import or export. Therefore, the concerned goods become non-competitive in a competitive environment.

Conclusions

Our empirical results confirm that the models adopted in maritime transport ports depend primarily on the characteristics of loading or unloading systems that differ from others across ships. This work also studied the foundations of DEA and demonstrated how DEA can be applied to measure the efficiency of Tunisian ports. The most frequently used models are DEA-CCR and DEA-BCC, corresponding respectively to constant returns to scale and variable returns to scale assumptions.

However, empirical results show that the majority of Mediterranean ports are efficient. This information is particularly useful for port managers or policymakers to decide on the scale of production. In contrast to other studies on port efficiency, this study attempts to explain inefficiency through variables under the control of operators.

Empirically, in our research, the results show that port improvement and efficiency depend on the characteristics of port structures. Maritime transport, in service of international trade, only reflects the trade imbalance that crosses the Mediterranean. The traffic of Mediterranean ports is shared among a significant number of ports, which exhibit considerable dispersion. Additionally, interport competition involves variability between ports. Similarly, trade in the Mediterranean maritime basin aims to improve trade relations between public and private operators in the maritime transport and logistics sector, as well as to improve maritime freight delivery times while contributing to the competitiveness of the transport and logistics sector.

The competence of operating personnel manifests itself in its influence on the quality of handling service and service speed. This situation is generally due to an overlap in the tasks and responsibilities of different operators. The quality of the handling service is a determining factor in customer loyalty and is often linked to the level of competition. A lack of competition does not promote the development of services or the improvement of the quality of services offered.

The interviewed shipowners at the port emphasize the importance of the following determinants: the availability of qualified workforce; the availability of loading and unloading equipment and sufficient infrastructure; the use of new communication technologies; and the simplicity of procedures and documentation. According to them, if these factors are confirmed in a port location, others will automatically assert themselves.

Going further in our analysis, we can say that the central determinants of the performance of the Mediterranean port are closely related to productivity and, consequently, profitability.

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