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# Performance assessment of major European ports: an empirical investigation

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ABSTRACT

In the recent literature, the strategic relevance of ports has improved, and this paper provides a comparative analysis of 24 European ports. The port performance has been evaluated considering data envelopment analysis and Shephard's distance function. This latter approach offers an alternative method to address a significant restraint of the standard Stochastic Frontier when the model needs to consider multiple outputs. From a policy point of view, the conclusion could offer valuable insights to support policy measures targeted to expand port efficiency. The findings obtained from the analysis reveal that several contextual indicators must be included in benchmark analysis.

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## 1 Introduction

Over recent years, the impact of maritime transport on national (and regional) economies has contributed to the increasing competition in Europe, and this competitiveness has encouraged management and port authorities to address performance evaluation methods and benchmarking models. The demand for performance indicators is also driven by several stakeholders (Ha, Yang and Lam, 2019). Among others, Wang (2013), Notteboom and Yap (2016), Huo, Zhang and Chen (2018) and López-Bermúdez, Freire-Seoane and González-Laxe (2019) analysed several perspectives and characteristics of port competitiveness. These authors highlighted that one main problem analysing the port performance is the selection of indicators that must be considered in the decision-making process. In fact, the complexity of the port structure and the activities linked to it have to be managed simultaneously. The implications of port growth also have to be considered. One of these implications is congestion, which is particularly relevant for the expansion of urban ports, and which is constrained due to the limited availability of land (Simoes and Marques, 2010). A port can also generate undesirable outputs that have to be investigated, including the environmental impact of port operations (Acciaro et al., 2014; Chang, 2015; Bouman et al., 2017).

From a policy perspective, every managerial inefficiency could expand the probability of port policy failure. Management and port authorities must have a deep understanding of this sector considering rigorous empirical research. The decision process includes plenty of features connected to shipping traffic, storage operation, port expansion, intermodal connections, industrial activities, environmental policies, regulation of the concession fees, penalty and incentive pricing, etc. If management has insufficient information, its determinations might entail an unplanned increase in costs. Significant investment is required to improve the competitiveness of ports, and the new technologies intensify this need. Simultaneously, excessive or inappropriate investments can create inefficiencies and a waste of resources. Different research papers analysed actions aimed to support EU transport policy, for instance, the public-private partnership (Cabrera, Suárez-Alemána and Trujillo, 2015). Due to recent policy changes in several European countries, the port administration system has been modified. The role of the government has strategic importance in regards to interventions aimed at a specific business, depending on the national legislative environment (ESPO, 2016; Castillo-Manzano et al., 2018; Chang et al., 2018).

The main objective of the current research is to offer a comparative investigation of the efficiency ratings of twenty-four European container ports. The top European ports ranked by Eurostat's database has been analysed. Although substantial literature exists on port performances, the subject is still quite debated. In this composite and competitive environment, it is crucial that benchmarking studies be conducted to achieve goals and strategies using the available information, considering potential threats, opportunities, strengths and weaknesses. An additional objective is to identify the causes of (in)efficiency involving several different contextual dimensions. Therefore, some relationships have been tested further in the analysis. In more detail, the following hypotheses have been considered: (1) whether the prevalence of a specific standardised legal form has a significant effect on the relative efficiency scores, and (2) whether the percentage variations of the total passengers has a significant effect on the relative efficiency scores.

The relevant topic of the selection of homogenous and comparable indicators that can be involved in the comparative analysis is also discussed. Both the input and output measurements involve dimensions obtained by means of an additive model, fixing the port activity boundaries and spatial perimeter of the firms investigated. An approach oriented towards port-related activities has been used to provide an estimation of several indicators.

As for the theoretical model, in the current article, the performance evaluation derives from the distance function as proposed by Shephard (1970) – instead of the standard Stochastic Frontier Analysis (SFA) – and from the Data Envelopment Analysis (DEA). The DEA estimations are calculated with the aim of verifying the consistency conditions of the distance function estimates. In the authors' opinion, the direct usage of inputs and outputs via the Shephard's distance function is a sustainable option to analyse European ports and, if the different techniques rank the ports similarly, the important result is that the policy conclusions do not depend on which frontier efficiency is used. Concerning contributions to the port policy analysis, this work proposes several advancements. First, this research fills the gap of performing the comparative efficiency analysis using the Shepard function via a specific additive approach to avoid the exclusion of significant dimensions. Although several authors have already attempted to analyse the port sector via the distance function (such as Gonzalez and Trujillo, 2008; Núñez-Sánchez and Coto-Millán, 2012), diverse issues are unexplored, and current research attempts to fill this gap. Second, the model considers several contextual port features. As for the remaining contents of the paper, section two briefly reviews the relevant theoretical background connected to the methods. Section three refers to data collection and variables. Section four combines the results and discussion. Finally, section five considers the concluding remarks.

## 2 Methods

The DEA and SFA have emerged as the most dominant methods to assess efficiency in many contexts in recent years. Among others, Coelli et al. (2005) and Cook and Seiford (2009) extensively debated the DEA technique, and Roll and Hayuth (1993), Cullinane et al. (2004) and Barros (2006) referred to this method in the port sector. In the DEA approach, all deviations from the production frontier are estimated as technical inefficiency. This procedure does not account for noise and does not need a specific functional relationship among inputs and outputs. Radial and non-radial efficiency measurements can also be assumed in the traditional model, considering constant (CRS, or CCR) and variable (VRS, or BCC) returns to scale. Liu, Lu and Lu (2016) provided an overview of the most innovative DEA models. Although additional considerations of the DEA technique are debated in appendix A, an extensive review of this topic is beyond this paper's scope, which refers to the radial DEA to validate the consistency conditions of distance function efficiency estimations.

Among others, Liu (1995), Barros (2005) and Cullinane et al. (2006) represent several examples of SFA approaches to assess the ports demonstrating the best performance compared to the entire cluster of observations. In the SFA technique, the specification of a functional form for production technology is required, and the general SFA model is given by equation (1).

$$y = f(x; \beta) exp(v - u) \tag{1}$$

In (1) $y$ is a scalar output; $x$ is a vector of inputs; $\beta$ is a vector of technology parameters. The error term $\varepsilon$ offers a decomposition into $v$ and $u$ ($\varepsilon = v - u$); $v \sim N(0, \sigma_v^2)$ is the primary error component and represents the statistical noise; the second error component $u$ [$u \sim N_+(0, \sigma_v^2)$] characterises the technical inefficiency. Among the diverse functional forms that can be used, the Cobb-Douglas (log) function is among the most diffused approach, and the parameters given by equation (2) are usually estimated through maximum likelihood method.

$$ln\left(y_j\right) = \beta_0 + \Sigma_i \beta_i ln(x_i) + v_j - u_j \tag{2}$$

In the current paper $j$ indicates each of the twenty-four ports. This method has several advantages – such as the structure of the error components – and disadvantages; one relevant criticism in the standard SFA perspective is the single-output production function. To investigate efficiency when multiple inputs are used to produce multiple outputs, the traditional approach aims to aggregate the outputs into a single index that requires the output prices. If the prices are missing, the Shephard distance function addresses this limitation since it does not need information about prices (Bogetoft and Otto, 2011; De Witte and López-Torres, 2017). Synthetically, the stochastic frontier model can also be written considering the Shephards' distance functions presented in equation (3).

$$D^I(x_j, y_j, z_j; \beta) = exp(v_j - u_j) \quad (3)$$

In these equations, $D^I$ is the and input distance function (or output $D^O$ distance function) and it represents the distance from the frontier; $y_j$ denotes the output matrix; $x_j$ is a matrix of inputs; $z_j$ indicates specific characteristics other than inputs; $\beta$ describes the structure of the technology. Thus, these equations lead to the following estimable stochastic distance functions:

$$\begin{aligned} (y_{1j})^{-1} &= D^o\left(x_j, \frac{y_j}{y_{1j}}, z_j; \beta\right) exp(v_j - u_j); \\ (x_{1j})^{-1} &= D^I\left(\frac{x_j}{x_{1j}}, y_j, z_j; \beta\right) exp(v_j - u_j) \end{aligned} \quad (4)$$

Among others, Bogetoft and Otto, 2011presented an extensive discussion on these topics.

## 3 Data collection and variables

The current study focuses the attention on 2018 (the last year available), but it is unknown if the coronavirus pandemic will prevent the growth of the port sector. Data has been obtained mainly from Eurostat, Amadeus and Word Port Source. Significant difficulties emerge around defining (1) the territorial districts that must be considered and (2) the specific activities involved in the maritime policies. A perspective based on specific NUTS2 categories and NACE codes is used to address these complications.[1] More precisely, NACE codes strictly dependent on maritime activities are used to evaluate the labour dimension and to fix a set of homogenous indicators. De Langen and Haezendonck (2012), Surís-Regueiro, Garza-Gil and Varela-Lafuente (2013), Rivera, Sheffi and Welsch (2014), Fernández-Macho, González,and Virto (2016) and Quintano, Mazzocchi and Rocca (2020a; 2020c; 2021) considered a similar perspective. In general, in the recent literature, the usage of NUTS levels and NACE codes in empirical analysis has improved. Moura, Garcia-Alonso and Salas-Olmedo (2017) noted that a firm's location near a specific port expands its possibility of depending on this port, and Eurostat (2016; 2017) involves NACE and NUTS2 codes to examine several maritime policies. Accordingly, in the present work, the active firms have been selected by fixing the NACE codes and the NUTS2 considered for each EU port. Table 1 shows the NACE classification proposed in the analysis.

[1] The 'Statistical Classification of Economic Activities in the European Community' is commonly called NACE. The NUTS 1, 2, and 3 levels are territorial districts allowing harmonized and comparable socio-economic analyses.

As aforementioned, the original data set included (active) firms identified from the Bureau van Dijk database. It encompassed 31,063 active firms (belonging to the countries involved) using the following search conditions:

- All active companies.
- Primary NACE codes quoted in Table 1.
- Firms located in European Union (28).

The authors' additional research strategy to fix the territorial district (NUTS2) has selected 10,668 firms, and the current analysis is based on this set of firms. The Amadeus database permits several kinds of Boolean searches. The NACE activity code, NUTS2 classification, number of employees and financial variables represent some examples. However, this Boolean selection might have some weaknesses since the NACE codes could change over several years or have limited relevance with specific port terminals (Quintano, Mazzocchi and Rocca, 2020b). In addition, some firms provide auxiliary services for maritime transportation even though not detected. Concerning the involvement of the NUTS2 districts in the research's assumptions, these areas could also include logistics activities not necessarily port-related; additional problems emerge for ports that handle various NUTS regions since they are close to the regional border. Further investigation is required to counter these issues, considering additional proxies, different NACE selection, and firms with strictly related activities to specific port sectors.

The dimensions investigated in this paper were determined considering the literature on maritime efficiency, and Table 2 summarises several indicators mentioned in some previous port studies.

Compared to the research papers listed in Table 2, the present work refers to efficiency measurements for the European ports using two inputs and four outputs. The authors consider the company attributes (in terms of 'number of employees' and 'total operating revenue'), the port features (in terms of 'liquid and dry bulk goods', 'large containers', and 'Ro-Ro and other cargo not elsewhere specified'), and a structural dimension (in terms of 'container terminal quay length'). Cullinane et al. (2006) pointed out that the production of container terminals depends on the efficient use of labour, land, and equipment. Concerning the labour dimension, if the objective of a port is to maximise its profits, then the labour should be counted as an input variable. In contrast, labour should be considered an output indicator if one target is to increase a specific port employment category. Since labour data was complicated to collect, Tongzon (2001) and Demirel, Cullinane and Haralambides (2012) analysed several dimensions that were strictly connected to labour force consistency to encompass the labour dimension in the analysis. In this paper, the number of employees (*IN_Nmb_empl*) represents the first input measurement that fixes the NACE and NUTS2 codes to perform the comparative analysis. A potential weakness of the model's as-

**Table 1** NACE codes and descriptions of the economic activities considered for each EU ports, and number of firms involved in each NACE code

| NACE code | NACE description | Number of firms |
|---|---|---|
| 3012 | Building of pleasure and sporting boats | 663 |
| 3011 | Building of ships and floating structures | 1109 |
| 5224 | Cargo handling | 3007 |
| 3831 | Dismantling of wrecks | 421 |
| 5040 | Inland freight water transport | 819 |
| 5030 | Inland passenger water transport | 322 |
| 5229 | Other transportation support activities | 17721 |
| 7734 | Renting and leasing of water transport equipment | 473 |
| 3315 | Repair and maintenance of ships and boats | 1241 |
| 5020 | Sea and coastal freight water transport | 2887 |
| 5010 | Sea and coastal passenger water transport | 602 |
| 5222 | Service activities incidental to water transportation | 1798 |
| | | 31063 |

Source: CENSIS (2015)

**Table 2** Input and output variables used in selected port studies

| Reference | Country or region | Research object | Outputs | Inputs |
|---|---|---|---|---|
| Almawsheki and Shah (2015) | Middle-East Region | Technical efficiency of container terminals | Throughput (TEU) | Terminal area<br>Quay length<br>Quay crane<br>Yard equipment<br>Maximum draft |
| Barros (2003) | Portugal | Efficiency of container ports | Ships<br>Movement of freight<br>Gross gauge<br>Break bulk cargo<br>Containerized freight<br>Solid bulk and liquid bulk | Total length of berth<br>Container berth length<br>Number of employees<br>Capital (Book value of asset) |
| Barros (2006) | Italy | Efficiency of container ports | Liquid bulk<br>Dry bulk<br>Number of ships<br>Number of passenger<br>Number of containers<br>Total sales | Number of employees<br>Value of capital invested<br>Size of operating Costs |
| Barros (2012) | Africa | Seaport performance | TEU<br>Dry bulk<br>Liquid bulk<br>Delays in handling ship cargo | Quay length<br>Seaport area<br>Labour |
| Barros and Managi (2008) | Japan | Seaport productivity | Container throughput (TEU)<br>Number of ships<br>Tonnes of bulk | Number of personnel<br>Number of cranes |
| Barros et al. (2011) | Middle Eastern and East African ports | Efficiency of container ports | Throughout<br>Number of ship calls | Number of employees<br>Total cost<br>Number of cranes |
| Coto-Millan, Banos-Pino, and Rodriguez-Alvarez (2000) | Spain | Seaport efficiency | Total of goods moved in the port<br>Passengers embarked and disembarked<br>Number of vehicle with passengers | Labour<br>Capital<br>Intermediate consumptions |
| Cullinane et al. (2006) | Worldwide | Efficiency of container ports | Container throughput (TEU) | Terminal length<br>Terminal area<br>Number of quayside gantry cranes<br>Number of yard gantry cranes<br>Number of straddle carriers |

| Reference | Country or region | Research object | Outputs | Inputs |
|---|---|---|---|---|
| Demirel et al. (2012) | Turkey and Eastern Mediterranean region | Efficiency of container ports | Container throughput (TEU) | Quay length<br>Terminal area<br>Quay cranes<br>Yard equipment<br>Maximum draft |
| Gong et al. (2019) | Worldwide | Shipping companies (73% involved in the container sector) | Cargo carried<br>Revenue<br>Undesirable outputs ($CO_2$; $SO_X$; $NO_x$) | Total assets<br>Capital expenditure<br>Capacity<br>Number of ships<br>Employees<br>Fuel cost |
| Liu (2008) | Asia-Pacific region | Port operational efficiency | Number of port calls<br>Volume of container Cargo handled | Container lot size<br>Number of bridge cranes<br>Container berth length<br>Number of deep-water berths |
| Luna et al. (2018) | Mexico | Efficiency of container ports | Number of containers | Number of quay cranes<br>Number of trucks<br>Number of yard cranes<br>Service time |
| Martinez-Budria et al. (1999) | Spain | Port performance | Total cargo movement (tonne)<br>Revenue | Labor cost<br>Depreciation charge<br>Other costs |
| Min and Park (2005) | Korea | Efficiency of container ports | Cargo throughput | Size of labour force<br>Total length of query<br>Number of cranes<br>Size of hard areas |
| Nguyen et al. (2016) | Vietnamese ports | Port efficiency | Cargo throughput | Cargo-handling equipment<br>Berth length<br>Terminal areas<br>Warehouse capacity |
| Notteboom, Coeck, and Van de Broeck (2000) | (36) European and (4) Asian container terminals | Efficiency of container ports | Container traffic | Terminal quay length<br>Terminal area<br>Number of gantry cranes<br>Average no. of workers per crane |
| Panayides, Lambertides, and Savva (2011) | (26 leading) International maritime firms | Efficiency of shipping companies | Market value of equity<br>Sales | Inputs profits<br>Book value of equity<br>Total assets<br>Number of employees<br>Capital expenditure |
| Rios and Maçada (2006) | America (Mercosur) | Efficiency of container ports | TEUs handled<br>Average number of containers handled per hour per ship | Number of cranes<br>Number of berths<br>Number of employees<br>Terminal area<br>Amount of yard equipment |
| Roll and Hayuth (1993) | Worldwide | Port performance | Container throughput<br>Service Level<br>User satisfaction<br>Ship calls | Size of labour force<br>Annual investment per port<br>The uniformity of facilities and cargo |
| Sharma and Yu (2010) | (70) Container terminals | Efficiency of container terminals | Container throughput (TEU) | Quay length<br>Terminal area<br>Quay cranes<br>Transfer cranes<br>Reach stackers<br>Straddle carriers |
| Tongzon (2001) | (4) Australian and (12) international ports | Efficiency of container ports | Cargo throughput (TEUs handled)<br>Ship working rate | Number of berths<br>Number of cranes<br>Number of tugs<br>Number of port authority employees<br>Delay time |

sumptions could be that this indicator considers a broad category of employees. Nevertheless, the characteristics of labour institutional arrangements (such as temporary or permanent), various port-related jobs, health and safety features, etc., could be relevant to the port managers and authorities. This issue is beyond the aim of this paper and requires further research.

The second input (*IN_Q_L_Cont*) involves the container terminal quay length of each port. This structural dimension appears to be an appropriate proxy for the land input (Notteboom et al., 2000; Sharma and Yu 2010; Barros 2012; Demirel, Cullinane and Haralambides 2012; Almawsheki and Shah 2015). It typically reaches high values for dry bulk vessels, and it is a crucial resource for port managers. Measuring the usage of the land in terms of waiting time or in terms of cargo volumes is a useful performance indicator. Nevertheless, vessels' operations differ significantly in terms of time to work in a port, and the comparison among ports is problematic. As for the equipment input factor, in this study, any suitable proxy is considered due to the lack of available data.

In regards to the outputs, Table 2 shows that container throughput (in tons or TEUs) is generally the most important and widely accepted indicator of container port output, and Talley (2012) noted that almost all previous studies have treated it as an output variable. In the current work, the first output indicator '*OTP_Lrg_contnrs*' considers the number of large containers handled in each port (in thousands of containers). The second output measurement (*OTP_LD_blk_gds*) includes the liquid and dry bulk goods transported to/from the main ports (thousands of tonnes). The third indicator (*OTP_Othr*) involves the Ro-Ro mobile (self and non-self) propelled units and other cargo not elsewhere specified in the total tonnage of goods (thousands of tonnes). The final output measurement (*OTP_Op_Rev*) denotes the total operating revenue. Assuming a similar approach, Martinez-Budria et al. (1999), Barros (2006) and Panayides, Lambertides and Savva (2011) and Gong, Wu and Luo (2019) discussed the usage of port revenue and financial data. Table 3 indicates the descriptive statistics connected to these indicators.

Table 3 shows that the dimensions are relatively heterogeneous. The standard deviation is higher than the average value for several variables, meaning that the firms analysed are very different in size. Compared to previous studies that focused on evaluating terminals within a single country, in the present research, ports significantly differ in scale, in the portfolio of services they provide, in ownership (public or private), in the availability of funds etc. Overall, in the DEA technique, the efficiency estimates do not change due to linear transformations; in addition, they do not depend on the measurement scale used for the different inputs and outputs (Bogetoft and Otto 2011). The authors estimate both the input and output-oriented DEA in the current research, even though the input-oriented perspective seems to be more suitable than the output orientation. In fact, the control over the outputs implies several restrictions. As for the technology, both VRS and CRS have been utilised.

**Table 3** Descriptive statistics of the indicators involved in the DEA and SFA (twenty-four ports, year 2018)

| Variable | Description | Minimum | Maximum | Mean | Standard deviation | Source |
|---|---|---|---|---|---|---|
| **Output** | | | | | | |
| OTP_Lrg_cont | Number of large containers (thousands of containers) | 15.00 | 105,293.00 | 23,834.54 | 29,277.36 | I |
| OTP_LD_blk_gds | Gross weight of liquid and dry bulk goods transported to/from main ports (thousands of tonnes) | 456.00 | 299,264.00 | 41,604.67 | 57,728.53 | I |
| OTP_Othr | Ro-Ro mobile (self and non-self) propelled units and other cargo not elsewhere specified (thousands of tonnes) | 2.00 | 32,386.00 | 7,224.50 | 6,803.71 | I |
| OTP_Op_Rev | Total of operating revenue (thousands of Euro) | 71.86 | 40,923.97 | 7,314.37 | 8,092.75 | II |
| **Input** | | | | | | |
| IN_Nmb_empl | Number of employees involved in economic activities belonging to the port NACE codes | 273.00 | 137,653.00 | 25,535.50 | 26,271.58 | II |
| IN_Q_L_Cont | Container terminal quay length | 1,000.00 | 17,000.00 | 5,286.13 | 5,041.00 | III |

Data sources:

I – Eurostat database, available at: http://ec.europa.eu/eurostat/data/database

II – Bureau van Dijk (Amadeus) database, available at: https://amadeus.bvdinfo.com

III – World Port Source, available at: www.worldportsource.com

## 4 Results and discussion

Table 4 (columns 3-11) indicates the performances according to the input (and output) oriented efficiency and according to the VRS, CRS and NIRS.

Table 4 suggests that different findings emerge. First, in the VRS, there are ten ports on the frontier (five in the CRS). In 2018, the following five EU ports have efficiency scores equal to one in both the CRS and VRS approaches: *Algeciras, Hamburg, Immingham, Marseille,* and *Sines*. Among the seaports involved in the analysis, the size feature is a distinctive attribute. Using the VRS, DEA provides various measurements of scale efficiency (and different positions of the ports on the frontier), expressing how

**Table 4** DEA technically efficient and super-efficiency scores for 24 European ports (input and output oriented orientations – VRS, CRS and NIRS approaches).

| Code | Port | Input oriented (I) | | | | I/O | Output oriented (O) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Technically efficient - variable returns to scale (VRS) model [*TE_VRSIO*] | Technically efficient, not - increasing returns to scale (NIRS) model [*TE_NIRSIO*] | Scale efficiency | Variable returns to scale - IRS versus DRS | Technically efficient, constant returns to scale CRS model [*TE_CRS*] | Technically efficient, variable returns to scale VRS model [*TE_VRSOO*] | Technically efficient, not - increasing returns to scale (NIRS) model [*TE_NIRSOO*] | Scale efficiency | Variable returns to scale - IRS versus DRS | Super-efficiency results constant returns to scale CRS model [*SPR_TC*] |
| | | $\theta$ | $\theta$ | | | $\theta$ & $\phi$ | $\phi$ | $\phi$ | | | |
| 1 | Algeciras | 1 | 1 | - | - | 1 | 1 | 1 | - | - | 1.165 |
| 2 | Amsterdam | 1 | 1 | 0.722 | DRS | 0.722 | 1 | 1 | 0.722 | DRS | 0.722 |
| 3 | Antwerp | 1 | 1 | 0.981 | DRS | 0.981 | 1 | 1 | 0.981 | DRS | 0.981 |
| 4 | Barcelona | 0.460 | 0.435 | 0.946 | IRS | 0.435 | 0.614 | 0.614 | 0.708 | DRS | 0.435 |
| 5 | Bremerhaven | 0.621 | 0.621 | 0.998 | DRS | 0.620 | 0.652 | 0.652 | 0.951 | DRS | 0.620 |
| 6 | Constanţa | 0.088 | 0.070 | 0.796 | IRS | 0.070 | 0.116 | 0.116 | 0.603 | DRS | 0.070 |
| 7 | Dunkerque | 0.290 | 0.282 | 0.973 | IRS | 0.282 | 0.519 | 0.519 | 0.543 | DRS | 0.282 |
| 8 | Genoa | 1 | 0.994 | 0.994 | IRS | 0.994 | 1 | 0.994 | 0.994 | IRS | 0.994 |
| 9 | Göteborg | 0.417 | 0.417 | 0.956 | DRS | 0.398 | 0.678 | 0.678 | 0.588 | DRS | 0.398 |
| 10 | Hamburg | 1 | 1 | - | - | 1 | 1 | 1 | - | - | 1.744 |
| 11 | Immingham | 1 | 1 | - | - | 1 | 1 | 1 | - | - | 67.121 |
| 12 | Le Havre | 0.826 | 0.826 | 0.787 | DRS | 0.650 | 0.870 | 0.870 | 0.747 | DRS | 0.650 |
| 13 | London | 1 | 1 | 0.519 | DRS | 0.519 | 1 | 1 | 0.519 | DRS | 0.519 |
| 14 | Marseille | 1 | 1 | - | - | 1 | 1 | 1 | - | - | 3.975 |
| 15 | Peiraias | 0.652 | 0.628 | 0.964 | IRS | 0.628 | 0.634 | 0.634 | 0.991 | DRS | 0.628 |
| 16 | Riga | 0.359 | 0.275 | 0.767 | IRS | 0.275 | 0.348 | 0.348 | 0.790 | DRS | 0.275 |
| 17 | Rotterdam | 1 | 1 | 0.687 | DRS | 0.687 | 1 | 1 | 0.687 | DRS | 0.687 |
| 18 | Sines | 1 | 1 | - | - | 1 | 1 | 1 | - | - | 2.151 |
| 19 | Southampton | 0.851 | 0.517 | 0.608 | IRS | 0.517 | 0.518 | 0.518 | 0.998 | DRS | 0.517 |
| 20 | Tallinn | 0.330 | 0.238 | 0.723 | IRS | 0.238 | 0.347 | 0.347 | 0.687 | DRS | 0.238 |
| 21 | Taranto | 0.572 | 0.297 | 0.520 | IRS | 0.297 | 0.342 | 0.342 | 0.870 | DRS | 0.297 |
| 22 | Trieste | 0.433 | 0.390 | 0.900 | IRS | 0.390 | 0.593 | 0.593 | 0.658 | DRS | 0.390 |
| 23 | Valencia | 0.826 | 0.826 | 0.643 | DRS | 0.531 | 0.855 | 0.855 | 0.621 | DRS | 0.531 |
| 24 | Wilhelmshaven | 0.580 | 0.241 | 0.415 | IRS | 0.241 | 0.332 | 0.332 | 0.723 | DRS | 0.241 |

Notes: IRS – increasing returns to scale; DRS – decreasing returns to scale

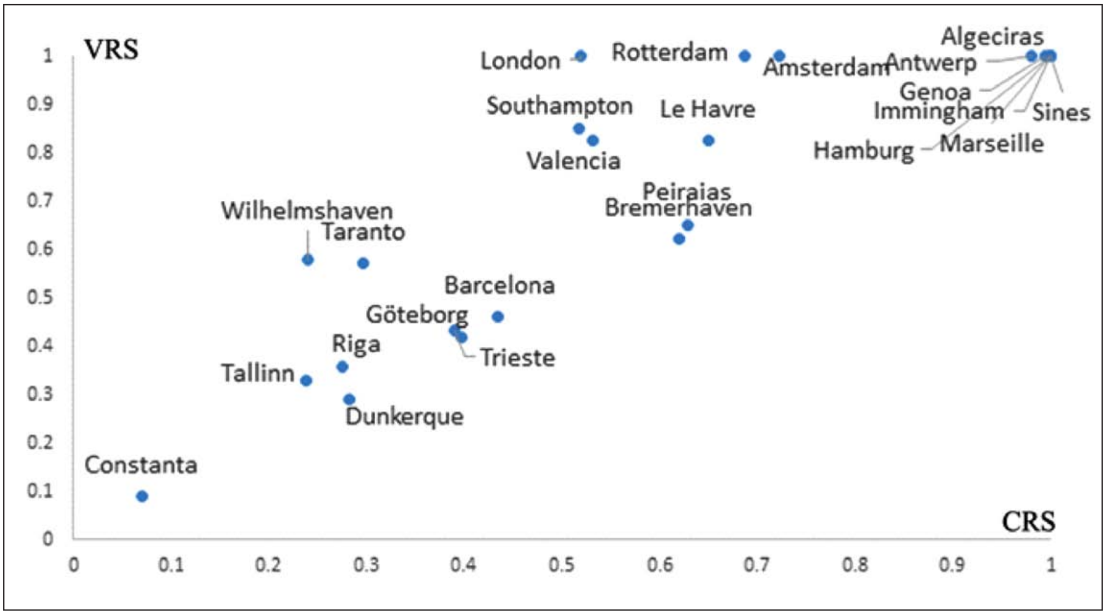


**Fig. 1** Graphical illustration of port efficiencies

close each firm is to the optimal scale size (Martinez-Budria et al., 1999).[2] Figure 1 shows CRS (horizontal axis) versus VRS efficiencies (columns 3 and 7 of Table 4). The graphical illustration exhibits (1) the pure technical inefficiency (VRS) and (2) the scale effects compared to the total technical efficiency. The graph can also be divided into four sections. The ports positioned at the upper part of the right side of the graph present elevated pure technical and scale efficiency values. The ports positioned at the lower-left section of the figure have relatively low pure technical value and low CRS efficiency; thus, they have a relatively high scale efficiency. For instance, the port of *London* is positioned in the middle part of the diagram since it has elevated pure technical efficiency and moderately low scale efficiency. *Amsterdam, Antwerp, Bremerhaven, Göteborg, Le Havre, London, Rotterdam* and *Valencia* exhibit decreasing returns to scale (DRS) technology in the output-oriented model, and in the input-oriented approach as well. In contrast, *Genoa* presents increasing returns to scale (IRS) in the output and the input orientations. The remaining ports present divergent returns to scale estimates. Theoretically, the ports with DRS are too large in dimension for their production results, and the size should decrease if DRS prevails. Therefore, management could consider these empirical results to reduce the scale production, while the dimension should increase if IRS prevails. Neverthless, Bogetoft and Otto (2011) highlighted several weaknesses of the appealing idea of using the of scale efficiency estimates to shape the planning process into an expansion and contraction strategy; they noted that the optimal size could not be easily summarised by considering the inputs and outputs involved in the model since it is necessary to consider a wide range of contextual dimensions.

If several ports are classified as efficient units at this stage, it may be interesting to consider ways to rank them. Thus, Table 4 (column 12) ranks the twenty-four ports according to their super efficiency scores, considering the CRS approach and the input orientation. The table shows that *Immingham, Marseille, Sines, Hamburg* and *Algeciras* appear on the top of the list. *Immingham* and *Marseille* present the best score, not to mention that they are the most identified peers across all the approaches considered. Each inefficient port is dominated by another port – peer port – that presents the best practice. Specific actions directed to inefficient ports can refer to these efficient peer ports to evaluate the inputs to decrease (and/or the outputs to increase) and improve the operational performances. For instance, the Romanian port of *Constanța*, which presents a low VRS input-oriented efficiency score (0.088, see Table 4) has five ports as its peers: *London* (VRS via output orientation), *Marseille* (CRS and VRS), *Rotterdam* (VRS via output orientation), *Immingham* and *Sines* (CRS and VRS, via input orientation).

The third-most efficient port (after *Marseille* and *Immingham)* most frequently indicated as a peer is the port of *Sines*. Torgersen, Foørsund and Kittelsen (1996) suggested ranking efficient DMUs according to the number of times they appear as a peer for other units in the sample, and Table 5 lists nine peers. The port of *Genoa* does not appear in the peer group showed in the matrix, even though it achieved an efficient score throughout the VRS approach (see Table 4). In contrast, this port is included among the inefficient ports, and it refers to *Marseille, Immingham* and *Hamburg* as its peers to address CRS inefficiencies.

[2] The scale efficiencies derive from calculating the ratio between CRS and VRS values (Färe, GrossKopf and Lovell, 1995). CRS identifies the global inefficiency, while VRS discerns between pure technical efficiency and scale efficiency.

**Table 5** DEA results: List of the peers considering VRS vs CRS approaches and input vs output orientations.

| | | **1** | **2** | **3** | **10** | **11** | **13** | **14** | **17** | **18** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **Algeciras** | **Amsterdam** | **Antwerp** | **Hamburg** | **Immingham** | **London** | **Marseille** | **Rotterdam** | **Sines** |
| 2 | Amsterdam | | | | | IIOO | | IIOO | | |
| 3 | Antwerp | IIOO | | | | IIOO | | IIOO | | IIOO |
| 4 | Barcelona | IIOO | | VRSOO | IIOO-VRSIO | IIOO-VRSOO-VRSIO | VRSOO | IIOO-VRSOO-VRSIO | VRSOO | VRSIO |
| 5 | Bremerhaven | IIOO-VRSIO | | VRSOO-VRSIO | IIOO-VRSOO-VRSIO | IIOO-VRSIO | VRSOO | IIOO-VRSOO-VRSIO | | |
| 6 | Constanta | | | | | IIOO-VRSIO | VRSOO | IIOO-VRSOO-VRSIO | VRSOO | IIOO-VRSIO |
| 7 | Dunkerque | | | | | IIOO-VRSIO | | IIOO-VRSIO | | |
| 8 | Genoa | | | | IIOO | IIOO | | IIOO | | |
| 9 | Göteborg | | | | | IIOO-VRSOO-VRSIO | | IIOO-VRSOO-VRSIO | VRSOO-VRSIO | IIOO |
| 12 | Le Havre | | | | | IIOO | | IIOO-VRSOO-VRSIO | VRSOO-VRSIO | IIOO-VRSOO-VRSIO |
| 15 | Peiraias | IIOO-VRSOO-VRSIO | | VRSOO | VRSIO | IIOO-VRSOO-VRSIO | | IIOO-VRSOO-VRSIO | | IIOO-VRSOO-VRSIO |
| 16 | Riga | | | | | IIOO-VRSIO | | IIOO-VRSOO-VRSIO | VRSOO | IIOO-VRSIO |
| 17 | Rotterdam | IIOO | | | | IIOO | | IIOO | | IIOO |
| 19 | Southampton | | | VRSOO | IIOO-VRSOO-VRSIO | IIOO-VRSOO | | IIOO-VRSOO-VRSIO | | |
| 20 | Tallinn | | | | | IIOO-VRSOO-VRSIO | | IIOO-VRSOO-VRSIO | VRSOO | VRSIO |
| 21 | Taranto | | | | | IIOO-VRSOO-VRSIO | VRSOO | IIOO-VRSOO-VRSIO | VRSOO | VRSIO |
| 22 | Trieste | | VRSOO | VRSOO | IIOO | IIOO-VRSOO-VRSIO | VRSOO | IIOO-VRSOO-VRSIO | VRSOO | |
| 23 | Valencia | | | VRSOO-VRSIO | | IIOO | | IIOO | VRSOO-VRSIO | IIOO-VRSOO-VRSIO |
| 24 | Wilhelmshaven | | | VRSOO | IIOO | | VRSOO | IIOO-VRSOO-VRSIO | VRSOO | |

Notes: IIOO: Input and output oriented CRS (the results are equal in both the CRS input and output approaches, and only the peer weights – or benchmarks $\alpha$ – are different); VRSIO: Input oriented VRS; VRSOO: Output oriented VRS.

In addition to the benchmarks (peer weights) that management should leverage to calibrate their regulatory interventions, the slacks for the efficient ports can also be considered (in the current analysis the calculations revealed non-zero slacks only for inefficient ports). The results presented in this paper do not analyse these coefficients entirely since special prominence has been devoted to the exploration of the possible causes of the variation in the efficiency, and a second-stage Tobit regression is conducted as suggested by Tobin (1958). Different research papers refer to the hypothesis tests of CRS technology versus VRS or to the bootstrapping technique, which has become particularly popular in the recent literature. The goal pursued in the current research to explain (and to validate) the variations in the model is commonly called post-efficiency analysis, and the Tobit regression is a fairly common methodology used to perform this analysis. The Tobit approach requires data censored from both the lower and upper bounds. Consequently, it is widely applied to truncated linear regression. Simar and Wilson (2007) debated the usage in the DEA context, and several authors (such as Banker and Natarajan, 2008) suggested alternative approaches for evaluating contextual variables using DEA. In the current article, the Tobit regression is designed to examine the relationship shown in equation (5).

$$y_i = f(\textit{standardized company's legal form}; \textit{transport of passengers}) \quad (5)$$

In equation (5) the VRS input efficiency score (*TE_VRSIO*) is considered as the dependent variable ($y_i$), but the results do not significantly change when using a different technology (and/or orientation). To detect the factors that affect the port efficiencies, the incidence of the most prevalent categories of the standardised legal forms has been considered. Several research papers have debated on port services, arguing that these services are best provided by the private sector. However, the scenario varies when considering the ownership of port authorities (Panayides, Parola and Lam, 2015). In the authors' opinion:

- the prevalence of a specific standardised legal form could have a significant influence on the relative efficiency scores of different ports
- the issue stemming from size differences among the firms involved in the analysis could be mitigated considering an additional dimension connected to the firm's legal form.

Therefore, several relative rates have been involved:

- The percentage of public limited companies in total firms.
- The percentage of private limited companies in total firms.
- The percentage ratio between partnerships and private limited companies.

The three rates mentioned above have been calculated in three different scenarios, considering the diverse sizes of firms (since the definition of the business size differs among countries, the European Commission recommendation 2003/361 for 'standards for small and medium-sized enterprises' has been utilised). Therefore, at the first step, the entire data set is considered, involving 10,668 firms. In the second step, only 7,823 medium-sized (<250 employees) firms are included. Finally, the remaining calculations refer to 5,725 small-sized (<50 employees) firms.

In regards to the passengers, Coto-Millan, Banos-Pino and Rodriguez-Alvarez (2000), Barros (2006) and Barros and Dieke (2007) used this measurement as output indicator. Wergeland (2016) and Sameni, Preston and Sameni (2016) discussed this dimension the concessions of the ferry routes (which require political choices). In the current paper, the second (independent) contextual dimension considers the 'percentage variations of the total passengers' (embarked and disembarked), which involves the percentage variations between the total number of passengers throughout 2014 to 2016.

The following hypotheses need to be tested:

$H_0^I$: the prevalence of a specific standardised legal form has a significant effect on the relative efficiency scores of the EU ports

$H_0^{II}$: the percentage variation of the total passengers (embarked and disembarked) has a significant effect on the relative efficiency scores.

Table 6 offers the descriptive statistics of dimensions used in equation (5).

**Table 6** Descriptive statistics of variables in Tobit regression

| Variable | Description | Minimum | Maximum | Mean | Standard deviation | Source |
|---|---|---|---|---|---|---|
| PASS_VR5_15_13 | Percentage variation of the total passengers (embarked and disembarked) | 0 | 100.000 | 57.604 | 19.931 | I |
| 10,668 firms | | | | | | |
| PBL_LMT% | Percentage of public limited companies of total firms | 0 | 80.183 | 18.704 | 24.945 | II |
| PRV_LMT% | Percentage of private limited companies of total firms | 18.293 | 100.000 | 77.933 | 23.958 | II |
| PSHP_PRV_LMT% | Percentage ratio between the partnerships and the private limited companies | 0 | 31.132 | 3.593 | 6.652 | II |
| 7,823 firms (<250 employees) | | | | | | |
| PBL_LMT%250 | Percentage of public limited companies of total firms | 0 | 81.067 | 20.830 | 26.289 | II |
| PRV_LMT%250 | Percentage of private limited companies of total firms | 17.067 | 100.000 | 75.528 | 25.359 | II |
| PSHP_PRV_LMT%250 | Percentage ratio between the partnerships and the private limited companies | 0 | 40.529 | 4.296 | 8.540 | II |
| 5,725 firms (<50 employees) | | | | | | |
| PBL_LMT%50 | Percentage of public limited companies of total firms | 0 | 77.347 | 20.055 | 23.584 | II |
| PRV_LMT%50 | Percentage of private limited companies of total firms | 19.592 | 100.000 | 75.711 | 23.888 | II |
| PSHP_PRV_LMT%50 | Percentage ratio between the partnerships and the private limited companies | 0 | 48.619 | 6.290 | 11.829 | II |

Data sources: I – Eurostat database; II – Bureau van Dijk (Amadeus) databases

As above-mentioned, these hypotheses are tested via the Tobit regression model, and the main findings are shown in Table 7.

As can be seen in the table, the selected explanatory variables have the *t*-values significantly different from zero; therefore, the tendency in the numbers is not purely incidental, and it has a significant effect on efficiency. The findings suggest that the prevalence of a specific standardised legal form significantly influences the EU ports' efficiency scores, although the effect on the efficiency changes when the firms' size changes. In the same way, the positive variation in the total passengers has a significant impact on the relative efficiency scores. The results of this analysis support the model's assumptions that (1) the incidence of the public limited companies, (2) the incidence of the private limited companies (in total firms), (3) the incidence of the partnerships (in private limited companies), and (4) the number of passengers, represent contextual features that management cannot exclude from the analysis.

Table 8 offers efficiency figures achieved using the input distance function approach. In these calculations, the efficiency scores (*SFA_DF_1)* have been established considering the 'total number of employees' variable (*IN_Nmb_empl)* as input for the normalisation of the distance function expression. Nevertheless, as can be seen in the table, almost the same efficiency estimates (*SFA_DF_2*) are obtained using the second input (*IN_Q_L_Cont*) instead of *IN_Nmb_empl.*

In further analysis, only the *SFA_DF_1* input distance function efficiency scores are considered. Ranking the highest *SFA_DF_1* individual efficiencies, *Marseille, Immingham, Sines, Barcelona* and *Le Havre* are at the top of the list.

Concerning the consistency conditions of the input distance function, the efficiency estimates resulting from the various methodologies should be consistent in their efficiency levels (and rankings). If the majority of the ports have equivalent ranks when using different approaches, management can plan the policies accordingly. Summary statistics for the derived efficiency estimates are exhibited in Table 9. This table refers to scores generated by the different approaches mentioned in Table 4. An extensive analysis of the control variables in the SFA perspective is beyond the aim of current research.

**Table 7** Tobit regression results

| Variable | Coefficient | Standard Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| PASS_VR5_15_13 | 0.014 | 0.005 | 2.632 | 0.009*** |
| PBL_LMT% | 1.363 | 0.705 | 1.932 | 0.053* |
| PRV_LMT% | 1.381 | 0.711 | 1.943 | 0.052* |
| PSHP_PRV_LMT% | 1.923 | 0.859 | 2.240 | 0.025** |
| PBL_LMT%250 | 1.838 | 0.819 | 2.244 | 0.025** |
| PRV_LMT%250 | 1.777 | 0.804 | 2.211 | 0.027** |
| PSHP_PRV_LMT%250 | 2.062 | 0.854 | 2.421 | 0.016** |
| PBL_LMT%50 | 0.746 | 0.258 | 2.897 | 0.004*** |
| PRV_LMT%50 | 0.674 | 0.239 | 2.820 | 0.005*** |
| PSHP_PRV_LMT%50 | 0.674 | 0.241 | 2.796 | 0.005*** |

Notes: * Represents statistical significance at the 0.1 level; ** Represents statistical significance at the 0.05 level; *** Represents statistical significance at the 0.01 level.

**Table 8** Efficient figures achieved using the input distance function approach (nine decimal places have been highlighted)

| Port | SFA_DF_1 | SFA_DF_2 | Port | SFA_DF_1 | SFA_DF_2 |
|---|---|---|---|---|---|
| Algeciras | 0.783847313 | 0.783847705 | London | 0.724450989 | 0.724451261 |
| Amsterdam | 0.791014399 | 0.791014611 | Marseille | 0.905482260 | 0.905482265 |
| Antwerp | 0.757735510 | 0.757735690 | Peiraias | 0.790024843 | 0.790024952 |
| Barcelona | 0.801476192 | 0.801476314 | Riga | 0.676993597 | 0.676994142 |
| Bremerhaven | 0.778816077 | 0.778816196 | Rotterdam | 0.696336073 | 0.696335778 |
| Constanta | 0.432041869 | 0.432042147 | Sines | 0.812562816 | 0.812562979 |
| Dunkerque | 0.742865651 | 0.742864749 | Southampton | 0.750736308 | 0.750737231 |
| Genoa | 0.799053123 | 0.799053681 | Tallinn | 0.792256537 | 0.792256364 |
| Göteborg | 0.789239296 | 0.789238631 | Taranto | 0.745319170 | 0.745319492 |
| Hamburg | 0.735474177 | 0.735474926 | Trieste | 0.722735390 | 0.722735938 |
| Immingham | 0.827629767 | 0.827629866 | Valencia | 0.743646409 | 0.743645850 |
| Le Havre | 0.795048517 | 0.795047952 | Wilhelmshaven | 0.755509982 | 0.755509859 |

**Table 9** Summary statistics of the efficiency scores by technique

| | TE_VRSIO | TE_NIRSIO | TE_CRS | TE_VRSOO | TE_NIRSOO | SPR_TC | SFA_DF_1 |
|---|---|---|---|---|---|---|---|
| Minimum | 0.088 | 0.070 | 0.070 | 0.116 | 0.116 | 0.070 | 0.432 |
| Maximum | 1 | 1 | 1 | 1 | 1 | 67.121 | 0.905 |
| Mean | 0.721 | 0.669 | 0.603 | 0.726 | 0.726 | 3.568 | 0.756 |
| Median | 0.826 | 0.727 | 0.576 | 0.767 | 0.767 | 0.576 | 0.768 |
| Standard deviation | 0.288 | 0.325 | 0.296 | 0.280 | 0.280 | 13.276 | 0.082 |

**Table 10** Spearman correlations among the efficiency scores obtained by different techniques

| | TE_VRSIO | TE_NIRSIO | TE_CRS | TE_VRSOO | TE_NIRSOO | SPR_TC |
|---|---|---|---|---|---|---|
| TE_VRSIO | 1 | | | | | |
| TE_NIRSIO | 0.951** | 1 | | | | |
| TE_CRS | 0.897** | 0.929** | 1 | | | |
| TE_VRSOO | 0.894** | 0.963** | 0.911** | 1 | | |
| TE_NIRSOO | 0.885** | 0.974** | 0.902** | 0.990** | 1 | |
| SPR_TC | 0.893** | 0.925** | 0.996** | 0.907** | 0.898** | 1 |
| SFA_DF_1 | 0.338 | 0.334 | 0.501* | 0.372 | 0.344 | 0.530** |

Notes: * Spearman correlation is significant at the 0.05 level (2-tailed); ** Spearman correlation is significant at the 0.01 level (2-tailed)

Cullimane et al. (2006) suggested using ANOVA to verify whether the average efficiency measurements diverge. The null hypothesis of the equality of the means of the different efficiency scores by the technique can be written as

$$H_0: \mu_{\text{TE\_VRSIO}} = \mu_{\text{TE\_NIRSIO}} = \mu_{\text{TE\_CRS}} = \mu_{\text{TE\_VRSOO}} = \mu_{\text{TE\_NIRSOO}} = \\ = \mu_{\text{SPR\_TC}} = \mu_{\text{SFA\_DF\_1}}$$

Several research papers suggested using a paired *t-test* for the difference of means in paired samples. The hypothesis tested is that the set of variable means (the mean vector) is the same across groups. A *t-test* can be used to evaluate the means of two samples, while in the multivariate situation (more than two groups to be compared) the *F-statistics test* can be used, and the corresponding *p-value* can be calculated. In this paper, ANOVA reveals that F=1.07 (the critical value is 2.06, *p-value*=0.386), meaning that the efficiency measurements obtained from applying each model do not appear to be significantly different. The Spearman correlations have been considered to verify whether the ports' ranks are (approximately) the same, and Table 10 provides the corresponding results.

The table shows the Spearman coefficients considering the DEA input and output perspectives (CRS and VRS orientations), the super DEA scores and the distance function efficiency figures (achieved using the input approach, *SFA_DF_1)*. The findings reveal that all the ranking correlations among the various techniques are positive and relatively high. In contrast, if the Spearman method had not ranked the ports similarly, the policy conclusions would have been relatively weak depending on the employed technique. Most of the ranking correlations are statistically significant at the 0.05 level, and several are significant at the 0.01 level. According to the findings mentioned above, the diverse approaches present similar results. Consequently, the frontier measurements do not originate from specific distributional assumptions. Therefore, management can legitimately use consistent efficient scores to evaluate the consequences of policy actions, and the model should be appropriate when aiming towards the dimensions mentioned above. It is necessary to highlight that DEA and SFA approaches might both describe the same erroneous conclusions; hence the above-mentioned consistent outcomes might not validate the method's assumptions, and a comprehensive analysis is needed in future research (Quintano, Mazzocchi and Rocca, 2020b).

## 5 Conclusions

This study presents a comparative analysis of the port performance, using an analytical approach based on estimates of two diverse methodologies, the Shephard's distance function and the DEA. The authors obtained the efficiency measurements involving data on two inputs and four outputs of twenty-four ports. The outcomes of this research provide several insights to develop future research. First, in a situation where it is necessary to consider multiple outputs and inputs (and their prices are unavailable), the distance function appears to be adequate. Furthermore, comparing the different parametric and non-parametric results, the statistical analysis confirmed that these techniques do not provide conflicting outcomes. The main consequence is that the policy conclusions do not depend on which frontier efficiency approach is used.

Second, since the NUTS2 and NACE codes have been fixed to determine a set of homogenous and comparable indicators of port activities, management should leverage the benchmarks connected to indicators proposed in the model considering specific regulatory interventions. Some efficiency dissimilarities may arise due to the differences in technology, which can be extremely expensive to replace in the short term. In general, management and port authorities usually have several difficulties in implementing new policies. The approach mentioned above could also be aimed to assess the entrepreneurial capacities.

Third, although this paper does not strictly focus on the company's legal information and transport of passengers, the hypotheses connected to these features have been addressed via the Tobit regression to detect the contextual factors affecting port efficiency. The results confirm that management cannot exclude from their efficiency analysis the impact of the contextual dimensions associated with the prevalence of a specific standardised legal form and the total number of passengers. Different – and more difficult to measure – dimensions, such as the costs, the investment in assets and quality of services, have not been discussed in this paper. Similarly, it would also be interesting to consider in further analysis:

- the characteristics of the concessions of the ferry route;
- the influence of the institutional context in which management;
- the calibration of shipping routes that overlap relatively close ports;
- the routes that could work as a substitute or complement;
- factors that might involve the internal regulatory system in the reorganisation process of each port;
- features connected to an adverse port morphology.

Since the port areas have inadequate resources that need to be allocated to several different activities, the policy implications must also be evaluated by combining funding sources, concession procedures and new regulatory reforms. Furthermore, the current paper does not encompass any control emission measurements; therefore, several indicators can be extended to the environmental impact. The performances of some ports could increase involving additional dimensions, but the results should be interpreted carefully to avoid an inaccurate assessment of the impact of external features.

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## References

[1] Acciaro, M., T. Vanelslander, C. Sys, C. Ferrari, A. Roumboutsos, G. Giuliano, J.S.L. Lam and S. Kapros. 2014. "Environmental sustainability in seaports: a framework for successful innovation." *Maritime Policy & Management, 41* (5), pp. 480-500.

[2] Almawsheki, E.S. and M.Z. Shah, 2015. "Technical efficiency analysis of container terminals in the Middle Eastern region." *The Asian Journal of Shipping and Logistics, 31* (4), pp. 477–486.

[3] Banker, R. D. and R. Natarajan. 2008. "Evaluating contextual variables affecting productivity using Data Envelopment Analysis." *Operations Research, 56* (1), pp. 48-58.

[4] Barros, C.P. 2005. "Decomposing growth in Portuguese seaports: a frontier cost approach." *Maritime Economics and Logistics, 7*(4), pp. 297-315.

[5] Barros, C.P. 2006. "A benchmark analysis of Italian seaports using data envelopment analysis." *Maritime Economics and Logistics, 8* (4), pp. 347–365.

[6] Barros, C.P. 2012. "Productivity assessment of African seaports." *African Development Review, 24* (1), pp. 67-78.

[7] Barros, C.P. and P.U.C. Dieke. 2007. "Performance evaluation of Italian airports: a data envelopment analysis." *Journal of Air Transport Management, 13* (4), pp. 184-191.

[8] Barros, C.P. and S. Managi. 2008. "Productivity drivers in Japanese seaports." *Working Papers* 15/2008/DE/UECE.

[9] Barros, C.P., H. Haralambides, M. Hussain and N. Peypoch. 2011. "Seaport efficiency and productivity growth." In K.P.B. Cullinane, (Ed.), *International Handbook of Maritime Economics* (pp. 363-382). Cheltenham, UK: Edward Elgar Publishing.

[10] Bogetoft, P. and L. Otto. 2011. *Benchmarking with DEA, SFA, and R*. Boston, MA: Springer.

[11] Bouman, E. A., E. Lindstad, A.I. Rialland and A.H. Strømman, 2017. "State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping." *Transportation Research Part D: Transport and Environment, 52*, pp. 408-421.

[12] Boussofiane, A. and R.G. Dyson. 1991. "Applied data envelopment analysis." *European Journal of Operational Research, 52* (1), pp. 1-15.

[13] Cabrera, M., A. Suárez-Alemána and L. Trujillo. 2015. "Public-private partnerships in Spanish Ports: Current status and future prospects." *Utilities Policy, 32,* pp. 1-11.

[14] Castillo-Manzano, J. I., M. Castro-Nuño, F. González-Laxe and D.J. Pedregal. 2018. "Legal reform and the devolution of the Spanish Port System: An econometric assessment." *Utilities Policy. 50*, pp. 73-82.

[15] Censis, 2015. The fifth maritime economy report. Rome, Italy. <http://www.federazionedelmare.it/images/pubblicazioni/VRapportoEconomiaMare_2015.pdf>.

[16] Chang, Y. T. 2015. "Environmental efficiency of ports: a Data Envelopment Analysis approach." *Maritime Policy and Management, 40* (5), pp. 467-478.

[17] Chang, Y. T., H.K. Park, S. Lee and E. Kim. 2018. "Have Emission Control Areas (ECAs) harmed port efficiency in Europe?" *Transportation Research Part D: Transport and Environment, 58*, pp. 39-53.

[18] Chen, Y. and A.I. Ali. 2002. "Output-input ratio analysis and DEA frontier." *European Journal of Operational Research 142* (3), pp. 476-479.

[19] Coelli, T. J., D.S. Prasada Rao, C.J. O'Donnell, and G.E. Battese. 2005. *An Introduction to Efficiency and Productivity Analysis*, II Ed. New York: Springer.

[20] Cook, W. D. and L.M. Seiford. 2009. "Data envelopment analysis – thirty years on." *European Journal of Operational Research, 192* (1), pp. 1-17.

[21] Cook, W. D., K. Tone, and J. Zhu. 2014. "Data envelopment analysis: Prior to choosing a model." *Omega,* 44, pp. 1-4.

[22] Cooper, W.W., L.M. Seiford and K. Tone. 2006. *Introduction to Data Envelopment Analysis.* New York: Springer.

[23] Coto-Millan, P., J. Banos-Pino and A. Rodriguez-Alvarez. 2000. "Economic efficiency in Spanish ports: some empirical evidence." *Maritime Policy & Management*, 27 (2), pp. 169-74.

[24] Cullinane, K.P.B, D.W. Song, P. Ji and T.F. Wang. 2004. "An application of DEA windows analysis to container port production efficiency." *Review of Network Economics, 3*(2), pp. 184-206.

[25] Cullinane, K.P.B, T.F. Wang, D.W. Song and P. Ji. 2006. "The technical efficiency of container ports: comparing data envelopment analysis and stochastic frontier analysis." *Transportation Research Part A: Policy and Practice, 40* (4), pp. 354-374.

[26] De Langen, P. W. and E. Haezendonck. 2012. Ports as Clusters of Economic Activity. In W. K. Talley (Ed.), *The Blackwell Companion to Maritime Economics* (pp. 638-655). Malden, MA: Wiley-Blackwell.

[27] De Witte, K. and L. López-Torres. 2017. "Efficiency in education: a review of literature and a way forward." *Journal of the Operational Research Society, 68* (4), pp. 339-363.

[28] Demirel, B., K.P.B. Cullinane and H. Haralambides. 2012. "Container terminal efficiency and private sector participation." In W. K. Talley (Ed.), *The Blackwell Companion to Maritime Economics* (pp. 571-598). Malden, MA: Wiley-Blackwell.

[29] Dyson, R. G. and E. Thanassoulis. 1998. "Reducing weight flexibility in data envelopment analysis." *Journal of the Operational Research Society,* 39 (6), pp. 563–576.

[30] ESPO. 2016. Trends in EU ports governance 2016. Bruxelles, Belgium. https://www.espo.be/media/Trends_in_EU_ports_governance_2016_final_version.pdf.

[31] Eurostat. 2016. Energy, Transport and Environment Indicators – 2016 edition, *Statistical Books Collection*, Publications Office of the European Union, Luxembourg. http://ec.europa.eu/eurostat/documents/3217494/7731525/KS-DK-16-001-EN-N.pdf/cc2b4de7-146c-4254-9521-dcbd6e6fafa6.

[32] Eurostat. 2017. Eurostat regional yearbook 2017, *Statistical books*, Luxembourg. http://ec.europa.eu/eurostat/documents/3217494/8222062/KS-HA-17-001-EN-N.pdf/eaebe7fa-0c80-45af-ab41-0f806c433763.

[33] Färe, R., S. GrossKopf and C.K. Lovell. 1995. *Production Frontiers*. Cambridge: Cambridge University Press.

[34] Fernández-Macho, J., P. González and J. Virto. 2016. "An index to assess maritime importance in the european atlantic economy." *Marine Policy, 64*, 72-81.

[35] Gong, X., X. Wu and M. Luo. 2019. "Company performance and environmental efficiency: a case study for shipping enterprises." *Transport Policy 82* (C), pp.96-106.

[36] Gonzalez, M.M. and L. Trujillo. 2008. "Reforms and infrastructure efficiency in Spanish's containers ports." *Transportation Research Part A: Policy and Practice, 42* (1), pp. 243-257.

[37] Ha, M.H., Yang, Z. and J.S.L. Lam. 2019. "Port performance in container transport logistics: A multi-stakeholder perspective." *Transport Policy, 73*, pp. 25-40.

[38] Huo, W., W. Zhang, P.S.L. Chen. 2018. "Recent development of Chinese port cooperation strategies." *Research in Transportation Business and Management*, 26, pp. 67-75.

[39] Lampe, H. W. and D. Hilgers. 2015. "Trajectories of efficiency measurement: A bibliometric analysis of DEA and SFA." *European Journal of Operational Research, 240*(1), pp. 1-21.

[40] Lin, L. C., and L.A. Tseng. 2005. "An application of DEA and SFA on the measurement of operating efficiencies for 27 international container ports." *Proceedings of the Eastern Asia Society for Transport Studies, 5*, pp. 592-607.

[41] Liu J. S., L.Y.Y. Lu and W.M. Lu. 2016. "Research fronts in data envelopment analysis." *Omega. 58,* pp. 33-45.

[42] Liu, C.C. 2008. "Evaluating the operational efficiency of major ports in the Asia–Pacific region using data envelopment analysis." *Applied Economics,* 40 (13), pp. 1737-1743.

[43] Liu, Z. 1995. "The comparative performance of public and private enterprises." *Journal of Transportation Economics and Policy, 29* (3), pp. 263-274.

[44] López-Bermúdez, B., M.J. Freire-Seoane and F. González-Laxe. 2019. "Efficiency and productivity of container terminals in Brazilian ports (2008–2017)." *Utilities Policy, 56*, pp. 82-91.

[45] Lovell, C.A. and J.T. Pastor. 1995. "Units invariant and translation invariant DEA models." *Operations Research Letters, 18*(3), pp. 147-151.

[46] Luna, J.H., J. Mar-Ortiz, M.D. Gracia and D. Morales-Ramírez. 2018. "An efficiency analysis of cargo-handling operations at container terminals." *Maritime Economics and Logistics*, 20 (2), pp. 190–210.

[47] Martínez-Budria, E., R. Diaz-Armas, M. Navarro-Ibanez and T. Ravelo-Mesa. 1999. "A study of the efficiency of Spanish port authorities using Data Envelopment Analysis." *International Journal of Transport Economics, 26* (2), pp. 237-253.

[48] Min, H. and B.I. Park. 2005. "Evaluating the inter-temporal efficiency trends of international container terminals using data envelopment analysis." *International Journal of Integrated Supply Management, 1*(3), pp. 258-277.

[49] Moura, T.G.Z., L. Garcia-Alonso and M.H. Salas-Olmedo. 2017. "Delimiting the scope of the hinterland of ports: Proposal and case study." *Journal of Transport Geography, 65* (C), pp. 35-43.

[50] Nguyen, H.O., H.V. Nguyen, Y.T. Chang, A.T.H. Chin and J. Tongzon. 2016. "Measuring port efficiency using bootstrapped DEA: the case of Vietnamese ports." *Maritime Policy & Management*, *43* (5), pp. 644–659.

[51] Notteboom, T. and W.Y. Yap. 2016. Port competition and competitiveness. In W. K. Talley (Ed.), *The Blackwell Companion to Maritime Economics* (pp. 549-570). Malden, MA: Wiley-Blackwell.

[52] Notteboom, T., C. Coeck and J. Van de Broeck. 2000. "Measuring and explaining the relative efficiency of container terminals by means of Bayesian stochastic frontier models." *International Journal of Maritime Economics*, 2 (2), pp. 83-106.

[53] Núñez-Sánchez, R. and P. Coto-Millán. 2012. "The impact of public reforms on the productivity of Spanish ports: a parametric distance function approach." *Transport Policy,* 24, pp. 99-108.

[54] Panayides, P. M. and N. Lambertides. 2011. Fundamental analysis and relative efficiency of maritime firms: dry bulk

vs tanker firms. In K.P.B. Cullinane, (Ed.), *International Handbook of Maritime Economics* (pp. 85-106). Cheltenham, UK: Edward Elgar Publishing.

[55] Panayides, P.M., F. Parola and J.S.L. Lam. 2015. "The effect of institutional factors on public-private partnership success in ports." *Transportation Research Part A: Policy and Practice,* 71 (1), pp. 110-127.

[56] Panayides, P.M., N. Lambertides, C.S. Savva. 2011. "The relative efficiency of shipping companies." *Transportation Research Part E: Logistics and Transportation Review, 47* (5), pp. 681-694.

[57] Quintano, C., P. Mazzocchi, and A. Rocca. 2020a. "Examining eco-efficiency in the port sector via non-radial data envelopment analysis and the response based procedure for detecting unit segments." *Journal of Cleaner Production*. 120979. doi:10.1016/j.jclepro.2020.120979.

[58] Quintano, C., P. Mazzocchi, and A. Rocca. 2020b. "A competitive analysis of EU ports by fixing spatial and economic dimensions." *Journal of Shipping and Trade* 5:18. doi:10.1186/s41072-020-00075-x.

[59] Quintano, C., P. Mazzocchi, and A. Rocca. 2020c. "A prospective analysis of the efficiency in the reorganisation process of Italian seaports", *Pomorstvo – Scientific Journal of Maritime Research*, 34, 3–15. https://doi.org/10.31217/p.34.1.1.

[60] Quintano, C., P. Mazzocchi, and A. Rocca. 2021. "Evaluation of the eco-efficiency of territorial districts with seaport economic activities." *Utilities Policy*, 71, 101248. https://doi.org/10.1016/J.JUP.2021.101248.

[61] Rios, L. R. and Maçada, A. C. C. 2006. "Analysing the relative efficiency of container terminals of Mercosur using DEA." *Maritime Economics and Logistics,* 8(4), pp. 331-346.

[62] Rivera, L., Y. Sheffi, Y. and R. Welsch. 2014. "Logistics agglomeration in the US." *Transportation Research Part A: Policy and Practice, 59*, pp. 222–238.

[63] Roll, Y. and Y. Hayuth. (1993). "Port Performance Comparison Applying Data Envelopment Analysis (DEA)" *Maritime Policy & Management, 20,* pp. 153-161.

[64] Sameni, M. K., J. Preston and M.K. Sameni. 2016. "Evaluating efficiency of passenger railway stations: A DEA approach." *Research in Transportation Business and Management, 20,* pp. 33-38.

[65] Serra, T., R.G. Chambers and A.O. Lansink. 2014. "Measuring technical and environmental efficiency in a state-contingent technology." *European Journal of Operational Research,* 236 (2), pp. 706-717.

[66] Sharma, M. J. and S.J., Yu. 2010. "Benchmark optimisation and attribute identification for improvement of container terminals." *European Journal of Operational Research. 201* (2), pp. 568-580.

[67] Shephard, R.W. 1970. *The Theory of Cost and Production Functions.* Princeton US: Princeton University Press.

[68] Simar, L. and P.W. Wilson. 2007. "Estimation and inference in two-stage, semi-parametric models of production processes." *Journal of Econometric, 136* (1), pp. 31-64.

[69] Simoes, P. and R.C. Marques. 2010. "Influence of congestion efficiency on the European seaports performance: does it matter?" *Transport Review, 30* (4), pp. 517-539.

[70] Surís-Regueiro, J.C., M.D. Garza-Gil and M.M. Varela-Lafuente. 2013. "Marine economy: A proposal for its definition in the European Union." *Marine Policy, 42*(C), pp. 111-124.

[71] Talley, W.K. 2012. Maritime carriers in theory. In W. K. Talley (Ed.), *The Blackwell Companion to Maritime Economics* (pp. 89-106). Malden, MA: Wiley-Blackwell.

[72] Tobin, J. 1958. Estimation of relationships for limited dependent variables. *Econometrica, 26* (11), pp. 24-36.

[73] Tongzon, J. 2001. Efficiency measurement of selected Australian and other international ports using Data Envelopment Analysis. *Transportation Research Part A: Policy and Practice*, *35* (2), pp. 113-128.

[74] Torgersen, A.M., F.R. Førsund and S.A.C. Kittelsen. 1996. "Slack-adjusted efficiency measures and ranking of efficient units." *Journal of Productivity Analysis,* 7 (4), pp. 379-398.

[75] Wang, D.H. 2013. "Confidential service contract promotes competition in the European shipping market." Eur*opean Journal of Law and Economics*, 36 (1), pp. 117-129.

[76] Wergeland, T. 2016. Ferry passenger markets. In W. K. Talley (Ed.), *The Blackwell Companion to Maritime Economics* (pp. 161-183). Malden, MA: Wiley-Blackwell.

[77] Zhu, J. 2015. *Data Envelopment Analysis – a Handbook of Models and Methods*. International Series in Operations Res. and Management Science, 221. Boston US: Springer.

## Appendix A

The DEA literature proposes several recommendations to select the dimensions in the model. For example, one empirical criterion considers the availability of inputs and outputs (Barros and Dieke 2007), while the 'measurements commonly adopted in previous studies' represents a diverse criterion (Cullinane et al., 2006). In addition to the homogeneity already mentioned in the previous section, the DEA requires several conditions to be preserved, such as the isotonicity condition. To validate this condition, Table A.1 shows the correlation matrix among outputs and inputs; the coefficients exhibit a positive relationship between the indicators.

Furthermore, the number of DMUs must be appropriate to avoid biased results. An extensive analysis of the 'minimum threshold' for the DMUs in the DEA technique has been proposed by Dyson and Thanassoulis (1998), Boussofiane and Dyson (1991) and Cooper, Seiford and Tone (2006). The present research involves twenty-four ports and six indicators, and the validity of the DEA model appears to be verified. Lovell and Pastor (1995) debated on the desirable indicators' properties in the DEA model, and examined situations in which data yields an ill-conditioned DEA matrix; Chen and Ali (2002) provided further formal recommendations; the sensitivity (and stability and robustness) analysis of DEA models have largely been covered in an extensive number of research papers. An extensive consideration of these themes, including the description of the infeasibility (and unboundedness) problems (and the weight restrictions with the VRS or CRS assumptions, and input or output orientations) are beyond the purposes of this paper. See Zhu (2015) for an extensive discussion of these topics.

**Table A.1** Correlation matrix between input and output variables

| | **OTP_LD_blk_gds** | **OTP_Lrg_cont** | **OTP_Othr** | **OTP_Op_Rev** | **IN_Nmb_empl** |
|---|---|---|---|---|---|
| OTP_LD_blk_gds | 1 | | | | |
| OTP_Lrg_cont | 0.596** | 1 | | | |
| OTP_Othr | 0.798** | 0.490* | 1 | | |
| OTP_Op_Rev | 0.228 | 0.159 | 0.288 | 1 | |
| IN_Nmb_empl | 0.064 | 0.110 | 0.109 | 0.885** | 1 |
| IN_Q_L_Cont | 0.394 | 0.227 | 0.452* | 0.050 | 0.001 |

Notes: * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed)