The Impact of Seaport Competition on Technical Efficiency: Simar–Wilson Analysis of European Container Ports

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This paper examines the effects of environmental factors (port-city GDP, population size, connectivity to hinterland, draught level and distance from the closest port Hub) and competition on the efficiency of a number of North and South European seaports. For this purpose, a bootstrap data envelopment analysis truncated regression approach was applied to 35 container ports, in the 2004 - 2018 period. Research findings indicate that the connectivity of a port's country and draught level have a positive impact on the efficiency of both Northern and Southern European seaports. In addition, our results revealed that the efficiency of Southern European seaports tends to increase with competition intensity, whereas that of Northern European seaports seems to decrease with intensified competition, due to investment discrepancies, necessary for attracting a wider range of customers.

KEY WORDS
~ Seaport efficiency
~ Seaport competition
~ Herfindhal–Hirschman index
~ DEA (Data Envelopment Analysis)
~ Bootstrapped regression,
~ European seaports
~ Shipping connectivity
~ Infrastructure

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doi: 10.7225/toms.v12.n02.w06

Received on: 17 Jan 2023 / Revised: 9 May 2023 / Accepted: 22 Jun 2023 / Published: 22 Jun 2023

1. INTRODUCTION

Economic conditions and technological innovations have significantly contributed to the consolidation of the economic role of container seaports in the global transport chain, while simultaneously intensifying the competitive pressures on intervening actors and stakeholders, including, shipping lines, local authorities and end users. Hence, interest in the capacity of container seaports to adequately respond to increased dock service demands and requirements has been of interest to governments, specialists and academics alike. Over the last decade, for instance, noticeable changes in container seaport policies have been made in several Southern European countries. In effect, and in a bid to increase port efficiency in conformity with the Northern European prerogatives, greater flexibility has been introduced, which increased efficiency levels in terms of management and financing. With higher fund allocations, the European port system keeps witnessing a myriad of rehabilitation and investment programs devoted to port terminal construction or expansion, as well as the acquisition of new equipment likely to improve logistics performances, and thereby enabling the port to compete efficiently on the European market (Bergantino and Musso, 2011; Barros et al., 2016).

Actually, innovative technological processes affecting the port industries, along with changes in port management and organization processes, have brought about a noticeable improvement in the nature of relevant operations, enhancing a remarkable specialization in used inputs and throughput, thus significantly affecting the technical efficiency of seaports.

In this respect, two major approaches have generally been recognized and frequently applied to analyze seaport productivity, efficiency and performance, namely, the Data Envelopment Analysis (DEA) and the Stochastic Frontier Analysis (SFA) methods. The main weakness associated with the efficiency measurement econometric approaches (including SFA) may lie in strong production technology a priori assumptions, opting for a relevant functional form (e.g., Cobb–Douglas or translog), as most of the production-technology distributional characteristics are a priori unknown. Noteworthy, however, is that the DEA approach neither entails maintaining any functional form of data (input and output), nor requires any assumptions with respect to the specific statistical distribution of error terms. Additionally, the Data Envelopment Analysis (DEA) is usually recognized as the most globally preferable technique, appropriate for identifying input surpluses and output shortages (dubbed slacks).

Please note that relevant literature indicates that the technical efficiency of seaports is influenced by several factors, most important of which are the institutional environment (Cullinane et al., 2002; Tongzon and Heng, 2005), scale efficiency discrepancies (Haralambides et al., 2001; Barros and Athanassiou, 2004), macro-economic factors (Cullinane et al., 2005; Bergantino and Musso, 2011; Niavis and Tsekeris, 2012) and competitive environment (De Oliveira and Cariou, 2015; etc.). Competition seems to have a dual effect on port efficiency. Indeed, in keeping with economic theory, we hypothesized that intensified inter-port competition improves port efficiency, assuming that a port exposed to fierce competition might engage in over-investment strategies, which are likely to reduce its efficiency (De Oliveira and Cariou, 2015). In this context, this paper examines the effects of environmental factors and competition on the efficiency of Northern and Southern European seaports in the 2004-2018 period. To this end, the DEA approach was used to measure the relevant technical efficiency and identify the origin of inefficiency. Truncated regression with Simar and Wilson bootstrapping methodology was then used to examine the effect of competition and environmental factors, especially the effects of port-city GDP, population size, connectivity to hinterland, draught level and distance from the nearest dock hub, on port efficiency.

Our empirical results actually indicate that the efficiency of Southern European ports tends to increase with the intensity of inter-port competition, whereas the technical efficiency of Northern European ports tends to decrease with intensified inter-port competition.

The remainder of this research is organized as follows. Section two gives a general overview of seaport efficiency analysis, while section three is devoted to describing the two-step methodology used in the study. The model variables are discussed in section four, while section five is dedicated to outlining and discussing the empirical results. Finally, section six gives major conclusions and paves the way for potential further research.

2. FACTORS AFFECTING SEAPORT EFFICIENCY: A BRIEF OVERVIEW

The analysis of determinants associated with seaport efficiency is a major subject of study, which frequently found itself in the center of attention of academicians and specialists over the last couple of decades (Liu, 1995; Notteboom et al., 2000; Coto-Millan et al., 2000; Tongzon, 2001; Valentine and Gray, 2001; Cullinane et al., 2002; Cullinane and Song, 2003; Park and De, 2004; Cullinane et al., 2004; Lin and Tseng, 2005; Tovar et al., 2007; Bergantino and Musso, 2011; Munisamy and Singh, 2011; Wang and Gao, 2012; Niavis and Tsekeris, 2012; Yuen et al., 2013; etc.). In this respect, Liu (1995) was a pioneer in applying an econometric frontier approach to analyze the relationship between efficiency and privatization in the performance of twenty-eight seaports. The conclusion was that private terminals mostly appear to operate at high efficiency. Notteboom et al. (2000) used a Bayesian stochastic Frontier model to investigate the different administrative and ownership modes of four Asian container ports and 36 European container terminals, and concluded that hub port terminals have the highest efficiency scores. The application of translog cost frontier to economic efficiency analysis on a sample of 27 Spanish ports in Coto-Millàn et al. (2000) showed that seaport type significantly affects economic efficiency. Cullinane et al. (2002) they applied the function matrix to assess major Asian container terminals. Their results highlighted that efficiency increases with size and private management.

Still, the DEA approach remains the most appropriate technique widely used in seaport efficiency research and to determine relevant advantages and disadvantages (Niavis and Tsekeris, 2012). In this regard, Martinez-Budria et al. (1999) opted for a DEA-BCC model to categorize 26 Spanish ports in terms of management complexity and divide them into three complexity-level groups. The high-level complex ports turn out to be the most efficient. Similarly, Valentine and Gray (2001) applied the DEA-CCR model to analyze the impact of explicit modes of administrative and organizational structures on the efficiency of 31 container seaports. As to Tongzon (2001), he analyzed the efficiency of 16 container ports in 1996, using the DEA-CCR and additive DEA methods, and arrived at the conclusion that the seaports of Rotterdam, Yokohama, Melbourne and Osaka are the most inefficient post, with a number of inefficiencies in their terminal areas, container quays and labor inputs. After applying both the DEA-CCR and the DEA-BCC model, Barros and Athanassiou (2004) considered analyzing the efficiency of four Portuguese and two Greek seaports, concluding that the seaport of Thessaloniki is the most inefficient, with noticeable inefficiencies in terms of container movements and handled freight. Similarly, Cullinane et al. (2005) used the same modeling frameworks to analyze the connection between efficiency and privatization in the world's largest container seaports and concluded that port privatization increases efficiency. In turn, Cullinane et al. (2004) applied cross section and panel data to assess the efficiency of 25 leading seaports worldwide, and deduced that panel data with window analysis appear to demonstrate a variety of port efficiency scores over time, while the traditional cross-sectional approach could only provide spurious results. Wang and Cullinane (2006) undertook to investigate the technical efficiency and economies of scale of 104 container terminals, measured via the DEA-BCC and DEA-CCR models. They reached the conclusion that large container terminals function more efficiently than small container terminals. Min and Park (2005) applied the DEA-Window to estimate the efficiency scores of eleven South Korean container terminals, and noted that terminal size does not seem to be correlated with technical efficiency. Using both cross-sectional and panel data for the 2000-2005 period, Ng and Lee (2007) applied the DEA-standard and DEA-Window to assess the efficiency of six Malaysian ports, reaching the conclusion that both PTP and Johor seaports operate most efficiently. Similarly, Al-Eraqi et al. (2008) implemented DEA-Window to analyze the efficiency of 22 Middle Eastern and African cargo ports, noting that the largest of these ports are inefficient. Adopting the same methodology, Nwanosike et al. (2012) sought to determine the impact of concession on the efficiency of Nigerian ports in the 2004-2010 period. Their findings revealed that efficiency proved to increase after 2006, with the port of Apapa standing out as the most efficient, with an average efficiency score of 84%. In turn, after applying the DEA-BCC and the DEA-CCR, Tetteh et al. (2016) estimated the efficiency of four Chinese and five West African ports. Their findings revealed that the Ghanaian port of Tema is the most efficient, whereas Chinese ports are inefficient mainly owing to excessive use of handling machinery and labor. Apart from DEA-CCR and DEA-BCC models, Qin and Panichakarn (2018) also used the super-efficiency model to estimate the efficiency of one Chinese and eight Pan-Beibu Gulf (PBGEC) ports. Their findings indicate that the most efficient port is the port of Hong Kong, while the Chinese port is inefficient mainly owing to insufficient output. Moreover, Seth and Feng (2020) used a four-year window analysis to assess the efficiency of US container ports. Their findings suggest that efficiency scores of these ports are noticeably critical for policy makers and useful for identifying a port' urgent investment areas likely to positively affect their potential commercial activity and trade. Munim (2020) used the DEA and Free Disposal Hull (FDH) approaches to examine a number of Asian container terminals, and reported that even though ports and terminals that do not actively invest in modern infrastructure and equipment are technically efficient in the short term, they provide poor service quality in the long run.

An increasing number of studies continue to focus on the two-step approach to examine the impact of environmental factors on seaport efficiency, including macro-economic factors such as market share, hinterland populations and connectivity to hinterland, as well as competitive environmental items, particularly, the Herfindhal–Hirschman Index (HHI), etc. Additionally, port characteristics often depend on the site-situation framework, where site refers to underlying local conditions, culminating in the definition of the term geography as the study of the interrelationship between man and the environment, while situation means the effects of phenomena characteristic of one area on another area (McCalla, 2009). In this regard, Barros and Managi (2008) used Simar and Wilson's approach (2007) to bootstrap the DEA-CCR scores with a truncated regression to pinpoint the efficiency drivers of 39 Japanese ports, with the major efficiency covariates being the yearly trend, population size, hub status and port-city GDP. They concluded that both the hub seaport and GDP have a positive impact on technical efficiency, while population size is statistically insignificant. Yeo (2010) applied truncated regression within parametric model, where electronic documents, handling capacity, convenient facilities and connectivity to hinterland were deployed to estimate the efficiency scores of 61 large Asian container terminals, observed in the 2004-2007 period. Their findings revealed that container terminal related facilities and service levels appear to be positively and statistically correlated with seaport performance. Bergantino and Musso (2011) used the stochastic input-by-input regression frontier analysis to evaluate the effect of environmental factors on port efficiency. Their selected efficiency-related explanatory variables are employment rate, GDP, population density and seaport accessibility. All variables except employment rate were found to have positive impact on efficiency. Wang and Gao (2012) examined the effect of intra-port competition on efficiency by initially computing the HHI value using total freight traffic prior to using the fixed-effect and SFA models to investigate the effect of competition on freight traffic as an efficiency proxy. Their examined variables were GDP, privatization, HHI, total length of quays and privatization, which lead them to conclude that intra-port competition has a low effect on technical efficiency owing to the diversification of products and services. They also concluded that the technical efficiency of ports tends to increase with decreased HHI values, which explains the noticeably stronger regional competition characterizing the economic zone of Bohai. Niavis and Tsekeris (2012) used Tobit and bootstrapped truncated regressions to study the effect of environmental factors on the technical efficiency of thirty South-East European container ports. Their findings indicated that the truncated

Table 1.
Literature overview of factors affecting seaport efficiency.

Authors	Units	Method	Inputs	Outputs
Liu (1995)	28 British port authorities, 1983-1990	Translog production function	Labor measured by total wage payments, capital, dummy variables representing ownership (private, trust and municipal)	Turnover
Coto-Millan et al. (2000)	27 Spanish ports, 1985–1989	Translog cost model	Cargo handled	Aggregate port output (includes total goods moved in the port, the number of vehicles and passengers)
Roll and Hayuth (1993)	Hypothetical numerical example of 20 ports	DEA-CCR model	Manpower, capital, cargo uniformity	Cargo throughput, level service, consumer satisfaction, ship calls
Valentine and Gray (2001)	31 container ports in 1998	DEA-CCR model	Total length of berth, container berth length	Number of containers, cargo throughput
Tongzon (2001)	4 Australian and 12 other international ports in 1996	DEA-CCR, additive model	Number of cranes, number of container berths, number of tugs, terminal area, delay time, number of employees	Cargo throughput, ship working rate
Barros and Athanassiou (2004)	2 Greek and 4 Portuguese seaports, 1998–2000	DEA-CCR and BCC models	Number of employees, capital	Number of ships, movement of freight, cargo handled, container throughput
Cullinane et al. (2004)	25 container ports	DEA Windows Analysis (DEA-CCR and BCC models)	Quay length, terminal area, number of quayside gantry cranes, number of yard gantry cranes, number of straddle carries	Cargo throughput
Cullinane et al. (2005)	57 international container seaports in 1999	DEA-CCR, DEA-BCC and DEA-FHD models	Terminal length, terminal area, number of quayside gantry cranes, number of yard gantry cranes, number of straddle carriers	Container throughput
Min and Park (2005)	Major container terminals in South Korea, 1999-2002	DEA Windows Analysis	Number of cranes, quay length, yard area, number of employees	Container throughput
Wang and Cullinane (2006)	104 container terminals	DEA-CCR and BCC models	Terminal length, terminal area, equipment costs	Container throughput
Al-Eraqi et al. (2008)	22 seaports in the Middle East and East African, 2000–2005	DEA-CCR Windows Analysis	Berth length, number of equipment area, ship call	Cargo throughput

Nwanosike et al. (2012)	Nigerian ports, 2004-2010	DEA window analysis (DEA-CCR and BCC models)	Total length of the quays, number of quays, number of employees, number of equipment	Cargo throughput, ship calls
Tetteh et al. (2016)	Chinese ports and five West African ports, 2008-2013	DEA-CCR and BCC models	Length of quay, number of cranes and number of berths	Throughput, vessel calls
Qin and Panichakarn (2018)	9 ports in the PBGEC in 2015	DEA-CCR and BCC models	Number of berths, berth length, terminal area	Container throughput
Seth and Feng (2020)	15 US container ports, 2000-2015	DEA Windows Analysis (DEA-BCC model)	Cost of port security measures, cost of container infrastructure facilities, dredging costs, total berth length, number of cranes, container terminal acreage	Net income, container throughput
Munim (2020)	17 Asian seaports, 2005-2015	DEA-CCR, DEA-BCC and FDH models	Number of berths, berth length, depth, terminal area, number of yard gantry cranes, number of quay gantry cranes	Container throughput
Barros and Managi (2008)	39 Japanese seaports, 2003-2005	DEA-CCR model, Simar and Wilson (2007) Procedure	Personnel, number of cranes	Number of ships, bulk throughput, container throughput
Yeo (2010)	61 Asian large container terminals, 2004–2007	Truncated regression with the parametric model	-	-
Bergantino and Musso (2011)	18 European ports, 1995–2007	DEA-BCC model, Stochastic Frontier Analysis	Quay dimension, number of terminals, port land area, number of handling equipment	Cargo throughput
Wang and Gao (2012)	9 Chinese ports, 1995-2010	Stochastic Frontier Analysis	-	-
Niavis and Tsekeris (2012)	30 seaports in South-Eastern Europe in 2008	DEA-CCR and BCC models, Simar and Wilson (2007) Procedure	Berths length, number of cranes	Container throughput
Yuen et al. (2013)	21 major container terminals, 2003-2007	DEA Malmquist, Tobit regression model, Simar and Wilson (2007) Procedure	Number of berths, berth length, port land area, number of quay cranes, number of yard gantries	Cargo throughput
De Oliveira and Cariou (2015)	200 container ports in 2007 and 2010	Simar and Wilson (2007), non-Parametric Frontier Technique	Port area, length of berth, storage area, number of yard cranes, number of quay cranes	Annual traffic

model significantly outperforms Tobit regression modeling. They also found that seaport distance from the Suez Canal, GDP per capita and population size have a positive impact on efficiency scores, as calculated using the DEA-CCR model. In turn, Chaouk et al. (2020) used a two-step approach with Tobit and bootstrapping technique to investigate the effect of macro-environmental factors on 59 international airports. They concluded that airport efficiency is highly affected by the macroeconomic environment, air transport productivity, safety and security, institutions, as well as human development. Using the same techniques, Yuen et al. (2013) undertook to compute the DEA-CCR efficiency scores of China's twenty-one largest container ports. They then provided explanation of such scores through Tobit and regression model with bootstrapping procedures. Following Yuen and Zhang (2009), they used the distance separating the port and its nearest competitor as a proxy to measure the inter-port competition intensity level. They concluded that privatization could significantly improve container terminal efficiency, and that intra- and inter-port competition could help increase the efficiency scores of container terminals. De Oliveira and Cariou (2015) used the two-step methodology of Simar and Wilson (2007) to examine the effect of competition on the inefficiency of 200 container ports. The authors found a significant and negative correlation between HHI and inefficiency, highlighting that the correlation between the dummy variable depicting the number of cranes frequently increasing during the study period and seaport inefficiency is significant and positive. For them, such correlations can be explained by the fierce competition forcing ports to over-invest in competitive advantage enhancing factors to reduce inefficiency. For D'Alfonso et al. (2015), who used a two-step nonparametric frontier-analysis approach, competition is negatively correlated with technical efficiency. According to Merkel and Holmgren (2017), who synthesized the outputs of 52 studies and regressed their estimates on country and seaport characteristics via meta-regression model, GDP per capita, i.e. investment capacity levels in developed and developing countries, negatively affect seaport efficiency, highlighting that the intra- and inter-port competition modes help boost the ports' estimated efficiency.

The above analysis shows that despite the remarkable effort made in previous studies to investigate and highlight the major determinants of seaport efficiency, the correlation between some of these factors and efficiency still remains unclear and needs further study.

3. METHODOLOGY AND MODEL SPECIFICATION

In keeping with the two-step procedure proposed by Simar and Wilson (2007), this study was initially designed to evaluate seaport efficiency level by using nonparametric linear methodology, prior to addressing the subject of environmental factors likely to help in determining seaport (in)efficiency level using truncated bootstrapped regression.

3.1. Data Envelopment Analysis

As part of the nonparametric line of thought, the DEA approach, initially advanced by Charnes et al. (1978), has been considered a major technical mechanism for establishing seaport efficiency. It consists of linear programming analysis used to describe seaport efficiency by identifying the inefficiently ones and determining the best practice.

It is worth recalling in this context, that as a non-parametric deterministic method, DEA neither determined any particular functional form for the production boundary, nor entails any specific form of the production function. Another noticeable advantage associated with this technique lies in its ability to simultaneously apply a wide variety of inputs and outputs expressed in different measurement units, e.g., meters, square meters, hectares, etc.

Ever since the introduction of the first DEA model, specifically the DEA-CCR model (Charnes et al. 1978), this technique was proven to have a theoretically and methodically remarkably wide application, particularly given the assumption of constant returns to scale (CRS) production technology, where an increase in production resource levels results in the proportionate increase in output levels. Accordingly, the CCR model helps calculate overall technical efficiency, likely to be decomposed into pure technical efficiency and scale efficiency for each company.

In addition, this approach is the most widely used modeling framework for the assessment of the overall technical efficiency[1] of every single organization. Hence, by applying a DEA-CCR model, the study analysis turns out to be either input-oriented, viewing each single seaport as using minimum input items while sustaining the given quantity of output, or output-oriented, i.e. maximizing the quantity of outputs at the level of each single seaport while sustaining the quantity of inputs. Thus, such an analysis might well apply the input-oriented model to identify any excess likely to be recorded in seaport resource utilization. This mode of analysis was most notably conducted by Tongzon (2001), Niavis and Tsekeris (2012), as well as Tetteh et al. (2016), among others. The input orientation of the DEA-CCR model is usually presented as follows:

$$\theta^* = \min \theta \tag{1}$$

$$s.t.\ \sum_{j=1}^{n} x_{ij} \lambda_j \leq \theta x_{i0} \qquad i=1,2,\ldots,m \tag{2}$$

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[1] This model enables combining pure technical efficiency and scale efficiency into a single value (Gollani and Roll, 1989).

$$\sum_{j=1}^{n} y_{rj}\lambda_j \geq y_{r0} \qquad r=1,2,\ldots,s \tag{3}$$

$$\lambda_j \geq 0 \qquad j = 1,\ldots, n \tag{4}$$

Where:

θ^* denotes the DEA efficiency index of DMU under evaluation (denoted as DMU_0),

y_{r0}, x_{i0} designates the value of the ith input and rth output for DMU_0, and λ_j stands for the decision variables describing the associated weighting of inputs and outputs of DMU_j.

In accordance with the advanced dual problem framework, Charnes et al. (1978) considered calculating the relevant efficiency scores by reducing the objective function into two constraint sets. In the initial constraint, the weighted sum of the non-focal DMUs resources has to be either equal to or smaller than DMU_0 resources. The second constraint is that the weighted sum of the DMUs outputs has to be either equal to or greater than the DMU_0. In this regard, for an inefficient seaport to shift towards the efficient frontier, Cooper et al. (2007) introduced slack variables s_i- (input) and s_r+ (output) as follows:

$$\theta^* = \min \theta - \varepsilon \left(\sum_{i=1}^{m} s_i- + \sum_{r=1}^{s} s_r+ \right) \tag{5}$$

$$\text{s.t.} \sum_{j=1}^{n} x_{ij}\lambda_j + s_i- = \theta x_{i0} \qquad i=1,2,\ldots,m \tag{6}$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j - s_r+ = \theta y_{r0} \qquad r=1,2,\ldots,s \tag{7}$$

$$\lambda_j \geq 0 \qquad j = 1,\ldots, n \tag{8}$$

$$s_i- \geq 0 \qquad i = 1,\ldots, m \tag{9}$$

$$s_i+ \geq 0 \qquad r = 1,\ldots, s \tag{10}$$

Where: s_i- and s_r+ designate the excess of input i and the shortfall of output r in DMU_0, respectively.

Accordingly, the three DEA-CCR model associated conditions can be summed up as:

-if $\theta^* < 1$; the DMU_0 is inefficient;

-if $\theta^* = 1$ and the values of slack variables are equal to zero, i.e., $s_i- = s_r+ = 0$, the DMU_0 is fully efficient;

-if $\theta^* = 1$ and some slack variables are non zero, i.e. $s_i- \neq 0$ and/or $s_r+ \neq 0$ for some input and output, the DMU_0 is considered inefficient.

For our model to be able to process time-varying and cross sectional data, we considered an extended version of the traditional DEA technique. This approach, also dubbed the DEA-Window analysis, was initially put forward by Klopp (1985). The idea behind this framework is to treat each DMU as a different DMU for each reporting date. Then, the DEA-Window analysis can be used to identify a company's performance trend over time (Seth and Feng, 2020). Actually, this procedure helps increase the number of seaports subject to analysis, thereby, enhancing the discriminatory power of the technique (Pjevčević et al., 2012). In effect, the DEA-Window approach selects window width K prior to estimating n*K efficiencies relevant for each window. The number of windows is: W=T-K+1, where, T designates the number of periods. The consecutive windows overlap K-1 periods. It is actually this overlapping procedure that facilitates data quality analysis and dynamic property assessment. At this level, the appropriate window width robust enough to evaluate efficiency is chosen by the following formula (Maidamisa et al., 2012):

If T is an odd number

$$K = \frac{T+1}{2} \tag{11}$$

If T is an even number

$$K = \frac{T+1}{2} \pm \frac{1}{2} \tag{12}$$

3.2. Second-step Regression

Throughout the first step, calculated efficiency scores could be explained by the set of covariates denoting environmental factors. If econometric analysis is applied, the ensuing second-step could be formulated as:

$$\theta_j = \alpha + \delta Z_j + \varepsilon_j \qquad j = 1, 2, 3, \ldots, n \tag{13}$$

$$\text{s.t.} \; (\theta_j) \geq 1 \tag{14}$$

Where:

θ_j is the bias-corrected efficiency score of the jth seaport,

δ is a vector of parameters to be measured,

Z_j is the vector of specific factors for the jth seaport,

α is the constant term, and

ε_j is statistical noise.

In this respect, a common measure in relevant literature is using Tobit regression to estimate this correlation. However that could result in the emergence of two major problems, as seen in Simar and Wilson (2007). Primarily, efficiency scores estimated by the DEA technique are expected to be inter-correlated, since the calculation of the efficiency of a single seaport entails accounting for the entirety of other seaports from the same data set. Consequently, the implementation of direct regression analysis is invalid owing to the interdependence of efficiency scores. Additionally, a strong correlation is also expected to exist between input/output and environmental variables, particularly in small scale samples, invalidating the regression assumption that ε_j is independent of Z_j. To overcome this problem, we considered applying the parametric bootstrap to the regression to increase bootstrap confidence intervals for estimated δ and σ_ε^2 e parameters, where, the distribution of the error term ε_k is $N(0, \sigma_\varepsilon^2)$, with left-truncation at $1- \beta Z_j$ to measure $\theta_j = \beta Z_j + \varepsilon_j$. At this level, the maximum likelihood estimation is applied to assess the truncated regression of θ_k and Z_k. This procedure was repeated a thousand times in the second step.

4. DATASET

The study seeks to examine Europe's 35 largest container ports from the Northern Range (NR) and the Southern Range (SR). Our dataset includes 525 observations, in the 2004-2018 period (15 years x 35 ports = 525 observations). Our dataset was gathered from various sources. The input and output related data have been obtained from the Lloyds database and port authority websites, while the data associated with explanatory variables have been collected from the published annual reports, Eurostat database and Statista database.

4.1. Variables Relevant for First-Step Efficiency Analysis

First-step inputs include berth length (Lberths) in meters, the number of quay gantry cranes (Ncranes), the number of workers (Nworkers) and storage reserved area (Sarea), which we believe to be the most convenient input variables for the DEA technique for investigating seaport operability, as done in several prior studies (e.g., Min and Park, 2005; Nwanosike et al., 2012, Munim, 2020, to name a few). The selected output indicator consists of port-throughput (Y) expressed in tons per year, as the major indicator of seaport or terminal capacity, as predominantly used in the relevant literature (Tetteh et al., 2016, among others).

Summary statistics of applied variables are provided below (Table 2). Noteworthy, in this respect, is that the four input variables associated with growth rates tended to range from 6% to 49% in the 2004-2018 period, while throughput appeared to improve by 22%.

4.2. Selected Variables for Second-Step Regression

Seven factors have been used in this step to explain the first step dependent-variable efficiency scores. The first indicator is variable draught level (Dra) used to determine the size of vessels that can enter the port, already defined in several published studies as the seaport competitiveness factor (Turner et al., 2004; Rios and Sousa, 2014). The second indicator is hinterland size (Pop), referred to as population inhabiting the area of a particular port. This criterion was used in several renown studies, particularly, Barros and Managi (2008), Bergantino and Musso (2011), and Niavis and Tsekeris (2012). The third factor is the regional gross domestic product of the port-city (GDP), expressed in millions of dollars, used to determine the economic status of the area where the port is located, as in Barros and Managi (2008), Wang and Gao (2012) and Yuen et al. (2013). The fourth factor is a dummy variable that takes the value 1 if seaport inputs are suitable for drawing investments (Inv) in the period of analysis, as in De Oliveira and Cariou (2015). The fifth index is the concentration of container port industry by region, measured with the Herfindhal–Hirschman Index($HHI = \sum^n_{i=1} (thr_i / \sum^n_i thr_i)^2$), where, thr_i is cargo handled in the i^{th} seaport, and n the number of seaports studied in a region (Northern range or Southern Range), as used in several relevant studies (e.g., Wang and Gao, 2012; De Oliveira and Cariou, 2015). Generally, the HHI index ranges between 0 and 1, with decreased values indicating increased competition, and increased values indicating the opposite. Accordingly, the HHI index of Northern Range ports appears to vary between 0.108 and 0.136, while the HHI value of Southern Range seaports varies between 0.09 and 0.107, gradually increasing over the years (Figure 1). Thus, one may conclude that the concentration of total freight traffic in Northern and Southern European seaports tends to be low as a consequence of fierce competition. In effect, throughout the period under review, the total throughput traffic of Europe's Northern Range seaports tended to grow from 1354.6 million tons in 2004 to 1626.6 million tons in 2018, which made De Lombaerde and Verbeke (1989) state that the growth of seaport freight traffic is a major indication of their competitive status. Indeed, the Northern Range area has three major seaports: Antwerp, Rotterdam and Hamburg, whose traffic dealings account for half of the overall Northern European transshipment volumes (599.8 million tons in 2004 versus 827.5 million tons in 2018). Actually, Rotterdam appears to be number one European port in terms of traffic, owing mainly to its favorable geographical position at the mouth of the Rhine and the Meuse. The sixth factor is the liner shipping connectivity index (LSCI), established by the United Nations Conference on Trade and Development (UNCTAD) to include five elements (the number of ships, ship container-cargo capacity, maximum vessel size, the number of service plants and companies dealing in container ships in a country's ports). Agbola and Chin (2013) and the UNCTAD (2019) hold that LSCI is a measure of seaport efficiency, and a proxy for De Oliveira and Cariou (2015) competitive pressure. The last variable is distance (Dis), calculated in kilometers, between a seaport and its closest hub seaport. In this regard, De Oliveira and Cariou (2015) identified hub ports by means of a proxy that rests on the United Nations (2007) ratio of 0.12 Twenty-foot Equivalent Unit (TEU) per one million inhabitants. If the number of TEUs traveling through a port exceeds the potential traffic of its port-city population rate twenty times (TEU >20* 0.12* Pop size), the port can be assumed to be a hub. Accordingly, 60 % of the 35 seaports were ranked as hubs during the study period. Hence, the twenty one hub ports are: Le Havre, Algeciras, Southampton, Dunkirk, Duisburg, Immingham, Hamburg, Rotterdam, Marsaxlokk, Felixstowe, Trieste, Piraeus Southampton, Liverpool, Genova, Milford Haven, Bremerhaven, La Spezia, Antwerp, Sines, Hartlepool and Wilhelmshaven. This variable was used by Yen and Zhang (2009).

Table 2.
Descriptive statistics.

			Obs	Min	Max	Mean	STD
First-step	2004	Y	35	1156000	345819000	53069789.5	57852314.5
		Lberths	35	1900	151000	24600.029	35506.86917
		Ncranes	35	2	320	50.428	61.549
		Nworkers	35	177	89491	14195.285	24309.540
		Sarea	35	5600	5560000	596250	1054376.25
	2018	Y	35	2848000	467354000	64459310.5	80664820.27
		Lberths	35	2003	172000	25769	38109.0206
		Ncranes	35	2	353	54	65.973
		Nworkers	35	163	358000	26052	64769.955
		Sarea	35	6130	6100000	625465.143	1127731.483
Second-step	2004						
		DEA-CCR	35	0.126	1	0.454	0.241
		Dra	35	9.5	25	16.846	3.514
		Pop	35	3434	7598000	775252.286	1519763.478
		GDP	35	8090	277344	52997.939	61254.406
		INV	35	0	1	0.70	0.466
		HHI	35	0.090	0.109	0.100	0.013
		Dis	35	90	1587	551.242	541.781265
		LSCI	35	15	79.95	63.12	17.237
	2018	DEA-CCR	35	0.120	1	0.441	0.259
		Dra	35	9.5	32	17.312	4.162
		Pop	35	3660	8992166	948656.818	1818588.64
		GDP	35	12600	483293	72767.774	92748.022
		INV	35	0	1	0.70	0.466
		HHI	35	0.115	0.134	0.125	0.013
		Dis	35	90	1587	551.242	541.781
		LSCI	35	48.700	98	83.739	14.264

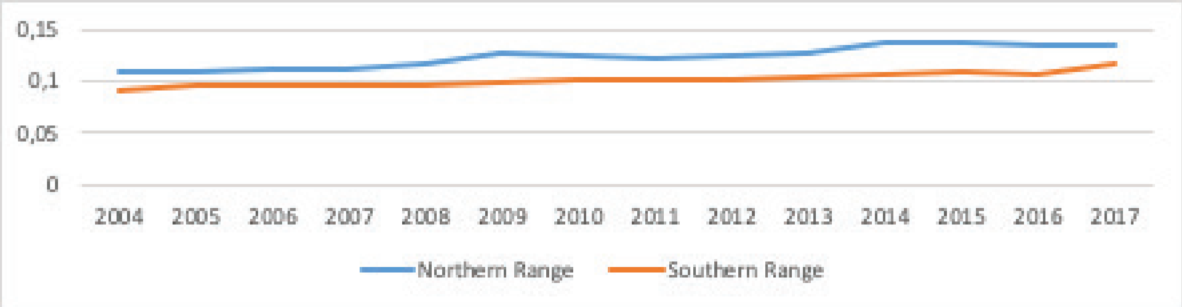

Figure 1.
HHI of Northern and Southern European Range ports (2004– 2018).

5. EMPIRICAL RESULTS

This section is dedicated to explaining and testing the hypothesis that the intensity of competition and other factors affect the efficiency of 35 container seaports by truncated bootstrap regression analysis. We first examined the efficiency of the studied seaports in the period under review (2004–2018) then proceeded with slack variable analysis to highlight the distinctive characteristics of each inefficient seaport.

5.1. Estimates Obtained Through First-Step Efficiency Analysis

First, the efficiency of thirty-five seaports in the 2004-2018 period was estimated with the EMS (Efficiency Measurement System) software. Their efficiency scores were calculated with DEA window analysis in keeping with the constant returns to scale set assumptions, where T=15, K=8 and W=8. It is worth noting, however, that owing to the largely quantity of data obtained, we decided to provide only the efficiency scores of the Felixstowe port (Table 3), which had the highest average efficiency score (0.919), as an example. The average yearly efficiency scores for each seaport range from 0 to 1 (Table 5). On average, no port realized the efficiency score 1. Only 10 ports appeared to have average efficiency scores between 0.602 and 0.92, 8 seaports had the scores between 0.42 and 0.56; while the rest had less than 0.4. In fact, the seaports of Hartlepool, Lisbon, Rotterdam, Gioia Tauro and Algeciras turned out to have remarkable efficiency scores of 0.771, 0.780, 0.812, 0.856 and 0.888, respectively.

Table 3.
Felixstowe port case study: DEA-CCR window analysis.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
W1	0.892	0.892	0.892	0.892	0.892	0.892	0.892	0.892							
W2		0.897	0.897	0.897	0.897	0.897	0.897	0.897	0.897						
W3			0.897	0.897	0.897	0.897	0.897	0.897	0.897	0.897					
W4				0.897	0.897	0.897	0.897	0.897	0.897	0.897	0.897				
W5					0.912	0.912	0.912	0.912	0.912	0.912	0.912	0.912			
W6						0.912	0.912	0.912	0.912	0.912	0.912	0.912	0.912		
W7							0.918	0.918	0.918	0.918	0.918	0.918	0.918	0.918	
W8								1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
mean	0.892	0.895	0.895	0.896	0.899	0.901	0.904	0.916	0.919	0.923	0.928	0.936	0.943	0.959	1.000

Among the thirty five examined seaports, eighteen ports, mostly from the Northern Range (NR), had decreasing efficiency scores in the study period. Our data suggest that decreasing efficiency can mainly be attributed to ineffective investments, and failure to improve freight throughput to anticipated extent.

The efficiency scores of Milford Haven and Liverpool seaports dropped mainly due to noticeable overstaffing. Similarly, the port of Piraeus suffered significant efficiency score decline in 2007-2010, despite the procurement of 5 additional quay cranes. The port of Antwerp noted a remarkable decline in efficiency scores in 2011, despite the construction of a second access lock to the Waaslandhaven and hiring additional labor. The efficiency scores of the seaports of Le Havre and Rotterdam dropped in 2011 in spite of increased total berth length, while the port of Bremen-Bremerhaven suffered a decline in 2011 despite significantly increasing it labor force.

The main sources of inefficiency can only be established by taking a closer look at the slack values of the inputs and outputs used. In effect, slacks are what remains after maximizing throughput and minimizing resources for an inefficient organization (Ozcan, 2014). In other words, the average efficiency score of investigated ports is 0.45. Overall, this finding implies that these seaports can increase their efficiency by reducing their actual input level to 55% = (1–45%).

Accordingly, the port of Le Havre had the lowest efficiency index of 0.109 in 2018, highlighting the persistence of two extra inputs. The port of Le Havre needs to decrease the number of active workers (Nworkers) to approximately 612.86, and its reserved storage area (Sarea) to 2,977.63 m2 (Table 4). The same prerequisite applies to the seaports of Nantes, London, Hartlepool, Hamburg, Bremen-Bremerhaven, Wilhelmshaven, Rotterdam, Lisbon, Milford Haven and Gioia Tauro, though with different magnitudes. It is also noteworthy that the port of Marseille needs to reduce the total length of its berths (Lberths) by 1,073.73 m, the number of its quay crane installations (Ncranes) by 17 and its reserved storage area (Sarea) by 615.05 m^2. The ports of Immingham, Southampton, Antwerp and Liverpool are in a similar situation.

With respect to other inefficient seaports, mainly the port of Amsterdam, the relevant findings reveal that it is characterized by a surplus of inputs and insufficient outputs. It must therefore reduce the number of operating quay cranes (Ncranes) by 7 units, its active labor force by 742.75 workers (Nworkers) and storage area by 7,114 m2. Inversely, however, for this port to become efficient, it needs to increase its throughput (Y) by at least 77 tons. The ports of Barcelona, Taranto, La Spezia and Marsaxlokk are in a similar situation. Nonetheless, the port of Felixstowe has neither input nor output related slacks, performing efficiently particularly in 2018.

Based on these result interpretations, one might notice that excessive inputs appears to be the major source of inefficiency characterizing most of the ports studied, e.g., Hamburg, Le Havre, Bremen-Bremerhaven, Antwerp. Efficiency can be improved through the adoption of new strategies which would maximize and optimally use inputs and throughput. The correlation between investment and efficiency was explored in detail in the second step of our analysis.

Table 4.
Average excess inputs and output shortages in 2018.

Seaport	Country	Range	Lberths	Ncranes	Nworkers	Sarea	Y
Felixstowe	United Kingdom	NR	-	-	-	-	-
Algeciras	Spain	SR	-	-	-	-	2
Gioia Tauro	Italy	SR	0	0	4481	1003.9	0
Rotterdam	Netherlands	NR	0	0	790.11	1705.07	0
Lisbon	Portugal	SR	0	0	15.56	116.25	0
Hartlepool	United Kingdom	NR	0	0	75.3	1569	0
Sines	Portugal	SR	1148.23	0	0	0	18
Valencia	Spain	SR	226.97	5.02	0	0	25

Genova	Italy	SR	0	16.81	54.46	1515.35	0
Trieste	Italy	SR	705.29	1.41	932.62	933.68	0
Taranto	Italy	SR	0	17.56	394.93	419.7	58
Bilbao	Spain	SR	625.08	24.15	0	0	0
Tarragona	Spain	SR	165.58	10.34	0	0	0
Marseille	France	SR	1073.73	17	0	615.05	0
Piraeus	Greece	SR	3960.12	38.51	0	1029.48	56
La Spezia	Italy	SR	0	8.02	733.81	824.88	25
Marsaxlokk	Malta	SR	0	13	789	4563	39
Gothenburg	Sweden	NR	678.16	0	156.83	2438.62	36
Amsterdam	Netherlands	NR	0	7	742.75	7114	77
Southampton	United Kingdom	NR	845.52	11	0	4843.66	0
Milford Haven	United Kingdom	NR	0	0	444.75	1853.7	0
Las Palmas	Spain	SR	1047.99	20.93	0	0	0
Liverpool	United Kingdom	NR	821.31	18.66	0	1238.55	0
Immingham	United Kingdom	NR	517.48	20	0	4401.95	0
Nantes	France	SR	0	0	8.9	996	0
Antwerp	Belgium	NR	926.62	12	0	8477.11	0
Barcelona	Spain	SR	0	5.87	584	1732.91	45
Wilhelmshaven	Germany	NR	0	0	243.17	227.99	0
Dunkirk	France	NR	1368.39	0	33.87	762.4	15
Duisburg	Germany	NR	1834.61	47.72	0	0	0
Bruges-Zeebruges	Belgium	NR	0	1.59	1335.77	1524.34	0
Bremen-Bremerhaven	Germany	NR	0	0	766.58	5893.03	0
Hamburg	Germany	NR	0	0	1082.82	1827.73	0
London	United Kingdom	NR	0	0	168.39	3536.76	0
Le Havre	France	NR	0	0	612.86	2977.63	0

Table 5.
Mean efficiency scores obtained with the DEA window analysis.

Seaport	Country	Range	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
Felixstowe	United Kingdom	NR	0.892	0.895	0.895	0.896	0.899	0.901	0.904	0.916	0.919	0.923	0.928	0.936	0.943	0.959	1.000	0.919
Algeciras	Spain	SR	1.000	1.000	0.832	0.832	0.872	0.892	0.896	0.845	0.848	0.843	0.851	0.855	0.858	0.898	0.998	0.888
Gioia Tauro	Italy	SR	0.806	0.818	0.818	0.824	0.851	0.842	0.842	0.818	0.851	0.871	0.871	0.871	0.892	0.898	0.912	0.856
Rotterdam	Netherlands	NR	0.884	0.886	0.887	0.823	0.843	0.872	0.861	0.791	0.782	0.784	0.791	0.791	0.768	0.753	0.726	0.812
Lisbon	Portugal	SR	0.716	0.766	0.766	0.766	0.768	0.774	0.774	0.774	0.775	0.777	0.777	0.796	0.796	0.781	0.828	0.780
Hartlepool	United Kingdom	NR	1.000	1.000	0.945	0.882	0.802	0.770	0.768	0.762	0.760	0.669	0.721	0.639	0.723	0.629	0.716	0.771
Sines	Portugal	SR	0.732	0.760	0.777	0.766	0.766	0.756	0.756	0.757	0.762	0.767	0.774	0.777	0.781	0.785	0.790	0.770
Valencia	Spain	SR	0.779	0.721	0.747	0.783	0.735	0.702	0.641	0.631	0.619	0.665	0.618	0.632	0.672	0.645	0.616	0.674
Genova	Italy	SR	0.619	0.627	0.647	0.642	0.615	0.688	0.678	0.678	0.669	0.655	0.663	0.683	0.683	0.698	0.700	0.666
Trieste	Italy	SR	0.514	0.613	0.618	0.614	0.615	0.605	0.602	0.609	0.602	0.595	0.593	0.590	0.592	0.591	0.591	0.602
Taranto	Italy	SR	0.513	0.533	0.544	0.577	0.561	0.533	0.522	0.529	0.533	0.516	0.537	0.591	0.588	0.622	0.622	0.558
Bilbao	Spain	SR	0.499	0.499	0.508	0.508	0.508	0.522	0.533	0.543	0.556	0.567	0.583	0.595	0.597	0.599	0.600	0.551
Tarragona	Spain	SR	0.473	0.482	0.508	0.537	0.519	0.502	0.536	0.558	0.547	0.546	0.586	0.586	0.587	0.587	0.587	0.548
Marseille	France	SR	0.472	0.484	0.487	0.482	0.482	0.457	0.464	0.466	0.461	0.551	0.546	0.552	0.551	0.547	0.558	0.506
Piraeus	Greece	SR	0.415	0.434	0.484	0.381	0.332	0.214	0.224	0.553	0.508	0.543	0.584	0.519	0.564	0.600	0.537	0.463
La Spezia	Italy	SR	0.427	0.487	0.485	0.518	0.543	0.491	0.418	0.428	0.381	0.416	0.411	0.403	0.356	0.425	0.454	0.444
Marsaxlokk	Malta	SR	0.414	0.414	0.420	0.420	0.420	0.420	0.420	0.420	0.423	0.426	0.428	0.432	0.435	0.438	0.441	0.426
Gothenburg	Sweden	NR	0.516	0.522	0.573	0.584	0.607	0.559	0.617	0.323	0.322	0.301	0.288	0.296	0.322	0.319	0.314	0.425
Amsterdam	Netherlands	NR	0.336	0.354	0.377	0.396	0.485	0.407	0.434	0.423	0.441	0.456	0.482	0.302	0.302	0.314	0.314	0.392
Southampton	United Kingdom	NR	0.377	0.381	0.381	0.418	0.391	0.356	0.373	0.364	0.364	0.342	0.350	0.364	0.344	0.328	0.330	0.364
Milford Haven	United Kingdom	NR	0.392	0.423	0.427	0.464	0.358	0.332	0.351	0.342	0.365	0.371	0.381	0.314	0.328	0.328	0.309	0.344
Las Palmas	Spain	SR	0.314	0.328	0.420	0.398	0.438	0.337	0.339	0.318	0.282	0.239	0.247	0.194	0.190	0.213	0.267	0.301
Liverpool	United Kingdom	NR	0.435	0.454	0.464	0.454	0.456	0.447	0.454	0.235	0.180	0.152	0.155	0.156	0.164	0.160	0.180	0.294

Immingham	United Kingdom	NR	0.273	0.302	0.314	0.328	0.323	0.271	0.268	0.284	0.298	0.311	0.294	0.293	0.270	0.267	0.274	0.293
Nantes	France	SR	0.311	0.323	0.322	0.319	0.315	0.277	0.293	0.287	0.276	0.253	0.265	0.234	0.235	0.276	0.299	0.284
Antwerp	Belgium	NR	0.313	0.316	0.328	0.358	0.371	0.277	0.313	0.242	0.208	0.217	0.224	0.239	0.250	0.253	0.259	0.276
Barcelona	Spain	SR	0.218	0.221	0.222	0.224	0.230	0.218	0.217	0.217	0.215	0.215	0.224	0.222	0.224	0.256	0.316	0.230
Wilhelmshaven	Germany	NR	0.294	0.299	0.280	0.277	0.263	0.222	0.164	0.160	0.174	0.160	0.156	0.174	0.179	0.181	0.183	0.205
Dunkirk	France	NR	0.219	0.224	0.234	0.235	0.234	0.174	0.170	0.180	0.180	0.174	0.181	0.179	0.179	0.180	0.181	0.193
Duisburg	Germany	NR	0.312	0.348	0.381	0.174	0.179	0.156	0.134	0.138	0.170	0.175	0.179	0.175	0.147	0.151	0.150	0.190
Bruges-Zeebruges	Belgium	NR	0.152	0.154	0.179	0.180	0.180	0.213	0.224	0.211	0.197	0.190	0.190	0.179	0.171	0.168	0.180	0.187
Bremen	Germany	NR	0.170	0.174	0.180	0.180	0.140	0.146	0.136	0.136	0.134	0.124	0.123	0.123	0.120	0.105	0.115	0.139
Hamburg	Germany	NR	0.142	0.136	0.140	0.144	0.145	0.103	0.119	0.136	0.136	0.140	0.147	0.138	0.138	0.136	0.160	0.137
London	United Kingdom	NR	0.136	0.129	0.125	0.128	0.128	0.109	0.116	0.118	0.105	0.104	0.105	0.109	0.122	0.120	0.128	0.118
Le Havre	France	NR	0.126	0.128	0.126	0.136	0.136	0.125	0.118	0.096	0.090	0.097	0.094	0.095	0.091	0.100	0.109	0.110

5.2. Results of Second-Step Regression

In the second step, we used the truncated bootstrapped regression to evaluate the effect of each explanatory variables on the efficiency of container ports (Table 7). We considered running three regressions on the STATA 15 software. The first covered the entirety of collected observations, while the second focused exclusively on observations pertaining to eighteen Northern container ports, and the third on the seventeen Southern container ports. Prior to conducting the regression test, the correlation analysis of variables was carried out. No high correlation matrix values have been recorded for the entirety of the variables used, as correlation coefficients between variables were under 0.7 (Table 6). Besides, no correlation was found between these variables. In addition, the variance inflation factor (VIF) analysis was conducted to establish potential multicollinearity between the implemented variables (Table 8). Tolerance statistics (1/VIF) were found to exceed 0.2 and the sum of all VIF variables was under 10. Hence, there is no noticeable multicollinearity issue, which makes the empirical results obtained by regression rather reliable (Myers, 1990).

Table 6.
Correlation matrix.

	Dra	LSCI	Pop	GDP	Inv	HHI	Dis	DEA-CCR
Dra	1.000							
LSCI	-0.041	1.000						
Pop	-0.063	-0.018	1.000					
GDP	-0.029	0.070	0.251	1.000				
Inv	0.335	0.000	-0.087	0.027	1.000			
HHI	0.026	0.030	0.030	0.070	-0.000	1.000		
Dis	0.332	-0.100	0.074	-0.225	0.006	0.000	1.000	
DEA-CCR	0.103	0.076	-0.023	0.014	-0.004	0.026	-0.004	1.000

Table 7.
Results of the econometric analysis of port efficiency determinants.

Variables	35 European seaports		Northern Range (NR)		Southern Range (SR)	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Dra	0.298	0.000***	0.150	0.000***	0.181	0.020**
LSCI	0.127	0.001***	0.068	0.001***	0.086	0.019**
Pop	0.067	0.182	0.009	0.414	0.039	0.157
GDP	-0.150	0.005***	-0.144	0.002***	0.144	0.008***
Inv	-0.289	0.023**	-0.071	0.030**	0.124	0.007 ***
HHI	0.362	0.000***	0.154	0.000***	-0.164	0.001***
Dis	-0.191	0.030**	-0.182	0.017**	0.142	0.010**
cons	0.417	0.000***	0.468	0.000***	0.366	0.000***
/sigma	0.325	0.000***	0.061	0.000***	0.469	0.000***
N	525		270		255	

Note : Significance levels are respectively: 1% (***), 5% (**) and 10% (*).

Table 8.
The multicollinearity test.

Variables	VIF	1/VIF
Dra	1.16	0.860
LSCI	1.01	0.986
Pop	1.63	0.614
GDP	1.82	0.550
Inv	1.28	0.778
HHI	1.01	0.992
Dis	1.34	0.744
Mean VIF	1.32	

With respect to the three regressions, our empirical results have revealed that draught (Dra) has a statistically significant positive impact on seaport efficiency and deep-draught ports tend to function rather efficiently. Actually, this variable helps predict cargo handling capacity and has often been considered a key factor of port productivity (Lyer and Nanyam, 2021). For simplicity reasons, seaports with deep-draughts can accommodate panamax ships capable of carrying large cargo volumes, thereby, noticeably increasing their production and boosting seaport performance (Nabee and Walters, 2018). It is also noteworthy that the LSCI factor, indicating the competition between shipping container companies, was found to have a statistically significant and positive effect on the efficiency of all thirty-five container seaports, from both the North-Range and the South-Range. Therefore, seaports located in countries well-connected with international shipping routes record higher efficiency levels. Such findings appear to corroborate those of Cariou and De Oliveira (2015). More particular, the Felixstowe seaport, considered to operate at a noticeable efficiency level in the first step of our analysis, stands as the best European seaport, benefiting from strategically favorable international connections, and attaining the rate of 95% in 2018. The effect of the population size variable (Pop) on seaport efficiency has turned out to be statistically insignificant with respect to the three regressions conducted on thirty-five Northern and Southern Range European container seaports.

At this stage, the differences in the significance of ports from both Ranges were examined. The port-city GDP factor appears to have a statistically significant and negative impact on the efficiency of ports from the North European Range. This finding coincides with the findings of Liu and Deng (2022) who argued that developed nations tend to make major capacity expansion investments, counting on predicted growth and expansion of the world trade, closely connected to the growing GDP ratio. Nevertheless, over-investment in seaport infrastructure may well lower efficiency scores. The investment factor (Inv) relevant for Northern Range seaports, i.e. an increase in resources used throughout the analysis period, was found to have a statistically significant negative impact on seaport efficiency. Thus, the results obtained indicate that seaports which have heavily invested in improving and expanding their infrastructure are inefficient. Such inefficiency could be attributed to the long time period required for the investment process to generate growth in productivity. The other explanation could be the willingness to construct and install a reserve capacity in seaport premises.

It is also worth noting that the HHI, relevant for Northern Range seaports, tends to be positive and statistically significant, which lead us to conclude that their technical efficiency tends to be inversely proportional to the intensity of inter-port competition. Such findings are compatible with those documented by De Oliveira and Cariou (2015) regarding a data sample of worldwide based container seaports. This correlation could also be explained by heavy investments made by large container ports to increase customer demand.

With respect to Northern Range seaports, the factor of distance (Dis) from the closest hub seaport was found to have a statistically significant and negative effect on seaport efficiency. Such a finding seems to be quite logical, as short distance from the closest competing hub port increases the attractiveness of the former to global maritime companies because they strive to reduce dwell time which is predominantly persistent in most hub seaports. In addition, a seaport could be forced to overinvest to keep specialized terminals and provide highly specialized services by acquiring innovative handling equipment likely to meet their customers' needs. However, installation of reserve capacity potentials could actually lower its efficiency. After the first step of our analysis, the above results suggested that two port hubs, Rotterdam and Felixstowe, were efficient. Their respective efficiency is largely due to the great distance between them (about 305 kilometers). On the other side of the spectrum however, there are the hub seaports of Bruges-Zeebruges and Dunkirk (only 90 kilometers apart) which have persistently manifested technical inefficiency.

The HHI index coefficient was found to be significant and negatively correlated with the efficiency of Southern Range seaports. The technical efficiency of ports from this Range seems to tend to increase with intensified inter-port competition levels, in keeping with the results of Yuen et al. (2013). It is also noteworthy that the distance variable (Dis) has a positive correlation with efficiency in the Southern Range. Indeed, the short distance between a Southern Range seaport and its nearest competing hub seaport increases service quality in the former due to heavy investments in the renovation of its infrastructure and recruiting new personnel, thereby, attracting more ship-owners, increasing freight traffic (going up from 594.158 million tons in 2004 to 733.707 million tons in 2018), and thus improving its efficiency score. For instance, the port of Lisbon largely owes its efficiency to its proximity to the Sines hub port (about 159 kilometers). Noteworthy, also, is that investment variable (Inv) has a positive and statistically significant effect in the Southern Range. For example, the efficiency of the port of Sines increased mainly owing to its decision to increase the number of workers and increased total throughput which went up from 24 million tons in 2004 to 45 million tons in 2018. Finally, it is important to note that the port-city GDP variable has a statistically significant and positive effect on the efficiency of ports from the Southern Range - a finding that coincides with those of Barros and Managi (2008).

6. CONCLUSION

Given the crucial role of container seaports for a country's economic development, improving their technical efficiency is a necessary prerequisite for expediting the movement of cargo in the modern competitive environment. A number of studies have been conducted to investigate the effects of environmental factors and competition on seaport efficiency (e.g., Bergantino and Musso, 2011; Wang and Gao, 2012; Yuen et al., 2013; D'Alfonso et al., 2015; etc.). However, the hypothesis that competition has a positive effect on seaport efficiency has yet to be confirmed. In effect, even though the intensity of inter-port competition has been assumed to prompt seaports to become more efficient, a large number of them might resort to over-investing in infrastructure and management procedures causing them to become inefficient (De Oliveira and Cariou, 2015).

In this context, the contribution of this paper is an attempt to analyze the effects of competition and environmental factors, such as port-city GDP, population size, connectivity to hinterland, draught level and distance from the closest port Hub on the efficiency of European ports from the Northern and Southern Range in 2004-2018. The major potential implications of research findings are intended to help port authorities develop effective annual forecasts of their freight throughput, and modify their future investment decisions. To this end, a two-step analysis was conducted, that combined DEA-Window and CCR input-orientation models in the first step, and used truncated bootstrapped regression in the second step.

Indeed, the results are quite interesting as they highlight that both deep draught and connectivity to the hinterland have a positive impact on the efficiency of all thirty-five container seaports from both the Northern and the Southern Range.

Another important conclusion is that the inefficiency of ports from the North European Range can mostly be attributed to low throughput and excessive resource deployment, in addition to other interfering factors. For instance, the considerable intensity of inter-port competition and proximity to the closest Hub seaport lower technical efficiency, which seems to confirm the findings of Cariou and De Oliveira (2015). However, the stronger the inter-port competition the more efficient the ports from the South European Range become, as they are forced to improve service quality and infrastructure in an attempt to attract larger numbers of ship-owners, which increases their productivity, in keeping with the findings of Yuen et al. (2013).

Nonetheless, this study is not without its shortcomings, the first one being the lack of data. The sample of seaports should be broadened to include seaports from other major regions, such as Africa, Latin America, and the Middle East. These regional seaports might provide further evidence that would greatly contribute to the objective of our study, i.e. the analysis of the determinants of seaport efficiency. Another potential research venue could involve investigating the effect of the COVID-19 pandemic on seaport performance.

CONFLICT OF INTEREST:

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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