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Source / Izvornik: **Pomorstvo**, 2021, 35, 372 - 387

Journal article, Published version

Rad u časopisu, Objavljena verzija rada (izdavačev PDF)

<https://doi.org/10.31217/p.35.2.19>

Permanent link / Trajna poveznica: <https://um.nsk.hr/um:nbn:hr:187:843812>

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Download date / Datum preuzimanja: **2024-07-11**



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<https://doi.org/10.31217/p.35.2.19>

Performance assessment of major European ports: an empirical investigation

Claudio Quintano, Paolo Mazzocchi, Antonella Rocca

Department of Management and Quantitative Studies, University of Naples Parthenope, Via G. Parisi 13, 80132, Naples, Italy,
e-mail: paolo.mazzocchi@uniparthenope.it; claudio.quintano@emerito.uniparthenope.it; antonella.rocca@uniparthenope.it

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.

ARTICLE INFO

Preliminary communication
Received 24 August 2021
Accepted 7 December 2021

Key words:
Performance measurements
European ports
Distance function
DEA

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 vari-**

ables. 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).

$$y = f(x; \beta) \exp(v - u) \quad (1)$$

In (1) y is a scalar output; x is a vector of inputs; β is a vector of technology parameters. The error term ε 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 [$u \sim N_+(0, \sigma_u^2)$] 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.

$$\ln(y_j) = \beta_0 + \sum_i \beta_i \ln(x_i) + v_j - u_j \quad (2)$$

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 informa-

tion 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; β describes the structure of the technology. Thus, these equations lead to the following estimable stochastic distance functions:

$$(y_{1j})^{-1} = D^O\left(x_j, \frac{y_j}{y_{1j}}, z_j; \beta\right) \exp(v_j - u_j); \quad (4)$$

$$(x_{1j})^{-1} = D^I\left(\frac{x_j}{x_{1j}}, y_j, z_j; \beta\right) \exp(v_j - u_j)$$

Among others, Bogetoft and Otto, 2011 presented 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
Almawshaki and Shah (2015)	Middle-East Region	Technical efficiency of container terminals	Throughput (TEU)	Terminal area Quay length Quay crane Yard equipment Maximum draft
Barros (2003)	Portugal	Efficiency of container ports	Ships Movement of freight Gross gauge Break bulk cargo Containerized freight Solid bulk and liquid bulk	Total length of berth Container berth length Number of employees Capital (Book value of asset)
Barros (2006)	Italy	Efficiency of container ports	Liquid bulk Dry bulk Number of ships Number of passenger Number of containers Total sales	Number of employees Value of capital invested Size of operating Costs
Barros (2012)	Africa	Seaport performance	TEU Dry bulk Liquid bulk Delays in handling ship cargo	Quay length Seaport area Labour
Barros and Managi (2008)	Japan	Seaport productivity	Container throughput (TEU) Number of ships Tonnes of bulk	Number of personnel Number of cranes
Barros et al. (2011)	Middle Eastern and East African ports	Efficiency of container ports	Throughout Number of ship calls	Number of employees Total cost Number of cranes
Coto-Millan, Banos-Pino, and Rodriguez-Alvarez (2000)	Spain	Seaport efficiency	Total of goods moved in the port Passengers embarked and disembarked Number of vehicle with passengers	Labour Capital Intermediate consumptions
Cullinane et al. (2006)	Worldwide	Efficiency of container ports	Container throughput (TEU)	Terminal length Terminal area Number of quayside gantry cranes Number of yard gantry cranes 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 Terminal area Quay cranes Yard equipment Maximum draft
Gong et al. (2019)	Worldwide	Shipping companies (73% involved in the container sector)	Cargo carried Revenue Undesirable outputs (CO ₂ ; SO _x ; NO _x)	Total assets Capital expenditure Capacity Number of ships Employees Fuel cost
Liu (2008)	Asia-Pacific region	Port operational efficiency	Number of port calls Volume of container Cargo handled	Container lot size Number of bridge cranes Container berth length Number of deep-water berths
Luna et al. (2018)	Mexico	Efficiency of container ports	Number of containers	Number of quay cranes Number of trucks Number of yard cranes Service time
Martinez-Budria et al. (1999)	Spain	Port performance	Total cargo movement (tonne) Revenue	Labor cost Depreciation charge Other costs
Min and Park (2005)	Korea	Efficiency of container ports	Cargo throughput	Size of labour force Total length of query Number of cranes Size of hard areas
Nguyen et al. (2016)	Vietnamese ports	Port efficiency	Cargo throughput	Cargo-handling equipment Berth length Terminal areas 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 Terminal area Number of gantry cranes Average no. of workers per crane
Panayides, Lambertides, and Savva (2011)	(26 leading) International maritime firms	Efficiency of shipping companies	Market value of equity Sales	Inputs profits Book value of equity Total assets Number of employees Capital expenditure
Rios and Maçada (2006)	America (Mercosur)	Efficiency of container ports	TEUs handled Average number of containers handled per hour per ship	Number of cranes Number of berths Number of employees Terminal area Amount of yard equipment
Roll and Hayuth (1993)	Worldwide	Port performance	Container throughput Service Level User satisfaction Ship calls	Size of labour force Annual investment per port The uniformity of facilities and cargo
Sharma and Yu (2010)	(70) Container terminals	Efficiency of container terminals	Container throughput (TEU)	Quay length Terminal area Quay cranes Transfer cranes Reach stackers Straddle carriers
Tongzon (2001)	(4) Australian and (12) international ports	Efficiency of container ports	Cargo throughput (TEUs handled) Ship working rate	Number of berths Number of cranes Number of tugs Number of port authority employees Delay time

assumptions 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; Almawshaki 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)				Super-efficiency results constant returns to scale CRS model [SPR_TC]
		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	
		θ	θ			$\theta & \phi$	ϕ	ϕ			
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	Constanța	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	Peiraia	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

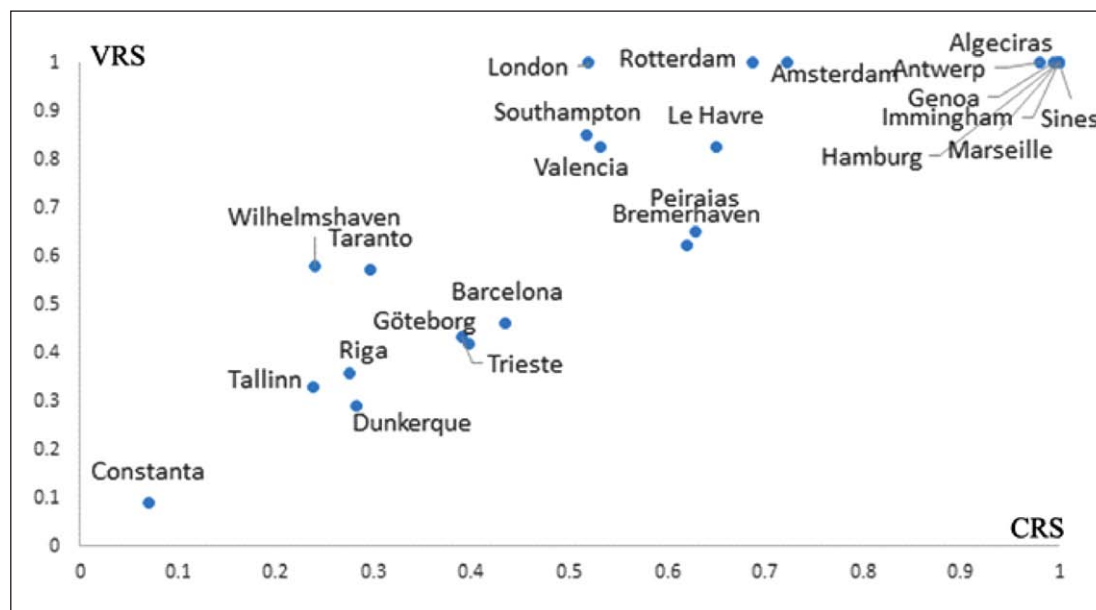


Fig. 1 Graphical illustration of port efficiencies

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. Nevertheless, 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					I100		I100		
3	Antwerp	I100				I100		I100		I100
4	Barcelona	I100		VRS00	I100-VRSIO	I100-VRS00-VRSIO	VRS00	I100-VRS00-VRSIO	VRS00	VRSIO
5	Bremerhaven	I100-VRSIO		VRS00-VRSIO	I100-VRS00-VRSIO	I100-VRSIO	VRS00	I100-VRS00-VRSIO		
6	Constanta					I100-VRSIO	VRS00	I100-VRS00-VRSIO	VRS00	I100-VRSIO
7	Dunkerque					I100-VRSIO		I100-VRSIO		
8	Genoa				I100	I100		I100		
9	Göteborg					I100-VRS00-VRSIO		I100-VRS00-VRSIO	VRS00-VRSIO	I100
12	Le Havre					I100		I100-VRS00-VRSIO	VRS00-VRSIO	I100-VRS00-VRSIO
15	Peiraias	I100-VRS00-VRSIO		VRS00	VRSIO	I100-VRS00-VRSIO		I100-VRS00-VRSIO		I100-VRS00-VRSIO
16	Riga					I100-VRSIO		I100-VRS00-VRSIO	VRS00	I100-VRSIO
17	Rotterdam	I100				I100		I100		I100
19	Southampton			VRS00	I100-VRS00-VRSIO	I100-VRS00		I100-VRS00-VRSIO		
20	Tallinn					I100-VRS00-VRSIO		I100-VRS00-VRSIO	VRS00	VRSIO
21	Taranto					I100-VRS00-VRSIO	VRS00	I100-VRS00-VRSIO	VRS00	VRSIO
22	Trieste		VRS00	VRS00	I100	I100-VRS00-VRSIO	VRS00	I100-VRS00-VRSIO	VRS00	
23	Valencia			VRS00-VRSIO		I100		I100	VRS00-VRSIO	I100-VRS00-VRSIO
24	Wilhelmshaven			VRS00	I100		VRS00	I100-VRS00-VRSIO	VRS00	

Notes: I100: Input and output oriented CRS (the results are equal in both the CRS input and output approaches, and only the peer weights – or benchmarks α – are different); VRSIO: Input oriented VRS; VRS00: 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).

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

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 effi-

ciency 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

$$H_0: \mu_{TE_VRSIO} = \mu_{TE_NIRSIO} = \mu_{TE_CRS} = \mu_{TE_VRSOO} = \mu_{TE_NIRSOO} = \mu_{SPR_TC} = \mu_{SFA_DF_1}$$

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 sig-

nificant 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.

Funding: The research presented in the manuscript did not receive any external funding.

Acknowledgement: The authors are grateful to the Editor and to two anonymous referees for their helpful reviews and suggestions.

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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), Boussofiene 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)