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The effect of privately managed terminals on the technical efficiency of the Spanish port system[☆]

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ABSTRACT

This paper analyzes the effects of privately managed terminals on the technical efficiency of Spanish ports for the period 2002–2018. Technical efficiency has been measured by both parametric and non-parametric methods. Port terminals are specialized infrastructures dedicated to container, solid and liquid bulk, non-containerized and passenger traffic. We show that the privately managed terminals improve Spanish ports technical efficiency regardless the approach followed. Besides, this increase in efficiency is the largest for solid bulk privately managed terminals followed by non-containerized general cargo, containers and liquid bulk terminals as compared to passenger ones. Also, large ports are more efficient independently of the approach. In addition, ports located in islands and those close to oil refineries are more efficient when using the non-parametric approaches. Finally, the reform introduced in 2003 had a significant negative impact on efficiency under the parametric approach.

1. Introduction

Sustainable economic activity and growth requires an efficient infrastructure transport system. In this respect, ports are key determinants to develop productive activities and promote commerce by allowing firms access to markets of imports and products at lower costs. In particular, the Spanish port system accounts for 60% of exports and 85% of imports and moves 53% of Spanish international trade with the EU and 96% with third countries. Additionally, it stands for the 20% of GDP in the transport sector and contributes with the 1.1% of the whole GDP (see Puertos del Estado, 2023). It is therefore important to enforce an efficient and appropriate management of the port infrastructures.

There are different models of port management classified according to the relative weight of the public sector and private initiative in the management of port activity. These are the public service port, the landlord port, the tool port and the private service port (see The World Bank, 2007). The Spanish port system includes 46 ports (see Fig. 1) that are managed by 28 port authorities under the control of the Ministry of Public Works through the state-owned entity"Organismo Público Puertos del Estado".[1] The port management model in Spain is an advanced landlord model where infrastructure, particularly terminals, are leased to private companies with the port authority retaining ownership of the land. Under the landlord model a concession agreement for a private company is granted in exchange for rent that is a function of the size of the facility as well as the investment required to build, renovate or expand the terminal. Alternatively, some ports keep a differentiated management system where the port authority performs the whole range of port-related services and owns all the infrastructure. [2]The landlord

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1 In the reminder of the paper, we will refer as ports what actually are port authorities for the sake of simplicity in the presentation.

2 A port infrastructure terminal is defined as a port space (quay, surface, and equipment) that is in charge of receiving, handling, storing, and dispatching goods. Port terminals are specialized and tailored to each type of cargo; for example, containerized terminals have gantry cranes and container stackers, among other things. The number of terminals in their ports is determined by port authorities, as are the terms of the concession contract for terminal private initiative management (duration, extensions, investments, maintenance, tariffs, safety and environmental issues, minimum activity, and so on).

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Fig. 1. Geographic location of the Spanish port authorities.

port model is the most common in the port industry. See for example, the port of New York, Singapore, South Korea, and in the EU: Belgium, Ireland, the Netherlands, Germany, and Spain among others.[3]

The evolution of the Spanish port system in the recent years has led to an increase in the use of the landlord system management. This process has favored the privatization of many port activities with the objective to increase ports efficiency, and hence, to improve the competitiveness of the Spanish economy and to reduce the high public expenses derived from new investments in port infrastructure and its maintenance. The different legal reforms recently undertaken in Spain went in that direction. In particular, the 2003 reform favored the participation of private initiative in the financing and provision of port services. The 2010 reform tried to directly foster the landlord model. In addition, it allowed a greater liberalization in setting port chargers and tariffs. Finally, the 2011 reform encouraged the participation of the private initiative in the construction of port infrastructures and allowed for a greater autonomy of the port authorities with respect to centralized regulatory entity.

Another interesting point in the evolution of the Spanish port system is the increase of dedicated terminals involved in the management and handling of specific traffic. Terminals are dedicated to different traffics (containers, liquids, solid or bulk traffic, non-containerized cargo and passengers) and have allowed a more intensive and effective handling of traffic. As for 2018, Spanish ports have 202 terminals with 25 container terminals, 55 dedicated to liquid and oil, 22 to solid bulk, 53 to non-containerized general cargo and 47 to passenger traffic.[4] The percentage of privately managed terminals has increased, except in the case of container terminals, which were all privately managed in 2002. In particular, solid bulk and non-containerized cargo privately managed terminals were above 90% in 2018 and the percentage for passenger terminals has almost doubled since 2002 reaching a 23.4% in 2018. Regarding the geographical distribution of privately managed terminals, 48% are in Mediterranean ports and 37% in Atlantic ones. There are similar percentages when we focus on liquids, solid or bulk traffic, and non-containerized cargo terminals. The three largest Spanish ports (Algeciras, Valencia and Barcelona) have 22.3% of total Spanish terminals and 34.8% of container terminals privately managed. Finally, some ports have specialized in specific types of terminals in order to achieve some advantages and cost savings in their operations.[5]

The Spanish port system is a good example for analyzing how a landlord management model performs. Specifically, we study how the type of management of port terminals (either private or directly by the port authority) affects technical efficiency, which has not previously been tested. Furthermore, the Spanish port system is important in Europe. It is worth noting that three of the top ten European ports in terms of container handling are Spanish: Valencia, Algeciras, and

[3] Regarding the other models of port management: i) Private Service Ports, in which the construction of infrastructure, superstructure and the provision of services corresponds to private initiative are found exclusively in the United Kingdom, New Zealand and the Port of Piraeus in Greece; ii) Public Service Ports, in which the port authority is the owner of the infrastructures, superstructures and is responsible for the provision of services, are common in developing countries (e.g., India, Sri Lanka, Indonesia) and; iii) Tool Ports, in which the port authority retains ownership of the infrastructure and superstructures, but the provision of services is carried out by private initiative; the Chittagong Port in Bangladesh and the “Ports Autonomes” in France are examples of this model.

[4] From 2002 to 2018, twenty-six more terminals (twenty-five of them privately managed) have been built.

[5] For instance, the Cartagena, Malaga and Huelva ports are specialized in liquid bulk terminals; the ports of Almería, Avilés, Gijón, Motril and Pasaia in solid bulk.

Barcelona. In terms of total tons handled, Algeciras ranks fifth and Valencia ranks ninth among the top ten European ports in 2021.[6] In view of all the above, our research question is: Is private managing of terminals increasing Spanish port efficiency? And if so, is the type of terminal relevant for such effect?

In response to the aforementioned questions, we have the following objectives. The first objective is to assess the impact of private management of port terminals on the technical efficiency of Spanish ports from 2002 to 2018. The second objective is to study that effect in relation to the type of terminal, i.e., whether the positive effect of private terminal management is dependent on the type of traffic. To achieve the above two objectives, we also include a set of environmental variables as determinants of technical efficiency, such as the location of ports on islands, the availability of oil refineries, the use of rail access, the coastline where the port is located, legal reforms and port size.

To achieve our objectives, we propose a two-stage approach. In a first stage we measure technical efficiency of the Spanish ports using two different methods: a parametric method using a stochastic production function (SFA) and a non-parametric method (DEA) assuming constant and variable returns to scale. In a second stage, a Tobit estimation for the index obtained by SFA and the Simar-Wilson algorithm for the indexes obtained by DEA (Simar and Wilson 2008) will be used to analyze the determinants of technical efficiency. In particular, we study how the evolution of the implementation of private management of terminals affects the efficiency of the port system. This analysis will be done considering the total number of terminal ports of any type and then, distinguishing the terminals by their traffic specialization. Additionally, other variables like the legal reforms, port size and other environmental or control variables were also analyzed as potential determinants of the efficiency. Our results show that Spanish ports with more privately managed terminals are more technically efficient, and this result remains valid regardless of the approach used. Regarding the effects according to the type of terminal, solid bulk and non-containerized general cargo terminals followed by container and liquid terminals implies larger increases in efficiency as compared to the passenger terminals privately managed. The latter result is reached regardless the approach used. Regarding environmental variables, large ports, those located in islands, those close to oil refineries and those having rail access are more efficient under at least one of the approaches used. Similarly, ports in the Atlantic coastline are less efficient than those in the Mediterranean one. Finally, only the reform introduced in 2003 had a significant negative impact on efficiency under the parametric approach.

1.1. Literature review

Several authors have recently analyzed the effects of port specialization on Spanish ports efficiency, although these studies focus on the port specialization in the type of cargo instead of on the type of terminal. Tovar and Wall (2017), for a sample in the period 1993–2012 and including all Spanish ports with the exception of Almeria, use the non-parametric methodology in a first stage and the Simar-Wilson methodology in the second stage. They conclude that port specialization has positive effects on technical efficiency, especially for large ports specialized in liquid bulk and non-containerized general cargo. Similarly, Tovar and Wall (2019), using the same Spanish ports as in Tovar and Wall (2017) and for the period 1993–2016, classify them into two clusters depending on the size and complexity of the port. Using non-parametric techniques, they show that larger and more complex ports are more technically efficient and also that ports specialized in solid bulk and containerized cargo attain greater productivity. Hidalgo-Gallego et al. (2020) estimate an input-oriented stochastic distance function for all Spanish ports except Sevilla for the period 1986–2015. They conclude that full specialization is not recommended to maximize technical efficiency since the ideal specialization consists of handling two different types of cargo. Pérez et al. (2020) estimate an output-oriented stochastic distance function for the full sample of Spanish ports in the period 2002–2011. They show that more specialized and larger ports are more technically efficient. Besides, these authors recommend specialization if possible and collaboration between small ports with different types of specialization. Finally, Hidalgo-Gallego et al (2022) focus on the allocative efficiency of the Spanish port system during the period 1992–2016, finding that recent reforms have had a significant effect.

Regarding the effects of the legislative reforms on the Spanish port system, González and Trujillo (2008) use an output-oriented stochastic distance function to conclude that the reforms of 1992 and 1997 had no effect on the technical efficiency of the nine ports with the largest containerized cargo in the period 1990–2002. Next, Díaz-Hernández et at. (2008), using non-parametric techniques, confirm the result of González and Trujillo (2008) for the effect of the 1997 reform. However, Núnez-Sánchez and Coto-Millán (2012) obtain total factor productivity, technical progress and technical efficiency using an input-oriented distance function to conclude that the reforms of the years 1992, 1997 and 2003 had improved total factor productivity but reduced technical efficiency. Similarly, Rodríguez-Álvarez and Tovar (2012) apply a short-run total cost distance function to show that the 1992 and 1997 reforms had positive effects on economic efficiency, while the 2003 reform did reduce economic efficiency. Coto-Millán et al. (2015) show that the 2003 reform has positive effects on the technical efficiency of the companies operating in the Spanish port system for the period 2000–2011. Finally, Coto-Millan et al. (2016) analyze the effects of the legislative reforms of the years 1992, 1997, 2003 and 2010 on technical efficiency using an input-oriented stochastic distance function, showing that the reforms of the years 1997 and 2003 had positive effects.

In the international context, most articles analyze the effects of privatization on port efficiency where the private firm also becomes the owner of port infrastructures, in contrast to the advanced landlord model used in Spain where ownership remains in the public sector. Liu (1995) analyzes three different types of ownership (private, trust and municipal) on the efficiency of British ports, where no pattern is found between the type of ownership and the improvement in port efficiency. Valentine and Gray (2001) compare the non-parametric technical efficiency of thirty-one ports in 1998 that are privately owned with ports that are publicly owned and also with ports that have elements of both private and public ownership. The main conclusion is that ownership structure has no influence on efficiency. However, Cullinane et al. (2002) obtain the economic efficiency of the fifteen largest container ports in Asia for the period 1989–1998 and show that large ports and those that have transformed their ownership structure from public to private improve their economic efficiency. Also, Cullinane and Song (2003) applying a stochastic frontier approach with a Cobb-Douglas functional form, show that the improvement of productive efficiency in five South Korean container terminal operators was due to deregulation and privatization policies in the Korean port system. Barros and Athanassiou (2004), using a non-parametric method for Greek and Portuguese ports, corroborate that privatization and competition have been found to be the best procedures for efficiency improvements as in Jones et al. (1990). Cullinane and Song (2006) calculate productive efficiency in the world container port industry following a DEA methodology. Cheon et al. (2010) assess port level efficiencies for the years 1991 and 2004 using a Malmquist Index and conclude that ports that shifted their ownership structure from public to private have had higher total factor productivity gains. Bichou (2013) for a sample of world container ports calculates a series of DEA models to measure operational efficiency. The results show that variations in operating conditions highly impact terminal efficiency. Besides, Serebrisky et al. (2016) use

[6] See https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Top_20_ports_handling_containers,_2008-2018_(thousand_TEUs).png; and https://ec.europa.eu/eurostat/databrowser/view/mar_mg_aa_pwhd/default/table?lang=en.

data from 63 container terminals worldwide for the period (1999–2009) and conclude that privatization and the landlord model account for the largest efficiency gains. Finally, Tongzon and Heng (2005) found efficiency gains derived from the landlord management Model. These authors analyze the efficiency gains of twenty-five container terminals worldwide using a stochastic production frontier and find that the largest technical efficiency gain occurs under the landlord management model.

Regarding port specialization in the international context, Chang and Tovar (2017) measure the productivity of port terminals by using the Malmquist index after calculating DEA in 14 Chilean and Peruvian ports for a sample from 2002 to 2014. They find that privatization and containerization of terminals positively influence the productivity of port terminals. Similarly, Adler et al. (2022) use a sample of 21 Indian ports for the period 1995–2015 and show that specialization and stakeholder participation have a positive impact on port performance.

Regarding the influence of port size on efficiency, Sohn and Jung (2009) obtain data for the 16 largest ports in Asia between the years 1995 and 2005. They employ SFA to measure the technical efficiency of ports and conclude that port size has a positive effect on technical efficiency when the annual container throughput reaches 5 million TEUs. Next, Perez et al. (2016) uses a sample of 40 Latin American container terminals for the period 2000–2010 and by a stochastic production frontier they show that ports with larger terminal size are more efficient. Similarly, Hynes et al. (2020) analyze the relationship between port size and efficiency for a set of Irish ports and those located on the Spanish Atlantic coast for the period 2000–2015. To achieve this, they apply a two-step, double-bootstrap data DEA approach and their results show the positive relationship between port size and technical efficiency in ports in peripheral regions.

The contribution of this paper is twofold. First, our work analyzes how the type of the terminal and the proportion of each type of terminal managed by private firms affects the efficiency of ports. There are many papers that analyze the impacts on efficiency of the output specialization. However, to the best of our knowledge, none of them addresses how the type of management affects port efficiency depending on the traffic to which the terminal is dedicated (i.e., container, liquid and oil, solid bulk, non-containerized general cargo, and passenger). Second, our paper studies how the landlord system based on the private management of the terminals has affected the efficiency of a relevant port system as the Spanish one.

The organization of the article is as follows. Section 2 presents the methodology of both the parametric method (SFA) and the non-parametric method (DEA-CRS and DEA-VRS). Section 3 describes the data. Section 4 shows the results of the production distance function, the technical efficiency indices, and the results of the determinants of the technical efficiencies. Finally, Section 5 concludes.

2. Methodology

We use a two-stage technique, as is common in the literature, in which we first estimate the efficiency indexes and then use exogenous factors to explain the efficiency indexes from the specification of a regression model. Technical efficiency measures of the Spanish port system are provided in the first stage empirical analysis. For robustness reasons, two methodologies are employed to quantify technical efficiency: a parametric way utilizing SFA and a non-parametric one, DEA with either constant or variable returns to scale. These are the first stage's outputs, which will be used in the second step. Now we explain the methodology used in each stage.

2.1. The first-stage: Estimates of the inefficiency indexes

2.1.1. Stochastic frontier analysis

The first approach will consist in the econometric estimate of the production function. Given that technology is characterized by the existence of multiple outputs, we will use a distance function (Shephard 1970, Coelli et al, 2005). A translogarithmic functional form of the distance function is chosen given their flexibility and easiness to calculate. According to Lovell et al. (1994) the distance function is normalized by an arbitrarily chosen output to be estimated. The output-oriented translog distance function for period $t = 1, 2, \ldots, T$, and for port $i = 1, 2, \ldots, N$, producing M outputs (where y_{mit} is the port's i m-th output level in period t) and using K inputs (where x_{kit} is input vector for port i, k-th input level in period t), is defined as follows:

$$ln\left(\frac{D_O}{y_M}\right)_{it} = \alpha_0 + \sum_{m=1}^{M-1}\alpha_m lny^*_{mit} + \frac{1}{2}\sum_{m=1}^{M-1}\sum_{n=1}^{M-1}\alpha_{mn} lny^*_{mit} lny^*_{nit} +$$
$$+\sum_{k=1}^{K}\beta_k lnx_{kit} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K}\beta_{kl} lnx_{kit} lnx_{lit} +$$
$$+\sum_{k=1}^{K}\sum_{m=1}^{M-1}\delta_{km} lnx_{kit} lny^*_{mit} + \sum_{a=1}^{A}\psi_a C_a + \sum_{s=1}^{S}\omega_s g_s + v_{it} + u_{it}, \qquad (1)$$

where $y^*_{mit} = \frac{y_{mit}}{y_{Mit}}$ and only $(M - 1)$ outputs are considered, C_a denotes environmental variables for $a = \{1,2, \ldots, A\}$; finally, time dummies, g_s, are also included for s starting in 2003 and ending in 2018, which take value one for the considered year s and zero otherwise.[7]

The error term is composed of two components. The first component (v_{it}) is iid variable following a $N\ (0,\sigma_v^2)$ distribution that captures the statistical noise arising from measurement errors and the omission of relevant variables. The second and non-negative component u_{it} is used to measure the technical inefficiency of each port in each time period. Denote $N^+(\mu,\ \sigma_u^2)$ the truncated-Normal distribution which is assumed with μ mean and variance σ_u^2 which defines u_i. Since we are considering the Battese and Coelli (1992) approach to take into account time effects, the inefficiency term, u_{it}, is defined by a specific function of time showing time-varying decay as follows:

$$u_{it} = \exp(-\eta(t - T)u_i \qquad (2)$$

where T the last period and η is the decay parameter. Thus, if $u_{it} = 0$, it means that port i is technically efficient, it is operating at the frontier.

2.1.2. Data envelopment analysis

DEA is based on the theory developed by Farrell (1957). The main difference with the SFA is that DEA is a non-parametric method which involves mathematical programming instead of the use of econometric methods. There are two different specifications. First, Charnes, Cooper and Rhodes (1978) developed a model to calculate efficiency indexes where technology is characterized by constant returns to scale (denoted DEA-CRS). Second, Banker, Charnes and Cooper (1984) proposed a more general specification by considering a technology characterized by returns to scale (denoted DEA-VRS). The choice between one specification or another is an unsolved matter. The literature offers mixed suggestions and findings, so that the appropriate choice depends on the homogeneity of the sample. If firms are similar in the technology and in size terms, DEA-CRS seems to be an appropriate assumption, but the second option is good when heterogeneity in technology and size are notable. Given that port size varies in our sample, but technology is relatively homogeneous, we opt to calculate both approaches to take advantage of all the possible results of the efficiency indexes.

[7] To ensure homogeneity of degree 1 in outputs, the $\sum_{m=1}^{M}\alpha_m = 1$, $\sum_{m=1}^{M}\alpha_{mn} = 0$, $\sum_{k=1}^{K}\delta_{km} = 0$ restrictions are imposed. Since ln Do_{it} is continuously differentiable $\alpha_{mn} = \alpha_{nm}$, $\beta_{km} = \beta_{mk}$.

Table 1
Descriptive statistics of inputs and outputs.

Variable	Obs.	MeMean	St. dev.	Min	Max
Quays (x_1) [m]	473	10,171	6,514	1,535	28,910
Surface (x_2) [m^2]	473	2,929,735	2,541,250	240,671	11,099,352
Labor (x_3) [*# of workers*]	473	198	111	43	578
Containers (y_1) [TEUs]	473	468,851	1,031,333	0	5,182,655
Liquids (y_2) [Tons]	473	5,498,762	7,649,714	0	31,763,061
Solid bulk (y_3) [Tons]	473	34.51,770	3.642,454	3.425	19.220,421
Non-container. general cargo (y_4) [Tons]	473	2,086,765	2,649,879	122,587	14,085,935
Passengers (y_5) [*# of pass.*]	473	973,899	1,703,909	0	8,942,434

Source: Own elaboration.

Table 2
Descriptive statistics for the second stage variables.

Variable	Obs.	Mean	Standard dev.	Min	Max
Priv	473	0.7692	0.2371	0	1
CON	456	0.1335	0.1817	0	1
LIQ	456	0.3639	0.2535	0	1
SB	456	0.3843	0.2586	0	1
NC	456	0.0735	0.1275	0	0.5
PAX	456	0.0448	0.0992	0	0.5
C_{Loc}	473	0.1078	0.3105	0	1
C_{Ref}	473	0.2875	0.4531	0	1
C_{Tra}	473	0.5793	0.4942	0	1
C_{Atl}	473	0.3954	0.4894	0	1
C_{Can}	473	0.1797	0.3843	0	1
C_{Med}	473	0.4543	0.4985	0	1
C_{Size}	473	0.2241	0.4174	0	1

Source: Own Elaboration.

Table 3
Description of the acronyms of variables used in the second stage analysis.

Acronyms of variables	Description
Priv	Proportion of privately managed terminals over total number of terminals
CON	Proportion of privately managed container terminals over total number of privately managed terminals
LIQ	Proportion of privately managed liquid and oil terminals over total number of privately managed terminals
SB	Proportion of privately managed solid bulk terminals over total number of privately managed terminals
NC	Proportion of privately managed non-containerized general cargo terminals over total number of privately managed terminals
PAX	Proportion of privately managed passenger terminals over total number of privately managed terminals
C_{Loc}	Dummy variable taking value one for ports located in island
C_{Ref}	Dummy variable taking value one for ports that have an oil refinery nearby
C_{Tra}	Dummy variable taking value one for ports that use railway access
C_{Atl}, C_{Can}, C_{Med}	Dummy variables taking value one for ports that are located on the Atlantic, Cantabric and Mediterranean coastlines, respectively
C_{Law03}, C_{Law10}, C_{Law11}	Dummy variables taking value one for the years 2003, 2010 and 2011 respectively to represent legal reforms
C_{Size}	Dummy variable taking value one for ports that have more than 15,000 linear meters of quay.

Similarly, to the SFA analysis, there are N ports. Each port, *i* produces *M* outputs combining *K* different inputs, where vector y_i is the port's *i* output vector, $y_i \in R_+^M$, and x_i is the input vector, $x_i \in R_+^K$. The measurement of the output-oriented technical efficiency under either CRS or VRS using DEA is obtained by solving the following mathematical programming problem, presented in its envelopment form. It is solved for each period t and each port, i, where ϕ_i is a scalar and λ_i a vector of non-negative constants:[8]

Table 4
TE averages per port using the SFA, DEA-CRS and DEA-VRS approaches.

Port	SFA	DEA-CRS	DEA-VRS
A Coruña	0.4160	0.6896	0.7084
Alicante	0.4247	0.2665	0.3086
Almeria	0.9235	0.8669	0.9103
Avilés	0.6782	0.8492	0.9072
B. Algeciras	0.9673	0.9506	0.9571
B. Cadiz	0.3812	0.2521	0.2580
Baleares	0.7290	0.8384	0.8421
Barcelona	0.8346	0.8447	0.8527
Bilbao	0.6198	0.7516	0.8168
Cartagena	0.4356	0.8721	0.8781
Castellón	0.5048	0.6680	0.7831
Ceuta	0.3676	0.4329	0.6108
Ferrol S.C.	0.7795	0.7622	0.8864
Gijón	0.9428	0.8834	0.8977
Huelva	0.4492	0.6907	0.7007
Las Palmas	0.5971	0.4577	0.4608
Malaga	0.3798	0.4319	0.4517
Marín and R.P.	0.4523	0.3636	0.6756
Melilla	0.3089	0.4384	0.4415
Motril	0.4788	0.3204	0.4311
Pasaia	0.5386	0.6087	0.8750
S.C. Tenerife	0.3969	0.7071	0.9068
Santander	0.5434	0.3623	0.3629
Sevilla	0.5990	0.5193	0.6670
Tarragona	0.4504	0.6843	0.7352
Valencia	0.9132	0.9115	0.9368
Vigo	0.2266	0.3631	0.3865
V. Arousa	0.3082	0.1807	0.2360
Average	*0.5587*	*0.6018*	*0.6160*

Table 5
Spearman's rank-order correlation coefficients between the different technical efficiency indices.

	SFA	DEA-CRS	DEA-VRS
SFA	1		
DEA-CRS	0.7176	1	
DEA-VRS	0.7066	0.9414	1

$$\begin{aligned} &\mathrm{Max}_{\phi_i,\lambda_i}\phi_i \\ &\text{subject to:} \\ -\phi_i y_{im} + &\sum\nolimits_{j=1}^{N}\lambda_{ij}y_{jm} \geq 0\,\forall m,\ \text{where } m = 1,...,M \\ x_{ik} - &\sum\nolimits_{j=1}^{N}\lambda_{ij}x_{jk} \geq 0\,\forall k,\ \text{where } k = 1,...,K \\ &\lambda_i \geq 0. \\ \sum\nolimits_{j=1}^{N}\lambda_{ij} = 1. &\quad \text{only for the DEA-VRS model.} \end{aligned} \tag{3}$$

[8] To make the presentation simpler, the sub-index *t* will be saved in the expressions.

Table 6
Results of the second stage.

Variable	SFA	Std. Err.	DEA-CRS	Std. Err.	DEA-VRS	Std. Err.
Priv	0.202***	0.056	0.172*	0.092	0.277**	0.115
CON	0.335***	0.108	0.667***	0.183	0.885***	0.219
LIQ	0.181**	0.088	0.547***	0.151	0.465***	0.173
SB	0.489***	0.092	0.817***	0.164	1.150***	0.203
NC	0.465***	0.121	0.815***	0.214	0.967***	0.257
C_{Loc}	−0.005	0.041	0.167**	0.069	0.249***	0.092
C_{Ref}	0.007	0.020	0.329***	0.037	0.481***	0.057
C_{Tra}	0.007	0.022	0.056	0.034	0.128***	0.042
C_{Atl}	−0.025	0.011	−0.155***	0.038	−0.162***	0.048
C_{Can}	0.045*	0.025	−0.008	0.043	−0.022	0.055
C_{Law03}	−0.055**	0.022	−0.008	0.044	0.004	0.054
C_{Law10}	−0.026	0.035	−0.060	0.054	−0.067	0.068
C_{Law11}	−0.033	0.034	0.049	0.052	0.064	0.066
C_{Size}	0. 211***	0.027	0.169***	0.049	0.114*	0.065
Constant	0.097	0.100	−0.274	0.176	−0.469**	0.214

***, ** and * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively.

Notice that $1 \leq \phi_i$, and that $\phi_i - 1$ is, precisely, the proportional increase in outputs that could be achieved by the *i-th* port with inputs held constant. Therefore, $\frac{1}{\phi_i}$ defines a technical efficiency measure that varies between zero and one, where the ports considered technically efficient are those with $\phi_i = 1$.

There are many papers that discuss the advantages and disadvantages of using parametric and nonparametric approaches in the calculation or estimation process of efficiency indexes (see Van Biesebroeck (2007) or Orea and Zofío (2019) for two good reviews of this discussion). A parametric technique, such as SFA, has the advantage of separating the error term into a part showing inefficiency and another idiosyncratic component reflecting usual measurement errors or the omission of relevant variables. Estimating a production (cost) function enables the identification of statistical features such as the returns to scale, marginal productivities of inputs, and marginal costs. One significant disadvantage of these strategies is the requirement to enforce a specific functional shape. Non-parametric approaches, such as DEA, do not have to impose any functional form, but the distance to the frontier cannot be divided into inefficiency and the idiosyncratic part. Furthermore, using several outputs and inputs is simpler and more reliable, especially with small samples. In any case, Orea and Zofío (2019) advise using and combining several methodologies. They claim that a good indication of robustness and consistency between different inefficiency indexes is that all the methods provide similar and stable rankings.

2.2. The second-stage: Estimates of the determinants of the inefficiency

In the second stage, we identity the determinants of the technical efficiency using the three indexes obtained above. Given that the dependent variable is a censored variable, we use a Tobit estimation for the efficiency index obtained by SFA. In the case of the indexes obtained by DEA, some authors (Simar and Wilson, 2007) have discussed the validity of the DEA efficiency scores in the two-stage applications. Simar and Wilson (2008) show the risk of presence of serial correlation, because treating the data as independent observations is not appropriate. To avoid this bias, Simar and Wilson (2007) develop a new algorithm, which defines an underlying data generating process that is consistent with a two-stage estimation procedure.

In particular, we propose the following equation to be estimated:

$TE_{it} = \beta_0 + \beta_i X_{it} + \varepsilon_{it}$ (4).

where TE_{it} denotes the inefficiency indexes (being u_{it}, as defined in Eq. (2) under the SFA, or ϕ_{it}, as defined in Eq. (3) under DEA assuming constant or variable returns to scale. In the first case, a Tobit model will be estimated, and Simar-Wilson method will be used in the second stage analysis for DEA efficiency indexes.[9]

3. Data

There is no general consensus, however most papers in the literature on port efficiency analysis use numerous inputs and outputs (see Núñez-Sánchez and Coto-Millán, 2012, and González and Trujillo, 2008, for two good reviews on this subject). They differentiate between freight and passengers, and within freight, they consider many types of cargo (containers, liquids and oil, solid bulk, and general or non-containerized goods). Some articles aggregate the outputs in terms of tons while ignoring the ports' multioutput capability. Finally, some articles utilize the number of ships arriving at ports, ship capacity measured in gross tonnage, or financial income from port services as output measures (see Bang et al., 2012; Coto-Millán et al., 2015). These works have the disadvantage again that they do not consider the heterogeneity of the cargo.

In terms of inputs, most articles use data on labor, infrastructure, and superstructure. Labor can be measured in both average number of workers and personnel expenditure. Infrastructure is measured in square meters in most articles. Data on port superstructure is used in some articles, including data on the number and type of cranes, stevedore equipment, and other types of assets (see Pérez et al., 2016; Pérez et al., 2020). Many articles, however, address the difficulty in obtaining sufficient information regarding this type of data due to its scarcity and ownership by private firms. Alternatively, total quay meters are employed as an input required for ship mooring (see Serebrisky et al., 2016; Pérez et al., 2016; Hidalgo-Gallego et al., 2020).

We build an unbalanced panel data composed of 473 observations from 28 ports in the period 2002 to 2018. Five outputs and three inputs have been considered. The variables selected as outputs are TEU's of containers (y_1), tons of liquid bulk (y_2), tons of solid bulk (y_3) tons of non-containerized general cargo (y_4) and number of passengers (y_5).[10,11] The inputs considered are the linear meters of quay[12] (x_1), the square meters of surface area (x_2) and the number of workers (x_3).

In terms of inputs, we adopt the same procedure as González and Trujillo (2008). As a result, input x1 (the linear meters of quay) is needed for ship mooring, which is required for the loading and unloading of cargo and passengers. This input is also a proxy for various superstructure assets, such as the number of cranes.[13] Input x2 (square meters of surface) stands for a measure of infrastructure that represents the space required for the storage and management of commodities, such as

[9] In the case of inefficiency indexes obtained by SFA, in order to gain efficiency in the estimates, Battese and Coelli (1995) developed a one-stage model incorporating the explanatory factors of efficiency simultaneously to the estimate of the production function. Given that in our work the determinants of efficiency obtained by DEA must be estimated in a second stage we have kept this second stage procedure for the three inefficiency indexes.

[10] Fresh fishing cargo, which represents 0.01% of the total tons of the Spanish port system, local traffic, which represents 0.28%, and provisioning, which represents 2.98%, have been disregarded. Therefore, our output sample represents more than 96% of the total tons, on average, for the period 2002–2018 and captures in an appropriate way the multioutput feature of the port system.

[11] According to Table 1, there are ports that have no activity in any of the defined outputs. To solve the problem of undefined natural logarithms, each zero has been replaced by a two. According to Battese (1997, pp. 252), this procedure does not affect the basic estimation of the parameters.

[12] Only linear meters of dock with a draft of more than 4 m have been used. Note that linear meters of quay and square meters of surface area managed by both private companies and the port authority have been considered.

[13] We have not considered other productive factors such as cranes, cold storage, or pipelines due to the lack of data, since most of this information corresponds to private companies that operate in the port and many data are not available or not reliable.

warehouses, roads, and buildings. Finally, x3 (denoting labor) is approximated using the number of port authority workers, which includes not only administrative staff but also more skilled technical workers.

Note that ports in islands can only be reached by air or sea, while those in the mainland have also the option of road and railway. Also, ports nearby a refinery have an advantage in attracting liquid bulk cargo, which is easy and quick to handle in this type of installation. In order to take into account these two characteristics of the ports, the C_{Loc} dummy stands for value one for ports located in islands (Baleares, Las Palmas and Santa Cruz de Tenerife ports), zero otherwise. The C_{Ref} dummy takes value one for the following ports, A Coruña, Bahia de Algeciras, Bilbao, Cartagena, Castellón, Huelva, Santa Cruz de Tenerife and Tarragona, which are located close to a refinery (see Fig. 1). Table 1 shows a summary of the descriptive statistics of outputs and inputs.

Among the determinants of technical efficiency, we include as relevant variables the privately managed terminals per port, several environmental variables that include the two used in the previous analysis (C_{Loc} *and* C_{Ref}) together with others that indicate whether the port uses its railway access, the coastline in which the port is located, several dummies to account for the effect of recent legislative reforms, and finally, a variable accounting for port size.

As we previously explained, ports have terminals specialized for different types of cargo, in particular, containers, general cargo, bulk (liquid, oil and solid) and passenger. To consider the effect of private management of terminals in port technical efficiency, we first introduce the variable *Priv*, defined as the proportion of all terminals managed under private initiative with respect to the total number of terminals per port and year. Then, to distinguish that effect by type of terminal, the variables *CON, LIQ, SB, NC* and *PAX* are the proportion of privately managed terminals of the container, liquid bulk, solid bulk, non-containerized general cargo and passenger terminal type with respect to the total number of privately managed terminals per port and year. Regarding environmental dummy variables, a group of dummy variables, C_{Atl}, C_{Can} and C_{Med} are introduced (see Fig. 1) indicating the coastline where the port is located either the Atlantic Ocean, the Cantabric Sea or Mediterranean Sea, respectively. Also, the dummy variable C_{Tra} which takes value one when a port has rail access and makes use of it. Besides, we define dummy variables C_{Law03}, C_{Law10} and C_{Law11} that take value one from the year 2003, 2010 and 2011, respectively, until the year 2018, to account for the legal reforms introduced in the Spanish port system legislation in such particular years. Finally, the C_{Size} dummy variable is used to account for the size of the ports. It takes value one for each port having more than 15,000 linear meters of quay.

Table 2 shows the descriptive statistics of the different types of port terminals and other second stage analysis variables. Note that variables *CON, LIQ, SB, NC* and *PAX* only have 456 observations since there is one port not having privately managed terminals. Table 3 includes the description of all variables used in the second-stage analysis.

4. Results

4.1. First stage analysis: The distance function estimation

As we explained in the methodology section, the technical efficiency indexes are obtained from the estimate of the econometric SFA, and from a non-parametric technique like DEA, assuming constant o variable returns to scale. Regarding the estimate of the SFA, Table A1 in the Appendix shows the estimates of the coefficients of all the variables of the translog function in Eq. (1). Additionally, fixed effects are included in the model in order to capture non-observable features in ports. First-order coefficients are significant and show the expected sign. Output variable coefficients are negative indicating that the distance from the frontier increases when production grows. On the other hand, all the input variable coefficients are positive, and their sum is greater than one. Therefore, when the use of inputs increases for a given output level, the distance from the frontier is reduced. These first order coefficients can be interpreted as elasticities evaluated on the data average, since data are in logs and deviated from its mean. The greatest value for the input elasticity corresponds to labor, reaching 0.9148, followed by the quasi-fixed input quays, with a value of 0.3857. The surface coefficient is not statistically significant. Our results are similar with those obtained in previous papers, as in Baños-Pino et al. (1999), González and Trujillo (2008), Núnez-Sánchez and Coto- Millán (2012) and Coto-Millan et al. (2016).

Regarding the environmental variables, the C_{Loc} variable is not significant, while the C_{Ref} variable has a positive and significant coefficient. Therefore, ports with nearby refineries benefit from a shift outward from the frontier. González and Trujillo (2008) find that both dummy variables are significant, and that the *refinery effect* is larger than the *island effect.* On the other hand, Pérez et at. (2020) also obtain a positive and significant result for the refinery dummy variable.

Table A2 in the Appendix displays the estimated values of the relevant parameters in the error term specification in Eq. (1). Note that a large proportion of the total error variance, i.e., 96%, is related to the component used to measure technical inefficiency, u. Also, parameter η has a negative sign indicating that efficiency has declined during the period analyzed. Additionally, Table A3 in the Appendix shows the average economies of scale by year. It is observed that there are increasing returns to scale during the whole period. This result confirms those obtained by Martínez-Burdía (1996), Coto-Millán et al. (2000), González and Trujillo (2008) and Coto-Millan et al. (2016) for a different period.

As a result of this first-stage analysis, Table 4 shows the average of technical efficiency indexes for each port and approach used. The average technical efficiency of the Spanish port system is 0.5587 for the parametric method (SFA) and 0.6078 and 0.6760 for the non-parametric methods DEA-CRS and DEA-VRS, respectively. Additionally, we compare the efficiency indexes among the different approaches using the Spearman's rank-order correlation index, that measures the ranking correlations of the different efficiency indicators. Table 5 shows that the ranking correlation coefficients obtained from different approaches (SFA and DEA) are above 0.7, showing that our inefficiency indexes are consistent (see Orea and Zofío, 2019).

4.2. Second stage analysis: The determinants of technical efficiency

Table 6 shows the second-stage results. Columns 2, 4 and 6 display the estimates of the second-stage analysis taking as dependent variable the technical efficiency indexes obtained using the SFA, DEA-CRS and DEA-VRS approaches, respectively. In general terms, the estimates are qualitatively similar for each technical efficiency index. Note that privately managed port terminals, variable *Priv* coefficient, have always positive effects on efficiency indexes with different levels of significance depending on the approach used. To take account of the effect of private management of terminals by type, we have introduced variables *CON, LIQ, SB,* and *NC* as determinants of technical efficiency (the proportion of privately managed passenger terminals, *PAX,* is chosen as the reference). We find that all types of terminals have positive and significant effects on technical efficiency as compared to the passenger terminals privately managed, regardless the approach used. In fact, the largest increase is due to solid bulk terminals, followed by non-containerized and containerized terminals and being liquid bulk terminals the ones with the lowest increase. Ports located on islands are more efficient than ports located on the peninsula when using the non-parametric approaches. CLoc captures whether captive shippers (more common in ports located on islands) can influence the efficiency positively or negatively. Our findings are consistent with those of González and Trujillo (2008) and Pérez et al (2020), who conclude that ports on islands are more productive than the rest. The availability of an oil refinery near the port has the same outcome. The fact that the existence of an oil refinery can increase efficiency might be explained by the fact that these installations can significantly increase liquid bulk traffic.

The use of rail access improves efficiency under the DEA-VRS approach. Regarding the location of the ports on the different coastlines, the ports on the Atlantic coastline are less efficient than the Mediterranean ones, when the non-parametric approaches are used. The legislative reform of 2003 has a significant negative effect only under the parametric approach. Finally, the ports categorized as large, those with more than 15,000 linear meters of quay, are significantly more efficient than the rest.

5. Conclusions

This paper analyzes the technical efficiency of the Spanish Port System by applying some alternative techniques, a stochastic frontier approach (SFA) using an econometric estimate of a distance function and Data Envelopment Analysis (DEA) assuming alternatively CRS and VRS in the analysis. The technical efficiency rankings obtained by the different techniques show a relative high correlation as shown by the Spearman's ranking-order correlation coefficient. The results of the determinants of technical efficiency are robust to the approach used. In particular, privately managed terminals have positive effects on technical efficiency for all the traffics considered. Regarding the effect by type of terminal, it is observed that the greatest improvement is obtained with solid bulk terminals, followed by non-containerized general cargo terminals, containerized terminals and liquid bulk terminals. Thus, the results suggest that ports with passenger terminals are less efficient with respect to ports with non-passenger terminals.

Additionally with respect to the environmental variables considered, it is observed that ports located on islands and those ports that have an oil refinery installed in their vicinity are more efficient in the non-parametric approach, which is in line to the results obtained by González and Trujillo (2008) and Pérez et al. (2020). The use of rail access has positive effect on technical efficiency only when the DEA-VRS approach is used. Ports located on the Atlantic coast are less efficient than ports located on the Mediterranean coast in the non-parametric approaches. Legislative reforms either have had a negative effect (only the 2003 reform under the parametric approach) or had no effect on technical efficiency in the same line as previous results obtained by González and Trujillo (2008), Díaz-Hernández et al. (2008) and Núñez-Sánchez and Coto-Millán (2012). Ports categorized as large are more efficient than the rest. This result is in agreement with Liu (1995), Martínez-Budría (1996) and Pérez et al. (2020). Finally, it is important to mention that although positive statistical evidence of the effect of the reforms cannot be assessed, their aim to favor private initiatives is in the good direction. The reason is that we find strong evidence supporting that private management of terminal increase ports efficiency and also that more than 95% of the increase in the number of terminals is in privately managed ones.

From our results, one theoretical implication is that computing the efficiency levels using different methodologies is advisable in order to check for the robustness and consistency of the results. The point is that when analyzing the determinants of technical efficiency, results are stronger when the rankings obtained from different methodologies are similar (see Orea and Zofío, 2019). Several practical implications for port management and port efficiency can be drawn from our results. First, port authorities should encourage privatization of terminals since this has positive effects on efficiency. That effect will be the strongest if privatization is in the case of solid bulk terminals, while for privatization of passenger terminals is the weakest. Second, in view of the positive effect on efficiency of oil refineries close to ports, we may conclude that large infrastructures that are complementary to port activities add synergies to port efficiency. Finally, our results show that port size is an important factor in port efficiency. According to the "Anuario Estadístico de Puertos del Estado", the size of ships is increasing and the number of ships on the move is decreasing. Therefore, a larger port has a greater capacity to attract large vessels and handle large volumes of cargo, which can result in greater efficiency. As such, the port policy manager should encourage the expansion of port facilities if possible.

Finally, there are some external factors that can affect port efficiency. Some of these factors include the duration of the concession, the scope of intra-port competition among terminals, the level of autonomy to invest in infrastructure assets, and the degree of financial independence. Many of these variables are related to policy concerns, concession design, or the intensity of port competition. Collecting appropriate information regarding these points may be a difficult and time-consuming effort that extends beyond the scope of our paper, but in any event, this analysis merits further investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Table A1 - A3.

Table A1
Estimated output-oriented distance function.

Variable	Coefficient	Estimates	Std. Error
$Ln(y_1)$	α_{y1}	−0.0712***	0.0093
$Ln(y_3)$	α_{y3}	−0.03391***	0.0232
$Ln(y_4)$	α_{y4}	−0.4016***	0.0259
$Ln(y_5)$	α_{y5}	−0.0751***	0.0098
½ $Ln(y_1)\ Ln(y_1)$	α_{y11}	−0.0135***	0.0019
½ $Ln(y_3)\ Ln(y_3)$	α_{y33}	−0.0946***	0.0087
½ $Ln(y_4)\ Ln(y_4)$	α_{y44}	−0.1088***	0.0161
½ $Ln(y_5)\ Ln(y_5)$	α_{y55}	−0.1000***	0.0017
$Ln(y_1)\ Ln(y_3)$	α_{y13}	−0.0224**	0.0100
$Ln(y_1)\ Ln(y_4)$	α_{y14}	0.0084	0.0097
$Ln(y_1)\ Ln(y_5)$	α_{y15}	−0.0007	0.0018
$Ln(y_3)\ Ln(y_4)$	α_{y34}	−0.1666***	0.0223
$Ln(y_3)\ Ln(y_5)$	α_{y35}	−0.0053	0.0077
$Ln(y_4)\ Ln(y_5)$	α_{y45}	0.0210***	0.0082
$Ln(x_1)$	β_{x1}	0.3857***	0.0647
$Ln(x_2)$	β_{x2}	0.0031	0.0446
$Ln(x_3)$	β_{x3}	0.9148***	0.0976
½ $Ln(x_1)\ Ln(x_1)$	β_{x11}	0.1503	0.2147
½ $Ln(x_2)\ Ln(x_2)$	β_{x22}	0.1888**	0.0857
½ $Ln(x_3)\ Ln(x_3)$	β_{x33}	0.4774	0.3457
$Ln(x_1)\ Ln(x_2)$	β_{x12}	−0.3548*	0.2086
$Ln(x_1)\ Ln(x_3)$	β_{x13}	−0.2202	0.1756
$Ln(x_2)\ Ln(x_3)$	β_{x23}	0.0112	0.1756
$Ln(y_1)\ Ln(x_1)$	δ_{y1x1}	−0.0106	0.0121
$Ln(y_1)\ Ln(x_2)$	δ_{y1x2}	−0.0020	0.0055
$Ln(y_1)\ Ln(x_3)$	δ_{y1x3}	0.0408***	0.0173
$Ln(y_3)\ Ln(x_1)$	δ_{y3x1}	0.1157***	0.0375
$Ln(y_3)\ Ln(x_2)$	δ_{y3x2}	−0.0131	0.0255
$Ln(y_3)\ Ln(x_3)$	δ_{y3x3}	0.0093	0.0401
$Ln(y_4)\ Ln(x_1)$	δ_{y4x1}	−0.1583***	0.0378
$Ln(y_4)\ Ln(x_2)$	δ_{y4x2}	0.0255	0.0291
$Ln(y_4)\ Ln(x_3)$	δ_{y4x3}	0.0506	0.00478
$Ln(y_5)\ Ln(x_1)$	δ_{y5x1}	0.0211	0.0134
$Ln(y_5)\ Ln(x_2)$	δ_{y5x2}	0.0089	0.0071
$Ln(y_5)\ Ln(x_3)$	δ_{y5x3}	−0.0261*	0.0136
C_{Loc}	ϕ_{Loc}	0.1899	0.1511
C_{Ref}	ϕ_{Ref}	0.3892**	0.1059

***, ** and * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively.

Table A2
Estimates for the distance function error term parameters.

Parameter	Estimates	Std. Error
μ	0.6904***	0.2377
η	−0.0254**	0.0054
σ_u^2	0.2923	0.1497
σ_v^2	0.0116	0.0008

*** ** and * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively.

Table A3
Average of economies of scale for each year.

Year	Economies of Scale	Std. Err.
2002	1.2363	0.0532
2003	1.2363	0.0573
2004	1.2386	0.0591
2005	1.2221	0.0619
2006	1.2380	0.0604
2007	1.2519	0.0629
2008	1.2805	0.0609
2009	1.3246	0.0636
2010	1.3214	0.0700
2011	1.3335	0.0677
2012	1.3400	0.0623
2013	1.3425	0.0669
2014	1.3421	0.0625
2015	1.3511	0.0587
2016	1.3552	0.0594
2017	1.3444	0.0635
2018	1.3435	0.0629
Average	*1.3005*	*0.0150*

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