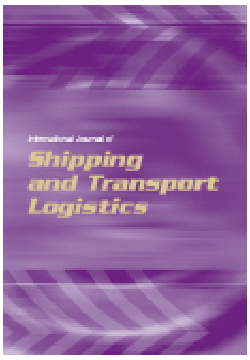

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The determinants of economic efficiency and market power of the Spanish port system

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Abstract: This paper estimates the economic efficiency of Spanish ports for the period 2002–2019. In a second stage, the main determinants of economic efficiency are analysed including the type of terminal management (public or private) and the traffic to which the terminal is specialised. Finally, market power is measured by applying the Boone index in two different geographical markets: the north and the south and east markets and six product markets for each of them. We show that the Spanish port system has improved efficiency and that private management of terminals has a positive effect on economic efficiency. Besides, larger ports and those with access to complementary assets (rail access and oil refinery) obtain better efficiency indexes. Regarding market power, the most competitive product market is containers in transshipment in the south and east geographical market. Also, the latter geographical market is more competitive than the north market.

Keywords: economic efficiency; market power; stochastic frontier approach; port terminals.

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1 Introduction

The port system is the most important link in the international transportation chain, and it is used by governments to stimulate the economy. According to the Observatory of Transport and Logistics in Spain (2018), 80% of international freight transport in Spain is carried out by maritime transport. Having an efficient and competitive port system is important to reduce export costs, thus increasing national products competitiveness, and to reduce prices paid by national consumers for imported products improving nation's welfare.

The Spanish port system includes 46 ports that are managed by 28 port authorities[1] under the control of the Ministry of Public Works through the state entity *Organismo Público de Puertos del Estado*. A total of 564.5 million tons were handled by Spanish ports in 2019, the third country in the EU, with a CAGR increase of 2.57% in the period 2002–2019. Spain is the leading EU country in container TEUs carried with 17,400 thousand TEUs in 2019, a CAGR increase of 4.68% in the same period. Three Spanish ports are ranked among the top 10 EU ports both in container and total cargo handling: Valencia, fourth and seventh respectively; Algeciras, sixth and fifth and Barcelona, eighth and tenth.[2] Those three ports are, precisely, the most well placed in the trans-oceanic container transport network. Most of the Spanish ports today have highly specialised terminals, with high levels of efficiency and operated by operators with expertise and investment capacity. The predominant management model in the Spanish ports is the landlord model, in which the public sector is the owner of port infrastructures, particularly terminals, and these are awarded by concession to the private sector, which is responsible for operation, maintenance, construction and financing. However, some port terminals are operated, maintained and financed by the public sector in the absence of private initiative.

The evolution of the Spanish port system in recent years is the intensification in the application of the landlord management model and the introduction of competition among ports. This process has led to decentralisation and increase in the participation of private initiative in the management and provision of port services. The main objectives of this process are to increase port efficiency and to reduce the public funds used to cover new investments and infrastructure maintenance costs. Recent Spanish legislative reforms have been passed in the pursuit of these objectives. In particular, the 2003 reform (LO 48/2003) encouraged the participation of private initiative in the financing and provision of port services. The 2010 reform (LO 33/2010) introduced the advanced landlord system in the Spanish port system and allowed a greater liberalisation in the setting of port tariffs. Finally, the 2011 reform (RDL 2/2011) encouraged private participation in the construction of port infrastructures and increased the autonomy of port authorities from the centralised regulatory entity.

The Spanish Government is particularly concerned with port efficiency. To reach economic sustainable ports and to offer efficient operations and competitive services are among the strategic lines incorporated on the new Strategic Framework for State-Ports (Puertos del Estado, 2022) to be accomplished by 2030. Also, the literature of port choice points out that users of container terminals consider important features in their election port infrastructure, port efficiency and hinterland accessibility; features that are under control of port authorities (see Martínez Moya and Feo Valero, 2017, for a review). In view on the above, port efficiency is of paramount relevance for both governments and port users. Thus, our general research question is the assessment of the efficiency and competition of the Spanish port system during the intensification of the landlord management model, especially considering the effect of private management of terminals.

Our results show that ports with a higher proportion of privately managed terminals are more efficient. Regarding the effects of terminal specialisation, it is observed that non-containerised general cargo and solid bulk terminals are more efficient compared to privately managed passenger terminals. Regarding environmental variables, it is observed that large ports, those using rail access and those located near an oil refinery are more efficient. Regarding the location of the ports, it is observed that ports located on islands are less efficient than ports located on the mainland and ports located on the Cantabrian coast are less efficient compared to ports located on the Mediterranean coast. Regarding legislative reforms, only the 2011 reform has positive effects on the efficiency of the Spanish port system. Regarding market power, it is observed that the ports located in the *south and east* of the peninsula face more competition than those located in the *north coast*. Finally, the transshipment container market in the *south and east geographical market* is the most competitive product market.

The organisation of this article is as follows. Section 2 defines several concepts used in the study. Section 3 offers a literature review. Section 4 presents the research design and the methodology for obtaining the short-run cost function. Section 5 describes the data. Section 6 shows the results of the estimation of the short-run cost function (i.e., the indices of economic efficiency and the marginal costs for each output), the estimation of the main determinants of efficiency and the analysis of market power. Section 7 presents a discussion of results and offer managerial implications. Finally, Section 8 concludes and proposes further lines of research.

2 Conceptual framework

In this paper we are using several economic concepts as efficiency, performance and competition and it is important to understand how they are related. Competition is about the existence and availability of alternatives. In an environment in which ports are in competition with one another they compete for cargo and passengers, that is, they are considered as feasible alternatives for users (shippers and carriers). Those port alternatives are competitors in the relevant market. The relevant market is defined both in terms of the product or service and geographical dimensions. When there are no port alternatives, users are captive in the sense that they must use the only port available. Competition is, therefore, what forces a firm to keep its price down, knowing that a user will be able to buy from someone else. To measure competition, economists have developed the concept of market power. Thus, a port has market power when a price increase above marginal costs does not lead to a loss of all (or most) of its demand. In a real-world example if ports compete with one another, the way users substitute among various pairs of ports can vary depending on the type of cargo since not every port's offering represents an equally good alternative and the degree of substitution may be different depending on the cargo. It is usual to define the ability a port has to attract cargo as port competitiveness, thus if a port is a good alternative, it is highly competitive or enjoys high competitiveness.[3] The widely used index to measure market power, is the Lerner index, defined as the difference between the price and marginal cost (i.e., mark-up) divided by the price. The index increases with the mark-up and a positive index indicates that the port enjoys market power. As firms' market power increase the market is considered less competitive. Since to measure market power we need an estimation of marginal costs, we are interested in finding the cost function for each port and how it evolves in the period of our analysis.[4] The stochastic frontier analysis (SFA) is a parametric method that allows us to estimate how far a port's cost function is from its frontier, so that, economic efficiency or cost efficiency is attained when such distance is nil. Therefore, a port is cost efficient if it provides a given throughput at a minimum cost. To be cost efficient a port has to be technically efficient, where technical efficiency means that a port cannot handle more throughput with the same resources taking into account the restrictions imposed by the available technology and other external constraints (see Nicholson, 1992; Talley, 2007).

Note that efficiency and performance are also different metrics. In a competitive environment, port's performance is based on how far the port is from its economic objective, which may differ depending on whether the port is owned by government or is private. Thus, a port is concerned not only with whether it is efficient (technically and cost), but also with whether it is effective in providing throughput. Effectiveness is concerned with how well the port provides throughput service to its users – shippers and carriers (ocean and inland). In order a port to be effective, it must be efficient, though efficiency is not guaranty for port performance, some other elements as strategic behaviour or other constrains affect performance (Talley, 2007).

Regarding the relationship between market power and efficiency, there is not a clear conclusion. On the one hand, the quiet life hypothesis (see Hicks, 1935) asserts that the higher market power, the lower the efficiency. The reason is that managers do not have incentives to work as hard to keep costs under control, enjoying a 'quiet life' (see also Leibenstein, 1966). Also, firms with market power may be tempted to follow other objectives or they may dedicate extra resources in keeping market power instead of procuring efficiency. On the other hand, other scholars propose a positive relationship between market power an efficiency based on several circumstances present in some industries that reduce the costs when firms have market power and information asymmetries between buyers and sellers are relevant. For instance, in the banking industry, banks with market power enjoy greater profits so that they select less risky projects with lower monitoring costs (see for instance Maudos and de Guevara, 2007; Färe et al., 2015). For the case of ports, there are examples of empirical papers that support either hypothesis. The quiet life hypothesis is supported by Fleming and Baird (1999), Cullinane et al. (2005), Tsakaridis et al. (2021), Yuen et al. (2013) and Ju et al. (2023) to mention a few. In contrast, De Oliveira and Cariou (2015) find that port efficiency decreases with competition intensity at the regional level (in the range of 400–800 km).

3 Literature review

There is a vast body of literature dedicated to estimating efficiency in the international port system. The majority of studies have focused on the evolution of technical efficiency, as the primary interest lies in analysing the productivity of ports. The literature can be categorised based on the methods used, including non-parametric approaches such as index numbers, productivity indexes, and data envelopment analysis (DEA), and parametric approaches for estimating production or cost functions. The two most commonly used methods are DEA and the stochastic frontier approach (SFA). The advantages and disadvantages of these techniques have been extensively discussed in the literature, with van Biesebroeck (2007) and Orea and Zofío (2019) providing excellent reviews on this topic. Nong (2023) conducted a comprehensive survey on the estimation of efficiency in the port system, categorising results by inputs, outputs, methods, and countries or regions considered, making it a valuable resource for interested readers.

In what follows we organise the related literature by first discussing papers that analyse non-Spanish port efficiency, with a focus on the effects of privatisation and environmental impact. Next, we consider research on Spanish port efficiency, which has concentrated on the effects of specialisation, size, complexity, and recent legislative reforms. We distinguish between papers that used either distance or cost functions, and also that measure Spanish market power.

In relation to non-Spanish ports, numerous studies have investigated efficiency and the impact of ownership and the type of port management on efficiency. Liu (1995) analysed three different types of ownership (private, trust ports operated by public entities, and local ports) in British ports and found no pattern between ownership type and port efficiency. Valentine and Gray (2001) compared the non-parametric technical efficiency of 31 privately-owned ports with publicly-owned and mixed-ownership ports in 1998, concluding that ownership structure has no influence on port efficiency. However, Cullinane et al. (2002) obtained the economic efficiency of the fifteen largest container ports in Asia for the period 1989–1998 and found that larger ports and those that transitioned from public to private ownership improved their economic efficiency. Additionally, Cullinane and Song (2003) applied a SFA to show that deregulation and privatisation policies led to improved productive efficiency in five South Korean container terminal operators. Cheon et al. (2010) concluded that private ports offer higher total factor productivity gains, while Pagano et al. (2013) estimated the effects of port privatisation in Panama and the United States, finding that privatised ports are more effective than publicly-owned ports. Tongzon and Heng (2005) used a sample of 25 container terminals to calculate a stochastic production function, finding that the largest technical efficiency gains occurred under the landlord management model. Similarly, Wanke and Barros (2016) applied a non-parametric method to a sample of the 27 largest Brazilian ports, showing a positive and significant impact of private management on port infrastructure efficiency. Finally, Chen et al. (2018) concluded that Asian ports are more efficient than European and US ports in container loading and unloading processes, although the latter are most efficient in container storage operations.

The study of port efficiency in developing or emerging countries has recently gained attention. Périco and da Silva (2020) examined the performance of a sample of Brazilian ports using DEA, concluding that low efficiency in public ports is more related to governance issues than infrastructure. Nong (2023), using a hybrid method that combines the Delphi technique with the KAMET principle and DEA on a sample of ports in Vietnam, determined that scale and management skills are key determinants of port efficiency. Hlali et al. (2023) found that most ports are not operating at their optimal scale and that ports located in developing countries face challenges in increasing and improving their port infrastructure.

Recently, some researchers have begun to analyse the environmental impact of port activities. Yang (2015) studied the concept of a green container terminal and determined assessment criteria for such terminals in East-Asian ports. Siqueira et al. (2017) found that higher returns in environmental efficiency do not necessarily translate to better technical efficiency scores. Castellano et al. (2020) concluded that ports with a lower environmental impact experience a significant increase in their efficiency indices. Pang et al. (2021) demonstrated that green shipping practices positively impact organisational performance and corporate reputation. Zhou et al. (2023) analysed the effect of provincial port integration in China on both provincial port efficiency and green provincial port efficiency, finding that only the former improved following integration.

Regarding the estimation of efficiency for the Spanish port system, there are numerous studies, but none have analysed the impacts of introducing the landlord system. Several authors have examined the effects of port specialisation on the technical efficiency of Spanish ports, although all papers focus on specialisation in the type of cargo, without considering terminal type specialisation or management type as we do in our paper. Tovar and Wall (2017), using a non-parametric technique on a sample of Spanish ports for the period 1993–2012, concluded that port specialisation has positive effects on technical efficiency, particularly for ports specialised in liquid bulk and non-containerised general cargo. Tovar and Wall (2019) used the same sample as their previous paper for the period 1993–2016 and classified ports into two groups based on size and complexity. Using non-parametric techniques, they found that larger and more complex ports achieve higher levels of technical efficiency, and that ports specialised in containerised general cargo and solid bulk obtain higher productivity indices. Hidalgo-Gallego et al. (2020) estimated an input-oriented distance function for a sample of all Spanish ports for the period 1986–2015, finding that specialisation in general cargo improves technical efficiency, while specialisation in bulk (solid or liquid) is not recommended. Pérez et al. (2020) estimated an output-oriented distance function for a sample of all Spanish ports for the period 2002–2011, showing that larger and more specialised ports are more technically efficient. Tsakaridis et al. (2021) applied a SFA to a sample of the five largest Irish state-owned ports and ten Spanish ports, also concluding that higher size and lower output diversification increase efficiency. Finally, Hidalgo-Gallego et al. (2022), using an input-oriented distance function for a sample of 26 Spanish ports for the period 1992–2016, reached a similar conclusion regarding allocative efficiency.

Concerning the effects of legislative reforms on the efficiency of the Spanish port system, results are inconclusive (see González and Trujillo, 2008; Díaz-Hernández et al., 2008; Núñez-Sánchez and Coto-Millán, 2012; Rodríguez-Álvarez and Tovar, 2012; Coto-Millán et al., 2016; Hidalgo-Gallego et al., 2022). However, most studies conclude that the 1997 reform, which promoted the implementation of the landlord system, had a positive impact on efficiency. During the sample period used in our work, as described in the introduction, there were three legal changes, which are considered in our paper.

In relation to the estimation of cost functions for the Spanish sector, some works have been devoted to measuring economic efficiency. Martínez-Budría (1996) used a cost function to measure economic efficiency for the period 1985–1989 and found that larger ports are less efficient. Baños-Pino et al. (1999) applied a SFA to show the existence of overcapitalisation in the Spanish port system. Finally, Rodríguez-Álvarez et al. (2011) used data from three port terminals for the period 1991–1998 and found that containerised terminals achieve higher levels of efficiency. Difficulties in obtaining cost data (especially input prices) justify why production function (or distance function) estimation has been more frequently considered than cost function estimation.

To the best of our knowledge, only one paper has measured market power in the Spanish port system. Núñez-Sánchez (2013) estimated the Lerner index using port fees as prices and considering tons of cargo and vessels as outputs. Marginal costs were obtained from cost function estimation. The results indicate that mark-ups for cargo are higher than mark-ups for vessels. Additionally, he showed the presence of significant economies of scale and overcapitalisation in the port system and suggested that actual port fees differ significantly from those that would maximise welfare.

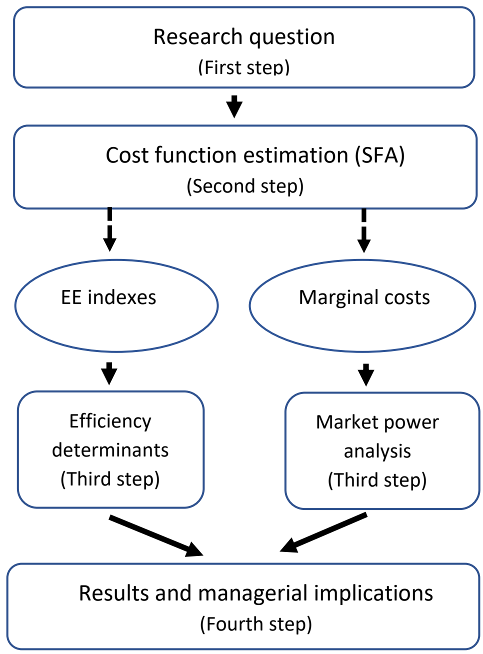
4 Research design and methodology

4.1 Research design

As indicated in the introduction, both policy makers and users are stakeholders highly interested in having an efficient and competitive national port system. Especially for the Spanish case which has been substituting a tool model of management for the landlord one. To address our general research question, which is the assessment of the efficiency and competition of the Spanish port system during the intensification of the landlord management model, especially considering the effect of private management of terminals, we will proceed by following the research process displayed in Figure 1.

In the first step, the general research question is articulated in three specific research questions which are sequentially addressed. The first one is: *which is the evolution of Spanish ports economic efficiency and which ports are more efficient in the period 2002–2019?* The second one is: *which are the determinants of economic efficiency?* In addition to the standard environmental variables (e.g., port location, the existence of refineries nearby, the use of rail access, and size) we contribute to the literature by including the type of terminal management (public or private) per type of terminal in terms of the output handled. For the third, we distinguish two geographical markets and six different product markets to answer the question: *in which markets do ports have market power?* Or put differently, *which markets are more competitive?*

Figure 1 Research process (see online version for colours)



The second step in Figure 1 corresponds to the estimation of a short-run cost function by using a SFA. We are interested in focusing on port economic efficiency, i.e., to provide a given throughput at a minimum cost, because we can obtain not only efficiency indexes per port and year but also estimates of marginal costs per type of output, port and year which will be necessary to answer our specific research questions two and three, respectively, indicated in the third step in Figure 1. The choice of a SFA method instead of a non-parametric approach like DEA is that SFA incorporates random and uncontrolled factors like environmental conditions, input shocks and even measurement errors that affect costs frontiers and use to be more suitable for panel data. Besides, by selecting an appropriate flexible functional form, a translog function in our paper, we have a richer specification to estimate relevant marginal effects for a multi-output multi-input port. In the next sub-section, we give all the details.

To address the second and third research questions, third step in Figure 1, we take the efficiency indexes from step 2 as the dependent variable of a Tobit estimation where the regressors are the determinants described in Section 5 below. Similarly, to undertake the market power analysis, we estimate the Boone indicator (BI), which uses the marginal costs obtained in the second step from the short-run cost function and market shares per type of output, port and year (see Boone, 2001, 2008).[5] The BI is the estimate of the slope parameter that relates the log of a port market share (the explained variable) with the log of the corresponding port's marginal cost for a given output and year (explanatory variable). Subsection 6.3 below includes the details for the BI estimation procedure. We use the BI as an approximation of the Lerner index since data in output prices per type of cargo and port are not available noting that our paper is the first using a BI approach to evaluate competition in the Spanish port system. Finally, step four in Figure 1 is the last step in the research process which includes the discussion of the results and the managerial implications that can be derived and that are the content of Section 7 below.

4.2 Methodology

Economic efficiency is estimated by using a frontier cost function, *TC*. This is defined as the minimum cost of producing a particular level of output given the prices of a set of inputs and technology. Formally, $TC(y, w) = \min\{w^T\!: g(x) \geq y\}$ for the case of one output, y, and a vector of inputs, x, where $g(x)$ is the production function and w is the vector of input prices. Obviously, when a producer is technically inefficient its production cost must exceed the above theoretically minimum cost. Note that when we are using the cost approach any source of inefficiencies, technical or allocative (the choice of the optimal mix of inputs) appear as higher cost.

In order to measure the economic efficiency, each observed total cost for any firm is compared with respect to the minimum cost defined by the short-run cost frontier function. That is,

$$TC_i \geq TC\left(y_{1i}, \ldots, y_{Mi}; w_{1i}, \ldots, w_{Bi}\right), \tag{1}$$

where TC_i is the observed total cost of firm i and sub-indexes m = {1, 2, …, M} and b = {1, 2, …, B} stand for the number of M different outputs and B input prices paid by the firms, respectively. An appropriate and compact specification of a usual stochastic cost frontier function is given by:

$$TC_i = TC\left(y_{1i}, \ldots, y_{Mi}; w_{1i}, \ldots, w_{Bi}\right)\exp\left(\varepsilon_i\right), \tag{2}$$

where $\varepsilon_i = v_i + u_i$, assuming that v_i accounts for the random effects that affect the location of the firm i's stochastic cost frontier, while $u_i \geq 0$ corresponds to the economic inefficiency.

To estimate the cost function, we use a multi-product translog stochastic frontier with five outputs, y_m for $m = \{1, 2, 3, 4, 5\}$, and three inputs, x_b, for $b = \{l, c, k\}$, where y_1 denotes containers; y_2, liquid bulk; y_3, number of passengers; y_4, solid bulk and y_5, non-containerised general cargo. Similarly, l denotes labour, c denotes intermediate consumption and finally k is capital. Since the total cost function is required to be homogeneous of degree one in variable input prices, the following restrictions on the translog cost functions are imposed, $\sum_{b=l,c,k} \beta_b = 1$, $\sum_{b=l,c,k} \beta_{bv} = \sum_{v=l,c,k} \beta_{bv} = 0$ and $\sum_{b=l,c,k} \gamma_{mb} = 0$ for all m. The expression presented below has been normalised with one of the input prices, to ensure that the function used is linearly homogeneous in inputs prices. The expression to be estimated is the following:

$$
\begin{aligned}
\ln\left(\frac{TC}{w_l}\right)_{it} &= \beta_0 + \sum_{m=1}^{M} \alpha_m \ln(y_m)_{it} + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{N} \alpha_{mn} \ln(y_m)_{it} \ln(y_n)_{it} \\
&+ \beta_k \ln\left(\frac{w_k}{w_l}\right)_{it} + \beta_c \ln\left(\frac{w_c}{w_l}\right)_{it} + \frac{1}{2}\beta_{kk} \ln\left(\frac{w_k}{w_l}\right)_{it} \ln\left(\frac{w_k}{w_l}\right)_{it} \\
&+ \frac{1}{2}\beta_{cc} \ln\left(\frac{w_c}{w_l}\right)_{it} \ln\left(\frac{w_c}{w_l}\right)_{it} + \frac{1}{2}\beta_{kc} \ln\left(\frac{w_k}{w_l}\right)_{it} \ln\left(\frac{w_c}{w_l}\right)_{it} \\
&+ \sum_{m=1}^{M}\sum_{b=c,k} \gamma_{mb} \ln(y_m)_{it} \ln\left(\frac{w_b}{w_l}\right)_{it} + \theta_k \ln K_{it} + \frac{1}{2}\theta_{kk} (\ln K_{it})^2 \\
&+ \sum_{m=1}^{M} \theta_{mk} \ln(y_m)_{it} \ln K_{it} + \omega_t T + \frac{1}{2}\omega_{tt} T^2 + \sum_{m=1}^{M} \omega_{mt} T \ln(y_m)_{it} \\
&+ \sum_{b=c,k} \omega_{bt} T \ln\left(\frac{w_b}{w_l}\right)_{it} + \omega_{kt} T \ln K_{it} + \varepsilon_{it},
\end{aligned} \tag{3}
$$

where β_0 stands for the constant, $\left(\frac{TC}{w_l}\right)_{it}$ refers to normalised total cost of port i where we have used labour price to do the normalisation ($i = 1, \ldots, 24$) in the period t ($t = 1, \ldots, 18$), while $\left(\frac{w_k}{w_l}\right)_{it}$ and $\left(\frac{w_c}{w_l}\right)_{it}$ refer to capital and intermediate relative input prices for port i in the period t, respectively. Since the function is continuously differentiable, the coefficients capturing second-degree effects from outputs and input prices, α_{mn} and β_{bv} will be symmetric, i.e., $\alpha_{mn} = \alpha_{nm}$, $\beta_{bv} = \beta_{vb}$. The interactive effects between outputs and normalised input prices are captured by the γ_{mb} coefficients. To have an estimation of the technical progress the typical terms including a trend, T, and its interaction with output, the quasi-fixed input (K), and the relative input prices captured by the ω coefficients are included. Also, first and second-degree effects corresponding to the quasi-fixed input together with its interactions with outputs are captured by the θ coefficients.

The error term includes two components. The first component (v_{it}) is a random variable that follows an i.i.d $N(0, \sigma_v^2)$ 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 how far the total cost of the port is operating with respect to the cost frontier. Denote by $N^+(\mu, \sigma_u^2)$ the truncated-normal distribution of u_i, which is i.i.d and truncated at zero with mean μ and variance σ_u^2. Since we are considering Battese and Coelli (1992) approach, the inefficiency term, u_{it}, is modelled as a truncated-normal random variable multiplied by a specific function of time showing time-varying decay as follows, $u_{it} = \exp(-\eta(t - \overline{T}))u_i$, where $\overline{T}$ is the last period and η is the decay parameter. Thus if $u_{it} = 0$, it means that port i is economically efficient and its operating cost is on the cost frontier.

5 Data

In order to estimate the cost function, we use a balanced panel data of 432 observations. This panel data includes 24 ports with annual observations for the period 2002–2019, the ports of Ceuta, Melilla, Motril and Vilagarcía de Aurosa are excluded due to their very small size.

The selection of outputs and inputs (and corresponding prices in the estimation of a cost function) is a recurrent issue in the port literature.[6] Regarding the outputs, most of the papers try to capture the multioutput feature of port activity. Literature usually distinguishes between freight and passengers, and inside freight they consider the different types of cargo (see, e.g., Barros, 2003, 2006; Ferreira et al., 2018 for technical efficiency). Additionally, some papers use the number of ships arriving at ports, the capacity of ships measured in gross tonnage or the financial income from port services as a measure of output (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 that we need include to obtain measures of ports market power per type of output and geographical market. Then to capture such heterogeneity, the outputs in our study are TEUs of containers (y_1), tons of liquid bulk (y_2), number of passengers (y_3), tons of solid bulk (y_4) and tons of non-containerised general cargo (y_5).

Regarding inputs, three inputs (labour, intermediate consumption and capital) are normally used in the literature in the estimation of a cost function for a port system. These three inputs are usually considered, because prices for these inputs can be relatively easy to define (see Baños-Pino et al., 1999; Rodríguez-Álvarez and Tovar, 2012). In particular, labour price is approximated as the total labour expenses divided by the number of employees. Intermediate consumption includes expenses on materials, external services and other supplies used by the ports, and the price of this input will be approximated by the value of this input divided by the number of total tons. Capital price is approximated dividing the depreciation of the fixed assets by the number of linear metres of quay. In view of that, the price of labour (w_l) is obtained as the quotient between the staff expenses and the number of workers. The price of intermediate consumption (w_c) is defined as the quotient between the expenses in operating and other current services and the total tons.[7] The price of capital (w_k) is obtained by dividing the depreciation of fixed assets by the linear meters of quay with more than four meters of draft. Finally, as it is usual in the literature, our model considers a quasi-fixed input. We use linear meters, as in Baños-Pino et al. (1999), as a measure of the quasi-fixed input (K). This input also is used as a proxy for some port superstructure assets as the number of cranes (Serebrisky et al., 2016; Pérez et al., 2016; Hidalgo-Gallego et al., 2020).

The dependent variable is the total cost (TC), which stands for the sum of variable and fixed costs. Variable costs are defined as the sum of staff costs, services expenses, and other current operating expenses. Fixed costs are the depreciation of fixed assets. Data on outputs are obtained from the 'Statistical Yearbooks of State Ports'; financial data, i.e., total cost and input prices, are obtained from the 'Profit and Loss Accounts' of each port authority published in the Spanish Official Journal (Boletín Oficial del Estado, BOE). Both types of data have been contrasted with the 'Annual Report' of each port authority. Finally, the information on the number of workers has been obtained from the port authorities 'Audit Reports' annually published in the BOE. Table 1 shows a summary of the descriptive statistics of all variables used in the cost function.

Table 1 Descriptive statistics

Variable	*Unit*	*Description*	*Obs.*	*Mean*	*Std. dev.*	*Min*	*Max*
TC	Th. €	Total cost	432	34,133.9	26,729.6	6,561.7	177,580.0
y_1	TEU's	Containers	432	547,323	1,118,417	0	5,439,827
y_2	Tons	Liquids	432	6,357,557	8,085,704	0	31,763,061
y_3	# of pass.	Passengers	432	1,031,953	1,850,382	0	9,524,740
y_4	Tons	Solids	432	3,958,924	3,660,734	234,910	19,220,421
y_5	Tons	Rest of cargo	432	2,386,688	2,876,703	138,829	14,585,870
K	Metres	Quay	432	11,475	6,299	2,514	28,910
w_l	€	Labour cost per worker	432	45,184.7	5,953.8	33,594.7	69,172.7
w_c	€	Intermediate consumption costs per ton	432	0.75	0.51	0.11	2.84
w_k	€	Capital cost per metre of quay	432	1,203.2	469.0	345.4	3,212.2

Source: Own elaboration

On the determinants of economic efficiency, we include as relevant variables the proportion of terminals privately managed by the ports, several environmental variables indicating whether the port is located on an island, whether it is located near an oil refinery, whether it has used rail access, the coastline where the port is located, some dummy variables to account for legislative reforms and a variable representing the size of the ports.

Port terminals are specialised for different types of cargo (containers, liquids, bulk solids, passengers and non-containerised general cargo). To take into account the effect of private terminal management on efficiency, we introduce the variable *PRIV%* which is defined as the proportion of privately managed terminals with respect to the total number of terminals per port and per year. In addition, to analyse the effect of terminal specialisation on efficiency, we introduce the variables *CON%*, *LIQ%*, *SB%*, *NC%* and *PAX%* which are respectively the proportion of privately managed terminals for containers, liquids, solid bulks, non-containerised general cargo and passengers with respect to the total number of privately managed terminals per port and per year.[8]

In addition, two environmental variables are used to account for port characteristics. The dummy variable C_{Loc} has value one for ports located on islands (Baleares, Las Palmas and Santa Cruz de Tenerife), and zero otherwise. The dummy variable C_{Ref} has value one for ports with an oil refinery installed nearby (A Coruña, Bahía de Algeciras, Bilbao, Cartagena, Castellón, Huelva, Santa Cruz de Tenerife and Tarragona) and zero otherwise.

Regarding the other environmental variables, the dummy variable C_{Tra} takes a value of one if the port has used a railway access. The variables C_{Atl}, C_{Can}, C_{Med} are a group of dummy variables indicating the coastline where the ports are located (see Figure 1). In addition, variables C_{Law03}, C_{Law10} and C_{Law11} take respectively value one from the reforms in 2003, 2010 and 2011, and they are defined to determine the influence of legislative reforms on efficiency. Finally, the dummy variable C_{Size} represents the size of the ports and takes value one for ports with more than 15,000 linear metres of quay. Table 2 shows the descriptive statistics of the variables used as determinants of economic efficiency.

Table 2 Descriptive statistics for the determinants of economic efficiency

Variable	*Obs.*	*Mean*	*Std. dev.*	*Min*	*Max*
PRIV%	432	.7912	.1861	.3571	1
CON%	432	.1492	.1834	0	1
LIQ%	432	.3598	.2488	0	1
PAX%	432	.0419	.0899	0	0.5
SB%	432	.3660	.2573	0	1
NC%	432	.0831	.1319	0	0.5
C_{Loc}	432	.1250	.3311	0	1
C_{Ref}	432	.4167	.4936	0	1
C_{Tra}	432	.6505	.4774	0	1
C_{Atl}	432	.4167	.4936	0	1
C_{Can}	432	.2083	.4066	0	1
C_{Med}	432	.3750	.4870	0	1
C_{Law03}	432	.8889	.3146	0	1
C_{Law10}	432	.5555	.4974	0	1
C_{Law11}	432	.5000	.5006	0	1
C_{Size}	432	.2639	.4413	0	1

Source: Own elaboration

6 Results

6.1 Efficiency indexes

Spanish ports are heterogeneous in size, traffic specialisation, location and other variables. This fact suggests the use of a fixed effects estimation technique to avoid the possibility of biased coefficient estimations and to capture non-observable differences in ports. Table A1 in the Appendix shows the estimates of the coefficients of the translog cost function in equation (3). The first-order coefficients for outputs, input prices and quasi-fixed capital are statistically significant and have the expected signs, showing that the cost function is increasing in outputs, input prices and quasi-fixed capital. These first-order coefficients can be interpreted as elasticities evaluated on the data average, since data are in logs and deviated from its mean. Table A2 in the Appendix shows that the inefficiency term u is responsible for the 99% of the total error variance and since the sign of η is negative but small, economic efficiency is moderately increasing across the period.

Note that dynamic effects are captured by the trend variable (T) in the cost function. Evaluating the total cost function with respect to T denotes the whole effects that the time trend provokes in the total costs (see Baltagi and Griffin, 1988). These time effects can be separated in different components. In particular, the pure technical change is estimated from the values of the coefficients of the variables T and $0.5T^2$ in the cost function (see

Table A1). The value of these coefficients is –0.0008*T*, expressing that the costs decrease over time and there is a positive technical change. Regarding the neutrality of the technical change, only the cross effect of time with the quasi-fixed input is positive and significant but at 0.1 level. This result denotes that there is a dynamic and slight effect to increase the costs derived of the quasi-fixed input (denoted by the linear metres of quay). However, the use of the rest of the inputs is not affected in the long run. And finally, technical change affects the economies of scale for three outputs, y_1 (containers), y_2 (liquids) and y_4 (solids), denoting that ports can take advantage of larger economies of scale of these outputs in the long run.

Table 3 Average of marginal cost and economic efficiency

Ports ranked	*Geogr. market*	*EE*	*MCy1 (Containers)*	*MCy2 (Liquids)*	*MCy3 (Passengers)*	*MCy4 (Solids)*	*MCy5 (NonContain.)*
Valencia	SE	0.8402	1.33	1.68	1.09	0.48	0.13
Barcelona	SE	0.8254	2.60	0.67	0.35	0.30	0.36
B Algeciras	SE	0.7368	1.17	0.15	0.25	0.20.	0.15
Huelva	SE	0.7290	n. a.	0.07	n. a.	0.94	2.00
Tarragona	SE	0.7049	16.46	0.10	n. a.	0.39	1.91
Bilbao	N	0.6586	4.78	0.20	3.07	0.42	0.61
Cartagena	SE	0.6486	18.90	0.04	11.89	0.32	0.42
Las Palmas	I	0.6319	3.32	0.88	0.64	0.26	0.74
A Coruña	N	0.6302	n. a.	0.14	4.65	0.91	1.19
Vigo	N	0.6226	6.53	n. a.	2.62	1.68	2.88
Castellón	SE	0.6066	7.90	0.05	n. a.	0.38	2.99
Gijón	N	0.6024	17.61	0.72	n. a.	0.32	2.26
Pasaia	N	0.5949	n. a.	n. a.	n. a.	3.21	1.37
Baleares	I	0.5857	14.28	1.83.	0.09	0.88	0.50
Sevilla	SE	0.5669	4.44	2.31	n. a.	0.74	1.57
Marín RP	N	0.5625	8.95	n. a.	n. a.	2.00	2.19
Santander	N	0.5561	n. a.	2.41	1.00	0.94	1.28
Ferrol SC	N	0.5518	n. a.	0.11	n. a.	0.28	1.74
SC Tenerife	I	0.5493	5.93	0.45	0.17	0.25	0.36
Málaga	SE	0.5478	10.22	8.67	0.65	0.87	3.44
B Cádiz	SE	0.5393	7.02	7.29	1.05	0.90	2.36
Almería	SE	0.5370	n. a.	4.05	0.33	0.52	1.05
Avilés	N	0.5277	n. a.	0.38	n. a.	0.91	1.08
Alicante	SE	0.5256	3.36	4.96	1.13	0.70	5.76
Average		*0.6200*	*7.93*	*1.77*	*1.93*	*0.81*	*1.60*

Note: N – a port in the north market; SE – a port in the south and east market;
I – a port in an island.

Table 3 reports information about the average marginal cost of each output and economic efficiency for each port considered in the period 2002–2019.[9] Ports are listed in the first column ordered according to their average economic efficiency score (EE) which appears in the third column. The second column identifies the geographical market in which the port is included and that will be relevant for the market power analysis in Subsection 6.3 below. The last five columns present the average of marginal cost for each type of traffic and port.[10]

6.2 Efficiency analysis

After obtaining the economic efficiency index for each port and given the heterogeneity in Spanish ports mentioned above, it is interesting to undertake a second stage analysis to identify the main determinants of economic efficiency. To analyse the determinants of economic efficiency, the following equation has been used:

$$\begin{aligned} EE_{it} &= \delta_0 + \delta_{Priv} PRIV\%_{it} + \delta_{Con} CON\%_{it} + \delta_{Liq} LIQ\%_{it} + \delta_{SB} SB\%_{it} + \delta_{NC} NC\%_{it} \\ &+ \delta_{Loc} C_{Loc} + \delta_{Ref} C_{Ref} + \delta_{Tra} C_{Tra} + \delta_{Atl} C_{Atl} + \delta_{Can} C_{Can} + \delta_{Law03} C_{Law03} \\ &+ \delta_{Law10} C_{Law10} + \delta_{Law11} C_{Law11} + \delta_{Size} C_{Size} + u_{it} \end{aligned} \tag{4}$$

where EE_{it} is the dependent variable and the explicative variables include the above-described determinants. Since the independent variable is defined between zero and one, we undertake a Tobit regression.

Table 4 reports the estimates for equation (4). Among the proposed determinants, only the port size may have a potential endogeneity issue. To address this issue, we have considered the GDP per capita of the region a port is located as an instrument. After running the regressions, the Hausman test indicates that the null hypothesis of exogeneity cannot be rejected. Note that a higher percentage of privately managed ports has a positive effect on efficiency. Similarly, non-containerised general cargo and solid bulk privately managed terminals have positive and significant effects on efficiency compared to privately managed passenger terminals. Ports located on islands are less efficient than ports located on the mainland and ports located on the Cantabric Sea are less efficient than ports located on the Mediterranean Sea. The main reason is that ports located on islands do not compete with other ports and their traffic may be considered as captive. As shown next, the analysis of market power shows that ports located on the Cantabrian coast (belonging to the *north* market) are less competitive than ports located on the Mediterranean coast (belonging to the *south and east* market). Ports that have an oil refinery installed in their vicinity are more efficient than the rest. Note that oil refineries attract liquid bulk cargo, and this is the fastest cargo to handle through the ports. This latter result is in line with González and Trujillo (2008) and Pérez et al. (2020). Similarly, ports that use rail access are more efficient in line with Wanke and Barros (2016) but in contrast to Hidalgo-Gallego et al. (2022). Regarding the impact of legislative reforms, no significant effects of the 2003 and 2010 reforms on efficiency are observed, confirming the conclusions obtained in González and Trujillo (2008), Díaz-Hernández et al. (2008), Núñez-Sánchez and Coto-Millán (2012) and Rodríguez-Álvarez and Tovar (2012). However, the 2011 reform has a positive and significant impact on efficiency. The latest reform encouraged private participation in the construction of port infrastructure and allowed port authorities greater autonomy from the centralising regulatory entity. Finally, ports categorised as large, those with more than 15,000 linear meters of quay, have higher efficiency scores than other ports. This latter result is consistent with the works of Liu (1995), Martínez-Budría (1996), Cullinane et al. (2002), Tovar and Wall (2019), Pérez et al. (2020); Tsakaridis et al. (2021) and Hidalgo-Gallego et al. (2022).

Table 4 Determinants of economic efficiency

Variable	*Coefficient*	*Tobit regression*		*Tobit regression with IV*	
		Estimates	*Std. error*	*Estimates*	*Std. error*
Constant	δ_0	0.4360***	0.0341	0.4454***	0.0457
PRIV%	δ_{Priv}	0.0557***	0.0176	0.0592***	0.0182
CON%	δ_{Con}	0.0589	0.0362	0.0467	0.0563
LIQ%	δ_{Liq}	0.0410	0.0312	0.0367	0.0400
SB%	δ_{SB}	0.0597*	0.0327	0.0467	0.0404
NC%	δ_{NC}	0.1978***	0.0408	0.1837***	0.0700
C_{Loc}	δ_{Loc}	–0.0319**	0.0124	–0.0342	0.0302
C_{Ref}	δ_{Ref}	0.0680***	0.0059	0.0661***	0.0069
C_{Tra}	δ_{Tra}	0.0359***	0.0068	0.0333***	0.0098
C_{Atl}	δ_{Atl}	–0.0092	0.0067	–0.0108	0.1209
C_{Can}	δ_{Can}	–0.0528***	0.0074	–0.0525***	0.0093
C_{Law03}	δ_{Law03}	–0.0003	0.0081	0.0000	0.0083
C_{Law10}	δ_{Law10}	0.0113	0.0109	0.0105	0.0117
C_{Law11}	δ_{Law11}	0.0241**	0.0105	0.0240**	0.0107
C_{Size}	δ_{Size}	0.1031***	0.0078	0.1062***	0.0300
Sample size		n = 432		n = 432	
Log-likelihood		693.66		612.16	
Hausman test		$\chi^2_{14} = 0.01$; p-value = 1.000			

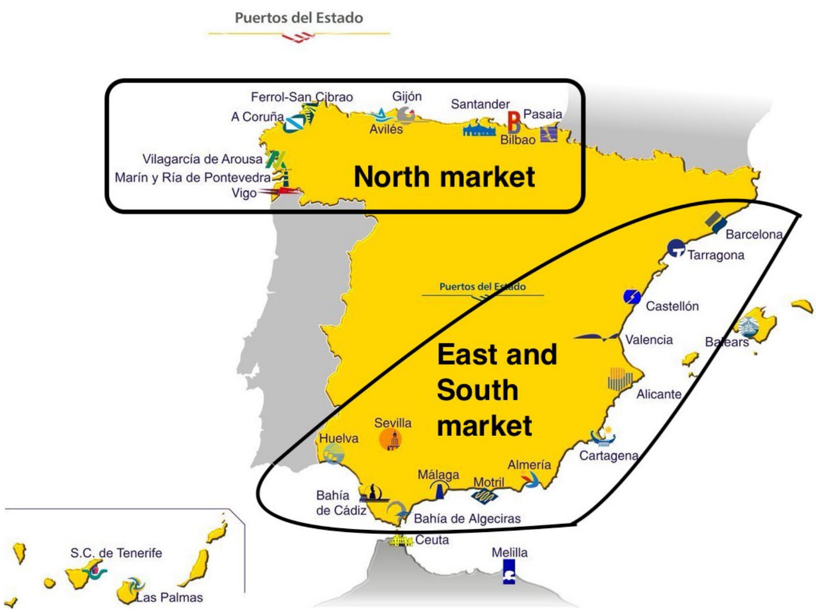
Note: ***, **, * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively.

6.3 Market power analysis

Once economic efficiency has been estimated and its main determinants have been analysed, we measure the market power of Spanish ports in order to address our third specific research question. Since data on ports prices per type of cargo are not available, we cannot obtain direct measures of market power per port and cargo, that is, we cannot estimate Lerner indices. Instead of using market concentration indices, which may be misleading in some circumstances, we propose an alternative method not used before in port market power analysis. The method applied is the Boone indicator (*BI*) that uses the marginal costs obtained in the short-run cost function and the market shares of each port in each output considered. Since as indicated above, ports do not compete in general, the relevant market needs to be defined; both for the geographic and the product dimensions. In particular and regarding the product dimension, the Spanish port activity is divided into six product markets that correspond to the five outputs used along this paper plus the sub-market corresponding to transshipment containerised cargo (denoted Tcontainers in Table 5). This new sub-market deserves differentiated attention since has its own particularities as the port handling the cargo is not its destination, so that ports are hubs in trans-ocean transport networks.

In addition, we consider that there is only port competition, or ports are considered feasible alternatives for users, when ports are located in the same broad geographical area. Therefore, to be more precise in estimating market power, two geographical markets are defined depending on the coastline where ports are located. The *north geographical market* includes the Spanish ports located in the Cantabrian Sea coast and those located in the north at the Atlantic Ocean coast, and the *south and east geographical market* for the Spanish ports located in the South at the Atlantic Ocean coast and in the Mediterranean Sea coast. Ports located on islands have been excluded in this sub-section (see Figure 2).

Figure 2 Distribution of ports between the *north* and *south and east* geographical markets (see online version for colours)



The *BI* assumes that the most efficient port (defined as the one with lower marginal cost) will get higher market shares if the market is competitive. This effect is stronger the higher the level of competition in the market. The functional form of the Boone indicator is show in equation (5):

$$\ln(MS)_{mit} = \alpha + \beta \ln(MC)_{mit} + z_{mit}, \tag{5}$$

where *MS* denotes market share, *MC* is the marginal cost, β is the Boone indicator and z is the error term. Also, sub-index m stands for the type of output, sub-index i stands for the port and sub-index t stands for the year. Parameter β is an elasticity parameter and it is negative because it relates a higher market share with a lower marginal cost. It is implicitly assumed that reductions in marginal cost pass-through prices to some extent affecting markets shares. The extent of such pass-through depends on the level of competition in the market. Thus, if $\beta = 0$ the marginal cost does not affect market shares and the extreme case of a monopoly is identified. Whereas a larger value of β, in absolute terms, means that a port, in order to achieve a higher market share and because of competition, has to reduce more its marginal cost. Therefore, larger values of β, in absolute terms, are related to more competitive markets.

The *BI* is obtained by using a *generalised least squares (GLS)* estimation when the random effects methodology (denoted by *RE* in Table 5) is applied; while a *within regression* estimation is used when fixed effects (*FE*) are considered. The second column in Table 5 shows the estimation method chosen for each market after running the corresponding Hausman test.

Table 5 Boone indicator estimates per market

Market	*Estimation method*	*# of ports*	*# of obs.*	*BI*	*Std. error*
		North geographical market			
Containers	RE	4	72	–0.1283	0.0979
Liquids	FE	6	108	–0.1384	0.0884
Passengers	RE	4	72	–0.3364***	0.0799
Solids	FE	8	144	–0.2047***	0.0529
NoContainerised	FE	7	126	–0.1889***	0.0346
TContainers	RE	2	36	–0.0587	0.9418
		South and east geogr. market			
Containers	FE	7	126	–0.8541***	0.0920
Liquids	RE	8	144	–0.5829***	0.0533
Passengers	FE	6	108	–0.5148***	0.0833
Solids	RE	9	162	–0.3463***	0.0471
NoContainerised	RE	7	126	–0.2966***	0.0513
Tcontainers	RE	4	72	–1.9472***	0.2660

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

Table 5 presents the results obtained for the *north* and the *south and east* geographical markets. The market shares used in the estimation of equation (5) are recalculated including only the ports in the corresponding geographical market. Note that the relationship between marginal costs and market share is negative in all cases. Furthermore, it is observed that all estimates are significant at the 1% level, except for the *containers* product market (both transshipment and non-transshipment) and *liquids* on the *north* market which are not significant. Note that transshipment containerised cargo in the *south and east* market is clearly the more competitive market. Regarding, the *north* market, we find that the product market where ports have less market power is that of passengers. As explained above, competition requires that several alternatives be considered attractive for port users. In this case, Bilbao and Santander seem to explain the *BI* estimated since they are actual competitors for passengers, and the same for Vigo and A Coruña but to a lower extent.

Finally, it is observed that the level of competition on the *south and east* market is higher than the level of competition on the *north* one in all product markets. Remember that, according to our former efficiency analysis, ports located in the Mediterranean Sea are more efficient than ports located in the Cantabrian Sea. Besides, according to the market power analysis ports in the Mediterranean face the more competitive product markets. Therefore, the greater competition between ports on the same geographical market and the competition with the rest of the Mediterranean ports in other countries, can help to explain why some ports located on the *south and east* market attain higher economic efficiency indices.

7 Discussion and managerial implications

There are interesting results that can be concluded from an integrated view of our results in Tables 3, 4 and 5. First of all, we find that the average economic efficiency during the period analysed is 0.62. Note that the average economic efficiency for 2002 was 0.587 while that for 2019 was 0.664, this means an CAGR growth of 0.73% in the whole period. The most economically efficient ports are Valencia, Barcelona, Bahía de Algeciras and Huelva; while Alicante, Avilés, Bahía de Cádiz and Málaga are the least efficient ones. In addition, total costs are shown to decrease over time with some technical progress attained.[11]

Note that, as we explained above, ports placed in the Mediterranean coastline are more efficient than ports located in the Cantabric coastline. In particular, the aforementioned Valencia, Barcelona and Bahía de Algeciras are the three most efficient ports in Spain, they are in the Mediterranean coastline and belong to the South-East geographical market. This is explained because their marginal costs in the movement and management of containers are clearly the lowest (also these three ports concentrate about the 73% of the Spanish port traffic). Regarding the other outputs, the existence of specialised infrastructures may explain also good cost efficiency scores. This is the case of the ports of Cartagena, Huelva, Castellón and Bahía de Algeciras with good platforms and infrastructures devoted to the handling of oils and liquids. This result explains the positive and significant coefficient in Table 4 of the dummy standing for the presence of an oil refinery close to a port. In the case of passengers, marginal costs are low in the ports with high movement of people (e.g., ports in islands as Baleares, S. C. de Tenerife and Las Palmas, and other ports with high intensity of traffic as Bahía de Algeciras). For the case of solids apart from the three largest ports, Gijon, Ferrol and Tarragona ports specialised in such type of traffic also show low marginal costs. Finally, for non-containerised general cargo ports in islands together with the largest ones are showing low marginal costs as they have a large proportion of ro-ro cargo.

Table 4 indicates that private management of the terminals has increased the cost efficiency. Besides, our results show that a higher privatisation in the management of terminals devoted to solids, and specially, non-containerised cargo will improve the efficiency. Then, an effort should be undertaken in the management of these terminals, because there is an important margin to promote the efficiency in the whole port system.

Also, there are relevant implications when efficiency results are connected with the *BI* displayed in Table 5. Firstly, our results show that ports in the *north* market present lower *BI* (in absolute terms) than in the *east and south* market for all type of outputs. Note that northern ports are less efficient. This result may be explained because most of the northern ports are specialised in the outputs whose product markets appear less competitive (i.e., solids or general cargo) and where many shippers and other port users are captive. Looking at the results per output in Table 5, the markets for containers, and specially, for transshipment containers in the *south and east* market are clearly the most competitive, because a reduction in the respective marginal cost would lead to a major change in the market share of the port for this type of output. However, this result does not arise in the *north* market. It is interesting to know that the transshipment container activity is concentrated only in three ports (Barcelona, Valencia and Bahía de Algeciras suppose the 85.94% of the total), showing that having few real competitors does not necessarily lead to low market competition or high market power. Summarising, our results indicate that the three more efficient ports coincide with those specialised in outputs in the most competitive markets.

From all these results, some managerial and policy implications can be derived. Firstly, it is true that, as of today, most of the terminals are privately managed (76.9% in 2019), but the effort to keep and promote the landlord system must be continued, especially in the terminals devoted non-containerised general cargo. These are precisely the type of terminal where the margin to introduce the private participation is bigger. Our results show that North coastline and East and South coastline are two markets clearly differentiated. Therefore, policy managers must devote efforts to promote competition especially in the *north* market. Policy managers should favour ports be perceived as closer or, in other words, be perceived by users as highly substitutive in terms of their services provided. For instance, increasing the port choices for users via more tariff competition between ports or fostering competition in port service quality. Those are mechanisms to favour more competition in markets, and at the same time, may be useful to promote higher efficiency in the industry. Finally, it is important to conclude this policy subsection noting that although the Spanish ports competing in the transshipment container market of the *east and south* market have been successful in attracting cargo, this is a highly competitive market dominated by large trans-oceanic shipping lines with high bargaining power that might move their activity to other ports located in other Mediterranean countries. Therefore, the Spanish Government and the other port stakeholders should consider further investments and improvements in efficiency and service quality in order not to lose their current strategic advantage. Obviously, each port system has its own characteristics, and these results are not directly applicable to other countries, but we think that some of them may be extrapolated to a more general context. The advantages in efficiency of the landlord system and the distinction of market power by type of output are two conclusions that can be extended to other international port systems.

8 Conclusions and further research

This paper analyses firstly the economic efficiency and market power of the Spanish port system by estimating a short-run cost function. Moreover, in a second stage analysis, the determinants of the economic efficiency have been identified and analysed. Finally, this paper provides an estimation of the market power distinguishing two different geographical markets (the north and the south and east) with five different product markets in each.

We find that ports placed at the South and East coastlines are more efficient than ports placed in the North area. Regarding the determinants of economic efficiency, it is observed that private management of port terminals (by means a landlord system) has a positive impact on economic efficiency. Regarding the effect by type of terminal, it is observed that improvements in efficiency can be obtained if private management is fostered for the terminals of solid bulk terminals and non-containerised general cargo terminals compared to privately managed passenger terminals.

Additionally, it is observed that ports located on islands are less efficient than the rest, due to the presence probably of more captive shippers in these ports. Besides ports that have an oil refinery installed in their vicinity are more efficient than the rest, Similarly, the use of rail access to the port has positive effects on economic efficiency. Regarding the reforms, it is observed that the 2003 and 2010 reforms have no effect on efficiency. On the other hand, the 2011 reform, which promotes the participation of private initiative, the decentralisation and higher autonomy of the ports and the greater liberalisation in the setting of tariffs, has had a positive and significant impact on efficiency. Finally, the largest ports (which, except for Bilbao, are located on the South and East coastline) are more efficient than the rest.

Regarding the market power analysis, it is observed that the *south and east* geographical market is more competitive than the *north* one in all the product markets considered. The main reason is that the ports located on the south and east coastlines are the ports with more traffic and are specialised in those markets (outputs) more competitive. In particular, containers and, especially transshipment containers are the markets in which ports have less market power, and these outputs are concentrated in the three largest Spanish ports (Valencia, Barcelona and Bahía de Algeciras). These ports are precisely the more efficient, showing that more efficiency is accompanied with less market power.

Several interesting lines are left for future research. We recognise our limitation in the definition of market power, because with our analysis only the dimension of the output is captured. To find appropriate data to set a Lerner Index could be a good approximation to measure the margin between the price and marginal costs per type of output and port. Secondly, estimates of economic efficiency must be complemented with other measures related with the performance of the ports in terms of environmental sustainability, ecological impact, or respectful integration with the cities. Lastly, future research will have to include international analysis introducing competition coming from large ports of North-Africa and rest of Europe, especially in the transshipment container markets.

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References

Baltagi, B.H. and Griffin, J.M. (1988) 'A general index of technical change', *Journal of Political Economy*, Vol. 96, No. 1, pp.20–41.

Bang, H.S., Kang, H.W., Martin, J. and Woo, S.H. (2012) 'The impact of operational and strategic management on liner shipping efficiency: a two-stage DEA approach', *Maritime Policy & Management*, Vol. 39, No. 7, pp.653–672.

Baños-Pino, J., Coto-Millán, P. and Rodríguez-Álvarez, A. (1999) 'Allocative efficiency and over-capitalization: an application', *International Journal of Transport Economics*, June, Vol. 26, No. 2, pp.181–199.

Barros, C.P. (2003) 'The measurement of efficiency of Portuguese sea port authorities with DEA', *International Journal of Transport Economics-Rivista Internazionale de Economia dei Trasporti*, Vol. 30, No. 3, pp.1000–1020.

Barros, C.P. (2006) 'A benchmark analysis of Italian seaports using data envelopment analysis', *Maritime Economics & Logistics*, Vol. 8, No. 4, pp.347–365.

Battese, G.E. and Coelli, T.J. (1992) 'Frontier production function, technical efficiency and panel data: with application to paddy farmers in India', *Journal of Productivity Analysis*, Vol. 3, Nos. 1–2, pp.153–169.

Boone, J. (2001) 'Intensity of competition and the incentive to innovate', *International Journal of Industrial Organization*, Vol. 19, No. 5, pp.705–726.

Boone, J. (2008) 'A new way to measure competition', *Economic Journal*, Vol. 118, No. 531, pp.1245–1261.

Castellano, R., Ferretti, M., Musella, G. and Risitano, M. (2020) 'Evaluating the economic and environmental efficiency of ports: evidence from Italy', *Journal of Cleaner Production*, Vol. 271, p.122560.

Chen, H-K., Chou, H-W. and Hsieh, C-C. (2018) 'Operational and disaggregate input efficiencies of international container ports: an application of stochastic frontier analysis', *International Journal of Shipping and Transport Logistics*, Vol. 10, No. 2, pp.113–159.

Cheon, S.H., Dowall, E.D. and Song, D.W. (2010) 'Evaluating impacts of institutional reforms on port efficiency changes: ownership, corporate structure and total factor productivity changes of world container ports', *Transportation Research Part E*, Vol. 46, No. 4, pp.546–561.

Coto-Millán, P., Casares-Hontañón, P., Sainz-González, R., Mateo-Mantecón, I., Agüeros, M., Badiola, A., Castanedo, J. and Pesquera, M.A. (2015) 'Regulation, competition, crisis and technical efficiency of companies operating in Spanish ports (2002–2011)', *Maritime Economics & Logistics*, Vol. 18, No. 3, pp.282–294.

Coto-Millán, P., Fernandez, X.L., Hidalgo, S. and Pesquera, M.A. (2016) 'Public regulation and technical efficiency in the Spanish Port Authorities: 1986–2012', *Transport Policy*, Vol. 47, pp.139–148.

Cullinane, K. and Song, D.W. (2003) 'A stochastic frontier model of the productive efficiency of Korean container terminals', *Applied Economics*, Vol. 35, No. 3, pp.251–267.

Cullinane, K., Song, D.W. and Gray, R. (2002) 'A stochastic frontier model of the efficiency of major container terminals in Asia: assessing the influence of administrative and ownership structures', *Transportation Research Part A*, Vol. 36, No. 8, pp.743–762.

Cullinane, K., Teng, Y.H. and Wang, T.F. (2005) 'Port competition between Shanghai and Ningbo', *Maritime Policy & Management*, Vol. 32, No. 4, pp.331–346.

De Oliveira, G.F. and Cariou, P. (2015) 'The impact of competition on container port (in)efficiency', *Transportation Research Part A: Policy and Practice*, Vol. 78, pp.124–133.

Díaz-Hernández, J.J., Martínez-Budría, E. and Jara-Díaz, S. (2008) 'Productivity in cargo handling in Spanish ports during a period of regulatory reforms', *Networks and Spatial Economics*, Vol. 8, Nos. 2–3, pp.287–295.

Färe, R., Grosskopf, S., Maudos, J. and Tortosa-Ausina, E. (2015) 'Revisiting the quiet life hypothesis in banking using nonparametric techniques', *Journal of Business Economics and Management*, Vol. 16, No. 1, pp.159–187.

Ferreira, D.C., Marques, R.C. and Pedro, M.I. (2018) 'Explanatory variables driving the technical efficiency of European seaports: an order-α approach dealing with imperfect knowledge', *Transportation Research Part E: Logistics and Transportation Review*, Vol. 119, pp.41–62.

Fleming, D.K. and Baird, A.J. (1999) 'Comment: Some reflections on port competition in the United States and Western Europe', *Maritime Policy & Management*, Vol. 26, No. 4, pp.383–394.

González, M.M. and Trujillo, L. (2008) 'Reforms and infrastructure efficiency in Spain's ports', *Transportation Research Part A*, Vol. 42, No. 1, pp.243–257.

Hicks, J.R. (1935) 'Annual survey of economic theory: the theory of monopoly', *Econometrica: Journal of the Econometric Society*, pp.1–20.

Hidalgo-Gallego, S., De La Fuente, M., Mateo-Mantecón, I. and Coto-Millán, P. (2020) 'Does cargo specialization improve port technical efficiency? The paradigm of specialized infrastructure', *Maritime Policy and Management*, Vol. 47, No. 2, pp.258–272.

Hidalgo-Gallego, S., Núñez-Sánchez, R. and Coto-Millán, P. (2022) 'Port allocative efficiency and port devolution: a study for the Spanish port authorities (1992–2016)', *Maritime Policy and Management*, Vol. 49, No. 1, pp.39–61.

Hlali, A., Ablanedo-Rosas, J.H. and Ruiz-Torres, A.J. (2023) 'Operational efficiency of major cargo seaports in some developing regions: results from a bootstrap DEA', *International Journal of Shipping and Transport Logistics*, Vol. 16, Nos. 3–4, pp.290–312.

Ju, S., Xie, J. and Tang, H. (2023) 'The impact of competition on operational efficiency of ports: empirical evidence from Chinese coastal port-listed companies', *Research in Transportation Business & Management*, Vol. 46, p.100939.

Ke, R. and Wang, C. (2017) 'Comparative analysis of the shipping center competitiveness of major port cities in China', *Transportation Journal*, Vol. 56, No. 1, pp.35–41.

Leibenstein, H. (1966) 'Allocative efficiency vs. 'X-efficiency'', *The American Economic Review*, Vol. 56, No. 3, pp.392–415.

Liu, Z. (1995) 'The comparative performance of public and private enterprise. The case of British ports', *Journal of Transport Economics and Policy*, Vol. 29, No. 3, pp.263–274.

Martínez Moya, J. and Feo Valero, M. (2017) Port choice in container market: a literature review', *Transport Reviews*, Vol. 37, No. 3, pp.300–321.

Martínez-Budría, E. (1996) 'Un estudio econométrico de los costes del sistema portuario español', *Revista Asturiana de Economía – RAE*, Vol. 5, pp.135–150.

Maudos, J. and De Guevara, J.F. (2007) 'The cost of market power in banking: social welfare loss vs. cost inefficiency', *Journal of Banking & Finance*, Vol. 31, No. 7, pp.2103–2125.

Nicholson, W. (1992) *Microeconomic Theory: Basic Principles and Extensions*, Dryden Press, Philadelphia.

Nong, N-M. (2023) 'Performance efficiency assessment of Vietnamese ports: an application of Delphi with Kamet principles and DEA model', *The Asian Journal of Shipping and Logistics*, Vol. 39, No. 1, pp.1–12.

Núñez-Sánchez, R. (2013) 'Marginal costs, price elasticities of demand, and second-best pricing in a multiproduct industry: an application for Spanish port infrastructure', *Journal of Transport Economics and Policy*, Vol. 47, Part 3, pp.349–369.

Núñez-Sánchez, R. and Coto-Millán, P. (2012) 'The impact of public reforms on the productivity of Spanish ports: a parametric distance function approach', *Transport Policy*, Vol. 24, pp.99–108.

Observatorio de Transporte y Logística en España (2018) *Yearbook 2018*.

Orea, L. and Zofío, J.L. (2019) 'Common methodological choices in nonparametric and parametric analyses of firms' performance', in ten Raa, T. and Greene, W.H. (Eds.): *The Palgrave Handbook of Economic Performance Analysis*, Palgrave Macmillan, Switzerland.

Pagano, M.A., Wang-Grace, W.Y., Sánchez, O.V. and Ungo R. (2013) 'Impact of privatization on port efficiency and effectiveness: results from Panama and US ports', *Maritime Policy & Management*, Vol. 40, No. 2, pp.100–115.

Pang, K., Lu, C-S., Shang, K-C. and Weng, H-K. (2021) 'An empirical investigation of green shipping practices, corporate reputation and organisational performance in container shipping', *International Journal of Shipping and Transport Logistics*, Vol. 13, Nos. 3–4, pp.422–444.

Pérez, I., González, M.M. and Trujillo, L. (2020) 'Do specialisation and port size affect port efficiency? Evidence from cargo handling service in Spanish ports', *Transportation Research Part A*, Vol. 138, pp.234–249.

Pérez, I., Trujillo, L. and González, M.M. (2016) 'Efficiency determinants of container terminals in Latin American and the Caribbean', *Utilities Policy*, Vol. 41, pp.1–14.

Périco, A.E. and da Silva, G.R. (2020) 'Port performance in Brazil: a case study using data envelopment analysis', *Case Studies on Transport Policy*, Vol. 8, No. 4, pp.331–346.

Puertos del Estado (2022) *Marco Estratégico. Sistema portuario de interés general*, October.

Rodríguez-Álvarez, A. and Tovar, B. (2012) ') 'Have Spanish port sector reforms during the last two decades been successful? A cost frontier approach', *Transport Policy*, Vol. 24, pp.73–82.

Rodríguez-Álvarez, A., Tovar, B. and Wall, A. (2011) 'The effect of demand uncertainty on port terminal costs', *Journal of Transport Economics and Policy*, May, Vol. 45, Part 2, pp.303–328.

Serebrisky, T., Sarriera, J.M., Suárez-Alemán, A., Araya, G., Briceño-Garmendía, C. and Schwartz, J. (2016) 'Exploring the driver of port efficiency in Latin America and the Caribbean', *Transport Policy*, Vol. 45, pp.31–45.

Shijaku, G. (2017) 'Bank stability and competition: evidence from Albanian banking market', *Eurasian Journal of Business and Economics*, Vol. 10, No. 19, pp.127–154.

Siqueira, G.A., Leal Jr., I.C., da Cunha, L.C., Guimarães, V.d.A. and Guabiroba, R.C.d.S. (2017) 'Analysis of technical efficiency and eco-efficiency in container terminals', *International Journal of Shipping and Transport Logistics*, Vol. 9, No. 5, pp.562–579.

Talley, W.K. (2007) 'Port performance: an economics perspective', *Research in Transportation Economics*, Vol. 17, pp.499–516.

Tongzon, J.L. and Heng, W. (2005) 'Port privatisation, efficiency and competitiveness: some empirical evidence from container ports (terminals)', *Transportation Research Part A*, Vol. 39, No. 5, pp.405–424.

Tovar, B. and Wall, A. (2017) 'Specialization, diversification, size and technical efficiency in ports: an empirical analysis using frontier techniques', *European Journal of Transport and Infrastructure Research*, Vol. 17, No. 2, pp.279–303.

Tovar, B. and Wall, A. (2019) 'Are larger and more complex port more productive? An analysis of Spanish port authorities', *Transportation Research Part A*, Vol. 121, pp.265–276.

Tsakaridis, A., Mateo-Mantecón, I., O'Connor, E., Hynes, S. and O'Donoghue, C. (2021) 'Efficiency benchmarking of Irish and North Atlantic ports: Implications for blue growth', *Utilities Policy*, Vol. 72, p.101268.

Valentine, V.F. and Gray, R. (2001) 'The measurement of port efficiency using data envelopment analysis', *Proceeding of the 9th World Conference on Transport Research, 2001, A2 Maritime Transport and Ports*, No. 1203.

Van Biesebroeck, J. (2007) 'Robustness of productivity estimates', *The Journal of Industrial Economics*, Vol. 55, No. 3, pp.529–569.

Van Leuvensteijn, M., Bikker, J., Kok, C. and Rixtel, A. (2011) 'A new approach to measuring competition in the loan markets of the euro area', *Applied Economics*, Vol. 43, No. 23, pp.3155–3167.

Wanke, P. and Barros, C.P. (2016) 'New evidence on the determinants of efficiency at Brazilian ports: a bootstrapped DEA analysis', *International Journal of Shipping and Transport Logistics*, Vol. 8, No. 3, pp.250–272.

Yang, Y-C. (2015) 'Determinants of container terminal operation from a green port perspective', *International Journal of Shipping and Transport Logistics*, Vol. 7, No. 3, pp.319–346.

Yuen, A.C.L., Zhang, A.M. and Cheung, W.M. (2013) 'Foreign participation and competition: a way to improve the container port efficiency in China?', *Transportation Research Part A: Policy and Practice*, Vol. 49, pp.220–231.

Zhou, Y., Li, Z., Duan, W. and Deng, Z. (2023) 'The impact of provincial port integration on port efficiency: empirical evidence from China's Coastal Provinces', *Journal of Transport Geography*, Vol. 108, p.103574.

Notes

1 Although there are port authorities managing several ports, throughout the paper we will employ the term port instead of port authority for the ease of the exposition.

2 Data obtained from Puertos del Estado and Eurostat.

3 See Ke and Wang (2017) for an interesting paper about competitiveness of major ports in China. Several factors affect port competitiveness including location, infrastructures, hinterland characteristics and port management.

4 The traditional approach to indirectly evaluate market power is firm's market share (e.g., using a Herfindahl Hirschman, HH, index to measure market concentration), although other variables such as the relative position of the competitor, the existence of potential entrants and the countervailing power of users, among others, are also important. The use of concentration indexes alone may be misleading. Note that it is possible to have high market concentration and firms setting prices equal to marginal costs (no market power), for instance in Bertrand duopoly competition.

5 The Boone indicator methodology has been applied mainly to banking competition; see, for instance van Leuvensteijn et al. (2011) and Shijaku (2017), among others.

6 See Núñez-Sánchez and Coto-Millán (2012) and González and Trujillo (2008), as two good reviews about this issue.

7 Total tons are obtained by the sum of the total tons of cargo and the number of passengers multiplied by 0.1.

8 Information on the number, type of output and type of management of terminals is obtained from the 'Statistical Yearbooks of State Ports'. In case of missing data in the yearbooks the authors have asked by phone each port authority about those missing data.

9 The acronym 'n.a.' in the last five columns appears when the corresponding port does not have enough traffic to obtain a marginal cost estimate.

10 These values are obtained by using the following expression: $MC_{mi} = \left. \frac{\partial \ln TC(y, w, K)}{\partial \ln y_m} \right|_i \frac{TC_i}{y_m}$, where TC_i and y_{mi} are the total cost and output m level of port i.

11 Economic inefficiency implies that ports can reduce the costs in a notable way without reducing the supplied outputs. Adjustments on labour are difficult to undertake because many of the workers are public employees and subject to important labour regulations. Adjustments on the other inputs (through levels or prices) could be more easily to do, with the condition that environmental restrictions be satisfied.

Appendix

Table A1 Estimated short-run total cost function

Variable	*Coefficient*	*Estimates*	*Std. error*
$\ln(y_1)$	α_{y1}	0.0330***	0.0035
$\ln(y_2)$	α_{y2}	0.0483***	0.0048
$\ln(y_3)$	α_{y3}	0.0104***	0.0030
$\ln(y_4)$	α_{y4}	0.1134***	0.0095
$\ln(y_5)$	α_{y5}	0.0641***	0.1056
$\frac{1}{2}\ln(y_1)\ln(y_1)$	α_{y11}	0.0048***	0.0005
$\frac{1}{2}\ln(y_2)\ln(y_2)$	α_{y22}	0.0034***	0.0007
$\frac{1}{2}\ln(y_3)\ln(y_3)$	α_{y33}	0.0028***	0.0005
$\frac{1}{2}\ln(y_4)\ln(y_4)$	α_{y44}	0.0305**	0.1203
$\frac{1}{2}\ln(y_5)\ln(y_5)$	αy_{55}	0.01350*	0.0082
$\ln(y_1)\ln(y_2)$	α_{y12}	–0.0003	0.0006
$\ln(y_1)\ln(y_3)$	α_{y13}	0.0002	0.0004
$\ln(y_1)\ln(y_4)$	α_{y14}	–0.0286***	0.0043
$\ln(y_1)\ln(y_5)$	α_{y15}	0.0005	0.0037
$\ln(y_2)\ln(y_3)$	α_{y23}	–0.0012*	0.0006
$\ln(y_2)\ln(y_4)$	α_{y24}	–0.2086***	0.0056
$\ln(y_2)\ln(y_5)$	α_{y25}	0.0029	0.0050
$\ln(y_3)\ln(y_4)$	α_{y34}	–0.0078**	0.0034
$\ln(y_3)\ln(y_5)$	α_{y35}	–0.0126***	0.0036
$\ln(y_4)\ln(y_5)$	α_{y45}	0.0249*	0.0133
$\ln(wk)$	β_k	0.4517***	0.0189
$\ln(wc)$	β_i	0.2472***	0.0101
T	ω_t	–0.0009	0.0017
$\frac{1}{2}T^2$	ω_{tt}	–0.0008***	0.0001
$\frac{1}{2}\ln(w_k)\ln(w_k)$	β_{kk}	0.0358	0.0388
$\frac{1}{2}\ln(w_c)\ln(w_c)$	β_{cc}	0.0412***	0.0139

Table A1 Estimated short-run total cost function (continued)

Variable	*Coefficient*	*Estimates*	*Std. error*
$\ln(w_k)\ln(w_c)$	β_{kc}	–0.1364***	0.0376
$\ln(K)$	θ_k	0.4813***	0.0259
$\frac{1}{2}\ln(K)\ln(K)$	θ_{kk}	–0.1396*	0.0808
$\ln(y_1)\ln(wk)$	γ_{y1k}	0.0049*	0.0029
$\ln(y_1)\ln(wc)$	γ_{y1c}	–0.0156***	0.0021
$\ln(y_2)\ln(wk)$	γ_{y2k}	0.0127***	0.0046
$\ln(y_2)\ln(wc)$	γ_{y2c}	0.0072**	0.0030
$\ln(y_3)\ln(wk)$	γ_{y3k}	0.0009	0.0025
$\ln(y_3)\ln(wc)$	γ_{y3c}	–0.0059***	0.0023
$\ln(y_4)\ln(wk)$	γ_{y4k}	–0.0242	0.0163
$\ln(y_4)\ln(wc)$	γ_{y4c}	–0.0005	0.0090
$\ln(y_5)\ln(wk)$	γ_{y5k}	–0.0895***	0.0163
$\ln(y_5)\ln(wc)$	γ_{y5c}	0.0505***	0.0073
$\ln(y_1)\ln(K)$	ω_{y1K}	–0.0062*	0.0032
$\ln(y_2)\ln(K)$	ω_{y2K}	0.0251***	0.0078
$\ln(y_3)\ln(K)$	ω_{y3K}	–0.0063	0.0038
$\ln(y_4)\ln(K)$	ω_{y4K}	–0.0319*	0.0182
$\ln(y_5)\ln(K)$	ω_{y5K}	0.0278	0.0208
$\ln(wk)\ln(K)$	ω_{kK}	0.0278	0.0352
$\ln(wc)\ln(K)$	ω_{iK}	0.0027	0.0218
$\ln(y_1)T$	ω_{y1t}	–0.0009***	0.0002
$\ln(y_2)T$	ω_{y2t}	–0.0009***	0.0003
$\ln(y_3)T$	ω_{y3t}	0.0000	0.0002
$\ln(y_4)T$	ω_{y4t}	–0.0016**	0.0008
$\ln(y_5)T$	ω_{y5t}	–0.0008	0.0007
$\ln(w_k)T$	ω_{kt}	0.0002	0.0018
$\ln(w_c)T$	ω_{ct}	0.0005	0.0010
$\ln(K)T$	ω_{Kt}	0.0052*	0.0026
Constant	β_0	–0.2140***	0.0256

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

Table A2 Estimates for the cost function error term parameters

Parameters	*Estimates*	*Std. error*
μ	0.2242	0.8094
η	–0.0406***	0.0050
σ_u^2	0.1322	0.1733
σ_v^2	0.0006***	0.0000

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

Table A3 Average market shares per port and output

Port	*MSy1 (%) (Containers)*	*MSy2 (%) (Liquids)*	*MSy3 (%) (Passengers)*	*MSy4 (%) (Solids)*	*MSy5 (%) (NonContainer.)*	*MSy1trans (%) (TContainer)*
A Coruña	0.02	5.08	0.38	4.27	1.88	0.00
Alicante	1.20	0.07	1.18	1.37	0.66	0.01
Almería	0.03	0.17	4.08	5.36	1.08	0.00
Avilés	0.03	0.44	0.00	3.18	2.09	0.00
B. Algeciras	28.08	15.60	21.06	2.49	9.53	50.85
B. Cádiz	0.88	0.16	1.24	1.90	2.16	0.15
Baleares	1.20	1.16	23.33	1.85	14.98	0.00
Barcelona	16.89	7.81	13.04	4.30	15.78	10.23
Bilbao	4.30	12.37	0.68	4.87	6.13	0.08
Cartagena	0.47	13.87	0.37	5.12	0.53	0.00
Castellón	0.96	5.34	0.00	4.15	0.80	0.06
Ferrol SC	0.01	1.25	0.03	9.59	1.20	0.00
Gijón	0.27	0.77	0.08	17.29	1.17	0.00
Huelva	0.08	11.70	0.07	6.12	0.95	0.00
Las Palmas	8.82	3.45	6.81	0.96	6.18	9.57
Marín RP	0.34	0.00	0.00	0.96	1.10	0.04
Málaga	1.73	0.06	2.79	1.47	0.79	3.06
Pasaia	0.00	0.03	0.00	2.07	3.65	0.00
SC Tenerife	3.16	5.04	20.81	1.03	5.97	0.34
Santander	0.03	0.21	0.77	3.78	2.64	0.00
Sevilla	1.07	0.20	0.06	2.42	1.82	0.00
Tarragona	0.75	12.73	0.06	10.74	1.92	0.62
Valencia	28.01	2.43	2.46	4.02	14.74	24.85
Vigo	1.65	0.05	0.67	0.47	2.33	0.09

Source: Own elaboration