Port allocative efficiency and port devolution: A study for the Spanish port authorities (1992-2016)

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ABSTRACT

This paper analyses the effect of port devolution on the Spanish port authorities' allocative efficiency across periods with different regulations during the port devolution process in Spain. To do this, we first obtain a measure of allocative efficiency from a distance system of equations using two different approaches: the error components approach and the parametric approach. Then, we evaluate whether port devolution has had effects on allocative efficiency by applying a quantile regression approach, taking into account control variables related to port characteristics. Our results suggest that allocative inefficiencies occur in the Spanish port system. We also demonstrate that port devolution reforms, both internal and external port characteristics have had a significant effect on the port authorities' allocative inefficiency.

Keywords: allocative efficiency, distance function, quantile regression, port devolution.

JEL codes: D24, L91, L92

1. Introduction

Economic globalisation, the growth of international trade, as well as the consolidation of the European single market have increased the strategic importance of commercial ports in Europe (European Commission 2011). These ports are crucial for the expansion of the productive economy and fundamental elements of transport systems (Bottasso et al. 2014). The role of ports becomes even more relevant in peripheral countries like Spain. In this sense, the last port reforms (Laws 48/2003 and 2/2011) state that the competitiveness of the Spanish economy strongly depends on efficient ports adequately integrated on integrated into global logistic chains.

However, the concern for efficiency in ports comes from much earlier. In this sense, during the 80s and 90s of the last century, the port management model was reconsidered in both developed and developing countries. The *decentralisation* of government responsibility and accountability (from central to local control), the *commercialisation* of certain port services, the *corporatisation* of the port assets, or the partial/total *privatisation* of port facilities have been some examples of port reforms with a common objective: To improve efficiency and responsiveness. These sets of reforms have been considered as different types of *port devolution* (Brooks and Cullinane 2007).

In Spain, four port reforms have transformed the port system since the early 90s[1]. Before the first of them came into force, Spanish ports operated as tool ports with marginal private participation. The port devolution process in Spain comes from Law 27/1992. This process means a change of the management model towards a landlord port management model. It created the state-owned entity *Puertos del Estado* (State Ports) and port authorities. On the one hand, *Puertos del Estado* is responsible for the coordination and control of the national ports. On the other hand, the port authorities are entities with legal personality and their own assets, which carry out their functions under the general principle of management autonomy. Port authorities' functions comprise the provision of the port land and the infrastructure, the regulation of the use of the port space, and they are responsible for the security within the port. On the other hand, private operators carry out the main handling operations under concession contracts, and they purchase and maintain their superstructure and equipment (Brooks 2004).

The second port reform, Law 62/1997, introduced the participation of regional governments in the decision-making processes of port authorities and the global objective of self-financing of the Spanish system as a whole was substituted by the requirement of self-financing for each port authority individually. Finally, this port reform continued to deepen the principles of a landlord mode and promoted the increase of private participation in port operations. Law 10/2003 encouraged the involvement of private agents in funding, construction and operation of port facilities. In this way, the private initiative was no longer only carried out the main cargo handling activities but also co-participates in the development and growth of port infrastructure. Finally, Law 33/2010 continues the liberalisation of port services and the economic and commercial activities that take place in the Spanish ports. Then, one of the main characteristics of these port reforms is their incremental nature, seeking a higher deepening of the landlord model.

This article presents three main objectives. The first one is to evaluate the efficiency in the resource allocation of the Spanish port system for the period 1992-2016. The analysis of efficiency and productivity of the port sector is considered as one of the most prominent transport economics' research lines (González and Trujillo 2009; Odeck & Bråthen 2012). Port allocative efficiency in input selection involves selecting the mix of inputs that provides a given output service at minimum cost, given the input prices (Coelli et al. 2005). Then, the optimal allocation of port resources is a necessary condition to minimise port infrastructure costs. If allocative inefficiencies exist, port authorities can reduce their costs by reallocating inputs. Secondly, we investigate the effect of port devolution on the port authorities' allocative efficiency. The literature on port productivity presents a significant number of studies that have already assessed the impact of port devolution reforms on technical efficiency. However, to our knowledge, there are no previous studies that have analysed the effects of those reforms on allocative efficiency. The distinction between both types of efficiency is especially relevant in this analysis since although

[1] Therefore, four periods of regulation can be distinguished. The first period of regulation covers the years from 1992 to 1996 with Law 27/1992 in force. The second begins in 1997 when Law 62/1997 is passed and ends in 2002. The third comprises the years between 2003 and 2009, being in force Law 10/2003. Finally, the fourth begins with the adoption of Law 33/2010 in 2010 and finishes in the last year of the sample.

technical efficiency has to do with purely technological aspects, allocative efficiency tries to analyse whether ports allocate efficiently according to their input prices. Finally, the third objective is to test whether port devolution reforms have had effects on allocative inefficiency regarding port infrastructure. We try to isolate the impact of private participation on port activities by considering other port reforms related to port devolution.

The Spanish port system provides an interesting case to carry out this study. On the one hand, cost reduction is a recurring objective in the port reforms carried out during the study period. Therefore, the assessment of allocative efficiency allows testing whether cost performance has improved through the implementation of different port reforms. On the other hand, the availability of both traffic and economic data for a long period allows analysing the evolution of the Spanish port institutional framework and its impact on allocative efficiency.

To carry out this analysis, we first estimate the allocative efficiency from a system of equations formed by an input-oriented distance function with their input cost share equations. This methodology improves the efficiency of the estimation, and it has been applied before in Baños-Pino et al. (2002), Rodríguez-Álvarez et al. (2004, 2007) and Hidalgo-Gallego et al. (2017). The use of a distance function allows calculating allocative efficiency independently of technical efficiency. Furthermore, the use of the distance function does not require assuming that port authorities minimise their costs, which in the case of public-owned port authorities could be convenient. Then, we evaluate the effect of port devolution on allocative efficiency using a *quantile regression* framework controlling for other contextual variables. This empirical methodology provides information about the relationship between the outcome and the regressors at different points in the conditional distribution of port allocative inefficiency measures considering the heterogeneity of port authorities. Additionally, we consider in our research strategy that those contextual variables are not part of the port infrastructure's technology, but they have an indirect effect through inefficiency. Under this setting, we could address some relevant questions regarding port management strategies conditional on the port infrastructure's technology.

The main results suggest that both systematic and relative allocative inefficiencies exist in the Spanish port system for the port devolution period. To be more precise, we find that labour and intermediate consumptions are underutilised systematically, whereas capital is overused. Regarding relative allocative inefficiency, labour and intermediate consumptions are both underutilised in relation to capital, whereas the pair labour and intermediate consumptions are optimally allocated at the sample mean. Moreover, we find that the port devolution process has influenced the Spanish port authorities' allocative efficiency.

The remainder of the paper is organised as follows. Section 2 reviews the previous empirical literature related to determinants on port technical efficiency and presents the hypotheses for port allocative efficiency. The methodology is introduced in Section 3.

Section 4 and 5 summarise the data used and the results of the estimations, respectively. Finally, in Section 6, we provide a general discussion and concluding remarks.

2. Literature review

2.1. Determinants of allocative inefficiency

The study of the firm's allocative inefficiency has been frequently ignored in cost efficiency studies. Only a few recent contributions try to analyse factors that might cause input misallocations, departing from the cost minimisation strategy. For instance, Gamberoni et al. (2016) analyse the evolution of input misallocation across firms in five European countries during the period 2002-2012. Their results show that macro determinants such as input market regulations, demand uncertainty or restrictive bank credit standards are relevant in input misallocation. Additionally, they find that the Great Recession, started in 2008, improved the allocative efficiency of both capital and labour. Other studies have focused on specific industry studies. For instance, Nair and Vinod (2019) investigate both internal and external determinants of allocative efficiency for Indian scheduled commercial banks. On the one hand, internal determinants are related to profitability, size and risk measures. They also control for qualitative variables such as ownership or pro-competitive reforms. On the other hand, exogenous macro-economic conditions related to economic growth rate, inflation rate and unemployment rate are analysed. Their results show that economic growth is negatively related to allocative efficiency. Musau et al. (2021) use data on Norwegian electricity distribution firms to study determinants of input misallocation. Cost of credit, changes in real turnover, or the economic recession are factors negatively related to input misallocation.

2.2. The role of economic cycles and hinterland conditions on port performance

Focusing on the port economics literature, economic cycles and port hinterland conditions are specific determinants of port allocative inefficiency. On the one hand, De Monie et al. (2011) point out the relationship between capital investment in ports and the economic boom during the first years of the 21st century. For the period 2001 to 2008, large sums of financial resources became available for intermodal improvements for the period 2001 to 2008. For instance, the development of more advanced port infrastructure to support export-oriented facilities. The perverse consequence was that port facilities were considered as a financial product perceived as liquid. This perception abruptly vanished at the end of 2008. However, the irreversibility of those investments would affect input allocation for the next years. On the other hand, Wan et al. (2014) consider different variables related to hinterland accessibility such as intra-port competition, rail service, on-dock rail facility, road congestion or the catchment area population as determinants of port technical efficiency for a sample of American ports. They find a negative relationship between container port efficiency and the provision of on-dock rail facility at container terminals. Moreover, larger ports tend to be more technically efficient.

2.3. Port devolution and port efficiency

A crucial phenomenon in the worldwide port industry has been the port devolution process. From the early nineties of the last century, governments have focused their efforts on controlling the port environment, letting private initiative be responsible for port operation. Therefore, private participation in port operations has increased gradually (Cheon et al. 2010), producing significant changes in port management. The primary justification of the devolution programs is the productivity gains related to better management carried out by private companies. However, the success of these programs is difficult to assess because it depends on the objectives of the devolution process (Brooks 2006).

The studies that analyse the effects of devolution on port efficiency play a central role within the academic debate of the success of devolution processes in the port industry. Therefore, not surprisingly, private ownership and participation are the most investigated efficiency drivers. This kind of analysis is mostly carried out for the case of technical efficiency. Also, it is possible to find some examples of cost efficiency, for instance, Rodríguez-Álvarez and Tovar (2012). Until to the best of our knowledge, this is the first study that investigates the effect of port devolution on allocative efficiency for the case of port infrastructure. Table 1 summarises efficiency studies that analyse this phenomenon.

The literature reviewed does not get a consensus about the effect of ownership in port efficiency. For instance, Liu (1995) and Cullinane et al. (2005) do not find significant differences in the technical efficiency scores between private-owned ports and public-owned ones. In a similar vein, Cullinane et al. (2002) suggest that there would be an inverse relationship between the degree of centralised government control and port efficiency. Still, they cannot obtain a relationship between efficiency and ownership. Chang and Tovar (2014) results indicate a negative relationship between private management and terminal efficiency. Tongzon and Heng (2005) find a U-shape relationship between private participation in ports and port efficiency. Within the body of studies that indicate a positive effect of private ownership in port efficiency, we find the following ones. Wanke (2013) obtain a positive relationship between private ownership and physical infrastructure efficiency, Niavis and Tsekeris (2012), Serebriski et al. (2016), and Súarez-Aleman et al. (2016) obtain that private participation in port operation improves technical efficiency whereas Wanke and Barros (2015) point out that public-private partnership increases scale efficiency. Similary, Chang and Tovar (2017) and López-Bermúdez (2019) get that private management contributes to improving terminals' productivity and technical efficiency, respectively. In a similar vein that the previous works, Yuen et al. (2013) shows that those Chinese container terminals with foreign ownership and local participation present higher efficiency scores than those with major Chinese ownership.

The ownership changes in port management and the introduction of private participation in port operations have been usually introduced through a series of port reforms. Therefore, there is a body of studies that analyse the effect of port reforms on port performance. For the Spanish case, we find González and Trujillo (2008), Rodríguez-

Álvarez and Tovar (2012), Núñez-Sánchez and Coto-Millán (2012) and Coto-Millán et al. (2016). González and Trujillo (2008) do not find a significant effect of Spanish port reforms for the whole system. However, analysing their results separately for each port authorities, results suggest that port reforms have a significant effect on port authorities' efficiency, but the sign on such effect depends on the port authority considered. Núñez-Sánchez and Coto-Millán (2012) find that Spanish port reforms have a positive impact on scale efficiency change, technical efficiency change and total factor productivity. Rodríguez-Álvarez and Tovar (2012) show that in the years in which Law 27/1992 and Law 62/1997 are into force, economic efficiency grows. However, after the adoption of Law 48/2003, the levels of economic efficiency begin falling. Coto-Millán et al. (2016) obtain a positive impact of Law 62/1997 and Law 48/2003 on technical efficiency. These reforms delve on the promotion of port autonomy, private participation and inter-port competition.

In other port contexts, Cheon et al. (2010) evaluate the policies related to the devolution process for a group of worldwide ports, finding a positive effect of such policies on port efficiency. Finally, Chang and Tovar (2014) observe higher levels of efficiency in Chilean terminals than in the Peruvian ones. Authors consider that this fact might be explained because the structural reforms carried out in both countries was first implemented in Chile.

INSERT TABLE 1 HERE

3. Methodology

The main questions of this analysis are the following: (1) are Spanish port authorities allocatively (in)efficient?; (2) Has the port devolution carried out in the Spanish port system improved the level of allocative efficiency of these authorities?; (3) What other factors can affect the port authorities' allocative efficiency?. A three-step procedure is proposed to answer these questions (Figure 1).

In the first stage, the technology of port authorities is modelled by the estimation of an input-oriented distance function and its associated share equations. The conditions under which port authorities operate[2] determine the choice of a distance function oriented to the inputs, instead of to the outputs. In this sense, port authorities have higher control over the inputs that they employ than over the traffics that pass through them.

In the second stage, using the estimated parameters in the previous step, we apply two different approaches to test whether port authorities are allocative (in)efficient or not (Atkinson and Cornwell 1994). The called *error components approach* allows calculating a measure of systematic allocative inefficiency for every single input. The second

[2] Studies such as Núñez-Sánchez and Coto-Millán (2012), Rodríguez-Álvarez et al. (2004 and 2007) and, Serebrisky et al. (2016) estimate input-oriented distance function for the port industry.

methodology, known as the *parametric approach*, provides indices of allocative inefficiency for each pair of inputs.

Finally, in the third stage, we regress the indices obtained from the parametric approach on a set of variables to evaluate the potential drivers of the allocative (in)efficiencies. Other recent studies have followed a similar procedure (e.g. Musau et al. 2020). In this stage, a quantile regression model is considered because it allows assessing the effect of such drivers at different levels of inefficiency. In the following subsections, these stages are explained in detail.

INSERT FIGURE 1

3.1 Input-oriented distance function

The use of an input-oriented distance function allows to model multi-output multi-input technologies but also represent them with convenient functional forms (Färe and Primont, 2012). This specification also avoids the "*Greene problem*," which refers to the difficulty to separate economic inefficiency into its technical and allocative components when using a cost system (Rodríguez-Álvarez et al. 2004).

The regularity conditions that the input-oriented distance function must fulfil are the following: (1) non-decreasing in inputs, (2) non-increasing in outputs, (3) homogeneity of degree one in inputs, and (4) quasi-concavity in inputs. Before the estimation, homogeneity of degree one must be imposed in the specification of the function. If a Translog distance function is specified, homogeneity is enforced by normalising the distance function with respect one input as equation 1 shows. Besides, the Translog functional form does not impose any restrictions on input substitution.

Therefore, the input-oriented distance function is specified as follows:

$$\begin{aligned} -\ln(x_{nht}) = {} & \beta_h + \sum_{i=1}^{n-1} \beta_i lnx_{iht}^* + \sum_{r=1}^{m} \beta_r lny_{rht} + \frac{1}{2}\sum_{i=1}^{n-1}\sum_{j=1}^{n-1} \beta_{ij} lnx_{iht}^* lnx_{jht}^* \\ & + \frac{1}{2}\sum_{r=1}^{m}\sum_{s=1}^{m} \beta_{rs} lny_{rht} lny_{sht} + \sum_{i=1}^{n-1}\sum_{r=1}^{m} \beta_{rs} lnx_{iht}^* lny_{jht} + \beta_t t_t + \frac{1}{2}\beta_{tt} t_t^2 \\ & + \sum_{i=1}^{n-1} \beta_{ti} lnx_{iht}^* t_t + \sum_{r=1}^{m} \beta_{tr} lny_{rht} t_t + v_{ht} - u_{ht} \end{aligned} \tag{1}$$

Applying the Shephard's lemma, the cost share equations are:

$$s_{iht} = \beta_i + \sum_{j=1}^{n-1} \beta_{ij} lnx_{jht}^* + \sum_{r=1}^{m} \beta_{rs} lny_{jht} + v_{iht} + A_{iht} \tag{2}$$

where y_r represents the output r, $x_i^* = x_i/x_n$ is the variable input i normalised in terms of an input n, s_i is cost share of input i, h relates to the h_{-th} authority, t refers to the period and finally, v_{ht} and v_{iht} represent the statistical noise in the distance function and the input share equations; u_{ht} y A_{iht} represent technical and allocative inefficiency, respectively.

We also impose the following symmetry conditions:

$$\beta_{ij} = \beta_{ji};\ \beta_{rs} = \beta_{sr} \tag{3}$$

The first-order coefficients can be interpreted as elasticities at the sample mean because variables are expressed in deviations with respect their means.

3.2 The *error components approach*

This approach measures the persistent allocative efficiency, due to the use of the corresponding variable input in a non-cost minimising mix, from the disturbances of the input cost share equations. A significant number of studies have used this approach in order to study systematic allocative inefficiency for individual inputs. For instance, Rodríguez-Álvarez & Lovell (2004) find a systematic misallocation of resources in Spanish hospitals, whereas Rodríguez-Álvarez et al. (2007) show that the port labour-specific regulatory environment impedes persistent allocative efficiency for regular labour in port cargo handling firms. In our case, the component A_{iht} approximates allocative inefficiency for input i. If the mean of A_{iht} for input share is statistically different from zero, then input i is being over or underused systematically[3]. Then, according to Ferrier and Lovell (1990), equation (4) is transformed as follows:

$$s_{iht} = (\beta_i + a_i) + \sum_{j=1}^{n-1} \beta_{ij} lnx_{jht}^{*} + \sum_{r=1}^{m} \beta_{rs} lny_{jht} + (v_{iht} + A_{iht} - a_i) \tag{4}$$

where the transformed error terms have means equal to zero.

A positive value of $a_i$means that input i is overused, which implies that the weight of input i in total cost is higher than the optimal. a_i equal to zero shows that input i is used optimally. Finally, a negative value of a_i suggests that input i is underused.

3.3 The *parametric approach*

Atkinson and Cornwell (1994) proposed that there are firms that do not minimise their costs, but they minimise their shadow costs. In this case, the marginal rate of technical substitution equals to the ratio of the input shadow prices (w_i^s) instead of input market prices:

$$MRTS_i^j = \frac{MP_i}{MP_j} = \frac{w_i^s}{w_j^s} \tag{5}$$

[3] Systematic inefficiencies in the Spanish port sector can arise by several issues: public regulation, lumping investments, difficulties to adjust capital or strategic planning.

A firm is minimising its costs when the shadow price ratio equals to market price ratio, and, in turn, it is efficient. However, if the market and shadow price ratios differ, this firm is inefficient in an allocative way.

Applying the Shepard Lemma to the input-oriented distance function allows obtaining the ratio of shadow prices (Färe and Grosskopf 1990):

$$\frac{\partial D_I(x_{ht}, y_{ht}, C_{ht}, t_t)/\partial x_{iht}}{\partial D_I(x_{ht}, y_{ht}, C_{ht}, t_t)/\partial x_{jht}} = \frac{w^s_{iht}}{w^s_{jht}} \qquad (6)$$

The direction and magnitude of the deviation between both shadow and market price ratios are defined using parametric price corrections and can be estimated from the parameters in (1)-(2).

$$\frac{w^s_{iht}}{w^s_{jht}} = z_{ij}\frac{w_{iht}}{w_{jht}} \qquad (7)$$

Therefore, the indices of allocative inefficiency for each observation are calculated according to equation (8):

$$z_{ijht} = \frac{x_{jht}w_{jht}}{x_{iht}w_{iht}} \frac{[\hat{\beta}_i + \sum_{j=1}^{n-1}\hat{\beta}_{ij} lnx^*_{jht} + \sum_{r=1}^{m}\hat{\beta}_{rs} lny_{jht}]}{[\hat{\beta}_j + \sum_{j=1}^{n-1}\hat{\beta}_{ij} lnx^*_{jht} + \sum_{r=1}^{m}\hat{\beta}_{rs} lny_{jht}]} \qquad (8)$$

Values z_{ij}=1 means port allocative efficiency, z_{ij}>1 means that input i is underused relative to input j, and z_{ij}<1 means that input i is overused relative to input j.

3.4 Technical change

Technical change in this framework is interpreted as the reduction of the distance to the optimal frontier over time, ceteris paribus. Then, the rate of technical change is defined in equation (9).

$$TC = -\frac{\partial lnD_I(x_{ht}, y_{ht}, C_{ht}, t_t)}{\partial t} = -(\beta_t t_t + \frac{1}{2}\beta_{tt} t_t^2 + \sum_{i=1}^{n-1}\beta_{ti} lnx^*_{iht} t_t + \sum_{r=1}^{m}\beta_{tr} lny_{rht} t_t) \qquad (9)$$

In equation (9), we identify three different components of technical change (Baltagi and Griffin, 1988; Bhattacharyya et al., 1997):

Pure technical change (PTC): $-(\beta_t t_t + \frac{1}{2}\beta_{tt} t_t^2)$

The PTC is neutral in the sense that it does not affect the demand of inputs in the distance function.

Non-neutral technical change (NTC): $-(\sum_{i=1}^{n-1}\beta_{ti} lnx^*_{iht} t_t)$

The NTC is referred to the technological change which alters the use of inputs. In this sense, we consider either input-saving or input-augmenting technological change. Scale-augmenting technical change (STC): $-(\sum_{r=1}^{m}\beta_{tr}lny_{rht}t_t)$

The STC is the technical change which affects the economies of scale. Then, a productive unit can take advantage (disadvantage) of greater (lower) economies of scale.

3.5 Effects of port devolution on allocative efficiency

Once the allocative inefficiency indices are obtained, we evaluate the effect of port devolution on allocative efficiency. Quantile regression has been chosen instead of a standard regression to carry out this analysis. Standard linear regression summarises the average relationship between the outcome variable of interest and the regressors. The average relationship is a partial view of this relationship, especially with a sample of heterogeneous agents, such as the Spanish port authorities. However, the quantile regression allows generating different regression lines for different quantiles of the dependent variable. Thus, the effect of the repressors on the dependent variable can be analysed at different points of its distribution.

The quantile regression is specified as follows.

$$z_{ij_{ht}} = f_{ht}\delta_q + v_{qht} \text{ with } Quant_q\left(z_{ij_{ht}}|f_{ht}\right) = f_{ht}\delta_q \quad (11)$$

Where z_{ij} is the dependent variable, f is a vector of explicative variables, δ_q is the vector of parameters and $Quant_q\left(z_{ij_{ht}}|f_{ht}\right)$ denotes the q_{th} conditional quantile of $z_{ij_{ht}}$ given f. The q_{th} regression quantile, $0 < q < 1$, is defined as the solution of:

$$\min_{\delta\in R^k}\left(\sum_{ht:z_{ij_{ht}}\geq f_{ht}\delta} q|z_{ij_{ht}} - f_{ht}\delta| + \sum_{ht:z_{ij_{ht}}<f_{ht}\delta}(1-q)|z_{ij_{ht}} - f_{ht}\delta|\right) \quad (12)$$

Expression (12) is often written as:

$$\min_{\delta\in R^k}\sum_{ht}\rho_q(z_{ij_{ht}} - f_{ht}\delta) \quad (13)$$

where $\rho_q(\varepsilon)$ is the check function defined as $\rho_q(\varepsilon) = q\varepsilon$ if $\varepsilon \geq 0$ or $\rho_q(\varepsilon) = (1-q)\varepsilon$ if $\varepsilon < 0$.

This objective function is not differentiable and so linear programming methods have to be used to solve the minimisation problem. The estimator that minimises $Q(\beta_q)$ is asymptotically normal under general conditions (Cameron and Trivedi, 2005).

On the other hand, the instrumental variable procedure can be applied in quantile regression estimations to solve econometric problems related to the likely endogeneity of some variables.

Quantile regression methods present important advantages (Koenker and Hallock 2001). First, they provide a richer characterisation of the data. Second, median regression is more robust to outliers than least-squares regression. Third, quantile regression estimators can be consistent under weaker stochastic assumptions than possible with ordinary least-squares estimations. Fourth, because the approach is semiparametric, assumptions on the distribution of the error term are no needed. Additionally, this methodology is suitable for heteroskedastic data. The major disadvantage of quantile regression models is related to the estimation of the parameters. Statistical inference on them can get complicated because the estimators for coefficients are not available in a closed form (Waldmann 2018).

4. Data

The data set includes 26 Spanish port authorities observed for 25 years, 1992-2016. The supervisor entity of the Spanish port system, *Puertos del Estado*, and the port authorities publish annual reports providing uniform statistical information on the performance of port authorities. Additional data comes from the Spanish National Statistical Institute (INE). Table 1 displays the main descriptive statistic of the variables used.

4.1. Variables of the input-oriented distance system

For the estimation of the distance system, we have collected information about inputs, outputs and input cost shares. The analysis considers three inputs: labour (l), variable capital (k) and intermediate consumptions (ic). Labour represents the number of workers hired by the port authorities. Variable capital is defined as by the ratio of depreciation expenses to capital price. Capital price is calculated in equation (14) following the standard methodology proposed by the OECD (2009). The OECD's methodology measures capital price by multiplying a building index price (bip) of public works and the sum of the long-run real interest rate ($rate$) plus the depreciation rate (dep) of the port authorities' infrastructure and equipment. The depreciation rate is obtained by dividing depreciation expenses by total assets. Thirdly, intermediate consumptions are proxied by intermediate supplies measured in tons.

$$r_{ht} = [bip_{ht}(rate_{ht} + dep_{ht})] * 100 \tag{14}$$

Regarding the outputs, we have considered five outputs: liquid bulk (li), solid bulk (sol), containerised general cargo ($cont$), non-containerised general cargo ($ncont$) and passengers (pax). Cost shares for labour and capital (s_l and s_k) have been calculated to estimate the distance function and the cost share equations jointly.

It is not common to consider the possible endogeneity of input variables in efficiency literature. Some exceptions are Baños-Pino et al. (2002) and Rodríguez-Álvarez et al. (2004). In both studies, inputs are considered endogenous when the efficiency of public-owned institutions is analysed. Rodríguez-Álvarez et al. (2004) justify the endogeneity of inputs due to these entities may have incentives to choose their inputs following different criteria than cost-minimisation. Another reason for considering input endogeneity is that port authorities may have greater control over the inputs they hired than over the traffic they served. Therefore, we also assume that inputs might be endogenous being correlated with the error terms of the distance function or share equations. Then, a set of instruments has been used to solve possible problems associated with inputs' endogeneity. The instruments considered are hinterland's GDP (*GDP*), hinterland's population (*Population*), a dummy variable that collects the characteristic of being a port authority that manages more than one port (*Multiport*) and a political dummy (*Politics*). This dummy variable takes values equal to one when the party in the regional government of port authorities' hinterland coincides with the one in the central government. On the one hand, these instruments are considered as exogenous for port authorities, but they affect directly to the amounts of input hired by ports. On the other hand, we assume that they are uncorrelated with possible omitted variables including in the error terms of the equations in the system.

INSERT TABLE 2 HERE

4.2. Contextual variables

Following the main objective of this research, variables related to Spanish port reforms and the degree of private participation in port activities are used to characterise the Spanish devolution process.

(1) The port devolution process in the Spanish port system has carried out mainly by four port reforms (Laws 27/1992, 62/1997, 48/2003 and 33/2010). The first one, Law 27/1992, was approved in 1992 and it was into force from 1993 to 1996. This period is taken as the base period. In this way, a set of time dummies are used to control changes in port authorities' allocative efficiency produced in the subsequent periods of regulation. The first dummy (*Law 62/1997*) takes values equal to one in the period 1997-2002, in which Law 62/1997 is in force, and zero otherwise. The second one (*Law 48/2003*) takes values equal to one for 2003-2009 in which Law 48/2003 is in force. Finally, the third one (*Law 33/2010*) takes values equal to one for 2010-2016 in which Law 33/2010 is in force.
(2) As we explained above, the devolution process supposes a transfer of responsibilities from governments to private companies. In this line, the share of cranes that belong to private companies (*Privatisation*) is used to approximate the degree of private participation in port activities[4].

Additionally, other variables previously used in port efficiency literature (e.g. Turner et al. 2004; Niavis and Tsekeris 2012; Wanke 2013) have been included in the second stage to control for port and hinterland characteristics.

(3) Hinterland size is proxied by the gross manufacturing value added of the region in which port authorities are located (*Manufac*).
(4) The effect of the global financial crisis of 2008 has been collected by including a dummy variable which takes values equal to one from 2008 ahead (*Recession).*

[4] We consider that this variable might be a valid proxy for the degree of private participation within the port activity given that it presents heterogeneity among the different Spanish port authorities.

(5) The Herfindahl-Hirschman index (13) is used to approximate the level of port authorities' specialisation (*Specialisation)*:

$$Spec_{ht} = \sum_{r=i}^{4} S_{rht}^{2} \tag{13}$$

where S_r is the share of cargo r in total cargo handled by the port authority h in period t.

(6) Port authorities have been grouped according to their complexity degree following the classification proposed by *Puertos del Estado*. Group *high complexity* comprehends those port authorities with the highest volume of cargo handled and highly specialised in containerised cargo and liquid bulks (Bahía de Algeciras, Barcelona, Bilbao, Huelva, Las Palmas, Tenerife, Tarragona and Valencia). Group *medium-complexity* comprises those authorities considered as medium-complexed (Alicante, Avilés, Cádiz, Cartagena, Ceuta, Gijón, A Coruña, Málaga, Mallorca, Pasajes, Santander, Sevilla and Vigo). In this group is possible to find, on the one hand, port authorities with high levels of traffic but also highly specialised in a specific type of cargo, especially in bulks; and, on the other hand, port authorities with medium levels of traffic. Finally, group *low-complexity* collects low-complexed port authorities. This group mainly contains those authorities with the lower levels of traffic and medium-size ones highly specialised in liquid or solid bulks (Almería, Castellón, El Ferrol, Melilla, Motril, Pontevedra and Vilagarcía).

(7) A dummy variable for those port authorities that manage more than one port is included (*Multiport).*

(8) The dummy variable *Train* is incorporated to collect the effect of intermodality on allocative efficiency. This variable takes values equal to one for those observations in which there is freight traffic by train.

Finally, the percentage of quays in concession (*Privquay*) is considered as an instrument to correct the potential endogeneity of the percentage of private cranes (*Privatisation*). Then, it is required that the percentage of quays in concession explain a significant amount of the variation in the percentage of private cranes, conditional of the controls. Additionally, we assume that the percentage of quays in concession only affects allocative efficiency through the percentage of private cranes. This is because the long periods of quay concession do not allow for a possible causal relationship between the percentage of quays in concession and allocative efficiency.

5. Results

5.1. Estimation of the allocative efficiency measures

System (1)-(2) has been estimated by Three-Stage Least Square to consider the endogeneity of inputs. Table 3 presents the estimation. We control for unobserved heterogeneity adding port authority-specific dummies[5].

The input-oriented distance function satisfies the regularity conditions required for an input-oriented distance function: non-decreasing and quasi-concave in variable inputs, non-increasing in outputs and homogeneous of degree one in inputs. First-order parameters are statistically significant and present their expected signs except for passengers, which has a positive coefficient, but not statistically significant. The sum of the first-order coefficient related to outputs is less than one, indicating the existence of increasing returns to scale for port technology at the sample mean. Besides, labour presents the highest input elasticity at the sample mean, whereas, in the case of output, non-containerised general cargo shows the largest output elasticity.

Table 4 presents different tests to analyse the underlying technology. (1) A Hausman test has been implied to examine the possible endogeneity of the input variables. The results of this test provide empirical evidence to reject the null hypothesis of exogenous inputs. Therefore, inputs have been instrumented using the instruments pointed out in section 4. (2) Secondly, a joint-significance test is carried out over the second-order parameter of the translog functional form. The null hypothesis is rejected. Therefore, the translog functional form explains better the technology than the Cobb-Douglas. (3) The null hypothesis of homothetic technology is also rejected. Then, input shares depend on the output volume. (4) Non-neutral technological change occurs; technological change is labour and capital saving on the input side, while it increases the importance of intermediate consumptions in costs. (5) Finally, we accept the existence of unobservable heterogeneity among port authorities testing the joint significance of the parameters associated with port authorities-specific dummies.

INSERT TABLE 3

INSERT TABLE 4

Tables 5 and 6 show the systematic (a_i) and relative allocative efficiencies (z_{ij}) at the sample mean, respectively. Table 4 shows that Spanish port authorities systematically underutilise labour and intermediate consumptions, whereas overuse capital. The proportion in which capital is used is above optimum, while that of labour and intermediate consumption is below optimum. Table 5 shows that the input combination is not optimal at the sample mean in the cases of labour and capital, and intermediate consumptions and capital. Specifically, labour and intermediate consumptions are underutilised regarding capital. However, labour and intermediate consumptions are optimally allocated regarding the other.

INSERT TABLE 5

[5] Parameters related to port authority-specific dummies are not displayed in Table 3. They are available upon request to the authors.

INSERT TABLE 6

Figure 2 shows the time evolution of the indices $z_{k,l}$ and $z_{k,ic}$. The evolution of the indices $z_{l,ic}$ does not appear in Figure 2 because the pair of inputs labour and intermediate consumptions are optimally allocated at the mean of the port system in every period of the sample. It can be observed that the values of $z_{l,k}$ and $z_{ic,k}$ are higher than one during the period analysed, which means that the relative overutilisation of capital with respect to labour and intermediate consumptions occurs over the whole period. We observe an improvement in relative inefficiencies over the first years of the sample. However, the overuse of capital relative to the other two inputs abruptly grows again in 2008. This year coincides with the beginning of the recession, which reduces considerably the volume of traffics served by the Spanish ports. This result can suggest that when port demand falls, Spanish port authorities adjust labour and intermediate consumption rather than capital. In the subsequent years, inefficiencies decrease in the case of intermediate consumptions and capital.

INSERT FIGURE 2

5.2. Determinants of port infrastructure allocative efficiency

The quantile regression (QR) is applied[6] to estimate the effect of port devolution on allocative efficiency. The QR (11) allows assessing the extent to which the impacts of the considered determinants on allocative efficiency may have varied throughout the efficiency distribution. Three different models have been estimated, one for each index ($z_{k,l}$, $z_{k,ic}$ and $z_{l,ic}$). Three percentiles have been considered to characterise the distribution of these indices. Percentile 25th has been included to characterise the observations with low values in the distribution. The percentile 50th represents the observation located in the median of the distribution. Additionally, percentile 75th characterises the observations with high values of these indices in the distribution[7]. Finally, it is considered that the percentage of private cranes might be endogenous. Therefore, a Hausman endogeneity test (Annex 3) has been carried out. The results of the test show that endogeneity occurs in those models related to $z_{k,ic}$ and $z_{l,ic}$, but not for the case of $z_{k,l}$ as the dependent variable. In the models with endogeneity, an instrumental variables procedure is applied to the QR regression, using the percentage of quays under concession ($Privquay$) as an instrument of the share of private cranes.

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[6] Annex 1 shows the kernel density distribution of the relative allocation indices (z_{ij}). It can be seen that almost all $z_{k,l}$ and $z_{k,ic}$ indices present values less than one. This finding implies that overuse of capital in relation to labour and intermediate consumption occurs along the port devolution period. However, the distribution of these indices suggests that the level of overcapitalization varies across port authorities. On the other hand, the distribution of the $z_{l,ic}$ indices is partially concentrated around the optimal allocation. Although, throughout the density distribution, it is possible to find observations that overuse labour in relation to intermediate consumptions; observations that efficiently allocate these inputs; or observations that underuse labour in relation to intermediate consumption. These results suggest that a quantile regression (QR) could provide a richer characterization than the OLS regression.

[7] Annex 2 shows the values of the relative indices for each percentile considered.

INSERT TABLE 7

Next, the results obtained in each model are analysed. Tables 7 and 8 show the estimation of models 1 and 2, in which the dependent variables are the measures of allocative inefficiency in the use of capital with respect to labour and intermediate consumption ($z_{k,l}$ and $z_{k,ic}$), respectively. In both models, the dependent variables present values below to one, which means that capital is overutilised related to labour and capital, respectively. Therefore, these models evaluate the factors that affect the overuse of capital with respect to the other inputs. A positive sign on the coefficient of any determinant implies that $z_{k,j}$ $(\forall j = l, ic)$ will increase and then, the cost of input misallocation will be reduced. Results show that private participation has a positive effect on the relative efficiency of capital allocation in both specifications, being these effects larger in those ports closer to the allocative efficiency. We also find that the Spanish downturn increased the allocative inefficiency, whereas port specialisation and hinterland size are positively correlated with allocative efficiency. Additionally, port authorities which manage two or more ports are less allocative efficient. The existence of freight traffic by train is negatively associated with allocative efficiency.

The complexity of ports affects capital-labour and capital-intermediate consumption misallocation differently. Highest complexity ports tend to be more efficient in terms of capital-labour. However, the medium-complexity ports are the closest to the allocative efficiency in terms of capital-intermediate consumption. In this case, we have not found any difference between the highest complexity and the lowest-complexity ports. In annex 4, the average inefficiencies of each port authorities grouped according to their complexity are shown graphically.

If we focus on the Spanish port devolution variables, we find that there is an improvement in the capital-labour allocative efficiency. This improvement is generalised, but it is more important at the lowest levels of overcapitalisation. In contrast, capital-intermediate consumptions misallocation increases during the period 2003-2009.

INSERT TABLE 8

Finally, Table 9 displays the results of the estimation for the model 3. The dependent variable in this model captures the labour-intermediate consumption allocative inefficiency. In this case, those port authorities that present values less than unity overuse labour with respect to intermediate consumption. Opposite, port authorities at 75th percentile underuse labour with respect to intermediate consumption. The optimal allocation of these inputs is around the 60th percentile of the distribution.

On the one hand, results suggest that there is a positive correlation between private participation and labour-intermediate consumption allocative efficiency for those ports that overuse labour with respect to intermediate consumption. However, private participation increases allocative misallocation for those port authorities that overuse intermediate consumption. Similar effects are related to port specialisation. On the other hand, we have found that after the adoption of Act 62/1997, inefficiencies in the allocation of labour and intermediate consumptions have increased when ports overuse labour. Moreover, input misallocation has decreased when there has been excessive use of intermediate consumption. We have found similar effects for those port authorities which manage two or more ports or move freight traffic by train.

Finally, port complexity and hinterland size have not affected labour-intermediate consumption efficiency.

INSERT TABLE 9

6. Conclusions

6.1. Discussion of the empirical outcomes

This article evaluates the effects of port devolution on the Spanish port authorities' allocative efficiency. Additionally, we test whether these effects differ among different levels of allocative efficiency. To the best of our knowledge, this is the first study that investigates the impact of port devolution on allocative efficiency.

The results show the existence of non-neutral technological change that suggests a process of substitution of labour and capital for intermediate consumptions for the port system. Regarding allocative efficiency, on the one hand, it is observed that labour and intermediate consumptions are systematically underused, whereas capital is overused in the Spanish port system. On the other hand, relative inefficiencies appear for the input pairs capital-labour and capital-intermediate consumptions, but the relative allocation of labour and intermediate consumptions is closed to the optimal.

Therefore, the main allocative inefficiencies in the Spanish system come from the overuse of capital respect the other inputs. There are previous works in the literature that demonstrate the existence of overcapitalisation in the Spanish port system (Hidalgo-Gallego 2015 and Tovar and Wall 2017 are some examples). Moreover, these inefficiencies grow in periods of economic turndown because it may be easier for port authorities to adjust labour and intermediate consumptions when they have to face a shock in their demand. The devolution process has partially improved these inefficiencies, mainly those associated with the use of capital with respect to labour. Still, its effect has not been the same for port authorities. It seems that the devolution process has a higher impact on those port authorities with a better allocation of capital concerning the other inputs.

Regarding the changes in allocative efficiency between the different periods of regulation, the results suggest the following. (1) There is an improvement of the allocative efficiency for the pair capital and labour during the analysed period. (2) In those years in which Law 48/2003 is in force, inefficiencies in the use of capital with respect to intermediate consumption raise.

It also demonstrates that those port authorities with a higher level of traffic specialisation present better levels of allocative efficiency. Opposite, those port authorities that manage more than one port show higher inefficiencies. These results can be partially explained by the fact that a higher traffic concentration or managing just one port could reduce uncertainties, and in turn, improve resource allocation. Moreover, the size of the hinterland measured by the gross manufacturing value added has a positive impact on capital-labour related inefficiencies.

Concerning the level of complexity, it is important to point out that the classification considered is mainly determined by its volume of traffic. Specialisation plays a secondary role in this classification. In this sense, a port authority highly specialised in liquid or solid bulks is included in a lower complexity group than the one that corresponds to it given its volume of traffic. Our results may indicate that high and medium complex port authorities are able to allocate capital in relation to labour better than small ones, while medium complex ports present the best allocation of capital with respect to intermediate consumption.

Finally, the use of labour with respect to intermediate consumption is close to the optimal level, but inefficiencies also exist. The effect of private participation on labour-intermediate input misallocation has been only positive when labour is over-utilised. Conversely, it presents negative effects for the rest of the port authorities. Regarding the impact of regulation, port reforms after the adoption of Act 62/1997, related to the participation of regional governments in the decision-making processes of port authorities, are positively correlated with a rise in labour-intermediate consumption misallocation in favour of labour. Then, the effects of port devolution and port decentralisation differ in this case.

6.2 Policy implications

Port governance has changed since the 1980s. As a result, the private operation of port facilities and the decentralisation in the decision problem of port authorities have gradually increased through the port devolution programs carried out by many governments around the world. The port devolution process began in Spain in the early 90s. Then, four port reforms have transformed the port system. One of the main justifications for the implementation of these programs is the consideration that the port devolution seeks the improvement of efficiency (Tongzon and Heng 2005).

The following policy recommendations arise from the analysis carried out. Port allocative inefficiency should not be ignored in cost efficiency studies as we have found that ports fail to minimise costs due to input misallocation motivated by institutional, structural or managerial failures. The main inefficiencies in the allocation of resources in the Spanish port system come from the excessive use of capital in relation to labour and intermediate consumptions. In the last stages on a port devolution process, the role of the port authorities is limited to the management of the basic port infrastructure and regulation of port activities of the different port operators. In this context, the strategy of the port authorities should focus on leveraging existing infrastructure rather than making new investments in capacity. This strategy is feasible for Spanish port authorities due to the existence of an excess of capacity that allows facing increments in their demand for port services with the existing utilities (Tovar and Wall 2017; Hidalgo-Gallego 2020). On the other hand, the private financing of the port infrastructure that characterises the advance landlord model raises as a solution in case of capacity would need to be extended. Moreover, our results show that increasing private participation in port operations and cargo specialisation may also be useful strategies to reduce the inefficiencies related to overcapitalisation in those port authorities which have not completed the port devolution process.

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Table 1: Summary of previous papers on evaluating the potential determinants of port efficiency and productivity.

Author	Data	Methodology	Measure	Efficiency determinants (effect on efficiency)
Liu (1995)	28 UK port authorities Panel 1983-1990	SFA	TE	Ownership: no effect Size: positive effect Location: ports on west coast less efficient
Cullinane et al. (2002)	15 container ports or terminals in Asia Panel 1993-1998	SFA	TE	Size: positive effect Control central government: negative effect
Cullinane et al. (2005)	30 container ports worldwide Panel 1992-1999	DEA	TE	Ownership: no effect
Tongzon and Heng (2005)	25 container terminals in Asia Cross section 1999	SFA	TE	Size: positive effect Private participation: U-shape effect
González and Trujillo (2008)	27 Spanish port authorities Panel 1990-2002	SFA	TE	Port reforms: individual significant effect
Cheon et al. (2010)	98 major world ports Panel 1991-2004	DEA	MPI	Port reforms: positive effect
Niavis and Tsekeris (2012)	30 container ports South-Easterm Europe Cross section 2008	DEA	TE	Port size: positive effect Private operation: positive effect Distance to Suez channel: negative effect Hinterland GDP: no effect Hinterland population: no effect
Núñez-Sanchez and Coto-Millán (2012)	27 Spanish port authorities Panel 1986-2005	SFA	MPI	Port reforms: positive effect

SFA (Stochastic frontier analysis), DEA (Data Envelopment Analysis), TE (Technical efficiency), CE (Economic efficiency), SE (Scale efficiency), MPI (Malmquist Productivity Index)

Table 1: Summary of previous papers on evaluating the potential determinants of port efficiency and productivity.

Author	Data	Methodology	Measure	Efficiency determinants (effect on efficiency)
Rodríguez-Álvarez and Tovar (2012)	27 Spanish port authorities Panel 1993-2007	SFA	CE	Port reforms: significant effect
Wanke (2013)	27 Brazilian ports Cross section 2011	DEA	TE	Ownership: positive effect on physical infrastructure Hinterland size: positive effect on shipment consolidation Cargo diversity: positive effect on shipment consolidation
Chang and Tovar (2014)	14 port terminals in Chile and Peru Panel 2004-2010	SFA	TE	Structural reform: positive effect Containerisation: positive effect Bulk rate: positive effect Occupancy rate: positive effect Private management: negative effect
Wanke and Barros (2015)	27 Brazilian ports Cross section 2011	DEA	SE	Public-private partnership: positive effect Output mix: no effect Railway connectivity: no effect Port infrastructure: positive effect Containerisation: negative effect
Coto-Millán et al. (2016)	27 Spanish port authorities Panel 1986-2012	SFA	TE	Port reforms: positive effect
Serebriski et al. (2016)	63 container ports in Latin America and the Caribean Panel 1999-2009	SFA	TE	Private participation in port operations: positive effect Corruption: no effect Country GDP per capita: no effect
Chang and Tovar (2017)	14 terminals in Chile and Peru Panel 2004-2014	DEA	MPI	Private management: positive effect Container/bulks: positive effect Bulk rate: negative effect
López-Bermúdez et al. (2019)	20 Brazilian port authorities Panel 2008-2017	SFA	TE	Private operation: positive effect

SFA (Stochastic frontier analysis), DEA (Data Envelopment Analysis), TE (Technical efficiency), CE (Economic efficiency), SE (Scale efficiency), MPI (Malmquist Productivity Index)

Table 2: Descriptive statistic of the variables

Variable	Definition	Units	Mean	Std. Dev.	Min	Max
		System variables				
l	Labour	Workers	211.34	113.24	56	823
k	Capital	Constant euros year 2001	1,613,164	1,516,164	109,761	1.21E+07
ic	Intermediate consumption	Tons	356,726	635,084.8	3,703	3718475
li	Liquid bulk	Tons	5,317,262	6,787,189	1	2.73E+07
sol	Solid bulk	Tons	3,307,220	3,438,980	3,425	1.97E+07
cont	Containerised cargo	Tons	3,824,031	9,551,449	1	6.02E+07
ncont	Non-containerised cargo	Tons	1,783,145	2,135,795	681	1.08E+07
pax	Passengers	Passengers	868,198.5	1,486,708	1	7,782,400
Sl	Labour cost share	Percentage	0.36	0.08	0.16	0.58
Sk	Capital cost share	Percentage	0.40	0.08	0.16	0.67
Sic	Intermediate consumption cost share	Percentage	0.25	0.07	0.09	0.56
		Instruments and determinants				
Manufac	Gross manufacturing value added	Millions of constant euros year 2001	13.15	10.28	0.06	47.07
GDP	Gross domestic product	Millions of constant euros year 2001	14.16	3.28	9.02	25.16
Population	Population	Thousand people	3,576.70	2,675.97	56.93	8,424.10
Politics	The coincidence of the same party in national and regional goverments.	Dummy variable	0.52	0.50	0	1
Recession	Global financial crisis in 2008	Dummy variable	0.36	0.48	0	1
Train	Freight traffic by train	Dummy variable	0.59	0.49	0	1
Multiport	Multiport port authority	Dummy variable	0.27	0.44	0	1
Specialisation	Traffic specialisation	Continuous variable from 0 to 1	0.48	0.13	0.25	0.85
Privatisation	Share private cranes over total	Percentage	0.65	0.39	0	1
Privquay	Share private quays over total	Percentage	0.17	0.17	0	0.68

Variable	Definition	Units	Mean	Std. Dev.	Min	Max
		Instruments and determinants				
High-complexity	High complex port authorities	Dummy variable	0.31	0.46	0	1
Medium-complexity	Medium complex port authorities	Dummy variable	0.38	0.49	0	1
Law 62/1997	Port reform 62/1997	Dummy variable	0.24	0.43	0	1
Law 48/2003	Port reform 48/2003	Dummy variable	0.28	0.45	0	1
Law 33/2010	Port reform 33/2010	Dummy variable	0.28	0.45	0	1

Table 3: Estimates of the input-oriented distance system

Variable	Coefficient	t-statistic		Variable	Coefficient	t-statistic	
Constant	-0.933	-5.480	***	*Log(k)*Log(ncont)*	-0.002	-0.160	
Log(l)	0.488	10.370	***	*Log(k)*Log(pax)*	0.001	1.930	*
Log(k)	0.112	4.550	***	*Log(ic)*Log(li)*	-0.030	-4.690	***
Log(ic)	0.400	9.020	***	*Log(ic)*Log(sol)*	-0.032	-2.800	***
Log(li)	-0.060	-5.840	***	*Log(ic)*Log(cont)*	0.000	0.110	
Log(sol)	-0.057	-2.500	**	*Log(ic)*Log(ncont)*	-0.018	-1.090	
Log(cont)	-0.042	-5.210	***	*Log(ic)*Log(pax)*	-0.014	-3.640	***
Log(ncont)	-0.081	-3.530	***	*Log(li)*Log(sol)*	-0.023	-3.510	***
Log(pax)	0.008	1.170		*Log(li)*Log(cont)*	0.001	1.410	
*Log(l)*Log(l)*	0.027	3.340	***	*Log(li)*Log(ncont)*	0.023	3.480	***
*Log(k)*Log(k)*	0.059	8.090	***	*Log(li)*Log(pax)*	-0.002	-3.720	***
*Log(ic)*Log(ic)*	0.144	5.980	***	*Log(sol)*Log(cont)*	0.006	1.550	
*Log(li)*Log(li)*	-0.004	-2.450	**	*Log(sol)*Log(ncont)*	0.036	2.330	**
*Log(sol)*Log(sol)*	0.023	2.280	**	*Log(sol)*Log(pax)*	0.006	2.010	**
*Log(cont)*Log(cont)*	-0.005	-3.740	***	*Log(cont)*Log(ncont)*	-0.013	-3.660	***
*Log(ncont)*Log(ncont)*	-0.019	-1.560		*Log(cont)*Log(pax)*	0.001	1.520	
*Log(pax)*Log(pax)*	0.004	2.450	**	*Log(ncont)*Log(pax)*	-0.002	-0.700	
*Log(l)*Log(k)*	-0.056	-10.290	***	*t*	0.008	4.060	***
*Log(l)*Log(ic)*	-0.004	-1.670	*	*t*t*	0.000	0.740	
*Log(l)*Log(li)*	-0.002	-3.040	***	*t*Log(l)*	-0.003	-10.860	***
*Log(l)*Log(sol)*	-0.008	-4.310	***	*t*Log(k)*	-0.002	-3.930	***
*Log(l)*Log(cont)*	-0.001	-2.830	***	*t*Log(ic)*	0.005	4.360	***
*Log(l)*Log(ncont)*	0.001	0.390		*t*Log(li)*	-0.004	-6.540	***
*Log(l)*Log(pax)*	-0.001	-1.880	*	*t*Log(sol)*	0.004	4.890	***
*Log(k)*Log(ic)*	-0.004	-1.250		*t*Log(cont)*	0.001	2.700	***
*Log(k)*Log(li)*	0.002	2.090	**	*t*Log(ncont)*	-0.002	-1.390	
*Log(k)*Log(sol)*	0.007	2.810	***	*t*Log(pax)*	-0.003	-6.960	***
*Log(k)*Log(cont)*	0.002	2.980	***				

Equation	Number of observations	Std. Error of regression	R^2
Input distance function	650	0.1412655	-
Labour share equation	650	0.0498587	0.6191
Capital share equation	650	0.0679531	0.2465

*Statistically significant at 10%; ** statistically significant at 5%; *** statistically significant at 1%.

Table 4: Statistical tests

Test	Null hypothesis	t-statistic	
Endogeneity test	H_0: Exogenous inputs	38181.63	***
Cobb-Douglas vs Translog	H_0: Cobb-Douglas	1004.42	***
Homothetic technology	H_0: Homotheticity	100.35	***
Technological change	H_0: No technological change	410.57	***
Neutral technological change	H_0: Hicks neutrality	407.09	***
Fixed effects vs pooled	H_0: Pooled	1041.29	***

* H_0 rejected at 10%; ** H_0 rejected at 5%; *** H_0 rejected at 1%.

Table 5: a_i components (systematic allocative efficiency)

	Coefficient	t-statistic	
a_l	-0.1189	-2.52	**
a_k	0.2858	11.62	***
a_{ic}	-0.1669	-3.76	***

*Statistically significant at 10%; **Statistically significant at 5%; ***Statistically significant at 1%.

Table 6: z_{ij} coefficients at the sample mean

	Coefficient	t-statistic	
$z_{k,l}$	0.1812	8.99	***
$z_{l,ic}$	1.0014	0.00	
$z_{k,ic}$	0.1815	9.92	***

The null hypothesis is H_0: $k_{ij} = 1$

*H_0 rejected at 10% level; **H_0 rejected at 5% level; *** H_0 rejected at 1% level.

Table 7: Estimates of model 1 (dependent variable $z_{k,l}$)

Variable	25th percentile	50th percentile	75th percentile
Constant	0.074***	0.086***	0.108***
	(4.50)	(5.85)	(3.75)
Privatization	0.026**	0.032***	0.049***
	(3.04)	(2.65)	(4.11)
Manufact	0.002***	0.002***	0.002***
	(5.57)	(6.85)	(4.66)
Recession	-0.097***	-0.111***	-0.149***
	(-12.77)	(-8.24)	(-14.13)
Specialization	0.075***	0.095***	0.134***
	(2.67)	(3.43)	(3.30)
High-complexity	0.028***	0.024***	0.021**
	(3.37)	(2.44)	(2.19)
Medium-complexity	0.015**	0.027***	0.030***
	(2.43)	(4.10)	(2.95)
Law 62/1997	0.046***	0.068***	0.056***
	(5.39)	(6.98)	(2.71)
Law 48/2003	0.058***	0.066***	0.063***
	(6.49)	(4.66)	(4.53
Law 33/2010	0.077***	0.095***	0.107***
	(7.75)	(6.31)	(5.80)
Multiport	-0.0008	-0.023**	-0.021*
	(-1.64)	(-2.45)	(-1.83)
Train	-0.014***	-0.019**	-0.016
	(-2.65)	(-2.38)	(-1.45)

*Statistically significant at 10%; **Statistically significant at 5%; ***Statistically significant at 1%.

Table 8: Estimates of model 2 (dependent variable $z_{k,ic}$)

Variable	25th percentile	50th percentile	75th percentile
Constant	-0.341***	-0.225***	-0.085
	(-3.5)	(-2.79)	(-1.16)
Privatization	0.498***	0.580***	0.679***
	(3.98)	(4.61)	(3.45)
Manufact	0.003**	0.002	0.001
	(3.80)	(3.06)	(1.12)
Recession	-0.156***	-0.209***	-0.272***
	(-5.05)	(-5.46)	(-4.17)
Specialization	0.504***	0.525***	0.550***
	(5.20)	(5.63)	(5.25)
High-complexity	-0.002	-0.021	-0.044
	(-0.11)	(-0.94)	(-1.15)
Medium-complexity	0.056**	0.048**	0.038
	(2.42)	(2.04)	(1.12)
Law 62/1997	-0.067*	-0.058**	-0.047*
	(-1.81)	(-2.02)	(-1.79)
Law 48/2003	-0.183***	-0.157***	-0.127**
	(-2.73)	(-2.73)	(-2.22)
Law 33/2010	-0.106	-0.097	-0.085
	(-1.54)	(-1.47)	(-1.06)
Multiport	-0.042	-0.092***	-0.152**
	(-1.45)	(-3.21)	(-2.54)
Train	-0.048**	-0.083***	-0.122*
	(-2.06)	(-2.71)	(-1.85)

*Statistically significant at 10%; **Statistically significant at 5%; ***Statistically significant at 1%.

Table 9: Estimates of model 3 (dependent variable $z_{l,ic}$)

Variable	25th percentile	50th percentile	75th percentile
Constant	-1.572*	-0.710	0.083
	(-1.72)	(-1.527)	(0.2231)
Privatization	2.816**	2.607***	2.414***
	(2.18)	(3.81)	(5.60)
Manufact	0.004	0.000	-0.003
	(0.83)	(0.001)	(-0.62)
Recession	-0.301**	-0.427***	-0.543***
	(-2.00)	(-2.87)	(-2.73)
Specialization	2.222***	2.192***	2.164***
	(4.88)	(5.607)	(4.71)
High-complexity	-0.100	-0.159	-0.212
	(-0.99)	(-1.44)	(-1.30)
Medium-complexity	0.268**	0.152	0.046
	(1.98)	(1.31)	(0.37)
Law 62/1997	-0.638**	-0.496***	-0.366***
	(-2.22)	(-2.81)	(-3.32)
Law 48/2003	-1.237***	-0.955***	-0.695***
	(-2.73)	(-3.07)	(-3.33)
Law 33/2010	-1.023**	-0.804**	-0.602**
	(-2.12)	(-2.50)	(-2.46)
Multiport	-0.259	-0.370***	-0.472***
	(-1.19)	(-3.46)	(-3.87)
Train	-0.206	-0.316***	-0.417***
	(-1.51)	(-3.03)	(-3.35)

*Statistically significant at 10%; **Statistically significant at 5%; ***Statistically significant at 1%.

Figure 1: Estimation procedure

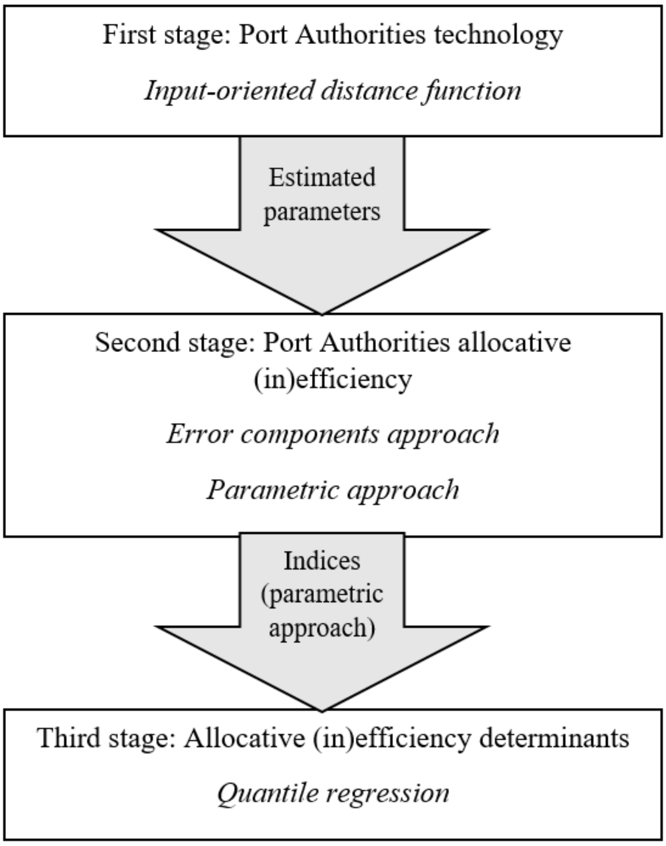
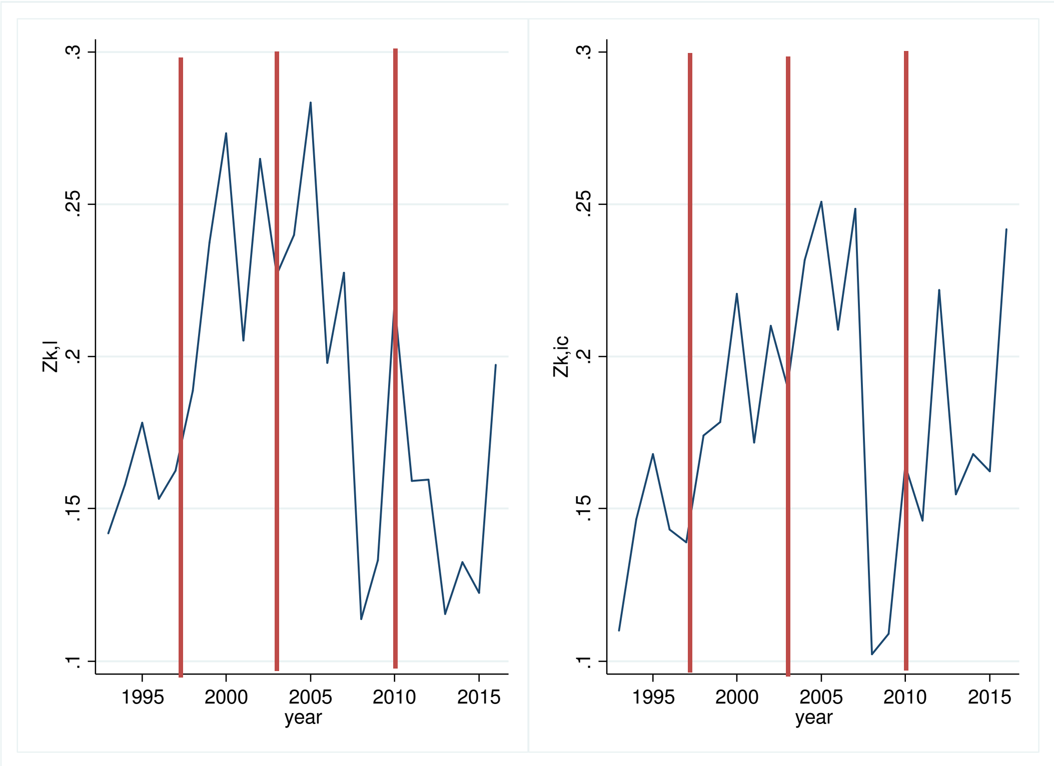
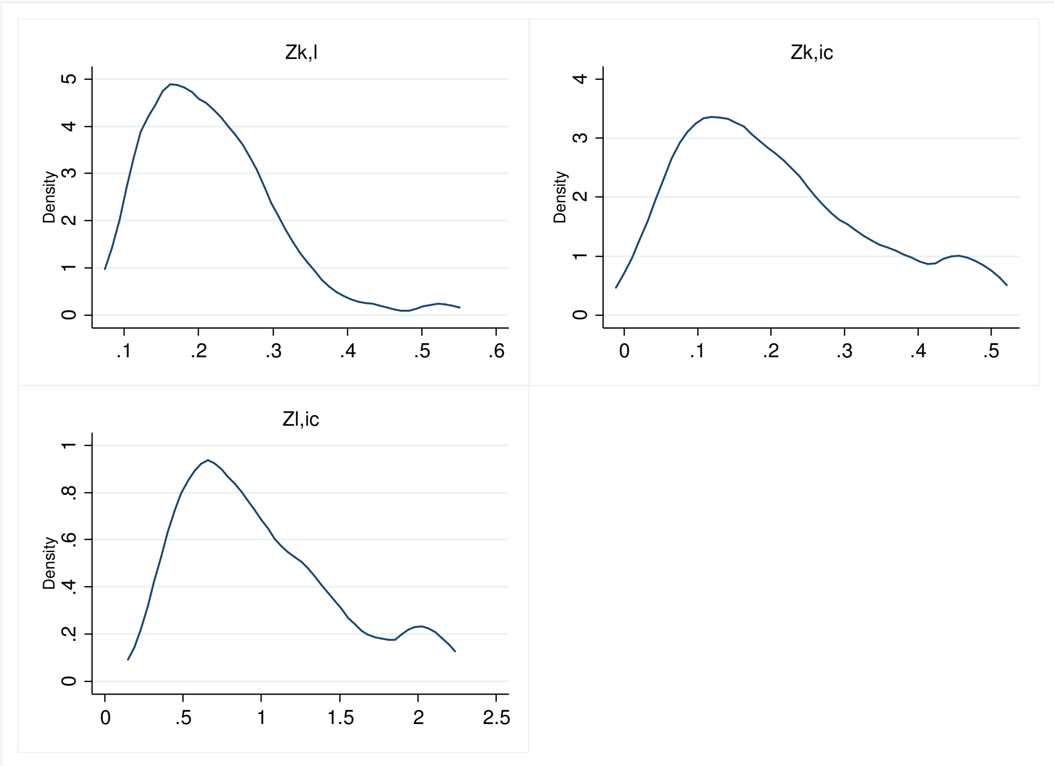


Figure 2: Time evolution of $z_{l,k}$ and $z_{ic,k}$indices



Annex 1: Kernel density estimate of indices z_{ij}



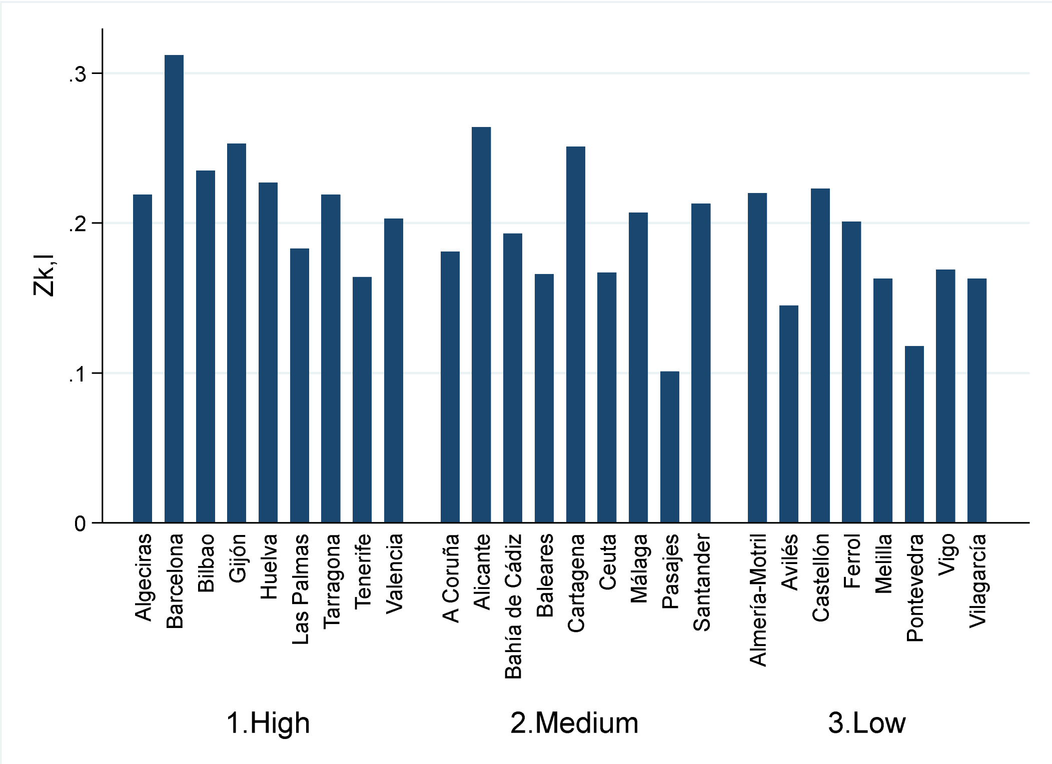
Annex 2: Percentiles of the distribution of the relative allocative (in)efficiency indices

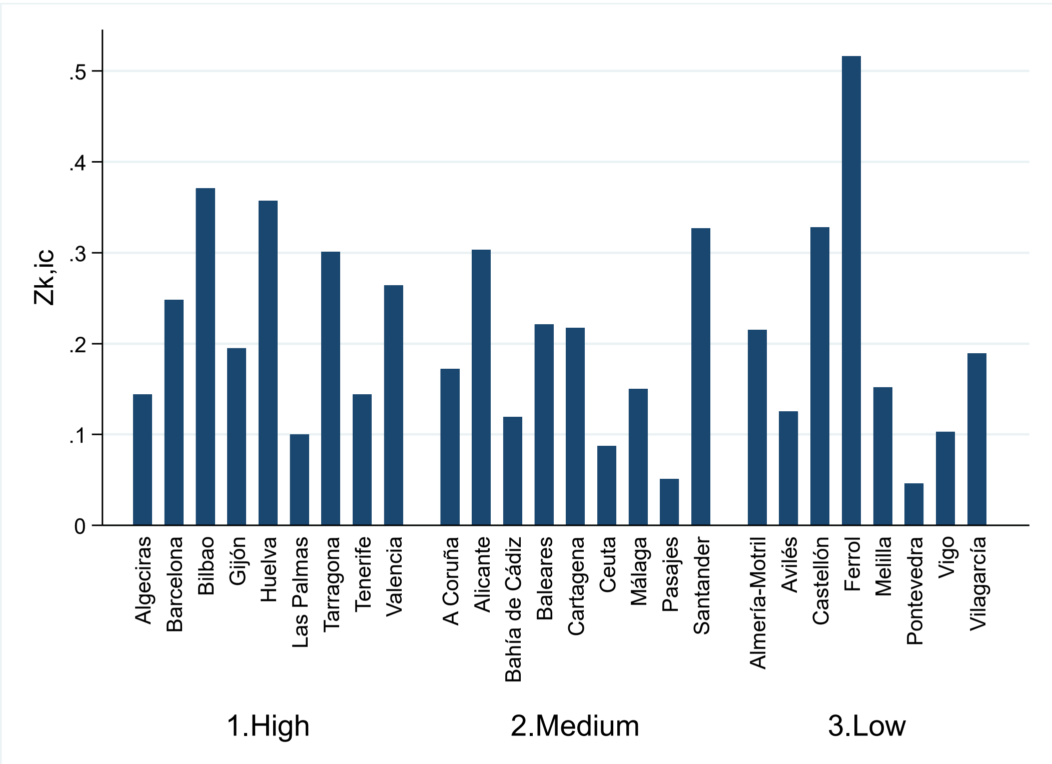
Percentile	$z_{k,l}$	$z_{k,ic}$	$z_{l,ic}$
25th	0.151	0.107	0.600
50th	0.201	0.184	0.871
75th	0.261	0.285	1.277

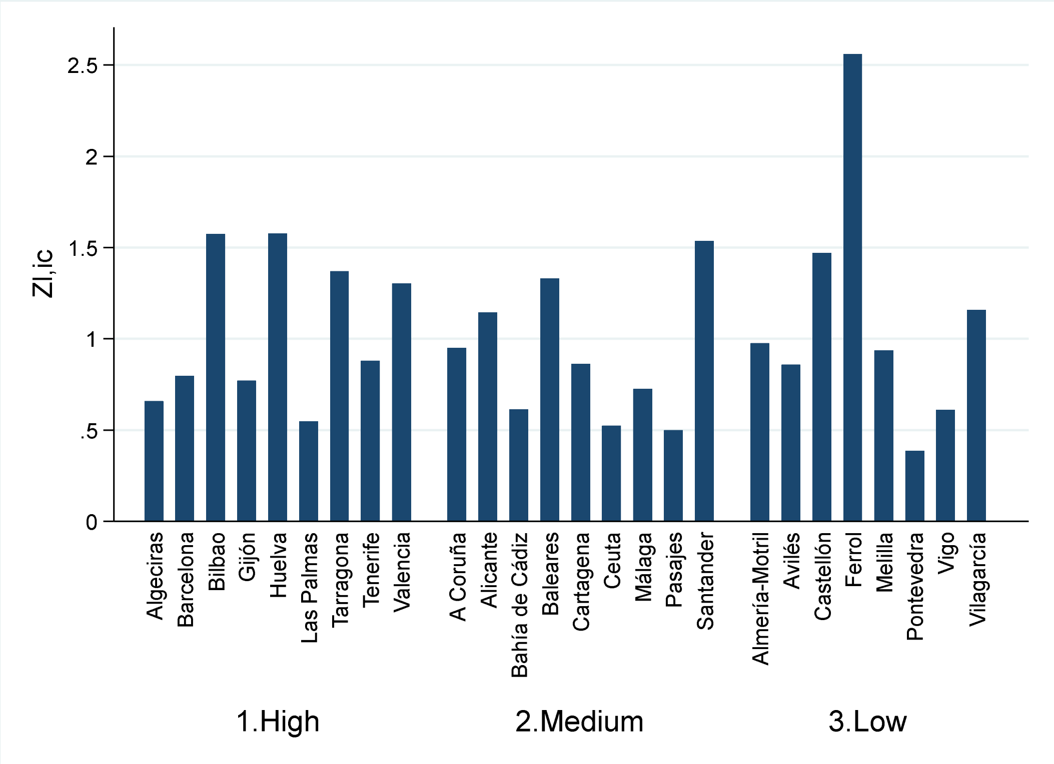
Annex 3: Hausman endogeneity test for the models in the second stage

Percentile	Model 1	Model 2	Model 3
25th	1.66	46.92***	42.41***
50th	0.26	45.73***	110.14***
75th	0.34	14.68***	59.76***

Annex 4: Port authorities' complexity and allocative inefficiency.






ZI,ic
2.5
2
1.5
1
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0
Algeciras
Barcelona
Bilbao
Gijón
Huelva
Las Palmas
Tarragona
Tenerife
Valencia
A Coruña
Alicante
Bahía de Cádiz
Baleares
Cartagena
Ceuta
Málaga
Pasajes
Santander
Almería-Motril
Avilés
Castellón
Ferrol
Melilla
Pontevedra
Vigo
Vilagarcía
1.High
2.Medium
3.Low