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Does cargo specialization improve port technical efficiency? The paradigm of specialized infrastructure

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ABSTRACT
This study analyses the effect of cargo specialisation on Spanish Port Authorities' technical efficiency. To the best of our knowledge, this is the first study to contend that the effect of cargo specialisation on port efficiency may vary at different levels of specialisation. Specialisation/diversification strategies are examined under different scenarios. A stochastic input-oriented distance function model that accounts for Port Authorities' heterogeneity is constructed. The results show that increasing specialisation in general cargo improves technical efficiency; however, specialisation in liquid or solid bulk cargo is not recommended—such cargo should ideally be handled jointly with other types of cargo. Finally, full specialisation is also not recommended in terms of technical efficiency gains.

KEYWORDS
Cargo specialisation; port efficiency; technical efficiency; specialised infrastructure; stochastic frontier analysis

1. Introduction

In a globalised world, ports are essential for international trade and logistics chains and are major accelerators of local economic development (Jung 2011). Adopting an effective specialisation strategy allows ports to reduce their operating costs and become more competitive (Lin and Tseng 2007). Hence, correctly assessing the different strategies that ports can adopt to improve their efficiency and competitiveness is crucial (Song and Yeo 2004).

This study investigates the efficiency gains of various specialisation strategies (considering different types of freights) using data from Spanish Port Authorities (PAs, henceforth). The proposed efficiency analysis allows an objective evaluation of the strengths and opportunities of ports in a highly competitive environment.

Spanish PAs are independent, publicly-owned entities that manage natural and physical capital to satisfy the demand for maritime transport and meet their economic and social goals. Port activities are essential in the global market to allow the import and export of local products (Ducruet, Koster, and Van der Beek 2010). Enhancing ports´ performance can increase their hinterland region's welfare (Mateo-Mantecón et al. 2012). In addition, improving port technical efficiency may facilitate the achievement of PAs' social goals. Ports have been long considered unpleasant spaces where maritime activities are carried out. However, cities and ports support one another. In the last few years, PAs have stood out for helping societies safeguard their living standards, meet specific environmental goals (e.g., maintaining pollutants below an acceptable threshold), and achieve sustainable regional economic growth (Daamen and Vries 2013).

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In terms of economic goals, the Royal Legislative Decree 2/2011 established a profitability criterion according to which PAs need to achieve a positive level of profitability, as previously set in their respective business plans, according to specific characteristics and conditions. The profitability criterion requires that the individual results achieved by PAs guarantee compliance with the annual objective of profitability for the whole port system, established at 2.5%. Port legislation provides PAs with a range of instruments to fulfil these requirements. Flexibility to set their charges and some degree of specialisation in a specific cargo to increase competitiveness (Coto-Millán et al. 2016a) are some examples.

The analysis of cargo specialisation in the port industry and its effects is quite recent in the Spanish context (Coto-Millán et al. 2016b). However, in the last decade, several studies on port specialisation have been conducted. For instance, Inglada and Coto-Millán (2010) evaluate the effect of traffic specialisation on technical change and port efficiency. Medal-Bartual, Jose Garcia-Martin, and Sala-Garrido (2012) estimate technical efficiency for Spanish PAs using a non-radial DEA model. This methodology allows users to obtain efficiency scores for each type of freight (liquid bulk, solid bulk, containers, and non-containerised general cargo). Reina and Villena (2013) address the degree of concentration for the main groups in terms of traffic in the Spanish port system. Tovar and Wall (2015) use three directional distance functions to obtain the proportion to which each type of port freight (solid bulk, containers, and non-containerised general cargo) can be increased, keeping productive factors constant. González-Laxe and Novo-Corti (2016) analyse the evolution of traffic concentration and container specialisation, paying particular attention to the effect of the 2008 financial crisis. Medal-Bartual, Molinos-Senante, and Sala-Garrido (2017) calculate the technical efficiency of Iberian PAs, grouping them according to their specialisation (liquid bulk, solid bulk, and general cargo). Tovar and Wall (2017a, 2017b) investigate the effect of traffic concentration and output specialisation on technical efficiency.

This study contributes to the port efficiency literature by evaluating the effect of cargo specialisation on technical efficiency. The novelty of this study lies in the proposed calculation of the marginal effects of specialisation on efficiency, which allows us to assess its impact at different levels of specialisation.

Port specialisation has been typically evaluated as a strategy to improve port performance and competitiveness. However, to choose a specialisation/diversification strategy, the characteristics of freights and transport demand need to be accounted for since both aspects may exert a significant impact on ports' performance and results (Meyler, Moiseenko, and Volkogon 2011; González-Laxe 2012; Coto-Millán et al. 2016a; Tovar and Wall 2017a, 2017b, 2015) and have consequences for investment decisions and port competition. Each specialisation/diversification strategy requires different investment policies, and influences intra-port competition in different ways (Meyler, Moiseenko, and Volkogon 2011). Therefore, assessing the impact of specialisation/diversification strategies on technical efficiency is of particular interest to port managers, who define and implement port policies.

The positive effects of specialisation are as follows. First, the cargo handled by ports is rarely homogeneous (González-Laxe 2012). Heterogeneity generates the need for different specialised facilities (Coto-Millán et al. 2016a), which increases the financial effort of PAs. Compared to a diversification strategy, specialisation may help save financial resources. In particular, diversification may require PAs to face additional investment costs or higher use of productive factors, which may not be fully compensated by the port's economic results (Riordan and Williamson 1985). Second, specialisation would favour economies of scale. Tovar and Wall (2017a, 2017b, 2015) show that specialisation improves port efficiency, especially for the largest ports (Tovar and Wall 2017a). However, Tovar and Wall (2017a) underline the trade-off for smaller PAs between the efficiency gains from specialisation and their vulnerability to market conditions for their primary output. Zhuang, Luo, and Fu (2014) show that specialisation may be considered a solution to overcapacity.

The literature also investigates the negative effects of specialisation on port performance. Diversification increases overall production and competitiveness, while reducing investment risks (Ducruet, Koster, and Van der Beek 2010; Tovar and Wall 2017b). Activity diversification is sometimes needed to achieve better results and allows PAs to benefit from economies of scope and reduced price competition (Tovar and Wall 2017b).

However, the recommendations regarding specialisation vary depending on the type of traffic or the current degree of specialisation. For instance, Mateo-Mantecón et al. (2012) find that specialisation in high value-added freights (containerised and non-containerised general cargo vs liquid or solid bulk) allows ports to achieve better economic results. Similarly, González-Laxe and Novo-Corti (2016) show that ports highly linked to solid and liquid bulk traffic seem to suffer a greater impact during economic recessions. In contrast, Medal-Bartual, Molinos-Senante, and Sala-Garrido (2017) find that the most efficient group of ports is specialised in liquid bulk. They explain this result with the fact that liquid bulk is a captive cargo,[1] which provides these ports with special competitive advantages.

This study evaluates the impact of strategies to specialise in the different types of freights using data from Spanish PAs and applying an input-oriented distance function model. The proposed approach accounts for PAs' heterogeneity by using a stochastic frontier analysis.

The remainder of this study is organised as follows. The second section presents the methodology and model specification and describes the data. The third section presents the estimation results. The last section discusses the study's findings and provides our concluding remarks.

2. Materials and methods

2.1. Methodology and model specification

The estimation of an optimal frontier allows us to measure technical efficiency and assess the influence of a group of variables on it (Coto-Millán et al. 2016a; Tovar and Wall 2017b). In this study, the efficient frontier is defined from the distance function (1), introduced by Shephard (1953)[2].

$$d_{it} = f\left(x_{1it}, \ldots, x_{nit}, \ldots, x_{Nit}, y_{1it}, \ldots, y_{pit}, \ldots, y_{Pit}\right) \tag{1}$$

The use of distance functions presents four main advantages. First, distance functions capture the multi-output activities carried out in ports. Second, they do not need to make any assumptions regarding the economic behaviour of PAs. Third, they provide reliable results based on physical data (González and Trujillo 2009). Fourth, they do not assume the endogeneity of input prices.

To construct the distance function, input orientation is chosen based on the following considerations. PAs have substantial control over productive factors as they can outsource services and select the quantities of labour or the amount of investment in new infrastructure. However, output control mainly depends on the shipping lines' business strategy (Chang, Lee, and Tongzon 2008; Guy and Urli 2006).

The true fixed-effects estimator (TFE) proposed by Greene (2005) is applied to estimate the input-oriented distance function. This estimator collects the unobservable heterogeneity among PAs. Moreover, the TFE allows for the temporal variability of (in)efficiency.[3]

Equation (2) specifies the distance function and the effects model. A flexible functional form for stochastic frontiers is widely adopted in the literature, being the translog functional form (Christensen, Jorgenson, and Lau 1973) one of the most commonly applied in production, productivity, and efficiency studies (Coto-Millán et al. 2016a; González and Trujillo 2008; Núñez-Sánchez and Coto-Millán 2012, among others).

$$
\begin{aligned}
lnd_{it}{}^{I} = \alpha_i &+ \sum_{n=1}^{N} \beta_n \ln x_{nit} + \sum_{n=1}^{N}\sum_{m=1}^{N} \beta_{nm} \ln x_{nit} \ln x_{mit} + \sum_{p=1}^{P} \gamma_p \ln y_{pit} \\
&+ \sum_{p=1}^{P}\sum_{q=1}^{P} \gamma_{pq} \ln y_{pit} \ln y_{qit} + \sum_{n=1}^{N}\sum_{q=1}^{P} \rho_{np} \ln x_{nit} \ln y_{pit} \\
&+ \theta_1 t_t + \theta_2 t_t^2 + Crisis_t + v_{it}
\end{aligned}
\tag{2}
$$

$$
u_{it} = \pi_0 + \sum_{r=1}^{R} \pi_r Specialisation_{rit} + C_{1it} + C_{2it} + w_{it}
$$

where:

d^I is the input-oriented distance function, which takes values greater than or equal to one.

α_i is a vector accounting for PAs' non-observable characteristics.

x is an N-dimensional vector of inputs; y is a P-dimensional vector of outputs.

t and t^2 are trend variables.

Crisis is a dummy variable that reflects the impact of the 2008 financial crisis.

v_{it} is the stochastic effect (random error or statistical noise) related to uncontrollable factors in the production activities and is independent and identically distributed (iid) according to a normal distribution with zero mean and constant variance, $N(0, \sigma_v^2)$.

Specialisation is a vector of specialisation index variables for the type of freight (liquid bulk, solid bulk, containerised cargo, and non-containerised cargo), which affect efficiency.

C_1 and C_2 are control variables.

w_{it} is a random error defined as $N(0, \sigma_w{}^2)$.

$u_{it} (= \ln d_{it}^I)$ represents technical inefficiency and is assumed to follow a truncated normal distribution with mean μ and variance σ_u^2.

Finally, β, γ, ρ, θ, and π are vectors of parameters subject to estimation.

The input-oriented distance function must be symmetric, not increasing and quasi-convex in outputs, and non-decreasing, concave, and homogeneous of degree one in inputs (Färe and Primont 2012). The imposition of homogeneity of degree one is specified in Equation (3) and the symmetry condition in Equation (4):

$$
\sum_{n=1}^{N} \beta_n = 1 \sum_{m=1}^{N} \beta_{nm} = 0 \sum_{n=1}^{N} \rho_{np} = 0 \tag{3}
$$

$$
\beta_{nm} = \beta_{mn} \quad \gamma_{pq} = \gamma_{qp} \tag{4}
$$

$$
(\mathrm{n}, \mathrm{m} = 1, \ldots, \mathrm{N}), \ (\mathrm{p}, \mathrm{q} = 1, \ldots, \mathrm{P})
$$

The distance function in Equation (2) needs to be normalised by one of the inputs to impose the homogeneity of degree one. Therefore, the final regression to be estimated is model (5):

$$
\begin{aligned}
-\ln x_{Nit} = {} & \alpha_i + \sum_{n=1}^{N-1} \beta_n \ln x^*_{nit} + \sum_{n=1}^{N-1}\sum_{m=1}^{N-1} \beta_{nm} \ln x^*_{nit} \ln x^*_{mit} + \sum_{p=1}^{P} \gamma_p \ln y_{pit} \\
& + \sum_{p=1}^{P}\sum_{q=1}^{P} \gamma_{pq} \ln y_{pit} \ln y_{qit} + \sum_{n=1}^{N-1}\sum_{q=1}^{P} \rho_{np} \ln x^*_{nit} \ln y_{pit} + \theta_1 t_t + \theta_2 t_t^2 \\
& + Crisis_t + v_{it} - u_{it}
\end{aligned} \tag{5}
$$

$$
u_{it} = \pi_0 + \sum_{r=1}^{R} \pi_r Specialisation_{rit} + C_{1it} + C_{2it} + w_{it}
$$

where $x^*_{nit} = {}^{x_{nit}}/_{x_{Nit}}$ represents the productive factor n normalised by the N-th input. The input variables included in the distance function have been introduced as deviations from the geometric mean so that the estimated first-order parameters can be interpreted as elasticities (at the sample mean).

The distance function, and the inefficiency effects model (5) have been estimated using the maximum likelihood method in a one-step process.

2.2. Data

The dataset used for analysis consists of 26 Spanish PAs[4] observed between 1986 and 2015. The primary source of data is the annual reports provided by Puertos del Estado and the PAs (Puertos del Estado several years a, several years b). Additional statistical information has been obtained from the National Statistical Spanish Institute. Table 1 reports the descriptive statistics of the main variables of interest.

Appendix presents the mean of the variables included in the analysis for each PA. The statistics reported in Table 1 and Appendix confirm that the Spanish port sector is highly heterogeneous in terms of the volume of handled cargo, passengers moved, and size. For instance, five PAs (Algeciras, Barcelona, Bilbao, Valencia, and Tarragona) move more than the 50% of the total cargo handled in the public interest Spanish port system; the other 23 PAs share the rest. Regarding passenger traffic, the dominance of a few ports is even more evident; in particular, three PAs (Algeciras, Tenerife, and Baleares) move more than 50% of the passengers that use Spanish ports. If we include Ceuta and Barcelona into this group, the percentage raises over 75%. However, passengers are an atypical

Table 1. Descriptive statistics of the variables of interest.

Variable	Units	Mean	Std. Dev.	Min	Max
Liquid bulk	Tonnes	5,111,653	6,441,413	1	2.73E+07
Solid bulk	Tonnes	3,079,009	3,303,578	3425	1.97E+07
Containerized general cargo	Tonnes	3,133,146	8,350,463	1	5.55E+07
Non-containerized general cargo	Tonnes	1,591,083	1,905,721	61,067	1.08E+07
Passengers	Passengers	787,956.2	1,372,694	1	7,057,817
Labour	Workers	217.6244	120.7152	41	823
Capital	Euros deflated 2001	1,498,630	1,350,494	109,761.1	1.12E+07
Intermediate consumptions	Tonnes	344,303.5	593,188.9	3703	3,718,475
Liquid bulk specialization index	Dimensionless	0.7756072	0.6626477	0	2.40114
Solid bulk specialization index	Dimensionless	1.355712	1.098416	0.009483	4.73998
Containerized general cargo specialization index	Dimensionless	0.7240203	0.8884585	0	3.50143
Non-containerized general cargo specialization index	Dimensionless	1.671272	1.480599	0.036215	7.07738
Total cargo	Tonnes	1.29E+07	1.41E+07	326,991	9.19E+07
Deposit area	Squared meters	780,643	988,936.5	11,354	5,005,767
Trend		15.5	8.660995	1	30
Crisis		0.2666667	0.4425004	0	1

Source: own elaboration based on statistical information provided by Puertos del Estado, Spanish PAs, and National Statistical Spanish Institute (INE).

variable, which takes values equal to zero in 130 observations and presents a high dispersion. This phenomena usually generates problems in the estimations. However, in many ports, passenger traffic is relevant in terms of volume[5] and costs;[6] hence, it should not be ignored.

Port operations are characterised by their multi-output nature. Hence, five outputs[7] have been included in the input-oriented distance function: liquid bulk (y_1), solid bulk (y_2), containerised general cargo (y_3), non-containerised general cargo (y_4), and passengers (y_5). Very few studies include passengers as output; some examples are Núñez-Sánchez, Jara-Díaz, and Coto-Millán (2011) and Núñez-Sánchez and Coto-Millán (2012). However, port inputs or statistical information about input quantities are not usually imputed to the activities for which they are employed; hence, not including them can lead to biased results (Bottasso and Conti 2012). The input variables considered to estimate PAs' technical efficiency are labour (x_1), capital (x_2), and intermediate consumptions (x_3). First, labour is defined as the number of PAs' employees. Second, capital is the result of dividing PAs' annual depreciation expenditures by capital price. Capital price has been estimated following the OECD (2001) methodology based on the perpetual inventory method of Jorgenson and Griliches (1967). Hence, the capital price is calculated as an index price of public works multiplied by the sum of the real long-term interest rate and the depreciation rate of the port's assets (Núñez-Sánchez 2013). Depreciation is obtained by dividing PAs' annual depreciation expenditures by their total assets. Third, intermediate consumptions are approximated by the sum of the tonnes of ship provision and operational supplies (petroleum products, ice, water, and provisions supplied to the ships).

As determinants of technical efficiency, this study uses various traffic specialisation indices: the liquid bulk-specialisation index (siy_1), solid bulk specialisation index (siy_2), containerised general cargo specialisation index (siy_3), non-containerised general cargo specialisation index (siy_4), the deposit area (sup), and the volume of total cargo ($y_{Tit} = \sum_{p=1}^{4} y_{pit}$).

With respect to specialisation indices, this study uses the relative specialisation, which is a measure of whether the port is more specialised in a given individual output than the port system as a whole. To calculate this index, a so-called Bird Index (Equation 6), which is one of the most common measures used in the literature (Frémont and Soppé 2007), is employed. The Bird Index has been used to measure relative specialisation in the Spanish system by González-Laxe and Novo-Corti (2012) and Díaz-Hernández and Estrán-Ramírez (2016). Some recent studies have analysed the degree of specialisation of Spanish ports and concluded that they are becoming more specialised over the years in terms of their traffic (González-Laxe and Novo-Corti 2012; Reina and Villena 2013; Díaz-Hernández and Estrán-Ramírez 2016; Tovar and Wall 2017a).

$$siy_{pit} = \frac{\dfrac{y_{pit}}{\sum_{p=1}^{4} y_{pit}}}{\dfrac{\sum_{i=1}^{26} y_{pit}}{\sum_{i=1}^{26}\sum_{p=1}^{4} y_{pit}}} \qquad (6)$$

where $\frac{y_{pit}}{\sum_{p=1}^{4} y_{pit}}$ is the share of y_p cargo to total cargo in PA i in period t, and $\frac{\sum_{i=1}^{26} y_{pit}}{\sum_{i=1}^{26}\sum_{p=1}^{4} y_{pit}}$ is the share of y_p cargo to total cargo in the whole port system in period t. Thus, $siy_{\cdot pit} > 1$ implies that the share of y_p traffic of the i_{th} PA in period t is higher than this share for the whole system, which suggests specialisation. High values indicate strong specialisation. A value below one indicates non-specialisation in this type of traffic. It can be observed (Appendix) that Spanish ports are quite different in terms of traffic specialisation. The highest level of specialisation in liquid bulk traffic is observed in the PAs of Cartagena, Castellón, and Huelva (the first two are located on the Mediterranean coast and the third one on the Atlantic South coast). Ports located on the North coast (Ferrol, Gijón, or Santander) along with Almería (Mediterranean South coast) present the highest levels of specialisation in solid bulk, with indices of specialisation that take values around three, which means that the share of solid bulk in these port authorities is three times the share of solid bulk in the Spanish port system. Algeciras, Barcelona, and Valencia (the three biggest container ports on the Spanish coast) along with Las Palmas (an important port in the Canary Islands) score the highest in container specialisation.

Finally, the highest levels of specialisation correspond to non-containerised cargo. In this case, Melilla (a strategic port in the North of Africa), Baleares (an important island port in terms of tourism), and Pasajes (a port on the North coast, crucial in terms of exports and imports) show values of this index over four, meaning that they are strongly specialised in this kind of cargo.

A time trend and a time dummy variable have been included in the input-oriented distance function to identify the effect of time on Spanish PAs' production process. On the one hand, the time trend allows us to capture the effect of various factors that vary over time (not included in the distance function specification), and are common to all Spanish PAs, on production. This effect is named 'technical change'. On the other hand, a time dummy related to the 2008 financial crisis is included in the model. This variable takes values equal to zero from 1992 to 2007 and values equal to one from 2008 to 2015. First, this variable allows us to determine whether the PAs performance has changed from the beginning of the financial crisis in 2008. Second, it indicates how this change has occurred.

3. Results

Equation (5) is estimated using the TFE model (Greene 2005). Tables 2 and 3 show the estimation results of the input-oriented distance function and the inefficient model, respectively. In Table 2, all the first-order parameters are statistically significant and show the expected signs (negative for outputs and positive for inputs), except passengers. As mentioned above, this variable usually presents an irregular distribution. In this case, there are 130 observations with zero values and many others with few passengers (in contrast with other types of traffic). Further, passenger traffic makes it necessary to invest in specific infrastructures (passenger terminals), but if the level of passenger traffic is low, those infrastructures will be under-utilised. Therefore, passenger traffic can cause overcapacity (Hidalgo-Gallego, Núñez-Sánchez, and Coto-Millán 2015) and requires more inputs than other types of traffic (Núñez-Sánchez, Jara-Díaz, and Coto-Millán 2011), which makes most PAs deviate from the efficient frontier.

As mentioned above, a quadratic trend and a dummy variable are included in the estimation model. The former captures the effect of time (or technical progress) on PAs' production process, while the latter reflects the impact of the 2008 financial crisis on Spanish ports´ performance. The estimation results show that continuous technological change has not occurred in the sample period (the coefficients on variables related to the trend are not statistically significant). However, it cannot be concluded that PAs did not experience technological progress. Maritime transport has evolved considerably in response to the changing environment both in terms of international trade and production activities (Trujillo and Tovar 2007). This phenomenon does not favour distance reduction as PAs have faced continuous change. Nevertheless, a discrete reduction in the distance to the optimal frontier is observed during the 2008 economic crisis and subsequent periods. This jump could be explained by the need of the Spanish port system to become more efficient in response to a reduction in international trade and public expenses and an increase in international port competition. The adoption of the Law 33/2010 could partially explain the improvement of PAs' performance. This law promotes the participation of private initiative not only in port activities but also in financing and building infra- and super-structures and strongly encourages the liberalisation of technical-nautical services (González-Laxe 2012) as instruments of cost reduction and efficiency improvement.

With respect to the determinants of PAs' technical efficiency, Table 3 reports the estimated parameters of the inefficient model. All parameters are statistically significant,

Table 2. Efficient frontier results.

	Coefficient.	Std. Err.	z	P>|z|	
x1*	0.636	0.023	27.63	0.000	***
x2*	0.253	0.017	15.10	0.000	***
x3	0.112	0.018	6.08	0.000	***
y1	−0.055	0.008	−7.27	0.000	***
y2	−0.024	0.017	−1.43	0.152	
y3	−0.021	0.006	−3.82	0.000	***
y4	−0.098	0.017	−5.72	0.000	***
y5	0.011	0.005	2.24	0.025	**
x1*^2	0.016	0.045	0.35	0.730	
x2*^2	−0.087	0.020	−4.43	0.000	***
x3^2	0.021	0.042	0.51	0.613	
y1^2	−0.006	0.001	−4.88	0.000	***
y2^2	−0.037	0.009	−4.12	0.000	***
y3^2	−0.004	0.001	−3.69	0.000	***
y4^2	−0.075	0.017	−4.55	0.000	***
y5^2	0.001	0.001	0.69	0.488	
x1*x2*	0.046	0.024	1.93	0.054	*
x1*x3	−0.062	0.040	−1.57	0.117	
x2*x3	0.041	0.018	2.21	0.027	**
x1*y1	0.037	0.006	6.08	0.000	***
x1*y2	−0.059	0.013	−4.76	0.000	***
x1*y3	0.002	0.004	0.61	0.539	
x1*y4	−0.016	0.019	−0.85	0.397	
x1*y5	0.017	0.003	5.18	0.000	***
x2*y1	−0.030	0.005	−5.48	0.000	***
x2*y2	0.080	0.011	7.14	0.000	***
x2*y3	−0.008	0.003	−2.56	0.010	***
x2*y4	0.009	0.014	0.66	0.511	
x2*y5	−0.010	0.003	−3.47	0.001	***
x3*y1	−0.007	0.006	−1.09	0.276	
x3*y2	−0.020	0.011	−1.76	0.079	*
x3*y3	0.005	0.004	1.22	0.221	
x3*y4	0.007	0.018	0.39	0.694	
x3*y5	−0.007	0.004	−1.97	0.049	**
y1y2	−0.018	0.004	−4.17	0.000	***
y1y3	0.001	0.001	2.43	0.015	**
y1y4	0.008	0.005	1.49	0.137	
y1y5	−0.001	0.000	−2.86	0.004	***
y2y3	−0.002	0.003	−0.93	0.350	
y2y4	0.040	0.011	3.80	0.000	***
y2y5	0.007	0.002	3.88	0.000	***
y3y4	0.005	0.003	1.57	0.115	
y3y5	0.001	0.000	3.85	0.000	***
y4y5	0.005	0.002	2.20	0.028	**
t	−0.003	0.004	−0.93	0.352	
t^2	−0.000	0.000	−0.43	0.667	
Crisis	−0.054	0.025	−2.12	0.034	**

Source: own elaboration.

Table 3. Results of the inefficiency effects model.

	Coef.	Std. Err.	z	P>|z|	
ieli	0.339	0.104	3.27	0.001	**
iesol	0.282	0.069	4.09	0.000	***
iecont	−1.540	0.719	−2.14	0.032	*
iencont	−0.605	0.186	−3.25	0.001	***
mtot	−7.81E-08	2.42E-08	−3.23	0.001	***
sup	3.73E-07	9.05E-08	4.12	0.000	***

Source: own elaboration.

indicating that the considered variables affect PAs' technical efficiency. The coefficient on the deposit area (*sup*) is positive, whereas the coefficient on total cargo (*mtot*) is negative. These results indicate that increasing port capacity increases inefficiency, ceteris paribus, and the growth in the volume of cargo handled by Spanish PAs improves technical efficiency. These results are explained by overcapacity in the Spanish port system (Hidalgo-Gallego, Núñez-Sánchez, and Coto-Millán 2015), which carried out significant investment efforts in the decade before the financial crisis (Hidalgo-Gallego, Núñez-Sánchez, and Coto-Millán 2017), reducing the ratio of total cargo (*mtot*) handled by PAs over their stocking area (annual tons per square meters). Therefore, the Spanish port system can handle increases in traffics with its current infrastructure (Tovar and Wall 2017b).

Concerning traffic specialisation indices, the results in Table 3 suggest that increasing containerised and non-containerised general cargo enhances ports´ technical efficiency. However, Figure 1 shows that these gains do not occur at all levels of specialisation: the higher the specialisation indices, the smaller the increase in the technical efficiency scores. On the one hand, Plot 1.a indicates that containerised general cargo produces gains in technical efficiency up to the average of the system. However, specialisation indices above the average of the system neither improve nor worsen technical efficiency scores. On the other hand, Plot 1.b indicates that efficiency gains associated with non-containerised general cargo specialisation occur until high levels of specialisation.

Large container terminals require specific (highly mechanised) assets to reduce vessels' waiting times and enhance competitiveness. Such mechanisation entails substantial investments that must

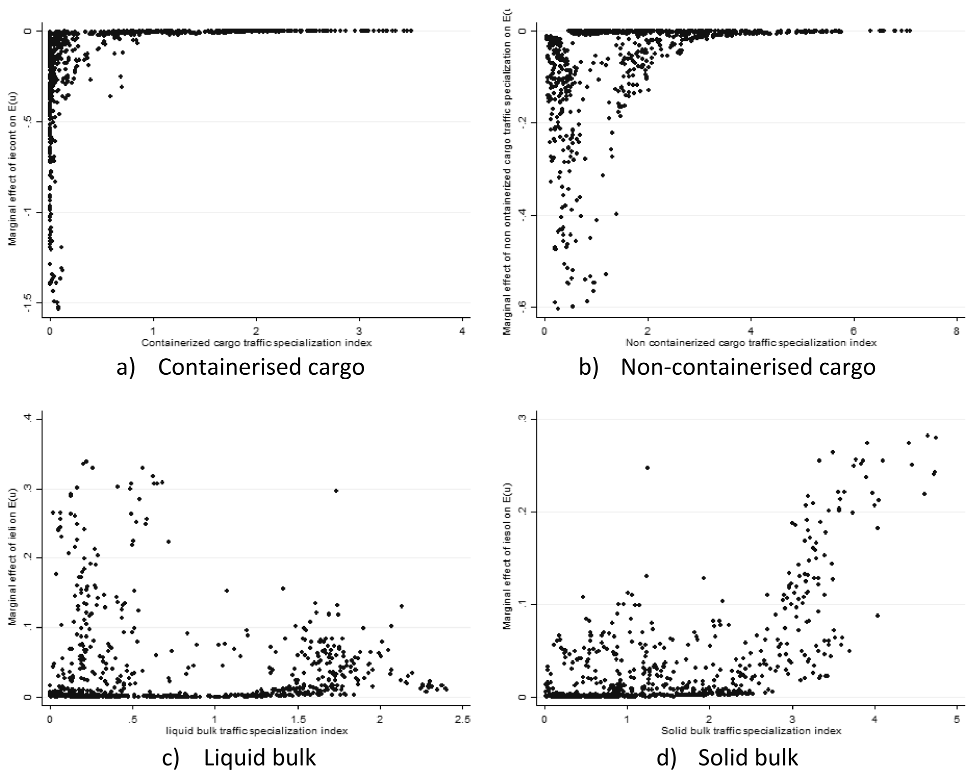

Figure 1. Marginal effects of specialisation.

Source: own elaboration.

be recovered to meet the profitability criterion (Royal Legislative Decree 2/2011). Moreover, a global trend towards the use of larger vessels on container transportation has emerged. Thus, PAs that manage large amounts of containerised cargo need to keep investing in general infrastructure (for instance, to dredge ship channels). In contrast, PAs that manage low quantities of containerised cargo may easily adapt generic cranes. No significant improvement in the general infrastructure is needed when low volumes of this cargo are transported from hub ports to secondary ports in (relatively) smaller ships. Therefore, PAs should consider the investment needed to increase containerised cargo along with the economic results.

It is possible to load and unload high amounts of non-containerised general cargo using the available equipment in a port (e.g., cranes); hence, specialisation produces high profits for far longer (Mateo-Mantecón et al. 2012). Moreover, a part of the cargo handled by ports (such as liquid bulk or containerised general cargo) does not require substantial investment because it is not highly mechanised, such as ramps to load and unload cars (Observatorio Permanente 2018). Therefore, technical efficiency can be easily improved.

In contrast with the result of Tovar and Wall (2017a), this empirical analysis shows that specialisation in liquid bulk reduces PAs′ technical efficiency. Liquid bulk is essential, as enormous quantities of freight can be loaded by using few 'direct' amounts of inputs (employees or consumptions as petrol) (Coto-Millán et al. 2019). Moreover, the vessels do not need to stay in a berth of the port occupying space that may be used by another ship (Mateo-Mantecón et al. 2012). The primary justification for the lack of specialisation in liquid bulk is the existence of economies of scope, as PAs can make use of the general infrastructure built for other cargo (Tovar and Wall 2017b). Thus, investment in liquid bulk infrastructure contributes to technical efficiency, but it should be developed as a complement to other freights (contrary to specialisation).

The results indicate that specialisation in solid bulk leads to a reduction of technical efficiency levels. Solid bulk typically consists of lesser value-added freight, and loading requires higher amounts of productive factors compared to general and liquid cargo.

Plots c and d in Figure 1 show the marginal effects of liquid and solid bulk specialisation, respectively. On the one hand, Plot d confirms that the specialisation in solid bulk worsens efficiency scores. On the other hand, specialisation in liquid bulk is characterised by two distinct trends. In the region of lower specialisation, with rates of specialisation below 0.75, the plot indicates that higher specialisation increases inefficiencies. This result could be explained by the need to build new specific infrastructure to handle this type of cargo. In this case, the investment needs to be amortised. However, when specialisation indices have values above 0.75, the adverse effect of increasing specialisation in liquid bulk decreases. This result discourages specialisation in this cargo. The reason for this result is likely the existence of economies of scope, although specific infrastructures are needed to load and unload liquid bulks.

4. Discussion

The cargo handled by PAs is typically heterogeneous (Jara-Díaz, Tovar, and Trujillo 2008). This heterogeneity moves ports′ technical efficiency in two opposite directions. On the one hand, heterogeneity (in the sense of diversification) means that ports can attend to a wide range of transport demands and, thus, benefit from economies of scope (Riordan and Williamson 1985), improving technical efficiency scores. On the other hand, to load and unload a wide range of freight, ports need to acquire (and invest in) specific infrastructure (Coto-Millán et al. 2016a), thus worsening technical efficiency scores. This study aims to assess whether port specialisation improves port technical efficiency, and, in consequence, make investment recommendations.

To assess the impact of a specialisation strategy, a stochastic distance function and the effects of specialisation on technical efficiency have been jointly estimated using a TFE model, a one-stage procedure proposed by Greene (2005). This model has been applied to a dataset of 26 Spanish PAs over the period 1986–2015.

The results show that specialisation in high value-added freights (i.e., general cargo) leads to higher technical efficiency scores. Moreover, the marginal effects show that the efficiency gains related to increasing general cargo (containerised and non-containerised) decrease when the level of specialisation grows. Therefore, the improvements associated with increasing specialisation in these cargos mainly arise when the initial level of specialisation is low.

With respect to liquid and solid bulk, the results suggest that handling these cargos jointly with others is a better strategy than full specialisation. Therefore, for PAs that are highly specialised in liquid and solid bulk, diversification strategies are recommended.

Finally, the main conclusion of this study is that full specialisation in any freight is discouraged, while finding a balance between the different types of cargo is recommended. In addition, the existence of overcapacity in the Spanish port system allows PAs to change their freight mix using the existing infrastructure (Tovar and Wall 2017b)

Notes

1. When the majority of a port's inbound cargoes are shipped short distances and most of its export products come from nearby areas, the port is called a captive cargo (in contrast with a transit port) (American Association of Port Authorities 2019).
2. In the economic literature, the distance function has also been used in the analysis of port efficiency in González and Trujillo (2008), Núñez-Sánchez and Coto-Millán (2012), Chang and Tovar (2014a, 2014b), and Coto-Millán et al. (2016a), among the others.
3. For a comprehensive review of stochastic frontier analysis applied to port efficiency, see Tovar and Wall (2015). Recent developments in the field can be found in Serebrisky et al. (2016), Coto-Millán et al. (2016), Suárez-Alemán et al. (2016), Barros, Chen, and Wanke (2016), Coto-Millán et al. (2016b), Tovar and Wall (2017), and Chen, Chou, and Hsieh (2018).
4. 28 PAs form the Spanish port system. However, this analysis includes only 26 PAs: (1) Seville is excluded from the sample because it is a fluvial port; hence, its technological conditions may differ from other PAs. (2) Almería and Motril belonged to the same PA until 2005. Then, they became independent PAs. However, both authorities are considered as a unique PA for the whole period of study to assure homogeneity in the sample.
5. See Appendix.
6. Núñez-Sánchez, Jara-Díaz, and Coto-Millán (2011) find that one passenger corresponds to two tons of solid bulk and about three tons of containerised general cargo in terms of marginal costs.
7. In efficiency analysis, outputs are traditionally measured by the throughput as 'physical outputs'. However, in recent years, studies such as Suárez-Alemán, Trujillo, and Cullinane (2014) and Talley and Ng (2016) have proposed to use 'service outputs' for taking into account the time consumed by the cargo handling operations. Using 'physical outputs' allows evaluating whether inputs are used appropriately with respect to outputs. On the contrary, addressing 'services outputs' instead of physical ones allows obtaining a measure of efficiency in terms of the time that a cargo is in port.

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Appendix. Means of the variables by PA

Port Authority	Liquid bulk	Solid bulk	Containerized general cargo	Non-containerized general cargo	Passengers	Labour	Capital	Intermediate consumptions
Algeciras	1.93E+07	2,025,189	2.54E+07	3,560,374	4,256,846	300	2,171,208	2,173,507
Alicante	331,655	1,178,385	811,812	343,831	213,113	160	671,722	40,074
Almería-Motril	919,891	6,147,537	19,645	557,719	733,821	157	645,552	96,255
Avilés	606,434	2,312,267	18,296	1,286,355	204	130	561,896	48,997
Cádiz	356,698	1,545,196	845,450	1,267,265	207,804	216	1,234,807	180,363
Barcelona	9,361,621	4,119,124	1.27E+07	5,335,092	1,889,148	551	4,940,507	739,374
Bilbao	1.64E+07	4,940,220	4,136,708	3,160,488	114,402	318	3,711,791	186,099
Cartagena	1.45E+07	3,169,471	435,881	289,856	31,949	188	1,111,959	96,214
Castellón	7,206,680	1,868,683	739,110	410,677	2,281	100	664,511	32,841
Ceuta	1,759,319	63,366	59,028	780,800	2,227,575	140	512,093	626,664
Ferrol	1,063,062	6,317,262	3,909	471,062	15,737	93	546,039	21,232
Gijón	1,276,796	1.40.E + 07	205,841	509,778	12,318	304	2,265,722	137,989
Huelva	1.19E+07	4,988,841	6,518	551,418	351,741	216	1,764,675	89,389
A Coruña	8,006,006	3,183,881	24,319	626,854	51,944	190	1,349,625	222,796
Las Palmas	4,022,646	943,694	7,262,702	2,755,556	1,092,767	308	2,613,572	1,986,006
Málaga	3,427,832	1,194,504	764,657	462,250	427,082	193	880,491	107,808
Melilla	312,077	81,250	146,197	495,891	484,300	81	422,518	22,042
Baleares	2,035,730	1,492,216	1,152,899	5,139,765	3,482,102	317	1,548,155	175,843
Pasajes	279,699	2,006,755	42,265	1,842,063	109	223	840,618	55,035
Pontevedra	7,277	665,573	248,120	475,780	13,684	73	334,881	62,163
Tenerife	7,958,334	1,081,835	2,472,963	2,643,409	3,755,722	223	1,992,651	1,013,789
Santander	442,329	3,229,492	22,960	1,116,623	149,508	216	1,355,667	65,207
Tarragona	1.83E+07	8,617,024	678,900	729,341	5,362	285	1,855,683	199,551
Valencia	2,627,709	4,054,943	2.18E+07	5,166,332	389,597	381	3,725,578	269,760
Vigo	313,022	473,729	1,450,142	1,211,509	573,879	231	1,008,566	294,138
Vilagarcía	198,086	360,356	47,484	178,057	3,864	65	233,897	8,756

Port Authority	Liquid bulk specialization index	Solid bulk specialization index	Containerized general cargo specialization index	Non-containerized general cargo specialization index	Total cargo	Deposit area
Algeciras	1.038	0.187	2.068	0.600	5.03E+07	1,487,172
Alicante	0.272	1.818	1.452	1.021	2,665,682	200,740
Almería-Motril	0.361	3.223	0.011	0.617	7,644,792	509,073
Avilés	0.356	2.277	0.014	2.640	4,223,352	290,900
Cádiz	0.198	1.594	1.253	2.645	4,014,609	1,770,953
Barcelona	0.763	0.616	1.941	1.256	3.16E+07	2,909,572
Bilbao	1.413	0.721	0.686	0.919	2.86E+07	1,871,794
Cartagena	1.951	0.713	0.128	0.149	1.84E+07	380,806
Castellón	1.784	0.702	0.222	0.348	1.02E+07	394,925
Ceuta	1.453	0.128	0.117	2.737	2,662,512	77,087
Ferrol	0.289	3.366	0.001	0.664	7,855,294	360,149
Gijón	0.200	3.639	0.047	0.265	1.60E+07	1,205,328
Huelva	1.662	1.226	0.001	0.280	1.74E+07	327,783
A Coruña	1.649	1.133	0.007	0.416	1.18E+07	297,672
Las Palmas	0.717	0.270	2.103	1.680	1.50E+07	1,391,441
Málaga	0.882	1.265	0.548	0.881	5,849,243	232,403
Melilla	0.274	0.228	0.844	5.432	1,035,415	21,909
Baleares	0.484	0.627	1.001	4.118	9,820,610	292,142
Pasajes	0.144	1.936	0.113	3.735	4,170,781	430,009
Pontevedra	0.021	2.033	0.503	3.117	1,396,751	121,757
Tenerife	1.389	0.300	0.901	1.510	1.42E+07	537,337
Santander	0.226	2.760	0.031	1.895	4,811,404	719,894
Tarragona	1.594	1.256	0.092	0.204	2.83E+07	1,175,238
Valencia	0.213	0.704	2.716	1.483	3.36E+07	2,617,260
Vigo	0.226	0.567	1.882	2.906	3,448,402	500,749
Vilagarcía	0.610	1.959	0.143	1.934	783,983	172,626