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TECHNICAL EFFICIENCY OF IBERIAN PORT AUTHORITIES BY SPECIALIZATION: A DEA METAFRONTIER APPROACH

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RESUMEN: La importancia de los puertos como enlaces en el transporte marítimo y su importancia para el desarrollo económico mundial es indiscutible. La identificación de los puertos más eficientes y las mejores prácticas son aspectos básicos para los gestores de los puertos, clientes y autoridades. Sin embargo, los puertos no son unidades homogéneas ya que están especializados en tipos de tráfico y servicios. En consecuencia, el objetivo de este trabajo es evaluar y comparar la eficiencia técnica de 33 puertos localizados en la Península Ibérica teniendo en cuenta su especialización en el tráfico de graneles sólidos, líquidos y mercancías generales. Para ello, utilizamos una metodología robusta y fiable como es el modelo de metafrontera. Por otra parte, el concepto de brecha tecnológica es utilizado para estimar la proximidad de la frontera de producción de cada grupo de puertos a la metafrontera. Los resultados obtenidos evidencian que los puertos analizados son en general muy eficientes, pero son los puertos especializados en el tráfico de graneles líquidos los que presentan el mejor desempeño. El tráfico de productos como el petróleo y sus derivados requiere de infraestructura especial y de la proximidad a ciertas industrias, haciéndolos tráficos 'cautivos'. Este hecho proporciona a algunos puertos una ventaja competitiva que les identifica como los puertos más eficientes.

Palabras claves: Análisis envolvente de datos (DEA); metafrontera, tecnología no homogénea, eficiencia técnica, brecha tecnológica, puertos.

ABSTRACT: The importance of ports as links in the maritime transport and their weight in the global economic development is unquestionable. Identifying the most efficient ports and the best practices is basic for ports' managers, customers and authorities. However, ports are not homogeneous units because they are specialised in terms of traffic and services. In consequence, the aim of this paper is to assess and compare the technical efficiency of the 33 Iberian port authorities taking into account their specialisation in the traffic of solid bulk, liquid bulk and general commodities. To do this, we use a robust and reliable methodology such as the metafrontier model. Moreover, the technological gap ratio concept is used to estimate the proximity of the production frontier of each group of ports to the metafrontier. The achieved results evidence that Iberian port authorities are quite efficient in general terms, but the ports specialised in the traffic of liquid bulks have the best performance. The traffic of products such as oil and its derivatives requires special infrastructures and proximity to certain industries, making them 'captive' traffics. This fact provides certain ports a competitive advantage that identifies them as the most efficient ports.

Keywords: Data envelopment analysis (DEA); Metafrontier; Non-homogeneous technology; Technical efficiency; Technological gap ratio (TGR); ports.

1. Introduction

Maritime transport is considered as one of the pillars of globalisation and economic development at the country level. The role of ports is essential as they are the main interface between sea and land (CEPAL, 2012). The principles of economy, effectiveness and efficiency in the use of resources must be taken into account in the management of any infrastructure and, therefore, in the management of ports (Medal-Bartual et al., 2012a). Port efficiency, together with other variables such as localisation or seaport infrastructure are key factors that influence which ports are used (Tongzon, 2009). Hence, ports are seeking to become more efficient and productive. Consequently, performance measurement of ports has become a subject of increasing importance and a fundamental tool for modernisation and competitiveness (Cullinane and Song, 2006; Figueiredo De Oliveira and Cariou, 2015). Relative efficiency assessment allows to compare the performance of ports and to identify the best practices as well as the sources of inefficiency (Carvalho and Marques, 2012).

As it was reviewed by Tovar and Wall (2015), several studies of efficiency assessment have been carried out in the port sector. However, most of the studies compared the efficiency of ports and terminals without taking into account that ports have become specialised in terms of traffic and services. Two exceptions are the studies by Caldeirinha et al. (2009) and Inglada and Coto-Millán (2010). In both papers it is evaluated the efficiency of a sample of ports using data envelopment analysis (DEA) method. In a second stage, they carried out a linear regression to determine some explanatory variables – including ports specialisation – of the efficiency scores obtained through DEA model.

From a methodological point of view, this approach suffers important shortcomings (Badin et al., 2014). Firstly, if the variables selected for the second estimation stage are expected to affect efficiency, they should have been included in the first modeling stage to obtain efficiency scores (Grosskopft, 1996). Secondly, if the variables used in specifying the original efficiency model are correlated with the explanatory variables used in the second stage, then the second-stage estimates will be inconsistent and biased (Simar and Wilson, 2007). Thirdly, erroneous results can be obtained mainly due to the serial correlation between the error term and the set of covariants in the second stage (Simar and Wilson, 2007).

Both parametric and non-parametric methods assume that units (ports in this study) have similar characteristics when efficiency is evaluated. In other words, it is assumed a common frontier technology. However, ports specialised in different traffics face different production opportunities to force them to make choices from a different set of feasible input-output combinations. Heterogeneity creates differences between ports which could skew efficiency assessment of them and restricts the direct cross-comparison. In other words, although every port uses inputs (labor, capital, fixed assets, etc.) in order to generate outputs (traffics or services) not every port has the same inputs to produce the same output. For instance, ports specialized in general commodities (GC) or containerized merchandise have not the same fixed assets, this is, the same kind of cranes, straddle carriers, docks, berths, or equipment than a port which predominates liquid bulks (LB). Hence, ports with high proportion of LB are directly comparable with those predominating in GC, but we need to assume different production frontiers.

In order to solve the incomparability of performance of units from different characteristics, Hayami (1969) introduced the metafrontier concept. A metafrontier may be considered as an umbrella of all possible frontiers that might arise as a result of heterogeneity between units (Chen and Yang, 2011). The metafrontier model takes into account any heterogeneity between units in the comparison of efficiency. Hence, this approach is a well-established tool for evaluating and comparing efficiency in non-homogeneous units such as ports specialised in different traffics since their aim is the same but they operate under different production frontiers. Since its introduction, the metafrontier model has been used to compare the efficiency of units covering diverse topics such as hotels (Huang et al., 2013); banks (Huang et al., 2015); tourism destinations (Assaf and Dwyer, 2013); wastewater treatment plants (Sala-Garrido et al., 2011); franchise enterprises (Medal-Bartual et al., 2012b); among others. However, to the best of our knowledge, the metafrontier approach has never been used to compare the efficiency of groups of port authorities based on their specialization in terms of traffic.

Against this background, the main objective of this paper was to assess and compare the technical efficiency of three groups of port authorities specialised or with a high proportion of solid bulk traffic (SB), liquid bulk traffic (LB) and general commodities (GC). In order to take into account the lack of comparability of data, we used the metafrontier model. An empirical application focussed on 33 Iberian port authorities was carried out. Moreover, the technological gap ratio (TGR) concept was used to estimate the proximity of the production frontier of each group of ports to the metafrontier. To our knowledge, this paper compares for the first time the efficiency of port authorities specialised in the traffic of SB, LB and GC using a robust and reliable methodology such as the metafrontier model.

From a policy perspective, the methodology and results of this study are of great interest to ports´ managers, stakeholders and authorities in the decision-making process. Efficiency comparison enables the identification of the best practices within each group of port authorities specialised in the traffic of SB, LB or GC. It provides meaningful information to cost containment and reduction. Moreover, it should be noted that the Spanish Act 33/2010 emphasized the need to improve the management and efficiency of ports. Hence, this study would be very useful for the State Ports to support the decision process of economic resources allocation among the different port authorities.

2. Brief literature review

Significant progress has been made in the assessment of ports´ efficiency using both parametric and non-parametric approaches (Tovar and Wall, 2015). Focusing on Spanish and Portuguese ports, some previous studies have evaluated their efficiency using stochastic frontier analysis approach (Baños-Piño et al. 1999; Coto-Millán et al., 2000; Rodríguez-Álvarez et al., 2007; Trujillo and Tovar, 2007; Gonzalez and Trujillo, 2008; Díaz-Hernández et al., 2008; Núñez-Sánchez and Coto-Millán, 2010; Rodríguez-Álvarez et al., 2011; Núñez-Sánchez and Coto-Millán, 2012; Rodríguez-Álvarez and Tovar, 2012; Tovar and Wall, 2015; Tovar and Rodríguez-Deniz, 2015; Medal-Bartual et al., 2016). On the other hand, other studies focused on non-parametric techniques such as DEA (Martínez-Budria et al., 1999; Bonilla et al., 2002; Barros, 2003; Bonilla et al., 2004; Barros and Athanassiou 2004; Inglada and Coto-Millán, 2010; Carvalho et al., 2010; Medal and Sala, 2011; Carvalho and Marques, 2012; Medal-Bartual et al., 2012a; Díaz-Hernández et al., 2014; Gutierrez et al., 2015).

Studies can be differentiated by those focusing on container terminal, such as González and Trujillo, (2008); González-Cancelas et al., (2013); Wilmsmeier et al., (2013) and Gutiérrez et al., (2015) and those focusing on general ports such as Martínez-Budria et al., (1999); Coto-Millán et al., (2000); Bonilla et al., (2002); Bonilla et al., (2004); Carvalho et al., (2010); Inglada and Coto-Millán, (2010); Medal and Sala, (2011); Rodríguez-Álvarez and Tovar, (2012); Medal-Bartual et al., (2012a); Díaz-Hernández et al., (2014); Tovar and Rodríguez-Deniz, (2015) and Tovar and Wall, (2015). Within the second group of studies, most of the papers provided a global score of efficiency without considering the different types of traffics namely LB, SB and GC. However, Inglada and Coto-Millán, (2010); Medal-Bartual et al., (2012) and Tovar and Wall, (2015) studied issues related to the specialization of ports. Inglada and Coto-Millán (2010) applied a second stage DEA to relate efficiency scores of ports and their traffic specialization. Medal-Bartual et al., 2012a computed an efficiency score for each type of traffic (LB, SB and GC) by applying a non-radial DEA model. Recently, Tovar and Wall, (2015) developed three parametric models which focused on three different outputs namely containers, SB and non-containerized general cargo.

The aforementioned literature covers a wide range of methodologies, specifications and objectives. However, as far as we are aware, no studies the metafrontier approach has never been used to compare the efficiency of groups of port authorities based on their specialization in terms of traffic.

3. Methodology

The metafrontier concept is illustrated in the Figure 1. Frontier group A and B represent group-specific best practice frontiers and they are estimated by performing two separate efficiency assessments. The all-encompassing metafrontier is obtained by pooling the data from the two groups and repeating the efficiency evaluation (Lin and Chiang, 2014). Following Tiedemann et al. (2011) a non-concave metafrontier was estimated in this study. It only envelopes the input-output combinations that are part of the delineated set at least one of the groups evaluated. Hence, the problem of infeasible input-output combinations is avoided (Medal-Bartual et al., 2012b). According to Figure 1, whether DMU U belongs to group A then the ratio of distance $\overline{Y_U U^*}$ to distance $\overline{Y_U U}$ reflects the input-oriented efficiency score of DMU U in relation to its own production frontier. On the other hand, for the same DMU U, the ratio of distance $\overline{Y_U U^{**}}$ to distance $\overline{Y_U U}$ is the efficiency score of DMU U in relation to the metafrontier.

It should be noted that the distance function and therefore, efficiency assessment, can take an input orientation or an output orientation. The choice is done on the basis of which inputs or outputs, the port has more control over (Chang and Tovar, 2014). An input orientation is more adequate when ports are characterized by endogenous inputs while outputs are related to the existing demand which is an exogenous variable (Inglada and Coto-Millán, 2010; Wilmsmeier et al., 2013). By contrast, whether port infrastructure investments are lumpy and ports have little control over adjusting inputs, an output orientation should be applied (Chang and Tovar, 2014). In this paper, we adopted an input orientation as other authors since Iberian ports authorities are a regulated industry characterized by endogenous inputs and exogenous outputs.

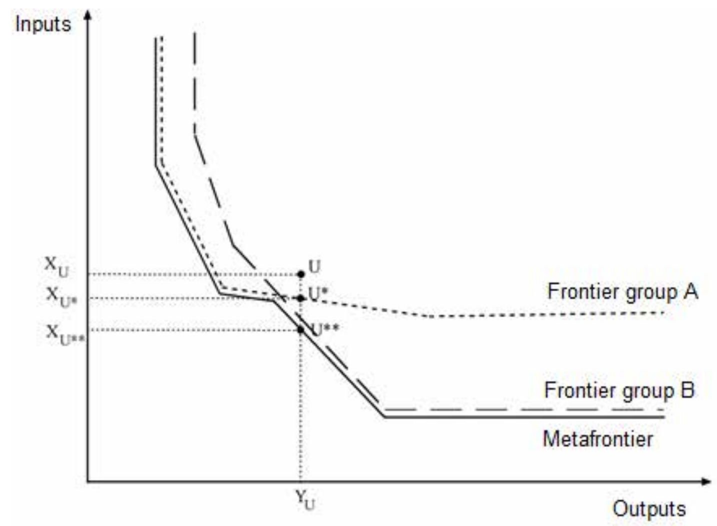

Figure 1. Non-concave metafrontier.
Source: Own elaboration

Let us assume that units use an input vector $x \in \Re_+^M$ to produce an output vector $y \in \Re_+^L$ while the production technology is defined as capability of transforming inputs to outputs. Suppose that there are K technology sets (groups) in total and $k = 1, 2, \dots, K$. The group-technology is defined as all feasible input-output combinations for a unit which belongs to group k:

$$T^k = \{(x, y) \in \Re_+^{\mathrm{M+L}}; \text{x can produce y in the group k}\} \tag{1}$$

The input set associated to T^k is defined as:

$$L^k(y) = \{x: (x, y) \in T^k\} \tag{2}$$

The input-oriented distance function for each group k can be expressed as:

$$D^k(x, y) = min_\theta\{\theta > 0: \ x\theta \in L^k(y)\} \qquad k = 1,2, \dots, K \tag{3}$$

Based on the metafrontier concept, if an output vector y can be produced using an input vector x in one group, the (x, y) belong to the set T defined as:

$$T = \{(x, y) \in \Re_+^{M+L}; x\ can\ produce\ y\ in\ some\ group\ T^k\ (k = 1,2, \dots, k)\} \tag{4}$$

where $T = \{T^1 \cup T^2 \cup \dots \cup T^k\}$. Hence, the input set associated to T is:

$$L(y) = \{x: (x, y) \in T\} \tag{5}$$

Analogously to the input-oriented distance function for each group-k, the metafrontier input-oriented distance function is defined as:

$$D(x, y) = min_\theta\{\theta > 0: x\theta \in L(y)\} \tag{6}$$

DEA models can be characterised by demonstrating constant returns to scale (CRS) (Charnes et al., 1978) or variable (increasing or decreasing) returns (Banker et al., 1984). Inefficiency scores estimated following CRS approach are the product of the scale inefficiency and pure technical inefficiency. On the other hand, inefficiency scores estimated through VRS approach consider only technical inefficiency. Based on previous works (Wanke et al., 2011; Bonilla et al., 2004) the efficiency of the Iberian port authorities was estimated assuming VRS. Moreover, we used an input oriented model since the aim of the port authorities is to minimise the use of resources keeping traffics.

To estimate the efficiency scores with respect to group-k (E^k) technology and to the metafrontier (E), the following linear programming must be solved for each port assessed:

$$\begin{aligned}
&Min\ \ \theta^k \\
&s.t: \\
&\sum_{j=1}^{n} \lambda_j x_{ij} \le \theta^k x_{i0} && i = 1,\dots m \\
&\sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{r0} && r = 1,\dots s \\
&\sum_{j=1}^{n} \lambda_j = 1 \\
&\lambda_j \ge 0 && j = 1,\dots n_k
\end{aligned} \tag{7}$$

where x_{ij} and y_{ij} represent the quantity of inputs $(i = 1, \dots, m)$ and outputs $(r = 1, \dots, s)$ for each port $(j = 1, \dots, n)$ being x_{i0} and y_{i0} the values of the DMU evaluated; n_k is the number of DMUs in the group k and; θ^k is a scalar whose value indicates the efficiency of the unit assessed, i.e., θ^k is the efficiency score of the DMU evaluated. $\theta^k \in (0,1]$ therefore, a DMU is efficient if and only if $\theta^k = 1$ and the slacks of all the restrictions in model (7) are equal to zero (Sala-Garrido et al., 2011). The difference between an efficiency score and the unity represents the potential to reduce the mix of inputs consumed to produce the same quantity of outputs.

The efficiency for each group (E^k) cannot be smaller than the efficiency with respect to the metafrontier (E) since the restrictions of the group problems are subsets of the constraints of the metafrontier problem (Tiedemann et al., 2011). To measure the proximity of the group-k frontier to the metafrontier, Battese et al. (2004) defined the TGR for the group-k DMUs (ports) as:

$$TGR^k = \frac{D\ (x,y)}{D^k(x,y)} = \frac{E}{E^k} \le 1 \tag{8}$$

The TGR measures the ratio of the inputs for the frontier production function for the k −th group relative to the potential inputs that are defined by the metafrontier function, given the observed outputs (Battese and Rao, 2002). An increase in the TGR involves a decrease in the gap between the group frontier and the metafrontier. Moreover, Eq. (8) evidences that the efficiency of a DMU relative to the metafrontier is the product of the efficiency of that DMU relatively to the frontier for a particular group and the technology gap for that group (Assaf, 2009).

4. Sample description

The sample evaluated in this research consists of 33 Iberian port authorities; 28 of them are Spanish and 5 are Portuguese. Many of the Spanish and Portuguese port authorities manage more than one port. Actually, The Spanish Port System is integrated by 46 ports of general interest, managed by 28 port authorities, whose coordination and control correspond to a public agency called “Puertos del Estado” (State Ports) which belongs to the Spanish Ministry of Public Works. These port authorities are managed following a “landlord” model. It means that governments own the land and water access, while private firms provide services related to port activity through concessions.

The Portuguese ports have also gradually moved to an intermediate public-private “landlord” model. The largest seaports are public enterprises, directly under control of the Ministry of Transportation. Two authorities, Ministry of transportation and “Instituto Marıtimo Portuario”, manage the ports located along the Portuguese Atlantic coast and the islands of Madeira and Azores. Concretely, there are 8 Portuguese port authorities in the continent (Viana do Castelo, Leixoes, Aveiro, Figueira da Foz, Lisboa, Setubal, Sines and Algarve), and 2 in the islands (Azores and Madeira).

Although the paper does not work with all the Portuguese ports authorities, those selected in this analysis (Leixoes, Aveiro, Lisboa, Setubal and Sines) represent more than 90% of the total freight traffic through Portuguese ports and therefore, they are highly representative of the Portuguese port system (Barros, 2003).

Instead of focusing just on the Spanish port authorities, it was considered more appropriate to extend the study to the Iberian ports for several reasons. Firstly, there is a geographical reason: 5 of the 28 Spanish port authorities are located in the Atlantic area. For instance, the distance between the Spanish port of A Coruña and Leixoes in Portugal is just 176 nautical miles. They can compete for traffics from the same geographical area. Secondly, there are commercial reasons. Portugal ports are well-placed to compete with Spanish ports due to their rail and road connections improvements in recent years. For example, the distance from Madrid to Lisboa is 628 Km while there are 623 km from Barcelona to Madrid. This fact allows the Portuguese ports to be a gateway to Spain and a viable alternative to many Spanish ports. Finally, it can be argued methodological reasons: the assessment of Spanish and Portuguese ports allows us to increase the number of units evaluated and avoids one of the main limitations of DEA models. As Schøyen and Odeck (2013) noted, a general rule of the literature implies that the number of units evaluated should be at least twice the number of inputs and outputs.

The Iberian port authorities are not a homogeneous group as it is shown in Table 1, which illustrates that many Iberian ports authorities are specialised in a specific type of traffic or supports a wide variety of traffic but stands out in one of them. According to CEPAL (2012), the 33 Iberian port authorities were categorised in three groups: (i) port authorities with high proportion of SB which involve the ports of Almeria, Aveiro, Avilés, Ferrol-San Cibrao, Gijón, Marín, Santander, Setubal, Sevilla and Vilagarcía; (ii) port authorities with high proportion of LB which involve the ports of A Coruña, Bilbao, Cartagena, Castellón, Ceuta, Huelva, Leixoes, Motril, S.C. Tenerife, Sines and Tarragona and (iii) port authorities with high proportion of GC traffic which involve the ports of Alicante, B. Algeciras, B. Cádiz, Baleares, Barcelona, Las Palmas, Lisboa, Málaga, Melilla, Pasajes, Valencia and Vigo. Several methodological approaches can be applied to cluster port authorities integrating multiple dimensions such as complexity, size and traffic specialization (Martínez-Budria et al., 1999; Tovar and Rodriguez-Deniz (2015). However, our study focused on assessing and comparing the efficiency of port authorities grouped based only on traffic specialization criterion. Hence, we adopted the classification suggested by CEPAL (2012) based on the data from annual reports. All data are relative to the year 2013 and were collected from the account and activities reports of port authorities.

Table 1. Sample description

GROUP		SB (10^3 x tones)	LB (10^3 x tones)	GC (10^3 x tones)	PAS (number)	FA (10^3 x €)	L (10^3 x €)
SB	**Mean**	4,165.37	626.04	1,703.86	100,052.10	293,003.37	5,368.95
	Std. Dev.	4,488.37	746.05	1,054.75	217,569.84	278,279.10	1,861.91
	Minimum	202.97	1.00	497.66	10.00	75472.00	3058.00
	Maximum	14,947.16	2,530.57	3,724.95	690,767.00	984,462.00	8,773.56
LB	**Mean**	3,181.16	11,753.99	4,001.84	716,959.09	418,443.09	8,292.14
	Std. Dev.	2,227.16	8,200.76	4,020.48	1,564,926.31	232,880.15	3,160.68
	Minimum	63.43	858.23	317.14	10.00	68,687.00	2,817.00
	Maximum	7,375.09	23,719.89	12,192.40	5,141,174.00	819,715.00	13,807.00
GC	**Mean**	1,667.60	3,910.99	15,333.47	1,704,193.83	571,926.26	12,180.54
	Std. Dev.	1,532.28	7,075.81	21,694.15	2,041,422.10	557,340.75	7,370.03
	Minimum	9.00	1.00	89,598.00	10.00	126,719.00	4.718.00
	Maximum	4,816.74	24,034.11	60,050.25	5,799,347.00	1,870,002.0	29,621.00

Selecting the output and input variables to be included in the efficiency assessment is always a difficult task due to the complexity of the port sector (Carvalho and Marques, 2012). Wilmsmeier et al. (2013) evidenced that diverse inputs and outputs have been used to measure the efficiency of ports. The most recent trend has been to consider the traffic of each port as its output. Hence, in accordance with Bonilla et al. (2004), Cheon et al. (2010), and Díaz-Henández et al. (2008), among others, we considered the traffic volumes as the output variables. Moreover, recent studies (Nuñez-Sánchez and Coto-Millán, 2012; Tovar and Wall, 2015) also integrate the number of passengers as output. Hence, taking into account the literature and the availability of data, four outputs were involved in the assessment: LB, SB, GC (each expressed in thousands of tons) and number of passengers (PAS).

Respect to GC traffic it should be clarified that Spanish official traffic statistics and Portuguese data includes two types of general commodities: conventional general merchandise (goods that must be loaded individually) and containerized merchandise. As many Iberian ports handle general cargos that are not transported in containers, our input refers to the broader term of GC. This fact requires us to measure GC in tons instead of TEUs (which is more common in containerized merchandise).

Following to Chang and Tovar (2014), two inputs were considered namely fixed assets (FA) and labour costs (L), both expressed in thousands of euros. According to Puertos del Estado (State Ports) (2014), FA are non-current assets that include intangible assets, real estate investments and long-term financial investments.

Table 1 summarises the average and standard deviation (SD) values of the inputs and outputs of each group of Iberian port authorities evaluated.

5. Results and discussion

To obtain an efficiency score for each of the 33 Iberian port authorities evaluated, we solved model (7) using MaxDEA software. The results with respect to the group frontiers are shown in Tables 2 and 3. It was illustrated that the Iberian port authorities have a high efficiency within their respective groups. For example, the mean efficiency score for port authorities that stand out in the traffic of SB was 0.975, indicating inputs could be reduced only by 2.5% keeping outputs – given the group frontier. Table 3 also shows that port authorities specialised in SB and LB display low variation in their efficiency scores since their standard deviation values are small. This finding means a high degree of homogeneity within each port group. On the contrary, port authorities with high proportion of GC traffic present the largest degree of heterogeneity. It should be noted that the minimum value of efficiency within this group was 0.246 (Vigo port). It indicates that given its outputs, this port could potentially reduce by 75% its inputs.

Table 2. Average efficiency scores with respect to the group frontiers (E^k) and the metafrontier (E) and technological gap ratio values (TGR) for the 33 Iberian ports.

Group of ports	Efficiency score with respect to group frontiers		
	Average	Std. Dev.	% efficient
Solid bulk	0.975	0.070	80
Liquid bulk	0.937	0.101	75
General commodities	0.865	0.264	64
	Efficiency score with respect to the metafrontier		
	Average	Std. Dev.	% efficient
Solid bulk	0.715	0.317	30
Liquid bulk	0.869	0.209	55
General commodities	0.589	0.308	25
	Technological gap ratio (TGR)		
	Average	Std. Dev.	
Solid bulk	0.727	0.305	
Liquid bulk	0.914	0.148	
General commodities	0.697	0.279	

If we focus on the port authorities that constitute the best practices within each group, i.e., those whose efficiency score is equal to unity, results illustrate slight differences for the three groups of port authorities. The SB group has the largest percentage of efficient port authorities since 8 out of the 10 ports of this group (80%) were efficient. Similar results were obtained for the GC group given that 9 out of the 12 port authorities specialised in this traffic (75%) were identified as efficient. In the case of the LB group, the percentage of efficient port authorities is slightly smaller than for SB and GC groups. Nevertheless, it continues to be medium-high since 7 out of the 11 port authorities with high proportion of LB (64%) are efficient.

While efficiency scores for each port authority estimated using the group frontiers (E^k) are very interesting and useful to improve the performance of the Iberian port authorities, it is not possible to compare the performance of the three groups of port authorities. To overcome this limitation, the efficiency of each Iberian port authority was computed with respect to the metafrontier (E), i.e., with respect to the envelope of the three groups' frontiers.

Table 3 shows that for all port authorities evaluated, the efficiency scores with respect to the metafrontier are smaller than those computed based on the group frontiers. However, this reduction in efficiency did not affect all groups of port authorities equally. Table 3 evidences that the largest mean efficiency was no longer associated with the SB group being replaced by the LB group. This finding indicates that port authorities specialised in the traffic of LB are performing the best. By contrast, port authorities specialised in the traffic of GC presented the lowest mean efficiency score, i.e., they have the worst performance. These results are consistent with the study by Inglada and Coto-Millán (2010), who concluded that the specialization of a port in LB traffic has a positive effect in its efficiency. It should be noted that the case study developed by Inglada and Coto-Millán (2010) embraced only Spanish port authorities and that their methodological approach was pretty different from our approach.

Table 3. Efficiency scores with respect to the group frontiers (E^k) and the metafrontier (E) for the 33 Iberian port authorities.

Group of ports	Iberian Ports	Efficiency scores (E^k)	Efficiency scores (E)	Technological gap ratio (TGR)
Port authorities with high proportion of solid bulk traffic	Ferrol-San Cibrao	1.000	1.000	1.000
	Gijón	1.000	1.000	1.000
	Setubal	1.000	1.000	1.000
	Marín	1.000	0.992	0.992
	Almería	1.000	0.983	0.983
	Avilés	0.971	0.683	0.703
	Vilagarcía	1.000	0.544	0.544
	Santander	0.777	0.349	0.449
	Sevilla	1.000	0.333	0.333
	Aveiro	1.000	0.265	0.265
Port authorities with high proportion of liquid bulk traffic	Cartagena	1.000	1.000	1.000
	Castellón	1.000	1.000	1.000
	Ceuta	1.000	1.000	1.000
	Motril	1.000	1.000	1.000
	S.C. Tenerife	1.000	1.000	1.000
	Tarragona	1.000	1.000	1.000
	Sines	1.000	0.932	0.932
	Huelva	0.909	0.909	1.000
	Bilbao	0.899	0.775	0.863
	A Coruña	0.782	0.480	0.615
	Leixoes	0.717	0.459	0.641
Port authorities with high proportion of general commodities traffic	B. Algeciras	1.000	1.000	1.000
	Baleares	1.000	1.000	1.000
	Valencia	1.000	1.000	1.000
	Barcelona	1.000	0.896	0.896
	Melilla	1.000	0.611	0.611
	Lisboa	1.000	0.588	0.588
	Pasajes	1.000	0.419	0.419
	Las Palmas	0.422	0.410	0.970
	Málaga	0.713	0.376	0.528
	B. Cádiz	1.000	0.296	0.296
	Alicante	1.000	0.282	0.282
	Vigo	0.246	0.191	0.775

To verify statistically whether the ports specialization affected its efficiency, Kruskall-Wallis test was performed considering as a null hypothesis that the efficiency scores for the three groups of ports had no significance difference. The p-value was <0.05. Hence, it can be concluded that the specialization of the Iberian ports authorities affects their efficiency.

It was also evidenced (Table 2) that when efficiency was calculated with respect to the metafrontier, the number of efficient port authorities decreased for the three groups of ports. Thus, the number of efficient ports was reduced by 50%, 20% and 39% for ports specialised in the traffic of SB, LB and GC, respectively. Nonetheless, the LB group is the one with the largest percentage of efficient ports since 6 out of the 11 ports specialised in LB traffic (55%) are efficient.

Table 3 illustrates that efficiency scores and consequently the relative position of each port analysed are divergent when efficiency was computed using the individual frontiers and the metafrontier as reference points. Regarding the group of port authorities with high proportion of SB traffic, it should be highlighted the port authorities of Aveiro and Sevilla. Both port authorities were efficient when the group frontiers were used as references to compute efficiency. However, their efficiency scores decreased to 0.265 and 0.333 respectively when efficiency was computed with respect to the metafrontier. Similar results were found for port authorities specialised in the traffic of GC. Thus, for example, Alicante and

Bahía de Cádiz ports were no longer identified as efficient when the metafrontier was used as a reference point but they had very low scores of efficiency. In the case of the LB group, some port authorities decreased their efficiency scores when efficiency was calculated with respect to the metafrontier but they did it in a very moderate rate unlike SB and GC groups. These results evidenced that specialised ports′ performance evaluating on a common frontier is not comparable with those under different frontiers. Our findings illustrated that the metafrontier approach is needed to compare the performance of ports specialised in different traffics.

The assessment of the efficiency with respect to the group frontier (E^k) and to the metafrontier (E) was used to calculate the TGR by using Eq. (8). TGR measures how close each group is to the metafrontier, i.e., it enables technological differences in efficiency to be disentangled (Wang et al., 2013). An increase in the TGR involves a decrease in the gap between the group frontier and the metafrontier (Sala-Garrido et al., 2011). Table 3 shows the average TGR for each group of port authorities. Specifically, the group of port authorities specialisedwith high proportion of LB traffic has the highest TGR (0.914) which is a value close to the unity, i.e., the maximum value.

Figure 2 illustrates that 7 out of the 11 port authorities of this group have a TGR equal to one. This means that for these ports its group frontier coincides with the metafrontier. Conversely, the group of port authorities specialised in GC had the lowest TGR value (0.697). It indicates that this group of ports on average could save potentially 30.3% of its inputs if it were operated under the metafrontier rather than its group frontier. Figure 4 shows that 9 out of the 12 port authorities specialised in GC traffic had a TGR value lower than unity. This finding evidenced that the group frontier of GC port authorities is the farthest from the metafrontier. The results of our assessment evidence that port authorities specialised in the traffic of LB have the best performance compared with the other group of port authorities, followed by ports specialised in SB and GC.

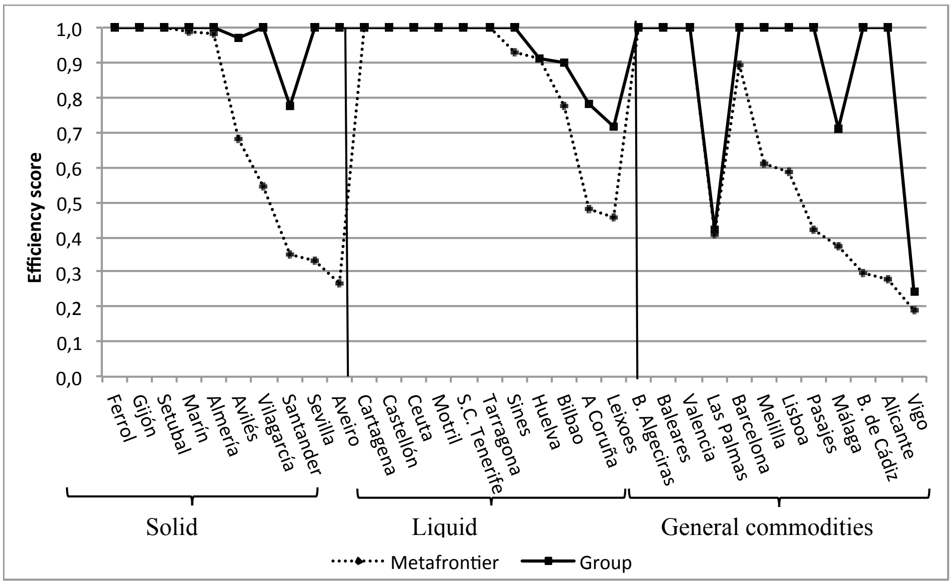

Figure 2. Group-k and metafrontier efficiency of the 33 port authorities grouped according its specialization: solid bulk, liquid bulk and general commodities.

These findings are consistent with those expected since liquid bulks transport has some special characteristics. Firstly, the vessels used for transporting LB are high tonnage ships whose holds have sealed tanks where liquid products are transported and this commodity must be downloaded in prepared port areas for its future refining or just wait for further distribution. Secondly, the main LB sold today is oil and its derivatives (gasoline, fuel oil, gas oil ...) followed by wine, spirits and beverages in bulk.

Therefore, the main port authorities specialised in this type of traffic have geographic proximity to heavy or refinery industries which supply those commodities.

For instance, thanks to the investment effort of Cartegena port authority, with the expansion of inner harbour of 'Escombreras' (finished in 2011), the surroundings of the port have been consolidated as a first rate energy centre (Cartagena Annual Report, 2013), attracting important investments, including Repsol's. The impact of the Repsol refinery in the Cartagena port authority and the economic development of the zone are amply proved with figures. Repsol generates 75% of liquid bulk traffic of the Port of Cartagena and, in 2014, more than 500 big oil tankers docked in Cartagena port authority carrying up to 21 million tons of crude (Opinión de Murcia, 2015).

Another efficient port authority, Castellon, increased its traffics over 12% in 2014 in relation to 2013 due to ceramics and petrochemical industry (Valencia económica, 2015). Castellon port authority has the first biodiesel plant in Europe and the first oil refinery of Valencia operates in West Dam berths of the port, what has meant a significant growth in liquid bulk traffics.

The port authority of Tarragona is also a good example of a port linked to chemist and hydrocarbons products. With the development of the petrochemical industry in the sixties, the port authority of Tarragona has been equipping itself with new adequate facilities for loading and unloading of petroleum products. In 2014, the expansion of the 'Chemistry dock' strengthened the port authority of Tarragona as one of the most important petrochemical platforms in southern Europe (http://www.porttarragona.cat).

In sum, it is said that liquid bulk traffic is usually a 'captive' traffic because it can hardly choose freely any port of the system. According to Artal (2002), a port enjoys a 'natural monopoly' that extends throughout its area of influence or hinterland. The magnitude of this 'captive traffic' will depend on various factors, such as geographical proximity to other ports, the degree of development of terrestrial infrastructure or degree of complementarity reached by different modes of transport.

The most efficient port authorities of our analysis (Cartagena, Castellón, Ceuta, Motril, S.C. Tenerife and Tarragona) are ports specialised in liquid bulk with little competition between them given the considerable geographical distance that separates them. This has enabled the creation of clearly defined areas of influence, with little overlap between them. Therefore, the development of each port has been closely linked to regional growth or its hinterland.

In this sense we can wonder if best equipped ports allow the development of their area of influence and invite the best investments or, by contrast, the progress of a certain industry, such as chemistry, enhances the closest ports. It seems a vicious circle, but the most efficient ports of our analysis are ports with significant investments, not only in their own installations but also in the complementary services for the treatment and transport of their commodities.

6. Conclusions

This paper proposes a metafrontier approach to compare for the first time the relative efficiency of 33 Iberian port authorities, depending on their specialisation or their relevance in the traffic of SB, LB and GC. Because their specialization, port authorities are not directly comparable since they are characterised by different production frontiers. It has been illustrated that efficiency scores of many ports differ if they are computed with respect to its group frontier or the metafrontier. Hence, it can be concluded that specialization of Iberian ports authorities affects their efficiency and metafrontier approach is needed to compare them.

As ports efficiency (together with other significant variables such as port charges, location, or seaport infrastructure) is a key factor to determine which ports are used. The most efficient ports should draw the most profitable investments or receive more funds from State Budgets. However, ignoring that port authorities are heterogeneous might lead to wrong conclusions. In this sense, the results of the investigation show that Aveiro and Sevilla, both classified as port authorities with high proportion of SB traffic, were completely efficient when the group frontiers was used to measure efficiency but they were poorly efficient when efficiency was computed with respect to the metafrontier. Ports users and investors should be aware that these ports authorities are a good reference in SB traffics. Something similar happens with port authorities specialised in the traffic of GC. For instance, Alicante and Bahía de Cádiz ports were no longer identified as efficient in the metafrontier analysis but they were reference units within the group of port authorities with high proportion of GC traffics. Then, it can be concluded that the specialization of Iberian ports authorities influences their efficiency and we need to use a metafrontier model, which compare units taking into account their heterogeneity, to avoid reaching misleading conclusions.

On the contrary, some port authorities had the same position when efficiency was computed using the individual group frontiers or the metafrontier as reference. From our findings, there were 12 Iberian port authorities (of the 33 analysed) that achieved the highest score within their own group and the metafrontier. 3 ports authorities (Ferrol-San Cibrao, Gijon and Setubal) are the best references within the ports with high proportion of SB traffic; 6 port authorities (Cartagena, Castellon, Ceuta, Motril, Santa Cruz de Tenerife and Tarragona) are the most efficient ports and the best references in ports with high proportion of LB traffic; and 3 ports authorities (Bahia de Algeciras, Baleares and Valencia) are the most efficient in GC traffic. These ports undoubtedly represent the best practices in the Iberian ports authorities and should be reinforced by private investors and public economic policies.

These results are corroborated by calculating TGR. It shows that the gap between the group frontier and the metafrotier is lower in the group of port authorities with high proportion of LB traffic. This result evidence that, in general terms, port authorities with predominance of LB traffic have the best performance compared with the other group of port authorities, followed by ports specialised in SB and GC.

A deeper analysis of the characteristics of the most efficient port authorities of this analysis (Cartagena, Castellón, Ceuta, Motril, S.C. Tenerife and Tarragona) reveals that they are port authorities specialised in LB, mainly oil and its derivatives, that have geographic proximity to heavy or refinery industries which supply those commodities. These ports development has been closely linked to their hinterland or regional expansion therefore, it can also be concluded that one of the keys of ports efficiency is investing not only in modern infrastructures but also in services and transport within their hinterland.

In addition to the conclusions and contributions of the paper made, we are aware of the limitations of this study. Firstly, DEA analysis is obviously sensitive to data variations. The study focused on 2013 data therefore, to generalise the conclusions, the assessment should be carried out in the next years. Secondly, DEA models are also sensitive to possible errors or uncertainties in the data. Although every input and output used in this investigation has been obtained by official Spanish and Portuguese statistics (from 2013), they are not free of possible errors. Hence, future research on this issue should involve the efficiency assessment of ports authorities applying alternative methods to deal with possible uncertainties and errors in data. In this context, the next step in this research will be identify the factors affecting efficiency scores. Following previous studies (Wanke and Barros, 2016), the bootstrapping technique proposed by Simar and Wilson (2007) will be applied. It allows computing bias-corrected efficiency scores and conducting truncated regression analysis to identify factors affecting efficiency scores.

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