# Transhipment: when movement matters in port efficiency

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**Abstract:** Container ports are leading actors in globalisation. They serve massed (increasingly larger ships) and planetary (organised in networks) logistics processes. There is evidence of a high relationship between containerised cargo and ports' performance. However, there is also a lack of literature regarding its sources. This paper uses frontier analysis techniques to investigate whether the type of activity (import/export, transhipment or cabotage) is crucial in explaining port efficiency. To this end, a two-stage procedure is proposed. In the first stage, the efficiency of ten Spanish ports specialised in container traffic is estimated by DEA techniques. In the second, the different types of container traffic activities are evaluated. Results suggested that port efficiency is: 1) highly related to the typology of containerisation activity; 2) through a non-linear form (inverted U-shape). Thus, ports that combine both *transhipment* and *import-export* activities outperform those specialised in one of these activities.

**Keywords:** efficiency, container ports, transhipment, import-export.

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**Biographical notes:** Fernando González-Laxe is a Professor at the University of A Coruña and Director of the University Institute of Maritime Studies. He has been president of the public entity 'Puertos del Estado' between 2009 and 2012. He has led numerous research projects in collaboration with companies and public bodies. Furthermore, he is the author of an extensive number of scientific publications in the field of maritime transportation.

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## 1 Introduction

### *1.1 Background*

In recent years, commercial dynamics have deepened the fragmentation of production, distribution and consumption processes. They rely on complex logistics systems and flexible networks that strengthen just-in-time and door-to-door transport.

The maritime markets have evolved to accommodate flexibility in maritime networks. As a result, the competitiveness, internationalisation and diversification levels have increased (Wang et al., 2003; Mengying et al., 2012; Yetkili et al., 2015). Companies in the current maritime business seek to satisfy their customers by improving services and quality (Bichou and Gray, 2004) while increasing productivity to attract new traffic and services. Thus, recent competition between logistics chains replaces shipping companies' old rivalries.

Technological advances and the globalisation of commercial networks have caused a very rapid growth of container traffic with various phases of development (Guerrero and Rodrigue, 2014). In the last phase of growth (exponential and global), logistics distribution systems based on hub and spoke structures and the gigantism of vessels were consolidated. As a result, Containerised maritime traffic doubled every ten years (1980–1990, 2000–2009, or 2005–2015), while the average size of the vessels doubled every 20 years (1960–1980, 1986–2006, or 2000–2020). In 2020, a maximum load capacity of 22,000 Teus was recorded, a far cry from the 1,500 Teus carried by the first container in the sixties of the last century. Other factors have been crucial in this process: the search for productivity, the growing inter-port competition, the development of regular shipping lines, the complexity of the equipment, the security conditions, the development of intermodality, the maritime alliances, and the automation of operations, are prominent examples.

The port concept has been radically revised in its operational, managerial, administrative and political form. It is no longer a simple interface between the maritime and land parts but a distribution centre and a service provider. Today's ports are levers for the economic development of territories. They participate in global logistics chains where productivity is obtained from time optimisation and cost reduction (Kavirathna et al., 2018; Alexandridis et al., 2018).

The ports of the 21st century are network ports (ports positioned in multi-port systems) that depend on the set of commercial, financial and distribution functions to sustain their activities (Kim et al., 2016). Thus, maritime routes, trade flows and vessel characteristics define the operation of today's ports where dedicated equipment, a qualified workforce, and an efficient organisation play an increasingly important role (Chang et al., 2008)

Port governance has had to adapt to this new context. It has gone from a central figure of institutional monopoly to a structurally fragmented form linked by new supply chains. The actors of the logistics chains have decided to increase their capacity and the speed of their responses proportionally. Rivalry does not occur, nor does it depend exclusively on the activities carried out in the infrastructures, but on their levels of participation in the transport chains. For example, shipping agents concentrate stopovers on specific terminals. The large ports respond by specialising in those indicators that allow them to accommodate new traffic and merchandise.

## *1.2 Transhipment ports*

In recent decades, the intense expansion of international trade stimulated new production processes in which efficiency played a relevant role. One of them is transhipment, which consists of the transfer of containers between shipments with an intermediary dock

Transhipment activities are present in most maritime routes, being one of the fastest-growing activities among container traffic. Thus, transhipment activities have gone from 11.1% of container traffic in 1980 to 28.6% in 2012 (equivalent to 174.6 million TEUs) (Drewry, 2015). Transhipment activities grow hand in hand with vessels' size and maritime services' coverage. Large transoceanic shipping companies use the flexibility and modulation provided by the container to reorganise and restructure the marine networks. The old traditional port-to-port routes are replaced by mesh articulated around interconnection platforms.

The large transoceanic ship owners initiated the transhipment. They sought to serve and connect highly competitive economic areas through services with lower costs and less time. Thus, they gave rise to the concept of networks (hub and spoke, from the 80s). Maersk initiates this dynamic in the Hong Kong port, followed by the ports of Algeciras and Dubai (Frémont, 2007). The main transhipment ports are located on the circum-equatorial routes: the Caribbean, the North Atlantic, the Mediterranean, the Arabian Sea, and the South China Sea.

Four categories can be distinguished in ports specialised in transhipment. First are ports that function as hubs in the Star-shaped network (hub and spoke), where containers are exchanged between mother ships and feeders. Second are ports that are part of relay networks, where containers are exchanged between ships deployed along different coastal routes. Third are ports that provide interlining services, where containers are exchanged between ships that perform ocean lines on parallel maritime services. Finally, ports that provide intra-regional traffic services.

The operation of a transhipment port is linked to five aspects:

- a The relative position. Centrality (McCalla, 2008) and intermediacy are fundamental (Fleming and Hayuth, 1994). The proximity to the main routes and the situation arising from the intersections of the longitudinal and latitudinal routes.
- b The secondary connections. The relationship with second-level ports is important (Notteboom et al., 2019). Flows with the hinterland and inter-modality must also be considered.
- c The transit times. Time is a crucial factor in transportation. It seeks to avoid delays, additional costs of operations, and unproductivity.

d The massification of flows. It is crucial to guarantee a high volume of traffic (Chou, 2010) and frequencies (Rodrigue and Notteboom, 2013) of globalised services.

e The cost of operations. Transhipment ports seek to be cost-competitive. The size of the vessels (Wu and Lin, 2015), the frequencies, the volumes of traffic (Imai et al., 2009), and the conditions of the infrastructures and equipment (Bae et al., 2013) contribute to cost competitiveness.

Chang et al. (2008) add three fundamental factors in a transhipment port:

a availability of equipment

b availability of skilled labour

c the efficient organisation of internal flows.

The factors above indicated seem to have been decisive in the growth of ports such as Singapore (Tongzon, 2005), Tanjung Pelepas (Paul, 2005), Kaohsiung, Dubai, Port Lang, Giaio Tauro, Algeciras, Jeddah, Panama, or Salaalah, among others.

**Table 1** Strengths and limitations of direct maritime services and transhipment services

| *Service types* | *Service strengths* | *Service limitations* |
|---|---|---|
| Direct maritime services | Beneficial in extensive maritime routes with large volumes of goods | Geographic and economic coverage |
| | Better transit-time | Traffic capacity, adjusted to regular lines |
| | Non-complex organisation | Lack of flexibility in a transport network |
| Transhipment services | It allows economies of scale and density | Dependence on the countries' port policies |
| | Boost the multiplicity of destinations | Need for large storage areas (effect on the cost of transit) |
| | It facilitates the flexibility of the transport network | Its success depends on the great maritime routes. |
| | It allows the operational development of vessels of different sizes | Dependence on intermodality and efficiency |
| | | It requires a complex organisation |

*Source:* Self-elaboration

Table 1 presents the main strengths and limitations of direct maritime services and transshipment services.

Transhipment activities have three fundamental advantages: economies of scale, lower unit costs, and accommodation to intermodal networks. Table 2 contextualises the advantages of transhipment for the business agents involved.

During the last decades of the 20th century and the first decades of the 21st, new countries joined the globalisation of international trade, which produced continuous modifications and adjustments in the maritime routes. Thus, global supply chains were born. International logistics interfaces were implemented while the pressure to reduce obstacles and border frictions increased.

**Table 2** Advantages of transhipment by business area

| *Area* | *Advantage* |
|---|---|
| Ship-owners | Better tariff conditions compared to competing ports |
| | Increase in successive direct port-to-port transports |
| | It improved transit times |
| Port authorities | Increasing the number of operations |
| | Despite the cost obtaining direct and indirect advantages (services, agencies, coordination) |
| Shippers | Improved quality/cost ratio |
| | Reduction of unproductive times and stock movements |
| | More efficient execution of transport contracts |

*Source:* Self-elaboration

## *1.3 The Spanish port system*

Spanish ports have experienced a very intense process of containerisation in recent years that responds to three global dynamics:

a strengthening of the trans-Pacific and East-West maritime routes

b increases in the size of container ships

c new port hierarchy determined increases by the selection of stopovers in specific ports.

These dynamics pose new challenges for ports. On the one hand, they must confront maritime gigantism; therefore, the ability to accommodate larger ships in their docks becomes a discriminating element. On the other hand, the ports must face market supply/demand adjustments and the oversupply of shipping companies.

The containerisation process has led to three critical changes in the Spanish port system. First, strengthening the leading ports (Valencia, Algeciras and Barcelona) in contrast to the rest (focused on meeting the needs of its hinterland). Second, a higher level of specialisation in traffic and routes. Dependence on international connections leads to port specialisation in container traffic (import/export, transhipment or cabotage). Third, the ability to insert into global supply chains defines the terminal type (national or international). With this, certain ports increase maritime connectivity, a fundamental element that supports their growth.

High heterogeneity characterises the Spanish port system (Fernández et al., 2021). This heterogeneity is reflected geographically. The Mediterranean arc ports have better connectivity with international routes and a more significant presence of multinational operators. Therefore, the largest level of container traffic is concentrated in them. The Cantabrian Sea and Galicia ports register lower cargo volumes and are highly dependent on the bilateral trade of companies located in the hinterland. Canarian ports have unique characteristics. They provide transhipment services to certain multinational companies. In addition, they maintain direct services of regular nature (intra-island, national or to Africa).

### 1.4 Motivation and contribution from the study

Studies of container port efficiency have grown in the transportation literature (Table A in Appendix reviews recent applications of container port efficiency estimations). However, the effect of the new dynamics of containerisation on port efficiency is a question that needs further study in the scientific literature. Studying the impact of new containerisation typologies on port efficiency will allow port managers to make decisions related to the strategic design of the port's output mix, future investments, or commercial policy. This is crucial in the case of Spanish ports for two reasons. First, port regulation encourages port authorities to improve efficiency levels to fulfil their profitability requirements. Second, the Spanish ports' peripheral location, close to the main transoceanic routes, allows them to compete for being centres of maritime transit and distribution of goods from southern Europe and West Africa.

The contributions of this study lie in three aspects: First, it analyses, for the first time in maritime literature, the relationship between the typology of containerisation activities (import/export, transhipment or cabotage) and the port efficiency. Second, it considers that the effect of containerisation activities on the port performance may not be linear. Third, it presents empirical results that can be useful for strategic decision-making by Port Administrators and Public Authorities.

The structure of the paper is as follows: Section 1 focuses on the background, a discussion of the transhipment ports and the objectives, motivation, and structure of the article. Section 2 presents the methodology and data and describes the research design. Section 3 compiles the results and discussion, and Section 4 concludes the study.

## 2 Methodology and data

### 2.1 DEA methodology

Based on linear programming and following the principles of the production theory, DEA is a mathematical programming technique that allows measuring a company's performance in an industry to the efficiency frontier set by the dominant companies in the industry. To determine efficiency, DEA provides a benchmark (frontier) against which competitors can establish areas of 'best practices' related to high-performance measures.

DEA analysis has been used to estimate production, costs, and profit frontiers, providing measures of comparative efficiency for a set of similar organisational units (DMUs) in an industry. A DMU can be operating either on or within the frontier, with the distance to the border revealing inefficiency (Sexton et al., 1986; Mantri, 2008). Farrell (1957) introduced the first naïve method of single output/single input efficiency measure. Charnes et al. (1978) developed a non-parametric approach (CCR-DEA model) for determining the relative performance (under constant returns to scale) of a set of similar organisational units (DMUs) by using sets of inputs and outputs. Banker et al. (1984) added a convexity constraint to the model (variable returns to scale), which allows estimating the efficiency that arises from optimal management practices and is known as pure technical efficiency (PTE).

The first naïve understanding of DEA method offered by Charnes et al. (1978) includes cost per unit, profit per unit, satisfaction per unit, and so on, which are measures stated in the form of the following ratio:

$$\frac{Output}{Input} \tag{1}$$

Which can be expressed mathematically as:

$$\max_{v,u} \theta = \frac{u_1 y_1 + u_2 y_2 + \cdots + u_s y_s}{v_1 x_1 + v_2 x_2 + \cdots + v_m x_m} \tag{2}$$

where $\theta$ is the efficiency score (value ranges between zero and one), $x$, $y$ are inputs and outputs. $u$, $v$ are the weights to be calculated to reach the maximum fraction value, and $s$, $m$ are the numbers of outputs and inputs.

Depending on the interest of the analysis, the DEA can be identified as an input- or output-oriented model. An objective of the input-oriented DEA model is to maximise the ratio of virtual output to virtual input while keeping the proportions for all the DMUs not more than one[1]. For example, the CCR-DEA input-oriented in envelopment form (sometimes referred to as the Farrell model) is:

$$Min\theta \tag{3}$$

subject to

$$\sum_{k=1}^{K} x_{nk} \lambda_k \le \theta x_{no}, \quad n = 1,, \cdots\cdots, N$$

$$\sum_{k=1}^{K} y_{mk} \lambda_k \ge y_{mo}, \quad m = 1,, \cdots\cdots, M$$

$$\lambda_k \ge 0, \qquad k = 1, \cdots \ \cdots, K$$

where $\theta$ is the DMU overall efficiency (OTE) score, $K$ is the number of DMUs in the dataset; $N$ is the number of inputs; $M$ is the number of outputs; $y_{mk}$ and $x_{nk}$ are positive outputs and inputs of the $k$-th DMU. A *DMU* is called CCR efficient if its objective value in the form (3) equals unity. Model (3) maintains a close relationship with the input distance function.

By adding to (1) a constraint of convexity $\left( \sum_{j=1}^{n} \lambda_j = 1 \right)$, the technical efficiency under variables returns to scale (PTE) is obtained (Banker et al., 1984). The scale efficiency (SE) is obtained by comparing OTE scores and PTE scores (Coelli et al., 2005).

The DEA methodology has strengths and limitations. As Nurmatov et al. (2020) pointed out, the main strength of the DEA is its objectivity. DEA does not require a priori weights for the variables. In addition, the DEA methodology can easily handle multiple inputs and outputs and does not require an explicit functional form linking inputs to outputs. The main limitation of DEA is that it can overlook environmental factors and statistical noise. In addition, DEA is an extreme point technique and therefore is very sensitive to errors in the measurement or recording of data.

### 2.2 Regression analysis (Simar and Wilson, 2007)

The characteristics (variables not included in the DEA analysis) of the environment (traffic typology or traffic specialisation model) in which the port production process takes place can explain the underperformance of the Ports Authorities under analysis. In DEA literature, it is common to use regression analysis as a second stage to evaluate the factors that determine the efficiency of a sector. (Simar and Wilson, 2008). In this research, the smoothing homogeneous bootstrap approach (Simar and Wilson, 2007) has been applied since it allows a more accurate inference in the regression analysis. Simar and Wilson (2007) describe a data-generating process under which two-step methods are consistent. Following the Simar and Wilson (2007) approach, the paper assumes and tests the following regression specification:

$$\theta_j = a + z_j\delta + \varepsilon_j \tag{4}$$

which can be understood as the first-order approximation of the unknown genuine relationship. In equation (4), a is the constant term, $z_j$ is a (row) vector of observation-specific variables for $DMU_j$ that are expected to be related to the DMU's (overall, pure and scale) efficiency set, $\theta_j$ $\varepsilon_j$ is the error term. In this study, the (4) expression is estimated by maximising the corresponding likelihood function concerning $\delta$ parameters and the variance of the error term. Algorithm#2 from Simar and Wilson (2007) is applied.

The main objective of this paper is to evaluate the relationship between the typological characteristics of container traffic in a port and its efficiency level. However, as they demonstrated (Fernández et al., 2021), the relationships between efficiency and containerisation may not be linear. Therefore, two variables have been included as external factors on the regression analysis to analyse the influence of the containerised traffic typology on port efficiency. Thus, the level of *specialisation in transhipment traffic* and *specialisation in import-export traffic* have been included as z-variables.

### 2.3 Data

Within the state-owned ports (classified as of general interest in Royal Legislative Decree 2/2011, September 5th) there are 46 ports managed by 28 Port Authorities. As mentioned in Section 3, there is a high degree of geographical and traffic heterogeneity within the Spanish port system.

In the last five years, ten Spanish ports have had at least a 25% containerisation ratio (containerised traffic to total traffic). Those ports are Valencia, Vigo, B.Algeciras, Las Palmas, Barcelona, Alicante, Marín, S.C.Tenerife, Villagarcía and Malaga. There is also a high relationship between transhipment ports with the existence of free zones.

Table 3 shows the specialisation of Spanish container ports by type of traffic. Analysing the data from our sample, we can see that B. Algeciras, Málaga, Las Palmas and Valencia present a high degree of specialisation in Transshipments within the container operation. In the case of Import-Export, the ports of Vigo, Marín, and Barcelona lead the Ranking. The other ports (Villagarcía and Alicante) have a Cabotage traffic specialisation.

The final sample of research work is a balanced panel of data from 10 port authorities over thirteen years (2007–2019). The database has been built from the management reports published by the state ports and the port authorities' annual reports and statistical information.

**Table 3** Specialisation in container traffic in Spanish ports

| *Port* | *Transhipment (% of TEUS)* | *Import-export (% of TEUS)* | *Cabotage (% of TEUS)* |
|---|---|---|---|
| Alicante | 0.85% | 13.73% | 85.41% |
| B.Algeciras | 91.84% | 7.89% | 0.27% |
| Barcelona | 29.73% | 60.10% | 10.17% |
| Las Palmas | 57.91% | 7.64% | 34.45% |
| Málaga | 77.66% | 12.73% | 9.61% |
| Marin | 7.29% | 60.32% | 32.38% |
| S.C.Tenerife | 4.79% | 11.35% | 83.89% |
| Valencia | 50.55% | 45.48% | 3.97% |
| Vigo | 3.52% | 76.99% | 19.50% |
| Vilagarcia | 0.80% | 15.28% | 83.92% |

*Source:* Own elaboration based on Puertos del Estado

**Table 4** Definition and descriptive statistics of the variables in the model

| | *Variables* | *Definition and units*[2] |
|---|---|---|
| Outputs | Container traffic | The total amount of container cargo in Thousands of tons |
| | Non-containerised traffic | The total amount of non-container cargo in Thousands of tons |
| | Turnover | Operating income in Thousand of 2010 Eur |
| | Labour | Number of employees |
| | Container dock length | Container dock length in metres |
| Inputs | Non-container dock length | Length in metres of the rest of the piers |
| | Intermediate consumption | Other operating expenses in Thousands of 2010 Eur |

| | | *Mean* | *Stand. dev.* | *Min.* | *Max.* |
|---|---|---|---|---|---|
| Outputs | Container traffic | 14,519.15 | 19,751.25 | 0.06 | 64,283.31 |
| | Non-containerised traffic | 3,525.43 | 3,732.26 | 122.59 | 14,085.94 |
| | Turnover | 52,402.02 | 49,703.14 | 4,138.13 | 163,599.4 |
| Inputs | Labour | 254.89 | 146.79 | 65.27 | 567.00 |
| | Container dock length | 2,793.06 | 2,077.97 | 406.00 | 7,861.00 |
| | Non-container dock length | 10,769.00 | 6,135.30 | 2,131.00 | 21,049.00 |
| | Intermediate consumption | 11,771.71 | 11,000.63 | 595.47 | 42,634.57 |

*Source:* Own elaboration

The choice of the input and output variables is crucial in the port efficiency analysis. This selection should reflect the port sector's multi-productive nature and technological heterogeneity. Therefore, variables related to the main productive factors (capital, labour and intermediate consumption) and the multi-production process of the ports have been considered. Finally, As the input vector (x), four variables have been considered (length of the container dock, length of docks for other loads, number of workers, and spending on intermediate goods), and the output vector three variables (containerised traffic, non-containerised traffic and turnover). Similar variables have previously been used in the literature to estimate port efficiency. Among others, they are Coto-Millan et al. (2000), Itoh (2002), Wang et al. (2003), Cullinane et al. (2005), Cullinane and Song (2006), Wu and Goh (2010), Coto-Millan et al. (2016).

As previously stated, the relationship between port efficiency levels and containerisation typology is studied in a second stage. To this end, two variables that refer to specialisation in international transit traffic (*transhipments*) and import-export traffic (*import_export*) have been included in the analysis for each port *i* and each year *t*.

$$transhipements_{it} = \left( \frac{Internationaltransit\ traffic\ (TEUS)_{it}}{Containerized\ traffic\ (TEUS)_{it}} \right) x100 \quad (5)$$

$$import\_export_{it} = \left( \frac{import - export\ traffic\ (TEUS)_{it}}{Containerizedtraffic(TEUS)_{it}} \right) x100 \quad (6)$$

Para concluir con la sección, la tabla 4 presenta un resumen de los estadísticos descriptivos y una breve definición de las variables input y output consideradas en este análisis.

## 3 Results

The DEA approach was used to estimate the levels of SE, PTE, and Overall Technical Efficiency (OTE) of Spanish ports specialised in container traffic. The OTE, PTE, and SE scores are relative measures ranging from zero (inefficient) to one (efficient). Table 5 displays OTE's efficiency scores (2007–2019). The ports reaching the high-efficiency levels are B. Algeciras, Barcelona and Valencia. However, the results also show that only two ports (B. Algeciras and Barcelona) remain at the SE frontier throughout the entire period. Furthermore, the average technical efficiency score is 0.65, which is dragged down by the low efficiency levels of most smaller ports.

The main objective of this work is to delve into the causes of efficiency in ports specialised in container traffic. In this sense, it is interesting to analyse the relationship between the typology of container traffic (*transhipment, import-export* and *cabotage*) and the levels of port efficiency. Furthermore, it must be taken into account that the nature of this relationship does not have to be linear (Fernández et al., 2021). With the above in mind, the model in equation (7) has been estimated.

$$\begin{aligned} \theta_i = \beta_0 + \beta_1 transshipmen_{it} + \beta_2 transshipmen_{it}^2 \\ + \beta_3 import\_export_{it} + \beta_4 import\_export_{it}^2 + e_i \end{aligned} \quad (7)$$

where $\beta_0$, $\beta_1$, $\beta_2$, $\beta_3$ and $\beta_4$ are parameters to estimate. Additionally, the squares of the *transshipmen* and *import_export* variables are included to capture non-linear relationships between efficiency and the typology of containerised traffic. Finally, the variable $\theta_j$ represents the efficiency scores estimated in the DEA analysis. That is:

$$\theta_1 = \textit{overall technical efficiency } (OTE)$$

$$\theta_2 = \textit{pure technical efficiency } (PTE)$$

$$\theta_3 = \textit{scale efficiency } (SE)$$

To overthrow the potential issue of biased results in the second-stage analysis, the present study applies the smoothing homogeneous bootstrap approach with 2000 iterations (Simar and Wilson, 2008).

**Table 5** Average scores for the efficiency in airports ranked by overall technical efficiency

| *Port authority* | *Overall technical efficiency – OTE* | *Pure technical efficiency – PTE* | *Scale efficiency – SE* |
|---|---|---|---|
| B. Algeciras | 0.98 | 0.99 | 1.00 |
| Barcelona | 0.98 | 0.98 | 1.00 |
| Valencia | 0.98 | 1.00 | 0.98 |
| Las Palmas | 0.71 | 0.78 | 0.91 |
| S.C. Tenerife | 0.60 | 0.73 | 0.82 |
| Marin | 0.59 | 0.97 | 0.61 |
| Vilagarcia | 0.49 | 0.99 | 0.49 |
| Vigo | 0.42 | 0.56 | 0.74 |
| Alicante | 0.40 | 0.73 | 0.55 |
| Málaga | 0.39 | 0.56 | 0.69 |

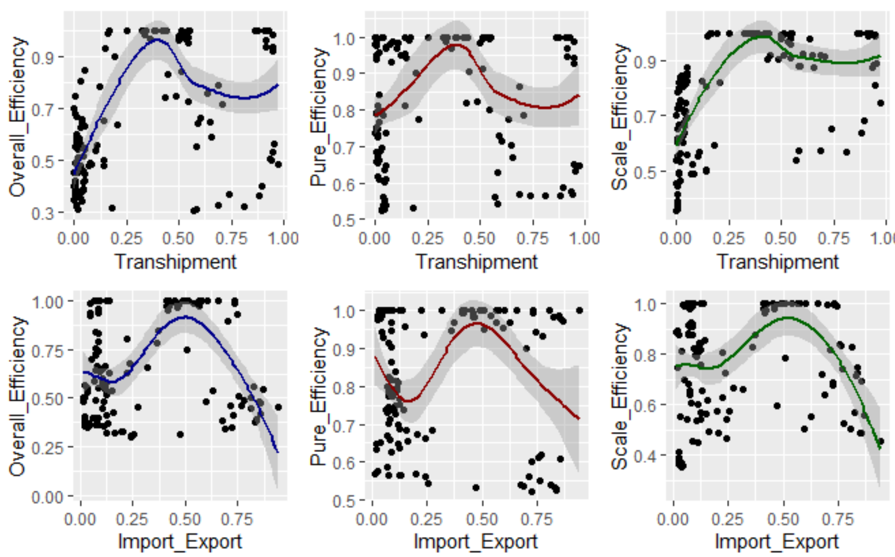
**Table 6** Parameter estimates for the Simar and Wilson regression model

| *Explanatory factors* | *Overall technical efficiency – OTE-(z-statistic)* | *Pure technical efficiency -PTE-(z-statistic)* | *Scale efficiency – SE(z-statistic)* |
|---|---|---|---|
| Transhipment | 1.088*** | 0.716 | 1.410*** |
| | 3.71 | 1.24 | 3.38 |
| Transhipment$^2$ | –1.854*** | –1.861 | –2.010*** |
| | –2.77 | –1.42 | –2.14 |
| Import-Export | 1.163*** | 0.001 | 1.133*** |
| | 3.04 | 0.00 | 2.55 |
| Import-Export$^2$ | –2.590*** | –0.273 | –2.412*** |
| | –3.03 | –0.18 | –2.44 |
| Constant | 0.358*** | 0.900 | 0.502*** |
| | 6.90 | 6.65 | 9.41 |

Notes: ***, **, and *: Below the 1%, 5% and 10% statistical significance thresholds, respectively. Wald chi2 (df = 2): 38.21 (p-value of 0.0000), 3.32 (p-value of 0.5059), 35.96 (p-value of 0.0000).

Table 6 shows the results of the estimation taking the overall (OTE), pure (PTE) and SE as dependent variables and *inport_export* and *transhipment* as explanatory variables. The truncated regression with a bootstrap model perfectly fits the data to explain OTE and SE variables[3], with explanatory variables statistically significant. Furthermore, parameters with positive signs reveal a positive interrelationship between the corresponding environmental variable and the dependent variable.

**Figure 1** Relationship between types of efficiency and types of containerisation (see online version for colours)




The variables *transhipment* and *import_export* are highly significant in explaining the OTE and SE of the Spanish container ports. Furthermore, the transhipment and import_export variables' first-order parameters are positive, whereas the second-order coefficient presents a negative sign. These results indicate, in both cases, an inverted-U shape relationship with the efficiency level. Thus, medium levels of specialisation in both types of container traffic are preferred to extreme levels.

There is a high relationship between specialisation in international transhipment, import-export traffics and optimal efficiency levels. This relationship also seems closely related to achieving the optimal size of operation (scale effects). It is recalled that a port is scale-efficient when its size of operation is optimal (Fare et al., 1993). Conversely, its efficiency will decrease if its size is reduced or increased. This result is in line with Asgari et al. (2013) and Andreou et al. (2014), who state that the success of a transhipment port lies in the efficient management of operations and services.

Figure 1 shows the relationship between types of efficiency and types of containerisation. Through Figure 1, it is possible to observe, graphically, the relationship between the type of container traffic and the levels of OTE, PTE and SE. The patterns in Figure 1 confirm the model's results (Table 6). In addition, it should be noted by the signs of the model and the graphic form (Figure 1) that the relationship between PTE and the typology of container traffic follows a similar pattern (inverted U-shape). However, the lack of significance in this model variables does not allow this statement to be generalised.

## 4 Conclusions

Maritime transport is the primary channel through which international trade takes place. It represents 84% of the weight and 70% of the value of world trade. As a result, ports have become the backbone of global logistics and supply chains. Moreover, they are the leading players in complex communication systems connecting places and agents and generating added transport value.

There is no doubt that containerisation has brought about the most significant technological change affecting seaports in recent times. Consequently, world port leadership is at stake in the field of containerisation. However, the impact of this phenomenon on ports' performance has not been studied deeply enough in the scientific literature. This work aims to contribute to maritime literature by analysing the relationship between the typology of containerisation activities (import/export, transhipment or cabotage) and obtaining port efficiency. To this end, a frontier analysis methodology based on the two-stage DEA is applied to a panel of data from 10 Spanish Ports over the 2007 to 2019 period. In the first stage, the efficiency scores are obtained. In the second stage, using the Simar and Wilson (2007) approach, the relationship between the type of containerisation activities and the efficiency levels of the ports is evaluated.

Results suggest a high relationship between specialisation in transhipment and overall and SE levels. A similar pattern is observed for import-export activities, in contrast to cabotage activities. It is also observed that the relationship between the typology of containerisation activity and port efficiency does not follow a linear pattern but an inverted-U shape. Thus, medium levels of specialisation in both types of container traffic are preferred to extreme levels.

Within the container ports of the Spanish port system, it is observed that the leading ports (Algeciras, Barcelona and Valencia) obtain the best efficiency levels. The difference in efficiency levels with the other ports is very noticeable. Canarian ports are in a second group in the efficiency ranking. It is evident that size and geographical position are closely related to efficiency. The Mediterranean arc ports have better connectivity with international routes and a more significant presence of multinational operators. Larger ports with more calls and larger ships show better performance and connectivity indicators. Concentrating cargo in fewer ports allows a smaller number of companies to obtain competitive advantages, generating economies of scale and cost savings. In addition, the dynamics of strengthening business alliances are accelerating (Crotti et al., 2020). The Canarian ports' particular geographical characteristics allow them to provide transhipment services to certain multinational companies.

As in any research, our study has its limitations. This study does not include the effect of the COVID-19 crisis. During the COVID-19 pandemic, terminal operators faced new challenges arising from changes in maritime supply chains, both in the foreland and hinterland. Some supply chains were interrupted or operated with reduced cargo volumes. In others, cargo volumes increased. These changes influenced both the size and the structure of port traffic.

As Lam and Su (2015) point out, the function of seaports is to constitute a point of connection. Consequently, an interruption in port operations could cause a knock-on effect throughout the supply chain. These effects are being confirmed by various studies in the scientific literature (for example, Notteboom and Haralambides, 2020; Zhang et al., 2020). However, the study of the sensitivity of the world economy to global supply chains should occupy a prominent place in scientific literature. Supply chains are transformed hand in hand with consumption and spending habits. The patterns of globalisation are called into question. Resilience is a rising value, as is the global sustainability and low-carbon agenda.

In this context, the ports of the 21st century operate in a highly changing and competitive market. With supply chain disruptions and reduced demand, shipping companies and port terminals are changing their commercial strategies. In addition, paradigm changes (concerning risk management) force maritime transport to adapt to new organisational forms and develop measures to ensure sustainability (Verschuur et al., 2020; Notteboom et al., 2021)

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## Notes

1 Spanish Port Authorities operate in a regulated sector. The authors consider that the Port Authorities have more power to control the level of inputs, adapting it to a level of output given by the economic situation of the area where they operate.

2 Variables' definition comes directly from the sources of data (annual reports of Puertos del Estado and port authorities)

3 In the case of PTE, the hypothesis that all slope coefficients are zero is accepted (p-value of 0.5059).

## Appendix

**Table A1** Studies of efficiency in container ports

| *Authors* | *Methodol ogy* | *Sample* | *Factors and their impact on efficiency* |
|---|---|---|---|
| Culliname et al. (2002) | SFA | 15 container ports in Asia (1993–1998) | Port size: positive effect<br>Privatisation: positive effect |
| Culliname and Wang (2005) | DEA | 30 container ports worldwide (1992–1999) | Ownership: privatisation does not increases efficiency |
| Culliname and Song (2006) | SFA | 74 European container terminals in 2002 | UK ports have the most efficient infrastructure usage |
| Liu et al. (2008) | DEA-MPI | 45 China container terminal (2004–2005) | Largest ports are more efficient |
| Trujillo (2008) | SFA (distance function) | 9 Spanish port authorities (1990–2002) | Ports reforms: no significant effect |
| Cheon et al. (2010) | DEA-MPI | 98 major container ports worldwide (1991–2004) | Ownership restructuring contributed to total factor productivity gains |
| Wu and Goh (2010) | DEA | 21 container ports worldwide in 2005 | None of the ports in the advanced markets are role models for the field |
| Bichou (2011) | DEA | 10 international terminals (2002–2008) | Variations in operating conditions highly impact the terminal efficiency |
| Rodríguez-Álvarez and Tovar (2012) | SFA (cost) | 26 Spanish port authorities (1993–2007) | Positive effect of mechanisation |

Notes: SFA = stochastic frontier analysis; DEA = data envelopment analysis; MPI = Malmquist productivity index.

**Table A1** Studies of efficiency in container ports (continued)

| *Authors* | *Methodology* | *Sample* | *Factors and their impact on efficiency* |
|---|---|---|---|
| Yuen et al. (2013) | DEA | 21 Asian container terminals (2003–2007) | Ownership: no effect<br>Hinterland population: negative effect<br>Intra-port competition: positive effect<br>Inter-port competition: negative effect |
| Schøyen and Odeck (2013) | DEA | 24 Norwegian container ports (2002–2008) | Port size: positive effect |
| Wan et al. (2014) | DEA | 13 US container ports (2000–2009) | On-dock rail facility at container terminals has a negative impact on efficiency |
| Almawsheki and Shah (2016) | DEA | 19 container terminals in the Middle Eastern region (2012) | Jebel Ali, Salalah and Beirut container terminals are the most efficient terminals |
| Perez et al. (2016) | SFA (Production) | 40 Latin American container terminals | Transhipment ports are less efficient than other type of ports |
| Serebrisky et al. (2016) | SFA (Production) | 63 container ports in Latin America and the Caribbean (1999–2009) | Positive effect of privatisation on port efficiency |
| Suárez-Alemán et al. (2016) | SFA | 203 container ports in developing countries (2000–2010) | Positive effect of private sector participation, reduction of corruption, connectivity and the existence of multimodal links |
| López-Bermúdez et al. (2017) | SFA-MPI | 20 container terminals in Brazilian ports (2008 to 2017) | Private terminal operators are more efficient |
| Schøyen and Odeck (2017) | DEA-MPI | 20 UK and Nordic countries container ports (2009–2014) | Norwegian ports perform better than their international counterparts |
| Chen et al. (2018) | Meta-Frontier-SFA | 35 international container ports (2004–2011) | Asia-Pacific group outperforms the Europe/America group in output efficiency for throughput and input efficiency for ship-to-shore cranes and trucks |
| Nguyen et al. (2020) | DEA | 10 container ports in Southeast Asia (2007–2017) | Tendency towards de-concentration<br>Ports gaining market share are 'inefficient' |

Notes: SFA = stochastic frontier analysis; DEA = data envelopment analysis; MPI = Malmquist productivity index.

**Table A1** Studies of efficiency in container ports (continued)

| *Authors* | *Methodology* | *Sample* | *Factors and their impact on efficiency* |
|---|---|---|---|
| Fernández et al. (2021) | Meta-frontier DEA | 26 Spanish port authorities (1993–2012) | Specialisation in container traffic is beneficial for medium-high-complexity ports |
| Iyer and Nanyam (2021) | DEA-MPI | 26 container terminals in India (2015–2018) | The efficiency major ports is on a declining path when compared with minor ports |

Notes: SFA = stochastic frontier analysis; DEA = data envelopment analysis;
MPI = Malmquist productivity index.