Reforms and Infrastructure Efficiency in Spain's Container Ports *

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Abstract

This paper quantifies the evolution of technical efficiency in port infrastructure service provision in the major Spanish port authorities involved in container traffic. The paper also analyzes the extent to which port reforms that took place in the 1990's had an impact on the efficiency of the Spanish container ports. Because of the multi-output nature of port activities, we have estimated a distance function, which is a novel methodology in the study of the port industry. The results show that the reforms resulted in significant improvements in technological change, but that technical efficiency has in fact changed little on average. However, there is a significant movement of the efficiency within ports over time as a result of these reforms.

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1 Introduction

The port sector has probably not received the attention it deserves from economists. In spite of this, there is a long history of highly specialized research on the sector, which has increased over time the coverage of the analysis. Economic studies of the sector date from the 1960's and focus on aspects such as pricing port facilities, port capacity and investment policies (Goss, 1967 and Heggie, 1974). During the following decades, the first manuals on port economics appeared (Peston and Rees, 1971, Bennathan and Walters, 1979, Jansson and Shnneerson, 1982). At about the same time the literature on ports broadened and started to deal with different aspects of the port industry: infrastructure, productivity and determining factors, investment and planning, costs and economies of scale, privatization of ports, promotion of port competition, port selection criteria, etc. The literature on efficiency and productivity of the port industry may be the latest topic of interest among the specialists since the second half of the 1990s. It is relatively new and modest, particularly if we compare it with similar studies carried out for other public services (electricity, water, banking, health, education, agriculture, etc.), including other transport modes.

One of the reasons for the most recent developments is the fact that ports consist of an interesting research case with many structural changes, both technical and policy, which have transformed the business. In recent decades maritime transport has indeed undergone important transformations with the increase of ship size and the development of containerized cargo transport. These changes forced ports to grow accordingly to meet the new needs arising from the larger number of containers handled by ships. However, not all ports have been able to increase both their mooring and storage capacity. Consequently, a substantial improvement of port operations efficiency has been required for a large number of ports. These concerns have emerged in Spain and has in many other countries, justifying a wave of reforms during the 1990s.

The main purpose of this paper is to quantify the evolution of technical efficiency in port infrastructure service provision in the major Spanish ports involved in container traffic. The analysis focuses on container traffic for the following reasons. First, container traffic promotes the integration of different transport modes. Containers are not a type of merchandise but a way of packing goods. They are boxes of a standard size which facilitates loading and unloading them as well as carrying them to other transport modes. The second reason is that the use of containers is still booming. If in Spain during 1992-2002, the accumulated growth rate of non-containerized merchandise was 3.5% p.a., containers grew 11.2% p.a. The third reason lies with the fact that container handling requires specific infrastructure (area, mechanical devices, etc.) for which a large amount of public funds is devoted every year: in 2002, 64% of total investment in Spanish ports was devoted to finance infrastructure works (60% of the investments in infrastructure were carried out in the ports analyzed in this paper). Finally, it is a generalized opinion among researchers that the development of containers also carries a substantial improvement to port efficiency. For instance, Kim and Sachis (1986) show that 85% of the increase in total factor productivity of Ashod Port (Israel, 1966-1983) is driven by containerization.

The second objective of the paper is to analyze the impact of port reforms carried out in the 1990's. The first and most important one took place at the end of 1992. It was characterized by the development of new management procedures and organization structures and its main objective was to decentralize the system and reinforce the autonomy of port authorities. In 1997, a second reform took place and emphasized the autonomy of port authorities, regulated the participation of the Regional Government in the structure and organization of ports and encouraged the participation of the private sector in port activities.

To assess the operators' efficiency, it is necessary to account for all factors that may place some of them in a favorable situation independently of any action they may take. If these factors are not included in the analysis, the efficiency estimated is biased. To avoid such biases, we model explicitly two main sources of differences between ports: (i) mainland vs. islands (i.e. ports subject to more competition vs. ports benefiting from captive shippers), (ii) the presence of refineries in some ports (which increases the importance of a specific type of traffic and increases the total traffic volume figures somewhat artificially for those ports).

Methodologically, the paper relies on a distance function in a multi-output port context and a new database covering the 1990-2002 period. Despite the fact that the multi-output nature of port industry has been treated in the studies applying DEA, there is no background of multi-output parametric applications in the port sector and the only distance function applied, considered just one product (Baños et al., 1999). Furthermore, this is the first study that, using a parametric methodology, explores the potential effects of port regulation on the efficiency of Spanish ports.

The paper is structured as follows. Section 2 surveys the literature. Section 3 presents the main economic characteristics of ports. Section 4 describes the theoretical aspects of a distance function. Section 5 deals with the empirical application, including a description of the data, the econometric model and the most important results. Finally, section 6 concludes.

2 Survey of the literature

The first attempts to assess the port efficiency and productivity effects from reforms and technological changes relied on partial indicators of productivity. Talley (1994) and Tongzon (1995a) use them to compare different ports in an academic paper but many organizations have also used them in practice as instruments for the promotion of competition among ports. However, the main drawback of partial indicators is that they do not analyze the joint contribution of all inputs to production nor give an acceptable treatment to multi-output processes. This problem becomes particularly relevant in the port sector since port products are very diverse and many different inputs are involved in their production.

To overcome the limitations of the partial indicators approach, a new generation of studies based on formal efficiency measures - stemming from the work by Chang (1978) developed. This study by Chang (1978) can be considered as the starting point in the estimation of a port production function and, in a way, it led the way to the estimation of production frontiers. Since that first paper, the academic research on the topic has grown in various directions. The methodologies used in the assessment of port efficiency are evenly distributed between stochastic frontiers and DEA (Roll and Hayuth, 1993; Martínez et al., 1999; Tongzon, 2001; Valentine and Gray, 2001; Martín, 2002; Bonilla et al., 2002; Pestana, 2003), thus evidencing the lack of consensus on the approach that best adapts to and defines the complex reality of the port sector. Among the authors relying on stochastic frontiers, four studies estimate a production frontier to calculate technical efficiency (Liu, 1995, Notteboom et al., 2000; Estache et al., 2002 and Cullinane et al., 2002) and three others (Díaz, 2003; Coto et al., 2000; Baños et al., 1999) quantify the economic efficiency through a cost frontier. The latter also estimates a distance function. The diversity of purposes for these papers is also important and ranges from analyzing the relation existing between type of ownership and port efficiency (Cullinane et al., 2002; Valentine and Gray, 2001; Liu, 1995) to showing the effects of port reforms (Estache, González and Trujillo, 2002; Martín, 2002; Díaz, 2003; Pestana, 2003), including international benchmarking of ports (Tongzon, 2001).

The heterogeneity of port activities (which include not only complex activities such as loading and unloading the cargo but also simpler activities such as mooring of ships) makes it difficult to consider the port industry as a whole, at least regarding the estimation of cost and production functions and, therefore, it is preferable to center the analysis on a particular activity. Some researchers on port efficiency does not specify clearly the activity whose efficiency is being analyzed and this introduces a certain degree of confusion. For example, Martín (2002) asserts that she is studying the efficiency of the port system as a whole but she considers the port authority as the unit for analysis, which only represents one of the parties involved in the port business. In this sense, the study presented here clearly determines the scope of research: infrastructure services rendered by port authorities. Therefore, the rest of the services or activities, whether of a maritime or port nature, which are also developed at port facilities, are not taken into account.

Even when focusing the study on a specific activity, there is still diversity. A port not only renders services to vessels but also to passengers and cargo. Moreover, the cargo cannot be considered as a homogenous good, since each type of commodity calls for very specific loading/unloading devices: containers use specialized cranes; bulks employ pipe systems, etc. However, even though the multi-output nature is well captured in the studies applying DEA, all the parametric applications use a simple measure of product.

From the point of view of economic and business policies, it is often useful to analyze certain variables that feature the environment in which the firms develop their activities (institutional factors, market characteristics, etc.) and affect their efficiency. Liu (1995) relies on four variables: ownership, port size, localization, capital intensity and Coto et al. (2000) uses two: a dummy that captures the influence of the organization type and the size of the port. In both studies, authors first estimate efficiency ratios and then, in a second stage, they make a regression of these ratios obtained from environmental variables to determine the intensity of these factors on the efficiency of ports.

While intuitively quite attractive, the idea of using these variables in a second stage to explain efficiency has been very much criticized. This criticism is based on the inconsistency between the assumptions of the first stage and the second. The different solutions proposed (Kumbhakar, Ghosh and McGuckin, 1991; Reifschneider and Stevenson, 1991; Battese and Coelli, 1995) consist of specifications where the effects of technical inefficiency are defined as a function of specific firm factors influencing efficiency, so the estimation of all parameters is performed in a single stage through a maximum likelihood method.

3 Characteristics of ports

Ports consist of the facilities whose main function are the transfer of passengers and merchandise between sea and land and vice versa. The European Union (European Parliament, 1993) defines ports in terms of the area made up of a group of berths, docks and land area where service operations to ships and cargo are performed. This area encompasses not only the infrastructure (berths, storage areas, shipyards, etc.) but also the superstructure which consists of fixed units built on infrastructure (buildings, repair shops, etc.) such as mobile equipment (cranes, etc.). To access the port area we need maritime access infrastructure (access channels, navigation aids, etc.) as well as land access infrastructure (roads, railways and inland rivers).

3.1 Economic relevance

The economic relevance of ports arises from the fact that most of the foreign trade of a region is carried out by sea. For instance, about 90% of the international trade of the European Union is performed by sea. This figure increases in relation to insular territories where most goods are traded through the ports.

Some authors argue that the ports constitute one of the main forces that move the economy (Suykens and Van de Voorde, 1998). Moreover, the actions by the European Union aimed at increasing investments in ports and transport infrastructure tend to promote the economic cohesion of the different regions.

Ports are an important link in the logistics chain so the level of port efficiency affects –to a large extent- the country's competitiveness, since port efficiency results in lower tariffs for exports which, in turn, favor the competitiveness of country products in international markets. Therefore, in order to keep a competitive position in those markets, the countries need to work on the factors that affect the efficiency of their ports and draw continuous comparisons on the degree of efficiency among them and with the ports of other regions.

3.2 Intermodal nature

Ports are economic and service provision units of a remarkable importance since they act as a place for the interchange of two transport modes, maritime and land, whether by train or road. Therefore, the essential aspect of ports lies in their intermodal nature. In this respect, the UNCTAD states that ports are interchangers of different transport modes and, thus, they are centers of combined transport.

3.3 Indivisibility, long duration and high cost of infrastructure

Most port infrastructure (as well as superstructure elements) have a minimum size, independent of the volume of traffic; that is to say, it can be used at its maximum capacity or below it. This means that the growth of such infrastructure is not constant and therefore, very frequently we see cases of overcapacity and congestion of port infrastructure. A great part of these port infrastructure and superstructure elements are very costly and have a long useful life. These are the reasons argued in favor of the provision of large port infrastructure by the public sector, since it would be very difficult for private firms to get a reasonable rate of return during a fairly long time so as to be able to recover very high costs. This may result in the provision of infrastructure below the optimal standard.

3.4 Port services “demand-nature”

As in other transport modes, port activity does not usually generate by itself but it arises as a consequence of the economic activity of a region. The economic growth and the development of industrial production and trade generate a larger demand of maritime transport services, thus increasing port business which –as can be observed- is highly affected by economic cycles.

Initially, the demand of port services was considered to be inelastic because of the small share that port costs represent in the logistics chain. However, the truth is that consideration of the generalized cost introduces –through the reduction of waiting time- a high degree of competition among port service providers (whether operating within the same port or in different ports of a certain region). This leads to the belief that the degree of substitution between ports is fairly high and, therefore, the elasticity of port service demand is important, particularly if we consider traffic that does not generate loading/unloading activities (for example, provisioning) or cargo in transit (Martínez Budría, 1993). Insular ports can be considered as exceptions because the captive traffic generated in them determines a quite inelastic port service demand, since air transport does not represent a feasible alternative, except for perishable goods.

3.5 Multi-output nature of port activity

Ports are not a kind of organization where only one service is rendered. On the contrary, multiple activities are developed in them and a great number of agents are involved in their provision (port authorities, tugs, consignees, repair shops, etc.), each of which pursues its own objective. Moreover, these operators deliver their activities with very uneven levels of competition and regulation. This diversity of activities hinders the analysis of ports as a whole and, on the contrary, calls for an analysis focused on a specific activity (Nombela and Trujillo, 1999), a specific cargo type and a limited number of ports (Tongzon, 1995a, 1995b, 2001).

At port facilities, not only passengers and cargo are exchanged but also services to vessels are provided and commercial and industrial activities are developed. Moreover, the merchandise handled at ports cannot be considered as a homogenous good since the different cargo types (containers, bulks, etc.) are so diverse that they require specialized facilities and services. This fact drives to consider that many port activities are developed in a multioutput context.

3.6 Port organization and management

The multiplicity of activities and operators taking place at ports calls for the existence of an organization in charge of coordination. Although in most countries port management is entrusted to port authorities, great differences can still be found between countries and, even more, between ports of the same country. These differences are obvious in terms of the type of ownership exercised by the port authority and its liability towards the management and provision of facilities and services. In this sense, in some countries port systems are managed by the central government, while other countries follow a more decentralized model and have ports managed by local governments or municipalities.

Therefore, we cannot state that there is a standard model of port management. On the contrary, numerous management styles can be found and they can be classified in many different ways. The literature on port economics generally recognizes two models of port authority (Goss, 1990; Heaver, 1995):

- Comprehensive. Under this model, the port authority provides and keeps direct responsibility for all port facilities and services. Independent operators are banned from performing any activity at these ports, although sometimes they are allowed to carry out minor tasks, such as garbage collection.
- Landlord. According to this model, the role of port authorities is limited to provision and maintenance of basic infrastructure (berths, roads, etc.) and essential services (for example, security), while the rest of the services (cargo handling, tug services, etc.) are rendered by third-party enterprises -owners of the port superstructure-- whether public or private. Nowadays, ports tend to adopt this type of organization. For instance, Buenos Aires, Rotterdam and Spain.

Other authors, such as Baird (1995) and Juhel (1997), introduce a new modality, so we can distinguish three types of ports: landlord (as classified above), services (sharing the characteristics of comprehensive ports) and tool. This last new category consists of an intermediate case between comprehensive and landlord ports. That is to say that in these ports, the port authority not only owns and manages the infrastructure but also the superstructure. Port services are provided by firms, under license and concession agreements. Some authors believe that tool ports represent a variation of landlord ports. For example, we can mention the ports of Antwerp (Belgium) and Seattle (United States).

The Spanish port system is landlord port and hence the analysis provided focuses on this particular mode of organization.

4 Methodology

The main contribution of this paper to the earlier approaches applied to the port sector, is the fact that it deals with the multi-output nature of the port activity with a parametric approach whose main feature –as compared to the DEA- is to allow separation of the effect caused by random exogenous factors from technical efficiency. To be able to do so, we also need to rely on a distance function.

4.1 The distance function

The distance function, introduced by Shephard (1953, 1970), allows estimation of the relative efficiency of firms in relation to the technological frontier described by the distance function. The reason behind the selection of this function lies in the advantages it presents over the other methods of frontier estimation. Regarding these advantages, we can mention the following, among others:

- It allows capturing multi-output processes. This cannot be achieved with a production frontier and it would require the use of a cost frontier, in which case it would be necessary to admit the assumption of cost minimization and to know input prices. This feature is particularly relevant for the study of the port sector because of the diversity of activities developed at ports. Moreover, even if the study focuses on a specific activity, such as port infrastructure services, it is important to bear in mind that said infrastructure is used not only by different types of merchandise but also by passengers.

- It does not require the use of optimizing assumptions. The validity of the cost minimization assumption has been very much challenged in the context of public or regulated firms. In the port sector, Coto et al. (2000) prove that such hypothesis is not met. Therefore, when analyzing the port sector it is very useful to apply a technique that does not impose an optimizing behavior on the firm.
- It only uses physical data and, therefore, it is not necessary to have information on outputs or factor prices. As in other regulated sectors, the literature on ports also agrees on the difficulty of getting reliable prices (for example, effects of subsidies of the European Union on input prices). In addition to this problem, the study of the Spanish port system encounters additional difficulties derived from the change in the accounting system that took place in 1992, when it changed from public to private account systems. Consequently, it is impossible to make comparisons of economic data from before and after that year.

Distance functions can be input-oriented or output-oriented. An input-oriented distance function features technology through the minimum equiproportional reduction of the input vector, given an output vector. An output-oriented distance function features technology through the maximum equiproportional expansion of the output vector, given an input vector.

An input-oriented distance function is defined as the largest scalar by which all output factors can be proportionally divided and still the same amount of output be obtained. Mathematically, it is expressed as follows:

$$D_I(y,x) = \max_{\delta}\{\delta : x/\delta \in L(y)\} \qquad (1)$$

where y is the output vector, x represents the vector of factors and $L(y)$ the input set, which defines the group of all inputs x that can be used to obtain the output vector y.

A value of D_I equal to one reveals that production is efficiently carried out, whereas a value of D_I greater than one will indicate the degree of technical efficiency achieved.

On the other hand, an output-oriented distance function is defined as the smallest scalar by which all outputs can be proportionally divided, using the same level of productive factors. Formally, it is defined as follows:

$$D_O(y,x) = \min_{\mu}\{\mu : y/\mu \in P(x)\} \qquad (2)$$

where $P(x)$ is the output set, which represents all output vectors y that can be obtained using the input vector x.

If the value of D_O equals the unit, it evidences technical efficiency of the producer, while a value smaller than one shows the degree of technical efficiency achieved.

Distance functions are required to meet the properties shown in table 1 (for more details see Färe and Primont, 1995).

Table 1: Properties of distance functions

Input-oriented	Output-oriented
Homogeneous of degree 1 in input	Homogeneous of degree 1 in output
Non-increasing in output	Non-increasing in input
Quasi-convex in output	Quasi-concave in input
Non-decreasing in input	Non-decreasing in output

Concave in input	Convex in output
Dual of cost function	Dual of income function
$D_I\,(y,x) \geq 1$, if $x \in L(y)$	$D_O\,(x,y) \leq 1$, if $y \in P(x)$
$D_I\,(y,x)=1$, if x is on the frontier of $L(y)$	$D_O\,(x,y)=1$, if y is on the frontier of $P(x)$

The analysis of the conditions under which port authorities develop their activities led us to the estimation of an output-oriented distance function. This is because in the provision of infrastructure services, port authorities have some power to decide on the production level through the use of two mechanisms: commercial policies and concessions. The port authorities also perform a significant amount of marketing for their services and facilities to attract new traffic. The commercial policies complement these efforts with tariff discounts offered within limits allowed. Furthermore, as long as port authorities decide on the type of firm that can operate at the different ports, they are also deciding on the ships and goods that will be handled. For instance, a port intended to attract fish to be processed needs that freezing companies be established there, and the final decision on that is subject to the port authority's board of directors.

Considering this capacity to influence output, port authorities encounter certain difficulties in adjusting the productive factors used in the provision of infrastructure services, basically: berths, area and labor. The first two are quasi-fixed factors that, due to their indivisibility nature, find it difficult to adapt to the changes in production, especially if the change is a decline. Furthermore, although investment decisions are taken by the board of directors of each port authority, the truth is that these decisions are coordinated by the State Ports (*Puertos del Estado*), which has a decision margin to allow or limit the finance for the construction of those infrastructure works. As for the labor factor, it is generally made up of officers and thus the difficulty of making adjustments, particularly when the number needs to be reduced.

4.2 The functional form

The empirical application of a distance function calls for the definition of an appropriate functional form. It is desirable that the functional form present the following advantages: it must be flexible, it must be easy to calculate and, lastly, it must allow imposition of the homogeneity condition. The translogarithmic functional form (hereinafter translog) meets these conditions and this is the reason why, at present, most authors use it in all research fields. It consists of a flexible functional form that provides a local second-order approximation to an unknown functional form. In other words, no *a priori* restrictions about production technology are assumed and, thus, the criticisms associated with some restrictive properties of the Cobb-Douglas function are overcome.

For all these reasons, this work estimates a translog distance function that, when output-oriented, can be expressed as follows:

$$\begin{aligned}\ln D_O = \alpha_0 + \sum_{m=1}^{M} \alpha_m \ln y_{mit} + 1/2 \sum_{m=1}^{M} \sum_{n=1}^{M} \alpha_{mn} \ln y_{mit} \ln y_{nit} + \\ \sum_{k=1}^{K} \beta_k \ln x_{kit} + 1/2 \sum_{k=1}^{K} \sum_{l=1}^{K} \beta_{kl} \ln x_{kit} \ln x_{lit} + \sum_{k=1}^{K} \sum_{m=1}^{M} \delta_{km} \ln x_{kit} \ln y_{mit} + \\ \sum_{h=1}^{H} \psi_h d_h + \sum_{t=1}^{T} \gamma_t f_t + \varepsilon_{it}\end{aligned} \qquad (3)$$

where y is a vector of M outputs, x is a vector of K factors, i relates to the *i-th* firm, t relates to the time trend, h refers to the environmental variables, Ψ_t is the coefficient of the environmental dummy variables d, γ_t is the coefficient for the time *dummy f* and ε_{it} is an error term which is discussed later. Variables are expressed in relation to their deviation from the geometric mean; therefore, the estimated coefficients can be construed as elasticities at the sample mean.

4.3 Homogeneity of degree 1 in outputs

In order to determine the frontier, D_O needs to be equal to the unit and, in that case, the term on the left of the equation, according to the neperian logarithm, will equal zero. Consequently, it is necessary that outputs meet the homogeneity condition of degree 1 so the following restrictions are verified:

$$\sum_{m=1}^{M} \alpha_m = 1\,; \qquad \sum_{m=1}^{M} \alpha_{mn} = 0\,; \qquad \sum_{k=1}^{K} \delta_{km} = 0 \tag{4}$$

The symmetry conditions requires: $\alpha_{mn} = \alpha_{nm}$, $\beta_{kl} = \beta_{lk}$ y $\delta_{kl} = \delta_{lk}$

Following Lovell et al. (1994), this condition has been imposed by normalizing the distance function with one of the outputs.[1] This starts from the assumption that homogeneity implies that:

$$D_O(x, wy) = wD_O(x, y) \tag{5}$$

for any $w > 0$. The output chosen does not influence the results (Cuesta and Orea, 2002).

If in a translog distance function any output is chosen, say y_M, so that $w = 1/y_M$, the following expression results:

$$\begin{aligned} \ln(D_0 / y_M) = \alpha_0 + \sum_{m=1}^{M-1} \alpha_m \ln y^*_{mit} + 1/2 \sum_{m=1}^{M-1}\sum_{n=1}^{M-1} \alpha_{mn} \ln y^*_{mit} \ln y^*_{nit} + \\ \sum_{k=1}^{K} \beta_k \ln x_{kit} + 1/2 \sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \ln x_{kit} \ln x_{lit} + \sum_{k=1}^{K}\sum_{m=1}^{M-1} \delta_{km} \ln x_{kit} \ln y^*_{mit} \end{aligned} \tag{6}$$

where $y^*_{mit} = y_{mit}/y_{Mit.}$ Note that when $y_{mi} = y_{Mi}$, the ratio y^*_{mi} is equal to 1 so that its logarithm is equal to zero. This is why the sum where they intervene always has one less term (M-1).

Equation (6) can thus be rewritten as:

$$\ln(D_O / y_M) = TL(x_{it,}\ y_{it} / y_{Mit}, \alpha, \beta, \delta) \tag{7}$$

yielding the final expression:

$$-\ln(y_{Mit}) = TL(x_{it,}\ y_{it} / y_{Mit}, \alpha, \beta, \delta) - \ln(D_O) \tag{8}$$

In equation (8), the $-ln(D_O)$ term can be interpreted as an error term which captures the technical inefficiency.

[1] This methodology has been applied in some empirical papers (Coelli and Perelman, 1999, 2000; Morrison et al. 2000; Orea, 2002, among others).

4.4 Structure of the error terms

The distance function estimated is stochastic. For the purpose of estimating equation 8, it is necessary to determine the random disturbance term. We applied the methodology developed by Battese and Coelli (1988) for panel data and apply an additive term as suggested by Cuesta and Orea (2002), to account for the fact that we are estimating an output oriented distance function. The error terms thus has the following form:

$$v_{it} + u_i \qquad (9)$$

where, v_{it} is a symmetrical error term, iid with a zero average (which represents the random variables un-controllable by the operator) and u_i is a one-sided negative error term (which measures the technical inefficiency of each operator that is constant over time) and is distributed independently of v_{it}.

Applied to the distance function, this yields

$$-\ln(y_{Mit}) = TL(x_{it,}\, y_{it}/y_{Mit}, \alpha, \beta, \delta) + v_{it} + u_i \qquad (10)$$

This equation can be estimated by the maximum likelihood method which requires distributional assumptions on the random shock. This assumes that v_{it} follows a $N(0, \sigma_v^2)$ distribution and u_i follows a $|N(0, \sigma_u^2)|$ distribution (Ritter y Simar, 1997).

This model thus assumes that the inefficiency effects are constant over time. To be able to assess the effects of policy changes on inefficiency levels, we structured the time horizon in 3 periods and considered the port authorities to be independent across periods. The three time periods are: (i) before the reform (1990-1992), (ii) after the first reform (1993-1997) and (iii) after the second reform (1998-2002). This way any change resulting from reform can be assessed within the period.

5 The estimation

5.1 The data[2]

The heterogeneity of activities developed at ports and the diversity of commodities handled suggests narrowing the study to a limited number of ports and a specific type of cargo. Following the foregoing recommendation, this study centers its analysis on Spanish ports particularly relevant from the point of view of container traffic.

Statistical information has been gathered from the data published annually by port authorities in their Annual Reports. Furthermore, information from the Statistical Yearbooks released by State Ports –the central agency entrusted with the coordination of the Spanish port system- has been used. Whenever anomalies or discrepancies were encountered, we resorted directly to the source and asked for additional clarifications - whether in person or on the phone- from the people responsible of each field.

The ports included in the sample coincide with the major commercial ports of the country and capture a broad typology of ports: insular ports (with high level of captive traffic), hub ports (relevant at the international level for their importance as merchandise distribution centers, such as the Port of Algeciras), and different specializations (for instance, Santa Cruz de Tenerife and Bilbao in liquid bulks, Alicante in dry bulks, etc). Furthermore, all waterfronts of the Spanish coastline are represented by the ports selected.

[2] For more details about the data and variables see González, M. (2004).

The time period under analysis covers from 1990 to 2002, and this allows the analysis of the effects that the modifications to the port system carried out in the 1990s had on the efficiency of each of the ports in particular and the port system in general.

The unit for analysis is the port authority, which can be in charge of one or more ports, as is the case of port authorities from the Balearic Islands (Palma de Mallorca, Alcudia, Mahón, Ibiza and Cala Sabina), Alicante (Alicante and Torrevieja[3]) Valencia (Valencia, Gandía and Sagunto), Las Palmas (Las Palmas, Arrecife and Puerto del Rosario), and Santa Cruz de Tenerife (Santa Cruz de Tenerife, Los Cristianos, San Sebastián de La Gomera, Santa Cruz de La Palma and La Estaca).

More than 70% of the ships going through Spanish ports fall under the control of the nine port authorities in the sample (Algeciras, Alicante, Baleares, Barcelona, Bilbao, Las Palmas, Santa Cruz de Tenerife, Valencia and Vigo). These sample authorities also handle 96% of container traffic, all of which evidences the high concentration of this kind of traffic.

To describe port technology, we have used three variables representing the port output (cargo, passengers and charges) and three productive factors (work, berths and area). In addition, we have also considered two factors that influence the environment of port authorities: the geographic location of ports (mainland and island ports) and the refineries near the port. All these variables are detailed below.

5.1.1 The output

Table 2 shows the mean values for the main outputs considered in this paper. We have already explained the need to properly reflect the nature of the port output in its multiple dimensions. **Cargo** represents the most immediate and important source of revenue for port authorities, distinguishing between containers, liquid bulk and other merchandises.[4] Although we could have considered different cargo types, problems related to the degree of freedom together with the need to include other types of products motivated us to measure merchandise in global terms, that is to say in tonnes of dry or liquid bulk, general cargo (including containers), fresh fish, supplies (fuel, water and ice) and local traffic.

Another variable expressing the output of infrastructure provided by port authorities is the number of **passengers**. Many of the passengers visiting Spanish ports choose the selected ports. In this sense, although at the beginning of the period the analyzed ports handled 58% of the passengers; in 2002 the percentage grew to 78%.

[3] In 2000 the Port of Torrevieja was transferred to Generalitat Valenciana.

[4]Operating revenue mostly arise from the services provided to ships and merchandise. The cargo arrives at ports in vessels and, therefore, these two elements are very much correlated. Actually, they constitute two alternative ways of measuring the same output.

Table 2: Output means per port authority: 1990-2002

Port Authority	Containers (tonnes)	Liquid bulk (tonnes)	Other Cargo (tonnes)	Passangers (number)
B. Algeciras	14,209,958	7,356,611	7,722,807	3,800,291
Alicante	625,242	385,326	1,610,922	185,242
Baleares	1,481,024	2,653,233	5,019,041	3,153,879
Barcelona	8,614,954	8,233,942	7,558,250	1,239,828
Bilbao	3,233,316	4,076,144	10,581,053	104,084
Las Palmas	3,854,494	3,601,112	5,265,526	985,888
S.C. Tenerife	2,292,871	7,792,254	4,580,726	3,609,534
Valencia	9,214,198	1,513,538	7,861,188	246,620
Vigo	964,664	409,051	2,161,053	1,350,561

Source: Own elaboration from data from Puertos del Estado (some years).

5.1.2 The factors

In order to perform their function as infrastructure service providers, port authorities use three productive factors (see table 3 for a quantitative summary). First, they employ the **labor** factor, approximated by the mean number of employees of port authorities, where not only administrative staff is included but also more specialized technical employees. The nature of the activities performed by this productive factor (supervision of port facilities, control of port operations, port promotion, management of garbage, etc.) makes labor a very important resource.

Another important factor consists of the **berths** necessary for ships' docking. Berths have been measured in linear meters and we have considered not only the berths owned by port authorities but also by private people (for example, shipyards). Only those berths not reaching a 4-meter depth have been excluded since they are places basically intended for water-sports activities.

Finally, the third factor is the **land area or surface** that has been measured in square meters and includes warehouses, roads and the rest (gardens, buildings, etc.). This area encompasses all port facilities, i.e. property owned by port authorities as well as property assigned under administrative concessions to port companies.

Table 3: Factor means per port authority: 1990-2002

Port Authority	Berths (meters)	Surface (squared meters)	Labor (employees)
B. Algeciras	10,239	2,486,245	282
Alicante	5,591	1,115,208	153
Baleares	16,470	1,545,945	279
Barcelona	19,976	7,404,316	487
Bilbao	16,473	1,830,255	374
Las Palmas	16,335	2,535,582	297
S.C. Tenerife	15,361	1,837,463	207
Valencia	11,628	4,355,749	369
Vigo	9,376	1,834,232	239

Source: Own elaboration from data from Puertos del Estado (some years).

5.1.3 Technical change

During the period covered here, several policy changes have taken place with a significant influence on the sector. This included regulatory changes, economic booms, a liberalization of maritime cabotage within the European Union, changes in the ship building technology, and technological changes in the handling equipment to address the large expansion in container traffic. These effects are accounted for by a time dummy for each year covered by the sample. This allows us to capture the effect of factors which influence all port equally at different points in time.

5.1.4 Environmental variables

Occasionally, some specific factors may influence the production activities without any possible interference from the port authorities. These include geographical location, the degree of competition in the sector, the type of ownership, etc. The following are the main factors to account for differences in the port environment.

The first variable is the existence of **oil refineries.** This will influence the statistics on liquid bulk. A dummy was thus introduced to account explicitly for the oil refineries in Algeciras, Bilbao and Santa Cruz de Tenerife.

The second dimension is the geographic location of the ports. Some ports are on islands and some others serve the mainland. Captive shippers are more common in island ports than in the others and this may influence the incentive for efficiency as suggested by Suykens (1986). This is taken into consideration by creating a dummy variable for the island ports (Baleares, Las Palmas and Santa Cruz de Tenerife).

Another factor is the change in the economic regulation of the sector that took place during the 1990´s. Since, in fact, there were three main regulatory changes, we divided the sample period into three and estimate the model as if the port authorities were different business units in each one of the three periods. This allows us to assess the impact on efficiency of the specific regulatory changes on each one of the ports individually and on each period.

5.2 The results

Table 4 shows the main results obtained with the output oriented distance function estimated by maximum likelihood. The output distance function is well behaved. It can be noted that first-order parameters present the expected signs and, in addition, they are significant. In other words, the parameters of output variables are positive and, thus, indicate that distance from the frontier increases when production grows (remember that the output-oriented distance function takes a value between zero and one). On the contrary, input parameters are negative, evidencing that if inputs increase, for a given output level, the distance will be reduced.

Table 4: Parameters estimated

Variable	Coefficient	t-test
Constant	0.4807	6.4365
L(passenger)	0.1636	6.7103
L(container)	0.2454	5.1408
L(liquid bulk)	0.1051	2.9630
L(other goods)	0.4860	8.3225
L(berth)	-0.3658	-2.6851
L(superface)	-0.2564	-4.0244
L(labor)	-0.7728	-6.4832
L(passenger).L(passenger)	0.0399	3.1733
L(container).L(container)	-0.0343	-2.0676
L(liquid bulk).L(liquid bulk)	-0. 0573	-2.0180
L(other goods).L(other goods)	-0.8545	-6.6035
L(berth).L(berth)	-2.0697	-4.1460
L(surface).L(surface)	-1.2459	-4.1467
L(labor).L(labor)	-0.7509	-0.9870
L(passenger).L(container)	-0.420	-0.9154
L(passenger).L(liquid bulk)	-0.766	-7.3477
L(passenger).L(othergoods)	0.1787	3.9464
L(passenger).L(berth)	0.3250	3.7631
L(passenger).L(surface)	0.0160	0.2619
L(passenger).L(labor)	-0.0633	-0.5816
L(container).L(liquid bulk)	-0.0283	-0.4953
L(container).L(other goods)	0.4135	3.0858
L(container).L(berth)	0.1501	0.7542
L(container).L(surface)	0.5119	2.6059
L(container).L(labor)	-0.0489	-0.2214
L(liquid bulk).L(other goods)	0.2622	3.7325
L(liquid bulk).L(berth)	0.4988	4.9583
L(liquid bulk).L(surface)	-0.1723	-2.3369
L().L(labor)	-0.1941	-1.8283
L(other goods).L(berth)	-0.9739	-5.1843
L(other goods).L(surface)	-0.3557	-2.0589
L(other goods).L(labor)	0,.064	1.5303
L(berth).L(surface)	0,.816	3.1361
L(berth).L(labor)	0.4278	1.1188
L(surface).L(labor)	0,.913	1.0311
D 1991	0.0149	0.4332
D 1992	-0.0081	-0.2045
D 1993	0.0783	1.6553
D 1994	-0.0592	-1.1537
D 1995	-0.2107	-3.6525
D 1996	-0.2862	-4.6233
D 1997	-0,3158	-4.9503
D 1998	-0,3845	-5.7436
D 1999	-0.4828	-7.3343
D 2000	-0.5065	-7.4198
D 2001	-0.5089	-7.3421
D 2002	-0.5034	-7.1543
Localization	-0.2523	-3.3298
Refinery	-0.4868	-7.7359
Sigma*	0.0164	3,.2144
Gamma*	0.7415	7.2053

The coefficients for the time dummies show the effects of factors which evolve over time and influence all the ports simultaneously. These coefficients are significant as of 1995, with the strongest effects taking place over the last 3 years of the total sample period.

The change of the time effects give a measure of the impact of technological change and show how the production function shifts year after year according to the following equation:

$$CT_{t+1,t} = \gamma_{t+1} - \gamma_t \tag{11}$$

A negative value for expression (11) shows technological progress, i.e. a shift outward of the distance function).

Table 5 shows the evolution of results over time. It shows that before the reforms, ports showed little progress and then improvements became impressive with the highest rates right after the first wave of reforms (13.8% and 15.1%). In terms of the 3 periods of interest, the average changes are 0.4% before the fist reform and 6.3% after the first reform and 3.8% after the second one. This is of course influenced by other changes as well, the slow world economy just before 1992, the EU (European Union) liberalization of cabotage in 1993 and other events which have probably mattered more than this methodology can reveal. This implies that these figures have to be used with caution.

Table 5: Technological Change

Period	Technological change
1990-1991	0.0149
1991-1992	-0.0230
1992-1993	0.0864
1993-1994	-0.1375
1994-1995	-0.1515
1995-1996	-0.0755
1996-1997	-0.0296
1997-1998	-0.0686
1998-1999	-0.0983
1999-2000	-0.0237
2000-2001	-0.0025
2001-2002	0.0056

The regression results also show that the refinery and the location variables matter. They both have a negative and significant coefficient. This means that the island ports as well as the refinery ports benefit from an outward shift of the frontier more than the others (*ceteris paribus*). The refinery effect is however stronger than the island effect (4.9 vs. 2.5).

Finally, graph 1 shows the technical efficiency in each port for each period with an alphabetical ordering of ports and the digits 1, 2 and 3 corresponding respectively to the first, second and third period of our sample. The graph shows that average technical efficiency for the overall port system was 91.9% during the period with a very strong stability over time and a minor drop in the last period. This suggests that if the reforms have influenced technological change, they have not impacted average technical efficiency. The average technical efficiency per port authority varied form 95.3% for the most efficient (Valencia) to 86.8% for the least efficient (Alicante) and did somewhat fluctuate overtime suggesting an adjustment within ports even if there was no major reranking of port performance. The top performers are Valencia, Bilbao, Bahía de Algeciras, Baleares, and Barcelona while the bottom ports are Las Palmas, Vigo, Santa Cruz de Tenerife and lastly, Alicante.

Graph 1: Evolution of technical efficiency across periods and ports

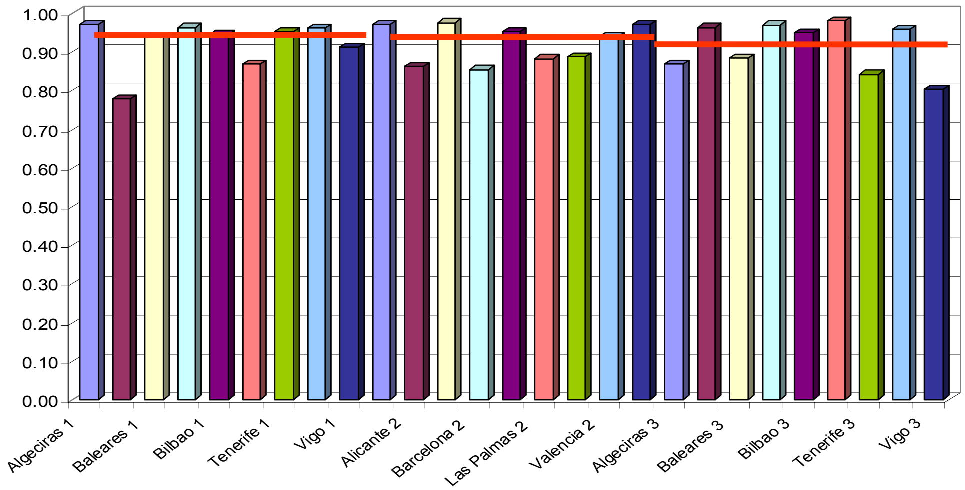

Table 6 gives a better sense of the evolution for each port. It shows both the efficiency and the changes over the first and third period. Note that the most efficient one are not necessarily those with the highest growth rates in efficiency, implying that reforms may have been effective at stimulating a catching up of the poor performers.

Table 6: Evolution of efficiency per port

Port Authority	1990-1992	1993-1997	1998-2002	Change rate 90-92/98-02
B. Algeciras	0.97	0.97	0.87	-10.57
Alicante	0.78	0.86	0.96	23.71
Baleares	0.94	0.98	0.88	-5.99
Barcelona	0.96	0.85	0.97	0.67
Bilbao	0.94	0.95	0.95	0.56
Las Palmas	0.87	0.88	0.98	12.90
S.C. Tenerife	0.95	0.89	0.84	-11.93
Valencia	0.96	0.94	0.96	-0.40
Vigo	0.91	0.97	0.80	-11.94
Todas	0.92	0.92	0.91	-0.89

6 Concluding comments

Conceptually, the paper has demonstrated the suitability of using a distance function to measure the technical efficiency of ports and its evolution. This function captures the multi-output nature of the sector without assuming rather implausible assumptions on the economic behavior of port authorities but instead using physical data, which are more reliable than economic data. This represents a novel approach to the estimation of the technical efficiency of ports. Of particular interest is the need to recognize the ability of port authorities to attract traffic (basically through tariffs), coupled with the difficulty in adjusting inputs (mainly quasi-fixed inputs), which implies that the likely desirable orientation of the distance function is an output-orientation.

Empirically, the paper has shown that the restructuring and the substantial reforms introduced not only changed the conditions for the development of port activities subject to regulation but also led to significant improvements in technological change. Technical efficiency has however not improved in a similar way and has in fact changed little on average. There is however a significant movement of the efficiency within ports over time as a result of reforms.

These results are particularly relevant in practice because a third wave of reforms has just been implemented and many more changes are expected to come from forthcoming European Union guidelines for the liberalization of port activities with potentially strong influence for container traffic. The results provided here however show that island and mainland ports are likely to be influenced differently if the past is considered to be a valid indication of the future reaction of port authorities to reform.

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