Universidad de La Laguna
Cátedra de Economía y Finanzas Internacionales

INSTITUTO UNIVERSITARIO DE DESARROLLO REGIONAL

Documento de Trabajo/Working Paper
Serie Economía

Measurement efficiency and returns to scale with quasifixed outputs: an application of dynamic DEA to infrastructure services in Spanish ports

by

Juan José Díaz-Hernández
Eduardo Martínez-Budría
and
Juan José Salazar-González

October 2011

DT-E-2011-11

ISSN: 1989-9440

Instituto Universitario de Desarrollo Regional, Facultad de Ciencias Económicas y Empresariales, Universidad de La Laguna, Camino de la Hornera s/n - 38071 La Laguna, Santa Cruz de Tenerife, Spain

MEASUREMENT EFFICIENCY AND RETURNS TO SCALE WITH QUASIFIXED INPUTS: AN APPLICATION OF DYNAMIC DEA TO INFRASTRUCTURE SERVICES IN SPANISH PORTS

Juan José Díaz-Hernández[1a]

Eduardo Martínez-Budría[b]

Juan José Salazar-González [c]

[a,b] Departamento de Análisis Económico. Instituto Universitario de Desarrollo Regional. Universidad de La Laguna.

[c] Departamento de Estadística, Investigación Operativa y Computación. Instituto Universitario de Desarrollo Regional. Universidad de La Laguna

ABSTRACT

Port facilities have indivisibilities and a long service life, which classifies them as quasifixed inputs, meaning that they cannot be immediately adjusted and that contribute to the production of port services over long periods of time. Properly handling these types of inputs requires a dynamic approach that acknowledges the intertemporal relationship between the inputs used and the resulting outputs. In this paper, we employ a dynamic non-parametric Data Envelopment Analysis methodology to calculate the intertemporal cost frontier for the services provided by Spanish port facilities from 2000 to 2007. Based on this frontier we estimate the overall efficiency for the 27 port authorities in Spain, as well as their technical, allocative and dynamic efficiency components. We also identify the returns to scale under which each port operates. The results reveal a global inefficiency which is explained mainly by the dynamic inefficiency and, to a lesser extent, by the inefficient use of labor and of the intermediate inputs. Finally, by comparing the results with those obtained from a static DEA model, we show that if the quasifixed condition of the infrastructure is ignored, all of the global inefficiency components are overestimated. The type of the returns to scale assumed to apply can also be distorted.

Key words: Efficiency, return to scale, dynamic DEA, quasifixed inputs, ports

JEL Classification: D21, L91.

[1] Corresponding author: Juan José Díaz-Hernández. Departamento de Análisis Económico e Instituto Universitario de Desarrollo Regional. Universidad de La Laguna. Camino de la Hornera s/n. 38071 La Laguna. Santa Cruz de Tenerife. España. Email: jjodiaz@ull.es ; Tfno: 34 845402; Fax: 34 922317204.

1. Introduction

The existence of an efficient transport system is required in order to promote international commerce and enhance economic development, particularly in a context of high globalization like today's. There are various studies that highlight the importance of a transport system that is capable of transporting cargo while minimizing time and cost. Limao and Venables (2001) estimate that doubling transport costs reduces international trade by 45%. As regards maritime transport, Márquez Ramos et al (2007) estimate that a 10% reduction in freight would increase Spanish exports by 6.1%. These figures underscore the strategic and economic importance of maritime transport and, by extension, that of ports to external competition and economic development. This is more obvious in the case of Spain when we consider that nearly 70% of its foreign trade, measured in tons, moves through ports.

The main function of a port is to serve as a transfer point between maritime and terrestrial modes of transport, this despite the growing trend observed in port environments to provide a wide variety of logistical services that add value and which has resulted in port activities growing in complexity. Thus, in a port there are numerous agents providing a wide variety of services to ships, cargo and persons[2]. As noted by Cullinane and Song (2002), there is a broad range of administrative systems and management and operational styles that differ in, among other traits, the ownership regime and in the assignation of responsibility for the decisions involving the use of port resources.

Port services can be summarized as being of two types: those provided by the infrastructure and those required for loading and unloading cargo and handling it on the ground. As noted by Cullinane, Song, Ji and Wang (2004), "it is possible that a port may provide sound service to vessel operators on the one hand and unsatisfactory service to cargo or inland transport operators on the other". This requires a clear definition of the agent being analyzed and of the port activity being performed, which may not be the same in the various existing port systems. If the services provided by the various agents were analyzed as a whole, it would not be possible to isolate the source of any potential inefficiencies, which would result in incorrect policy or business

[2] Bichou and Gray (2005) offer a critical review of the conventional terminology used to classify the ample variety of existing ports, describing the significant differences between ports in terms of aspects such as assets, roles, functions, institutional organization structures and ownership models.

management decisions. In this sense, this paper focuses on analyzing the productive efficiency of Spanish Port Authorities, which are responsible for managing and planning construction and for overseeing the use of port facilities.

An infrastructure has a series of characteristics that must be considered in any economic analysis in which the use of its facilities is relevant, as is the case with the transport sector. Specifically, both the long construction periods, on the order of four years, and the indivisibilities, adjustment costs and the long service life inherent to any infrastructure mean that an exact and timely adjustment that constantly reflects production needs is impossible to perform. The presence of so-called quasifixed inputs at a port means that any efficiency analysis requires a suitable handling of said inputs so as to avoid distortions in both the measurement of the efficiency as well as in aspects of importance to the analysis of the production structure, such as, for example, the type of returns to scale.

The primary objective of this paper is to measure the efficiency in the use and provision of infrastructure services in Spanish ports. Keeping in mind the nature of the inputs involved, we opted to estimate an intertemporal frontier using a dynamic Data Envelopment Analysis (DEA) approach. The second objective is to illustrate the distortions that result when a port infrastructure is not regarded as a quasifixed input. We do this by conducting two exercises. In the first, we calculate the overall efficiency index and isolate its technical, allocative and dynamic components. In the second, we calculate and decompose the cost efficiency based on a static model that assumes all of the inputs are variable in the long term. A comparison of the results will illustrate the distortion introduced by not considering the presence of quasifixed inputs. We will then identify the returns to scale obtained for each port from both the dynamic and static models so as to illustrate how this characteristic can also be affected by ignoring quasifixed inputs. Both exercises rely on a database for Spain’s 27 port authorities for the period from 2000 to 2007. The rest of the paper is structured as follows: Section 2 presents the dynamic model used, along with the conventional static version. Section 3 presents the data and in Section 4, the dynamic and static models are applied to the Spanish port system. Finally, in Section 5 we present the most significant conclusions drawn from our work.

2. Methodology

The literature specializing in efficiency analysis has developed a set of methods to yield the technological frontier as a representation of optimal decisions by producers. Based on this frontier, the behavior of agents is evaluated by measuring the distance between the observed values and those that comprise the reference frontier. Most studies on efficiency, however, have adopted a static approach that implicitly assumes that while technology can change over time, the technology in a given period is independent from that of all other periods. Static models study changes in time by comparing the results yielded by the frontiers calculated for each time period studied, without considering the interconnection between the technology of one period and another.

This static approach to production activity means that the outputs obtained for a period are the sole result of the inputs used for that same period. The implicit assumption is that any adjustment, including infinitesimal variations, can be made to the period at any desired level for all of the inputs as a function of the outputs that are obtained. There are, however, productive sectors where technology does not allow for such adjustments; rather, the decisions made regarding the levels of certain inputs can only assume discrete values, with decisions spanning over several time periods. In these cases, between which the use of a port infrastructure lies, the production obtained in a given period depends on the inputs used for that period and on the levels of other inputs decided in previous periods. This situation requires considering a model with a dynamic approach that acknowledges the existence of an intertemporal relationship between the inputs used and the resulting outputs.

Emrouznejad and Thanassoulis (2005) describe the following causes for this intertemporal relationship: i) the existence of a stock of capital whose useful service life and the effects of the investment extend over several periods; ii) the presence of lagged outputs which, in addition to the contemporaneous effects of the inputs, depend on the inputs used in previous periods; and iii) the production of intermediate outputs, that is, production obtained in a given period that is used as an input in a future period. In the case of transport economics, and of port activity in particular, several of these conditions coexist, thus warranting the use of a dynamic model. The efficiency, then, with which the cargo and passengers that transit through a port are transferred depends on, among other things, the amount of capital available, whose durability results in its contribution extending well beyond the time period in which it is put into use. The increase in the infrastructure in a period can be treated as an intermediate output that will be used as an input in subsequent periods.

Some of the research into efficiency using the non-parametric Data Envelopment Analysis (DEA) technique has involved the development of models that incorporate this dynamic vision of production activity in order to consider this interrelationship between the technology used in different periods. Along this new line of research, Sengupta (1995) present a dynamic DEA model that uses linear programming techniques to measure the shadow values of the quasifixed inputs and their optimal pattern of change. Färe and Grosskopf (1996) propose a series of models that incorporate several types of time interdependencies among the underlying technologies of various periods. In particular, they introduce the idea of a technological network that acknowledges the temporal link, thus avoiding having to measure changes in productivity by comparing a series of static models, as was the case with research conducted to calculate the Malmquist productivity indices. These new dynamic models connect each period's technology by using storable inputs and intermediate outputs that continue to contribute to future production, thus doing away with the separation in time that characterizes static DEA models. Moreover, Färe and Grosskopf (1996) developed this dynamic view into models that describe production technology on the basis of both the distance function and of a cost function that incorporates an intertemporal budget constraint.

In keeping with this dynamic vision of production activity, Nemoto and Goto (1999, 2003) propose a procedure based on the use of the dynamic DEA methodology to measure and decompose the cost efficiency of production activities in which quasifixed inputs are used. Their proposal considers the available levels of these inputs at the end of a period as another output of said period, but which they then use as inputs for the next period. This way, they account for the fact that if, based on an initial quantity of inputs, a productive agent decides to increase the available levels of quasifixed inputs, that agent would be opting to reduce the current production of the remaining outputs so as to increase future production. Faced with this possibility for an intertemporal substitution, the procedure proposed by Nemoto and Goto evaluates the production performance of agents that aim to minimize the discounted sum of costs over time.

Emrouznejad and Thanassoulis (2005) define a set of dynamic production possibilities that evaluates the behavior of a DMU not at a specific period, but along a time window comprising several time periods. This dynamic proposal considers the level of capital stock in a period of time as an input that contributes to production in future periods, and considers the level of capital stock present during the last period analyzed within the time window as yet another output to be used beyond the time window. In addition to measuring efficiency, the DEA technique has also been used to measure the change over time of productivity and to identify its technical change and efficiency components. Along this line, Ouellette and Vierstraete (2004) propose that the presence of quasifixed inputs requires that these be properly treated if the technical change and efficiency are to be correctly measured, thus avoiding overestimating the capacity of the production agents to adjust, which would skew the results. Ouellette and Vierstraete (2010) later entered these quasifixed inputs into Malmquist indices, which allowed them to decompose the changes in productivity and thus identify the contribution of the changes in pure technical efficiency and in scale efficiency, as well as the technical change. The Malmquist productivity index and its components are based on two periods of time which can capture only a part of the impact of investment in long-lived assets. The effects of lags in the investment process on the capital stock have been ignored in the current Malmquist index model. Emrouznejad and Thanassoulis (2010) extend the recent dynamic DEA model for the dynamic Malmquist index.

Another aspect that is closely related to quasifixed inputs and which has been addressed by the dynamic DEA technique is the presence of adjustment costs, meaning those costs incurred by a firm when it adjusts the amount of an input. Along these lines, De Mateo et al (2006) incorporate the presence of these costs *ex ante* in a context featuring investment budget constraints. They then calculate the path that the firm should take in order to reach the optimal point. Additionally, they outline some extensions to their basic model to allow for considering asymmetric adjustment costs, non-static output quantities, non-static input prices, non-static costs of adjustment, technological change, quasifixed inputs and investment budget constraints. By also considering the presence of adjustment costs, Ouellette and Yam (2008) propose a dynamic DEA model that takes into account the intertemporal restrictions by which a producer is bound when deciding on investment.

As regards the analysis of port activity, Woo et al. (2011) offer a structured review of the literature on methodological issues pertaining to research on ports. Their paper presents an exhaustive review of the literature published on ports in the last three decades, classifying it on the basis of the research strategy adopted, the disciplines the papers are based on or related to, the theoretical models on which papers are based, the research methods used and the type of data analysis techniques used. In the specific case of analyzing port efficiency, much of the literature has used both parametric and the DEA technique. Cullinane, Wang, Song and Ji (2006) apply both techniques to study the technical efficiency of a sampling of the largest container ports in the world. They conclude that the results are relatively robust to the methodology employed. Focusing our interest on that research that has relied on the non-parametric technique, we note the surveys conducted by Panayides et al. (2009) and Cullinane and Wang (2007) for the specific case of container ports. In the first case, the authors present a critical analysis of DEA applications to seaport economic efficiency measurement and note the problems and limitations of applying this technique in a port context. These limitations specifically involve the model specification, the definition of variables, the implications derived from the number of inputs, outputs and DMUs, and the type of data utilized.

One of the methods for organizing the extensive amount of literature that uses the DEA methodology is to arrange the studies by the type of data used, which conditions the model employed in each case. The use of cross-sectional data only allows comparing one DMU with the remaining agents that comprise the database, while the use of panel data also allows for an analysis of the change in time of a DMU, which could help avoid possible biases derived from the use of cross-sectional data. Cullinane and Wang (2007) review various options offered by the DEA methodology for handling the information contained in panel data, distinguishing among four approaches based on whether the calculated frontier is contemporaneous, intertemporal, sequential or the DEA version known as window analysis. Cullinane and Wang (2007) apply the contemporaneous, intertemporal and window approaches to a sampling of the world's leading container ports and show how the highest measure of efficiency is obtained with the contemporaneous model, while the lowest is yielded by the intertemporal frontier.

A common trait of these different DEA models is that they all adopt a static vision of technology, and therefore do not incorporate the existence of an interconnection among the technologies in each of the reference periods into which the panel data are divided. This paper, then, is, to the best of our knowledge, the first application of dynamic DEA to ports. A producer's goal in using an intertemporal cost frontier is to minimize the discounted sum of the costs for the group of periods analyzed. This way, the production effects of the quasifixed input are accounted for not only in the periods in which the input is first used, but also in subsequent periods during which said input remains in use.

Next, we calculate the dynamic DEA model that will allow us to calculate the intertemporal cost frontier to represent technology. The mathematical description of the production possibility set and the different linear problems are taken from Nemoto and Goto (2003), to which we incorporate the decomposition of the technical efficiency into the pure technical and scale efficiencies. To do this, and after defining the set of production possibilities in the presence of quasifixed inputs, we present the various linear programming problems intended to minimize costs. This will allow us to calculate the various costs necessary to measure the overall efficiency for each DMU analyzed, as well as to decompose it into its technical, allocative and dynamic components.

Let x_t be the vector $l \times 1$ of the amounts of the variable inputs used in period t, k_t the vector $m \times 1$ of the amounts of quasifixed inputs at the end of period t, and y_t an $n \times 1$ vector of the output levels produced in period t. Then, in a period t, a company uses the vector in variable inputs x_t along with the vector of quasifixed inputs it had at the end of the previous period, k_{t-1}, to produce a vector of outputs y_t that it offers the market and a quasifixed input k_t at the end of period t, that will be used as an input in the next period.

Every combination of outputs $(k_t, y_t) \in \Re_+^{m+n}$ is obtained from the combinations of variable and quasifixed inputs $(x_t, k_{t-1}) \in \Re_+^{l+m}$, which comprise the so-called set of production possibilities for period t, that it:

$$\Phi_t = \left\{ (x_t, k_{t-1}, k_t, y_t) \in \Re_+^{l+m} \times \Re_+^{m+n} \mid (x_t, k_{t-1}) \text{ allows production of } (k_t, y_t) \right\}$$

Assuming that both the prices of the inputs and the levels of the outputs are exogenous, the intertemporal cost frontier is given by:

$$C(\bar{k}_0) = \min_{\{x_t, k_t\}_{t=1}^T} \left\{ \sum_{t=1}^{T} \gamma^t (w_t' x_t + \upsilon_t' k_{t-1}) \mid (x_t, k_{t-1}, k_t, y_t)_{t=1}^T \in \times_{t=1}^T \Phi_t, k_0 = \bar{k}_0 \right\} \qquad (1)$$

where γ is a temporal discount factor, and w_t and υ_t are the $l \times 1$ and $m \times 1$ price vectors of the variable and quasifixed inputs for period t, respectively. The bar over the variables indicates exogenous observed values, while $\bar{k}_0$ represents the initial value of the quasifixed inputs.

The non-parametric DEA technique will be used for the empirical calculation of the intertemporal cost frontier, which will yield a data envelope that bounds the set of production possibilities Φ_t. With this goal, we will solve, for each of the *N* DMUs, the following linear programming problem, which will yield an estimate for $C(\bar{k}_0)$:

$$
\begin{aligned}
\hat{C}(\bar{k}_0) = & \min_{\{x_t, k_t, \lambda_t\}_{t=1}^{T}} \sum_{t=1}^{T} \gamma^t (w_t' x_t + \upsilon_t' k_{t-1}) \\
s.t.\ & X_t \lambda_t \le x_t, \qquad t = 1,2,..., T \\
& K_{t-1} \lambda_t \le k_{t-1}, \qquad t = 1,2,..., T \\
& K_t \lambda_t \ge k_t, \qquad t = 1,2,..., T-1 \\
& Y_t \lambda_t \ge y_t, \qquad t = 1,2,..., T \\
& i' \lambda_t = 1, \qquad t = 1,2,..., T \\
& k_0 = \bar{k}_0,\ x_t \ge 0, k_t \ge 0, \lambda_t \ge 0, t = 1,2,..., T
\end{aligned}
\tag{2}
$$

where $X_t = (x_{t1}, x_{t2},..., x_{tN})$ and $K_{t-1} = (k_{t-11}, k_{t-12},..., k_{t-1N})$ are, respectively, the vector of the amounts of variable and quasifixed inputs available at the start of period *t* and used in this period to produce a vector of outputs $Y_t = (y_{t1}, y_{t2},..., y_{tN})$ and of quasifixed inputs $K_t = (k_{t1}, k_{t2},..., k_{tN})$ at the end of period *t* that will be used as inputs in the following period. Vector $\lambda_t = (\lambda_{t1}, \lambda_{t2},... \lambda_{tN})$ represents the weight factors used to identify the reference DMU, while the restriction $i'\lambda_t = 1$ imposes the assumption of variable returns to scale, where *i* is a vector of N x 1 ones.

Once this optimal cost level is calculated, the overall efficiency is calculated as the ratio between the value for the efficient cost $[C(\bar{k}_0)]$ and the discounted sum of the cost observed over the period ranging from 1 to T, namely, $(\bar{C})$, that is,

$$
OE = C(k_0) / \bar{C} \tag{3}
$$

This measure of overall efficiency is a per unit rate that represents the discounted sum of the observed costs that the DMU being analyzed should have incurred if it had acted efficiently, but over the total duration of the period studied. A value for this index below unity represents a situation in which the accumulated inefficiency over the period is equal to 1-OE.

Next, this measure of overall efficiency is decomposed into three efficiency types: technical static (TE), allocative static (AE) and dynamic (DE). The first two components are defined as static because they make reference to the inefficient use of the variable inputs and accept the observed values for the levels of the quasifixed inputs. The dynamic efficiency component measures the impact on costs of not using the quasifixed factors optimally, indicating the possibility of cutting costs by reducing the use of the quasifixed inputs.

In order to calculate these three components of overall efficiency, we first evaluate the static efficiency (SE) as the product of the technical and static allocative efficiency indices, that is, $SE = TE \times AE$. The dynamic efficiency is calculated as that part of the overall efficiency that does not depend on the static efficiency. The static efficiency (SE) index is calculated as the ratio between the minimum static cost of the quasifixed inputs (C_{SE}) and the observed cost $(\bar{C})$, that is:

$$SE = C_{SE} / \bar{C} \tag{4}$$

The minimum static cost represents the expense if the minimum amount of variable inputs is used (technical efficiency) in the optimal proportion given their prices (allocative efficiency) for the observed levels of the quasifixed inputs. This cost is estimated by solving the following linear programming problem for each DMU:

$$\begin{aligned}
\hat{C}_{SE} &= \min_{\{x_t,\lambda_t\}_{t=1}^{T}} \sum_{t=1}^{T} \gamma^t (w_t' x_t + \upsilon_t' \bar{k}_{t-1}) \\
s.t.\quad & X_t \lambda_t \le x_t, && t = 1,2,\ldots,T \\
& K_{t-1}\lambda_t \le \bar{k}_{t-1}, && t = 1,2,\ldots,T \\
& K_t \lambda_t \ge \bar{k}_t, && t = 1,2,\ldots,T-1 \\
& Y_t \lambda_t \ge y_t, && t = 1,2,\ldots,T \\
& i' \lambda_t = 1, && t = 1,2,\ldots,T \\
& x_t \ge 0, \quad \lambda_t \ge 0, && t = 1,2,\ldots,T
\end{aligned} \tag{5}$$

Once OE and SE are obtained, DE is calculate as follows:

$$DE = OE / SE \tag{6}$$

In order to decompose the static efficiency into its technical and allocative components, we have to calculate the cost if the DMU reduces the utilization of all the variable inputs radially, even if they are not used in a way that is allocatively efficient, that is C_{TE}. This cost is estimated by solving the following linear programming problem:

$$\begin{aligned}
\hat{C}_{TE} &= \min_{\{\phi_t, \lambda_t\}_{t=1}^{T}} \sum_{t=1}^{T} \gamma^t (\phi_t w_t' \bar{x}_t + \upsilon_t' \bar{k}_{t-1}) \\
s.t.\quad & X_t \lambda_t \le \phi_t \bar{x}_t, \qquad t = 1,2,..., T \\
& K_{t-1}\lambda_t \le \bar{k}_{t-1}, \qquad t = 1,2,..., T \\
& K_t \lambda_t \ge \bar{k}_t, \qquad t = 1,2,..., T-1 \\
& Y_t \lambda_t \ge y_t, \qquad t = 1,2,..., T \\
& i' \lambda_t = 1, \qquad t = 1,2,..., T \\
& x_t \ge 0, \quad \lambda_t \ge 0, \qquad t = 1,2,..., T
\end{aligned} \tag{7}$$

where ϕ_t is the radial measure of static technical efficiency, interpreted as the minimum per unit rate at which the variable inputs must be used in order to be employed in a technically efficient manner. Based on this estimate for $\hat{C}_{TE}$, the static technical efficiency index is calculated as follows:

$$TE = C_{TE} / \bar{C} \tag{8}$$

The impact on costs resulting from the use of a non-optimal proportion of variable inputs, given their prices, is measured using the static allocative efficiency index proposed by Farell (1957):

$$AE = SE / TE \tag{9}$$

Lastly, we note that the overall efficiency index is the product of the static technical efficiency, static allocative efficiency and dynamic efficiency indices, that is:

$$OE = TE \times AE \times DE \tag{10}$$

In order to gain a deeper understanding of the source of technical inefficiency, the specialized literature has distinguished between pure technical efficiency (*PTE*), which is the component related to the improper use of the technology available, and scale efficiency (*SCE*), which accounts for the use of a non-optimal scale size, with *TE=PTE×SCE.*

First, as shown in Cooper, Seiford and Tone (2000), scale efficiency is calculated as the ratio of the technical efficiency obtained using the model under constant returns to scale

(ϕ_{CRS}) proposed by Charnes et al (1978), and the pure technical efficiency calculated under the variable returns to scale (ϕ_{VRS}) proposed by Banker et al (1984), that is: $SCE = \phi_{CRS} / \phi_{VRS}$. If *SCE*=1, there is scale efficiency and the producer is operating at the optimal scale; while if *SCE*<1, there is scale inefficiency and the type of returns to scale which is resulting in the inefficiency has to be calculated. To do this, and following the procedure proposed by Färe, Grosskopf and Lovell (1985, 1994), in addition to the model assuming variable returns to scale described in Section 2, we will calculate the technical efficiency under two additional models. In the first case, the model for returns to scale is calculated in which the restriction $i'\lambda_t = 1$ is eliminated. This yields a measure for technical efficiency under variable returns to scale (ϕ_{CRS}). We will next estimate the technical efficiency assuming no increasing returns to scale (ϕ_{NIRS}), which requires incorporating the restriction $i'\lambda_t \leq 1$ to the previous models. Finally, based on a comparison of the results obtained for each case, it will be possible to identify the type of returns under which the producer is operating. The returns will be constant if $\phi_{VRS} = \phi_{CRS}$, while the scale inefficiency will be due to increasing returns to scale if $\phi_{CRS} = \phi_{NIRS}$, or due to decreasing returns to scale if $\phi_{CRS} < \phi_{NIRS}$.

The second objective of this paper is to illustrate how measurements of intertemporal efficiency can be distorted by ignoring the presence of quasifixed inputs and the dynamic nature of production activity. To this end, we will use a static production approach to recalculate the overall efficiency index and its technical and allocative components. The static model treats all of the inputs (x_t and k_t) as variables; moreover, it does not consider quasifixed inputs at the end of a period as simply more outputs to be used as inputs in the subsequent period. With this approach, calculating the static technical efficiency (TE^S), allocative (AE^S) and overall (OE^S) indices based on a static DEA model requires reviewing the linear programming problems indicated earlier so as to estimate the components needed to calculate these indices, that is, $\hat{C}^S(\bar{k}_0)$ and $\hat{C}^S_{TE}$. Thus, to estimate the first of these terms, we must solve this new problem:

$$
\begin{aligned}
&\hat{C}^S(\bar{k}_0) = \min_{\{x_t, k_t, \lambda_t\}_{t=1}^T} \sum_{t=1}^{T} \gamma^t (w_t' x_t + \upsilon_t' k_{t-1}) \\
&s.t.\ X_t \lambda_t \le x_t, \qquad t = 1,2,...,T \\
&\quad K_{t-1}\lambda_t \le k_{t-1}, \qquad t = 1,2,...,T \\
&\quad Y_t \lambda_t \ge y_t, \qquad t = 1,2,...,T \\
&\quad i'\lambda_t = 1, \qquad t = 1,2,...,T \\
&\quad k_0 = \bar{k}_0,\ x_t \ge 0, k_t \ge 0, \lambda_t \ge 0, t = 1,2,...,T
\end{aligned}
\tag{11}
$$

Notice how this new problem eliminates the restriction stating that the levels of the quasifixed inputs at the end of a period are regarded as just another output of the production activity.

To calculate $\hat{C}_{TE}^S$ we must solve the static version of problem (7), namely:

$$
\begin{aligned}
&\hat{C}_{TE}^S = \min_{\{\phi_t, \lambda_t\}_{t=1}^T} \sum_{t=1}^{T} \gamma^t \phi_t (w_t' \bar{x}_t + \upsilon_t' \bar{k}_{t-1}) \\
&s.t.\ X_t \lambda_t \le \phi_t \bar{x}_t, \qquad t = 1,2,..., T \\
&\quad K_{t-1}\lambda_t \le \phi_t \bar{k}_{t-1}, \qquad t = 1,2,..., T \\
&\quad Y_t \lambda_t \ge y_t, \qquad t = 1,2,..., T \\
&\quad i'\lambda_t = 1, \qquad t = 1,2,..., T \\
&\quad x_t \ge 0, \quad \lambda_t \ge 0, \qquad t = 1,2,..., T
\end{aligned}
\tag{12}
$$

We must point out that in this static version, in addition to ignoring the production of quasifixed inputs, the radial reduction of the variable inputs affects not only the variable inputs but the quasifixed inputs as well.

If the dynamic aspect that differentiates between variable and quasifixed inputs is ignored, errors could also be introduced into the study of the components of technical efficiency that could lead to improper business or policy decisions. To evaluate this potential distortion, we will next decompose the technical efficiency into its pure and scale components as mentioned above, and identify the returns to scale by adhering to the proposal made by Färe, Grosskopf and Lovell (1985 and 1994) for both the dynamic and static models. Based on a comparison of the results, we will provide empirical evidence on the potential risk of ignoring the dynamic view when evaluating returns to scale.

3. Data

Ports have always and in every country been regarded as strategic sites. As a result, the State defines the legal regime of the ports and the degree to which the port authority is bound by said regime. Port services are usually provided through the direct oversight of part of the operations by the public sector via port authorities or other similar legal bodies, with private companies being authorized to engage in the remaining operations. The sector is, therefore, one whose regulation affects certain fundamental market aspects, such as the freedom of entry and exit, the capacity offered and the prices.

As happened in other European countries, the port system in Spain underwent a series of profound legislative reforms starting in the early 1990s, the main milestones of which were: i) Law 27/1992 on National Ports and Commercial Maritime Lines, which created the port authorities responsible for managing, planning and organizing the port infrastructure and which are coordinated by the state-owned Puertos del Estado (National Ports); its update (Law 62/1997), which allowed for the increased participation of regional authorities in the task of managing their respective ports, and Law 48/2003, which aims to promote inter-port competition by giving port authorities greater financial oversight of their financial affairs and of the costs they charge for providing their services. This reform significantly changed the institutional model of the Spanish Port System (SPS), steering it toward a landlord model and bestowing greater autonomy on ports, thus providing for greater flexibility in adapting to the changing conditions of the worldwide and regional economic scenario. The effects of this change on the SPS have been analyzed from various perspectives. Castillo-Manzano et al. (2008) found empirical evidence for the impact of the legislative changes on cargo traffic, while González and Trujillo (2008) show that these reforms have led to an improvement in technical change for a sample comprising the largest ports in the system.

The agents analyzed in this paper are all the 27 Spanish Port Authorities (PA) - Alicante, Almería, Avilés, Bahía de Algeciras, Bahía de Cádiz, Baleares, Barcelona, Bilbao, Cartagena, Castellón, Ceuta, Ferrol, Gijón, Huelva, La Coruña, Las Palmas, Málaga, Marín-Pontevedra, Melilla, Pasajes, Santa Cruz de Tenerife, Santander, Sevilla, Tarragona, Valencia, Vigo and Villagarcía – from 2000 to 2007, both inclusive.

Given the model selected for evaluating efficiency, which was presented in Section 2, this study requires data for the following variables for each PA and for each year in the period. C_t, which is the financial cost of using and providing the port infrastructure, and includes: i) the cost of the labor employed by the PA (C_{Lt}), both the administrative staff as well as the more specialized technical employees; ii) a cost of the intermediate inputs (C_{It}), which includes office supplies, water, electricity, maintenance and external services and provisions paid by Port Authorities; and iii) the capital cost (C_{Kt}), which was calculated as follows:

$$C_{Kt} = A_t + p * NPV_t \tag{13}$$

where A_t is the amortization of period t, p the profitability in real terms required of the PA, in this case 3% following Law 48/2003 modified by Law 33/2010, on the economic regime of ports, and NPV_t is the net present value.

The variable inputs (x_t) are labor (L_t) and the intermediate inputs (II_t). The quasifixed inputs (k_t) are the port infrastructure, which in this paper is represented by the following two variables: length of docks in meters (LM_t) dedicated to commercial activities and total surface area (S_t), which includes docks, warehouses, roads, buildings, etc.

As shown in Jara-Díaz et al. (2006), it is important to consider the multiproduct nature of port activities so as to correctly characterize their production structure. To do this, we distinguish between six types of outputs. The first four refer to the cargo that flows through ports. We distinguish between general cargo in containers (GCC), non-containerized general cargo (NCGC) – which includes, among others, pallets – liquid bulk (LB) and solid bulk (SB). The number of passengers (PAS) that go through the ports was also included as an additional output in order to consider its growing importance to the costs of the PAs, as noted by Nuñez-Sánchez et al. (2011). Finally, the surface area that is under concession (CS) to private companies that operate within the port complex and which pay the PA was included as an additional output of the activity carried out by the PA. The CS aims to account for the more commercial activities that take place in the port, as reflected by the surface area that the PAs rent to private companies in exchange for a fee. The companies use these areas to provide services involving cargo and the passengers, crew, individuals and other firms that operate at the various port facilities. To the best of our knowledge, this commercial activity variable has only been considered in Jara-Diaz et al. (2002), though in that study it was measured in monetary units, and thus included price effects, while in our study, it is expressed like the other outputs as a physical unit, in this case as square meters rented.

The data corresponding to these four cargo types, passengers, as well as the linear meters of dock were obtained from the Annual Reports issued by the public agency Puertos del Estado. The data needed to calculate the costs for labor, intermediate inputs and capital, as well as the number of employees and the total revenue of the PAs, were obtained from the Management Reports of the state-owned port system, which are published annually by Puertos del Estado and show this information for each PA. The information on the surface area rented from the PAs and the port surface area was obtained directly from Puertos del Estado.

The prices of the factors were obtained by dividing each factor's cost by a representative measure of the factor's amount: the number of PA employees for the price of labor (w_L), the PA's total revenue as representative of the set of PA activities for the intermediate input (w_{II}) and, finally the prices of the quasifixed inputs (v_{LM} and v_S) were obtained by dividing the corresponding capital expense by the amounts of the factors LM and S, respectively. The initial levels of the two quasifixed inputs (k_0) considered in this study, linear meters of dock and total surface area, are those associated with the values observed at the start of 1999. Table 1 provides statistical information for the descriptive variables used in our research.

Table 1.- Descriptive statistical

Variable	Units	Average	Standard deviation
Total cost	Thousands of euros	33505	24722
Labor cost	Thousands of euros	8025	5311
Intermediate input cost	Thousands of euros	6562	5575
Capital cost	Thousands of euros	18917	14646
Containerized general cargo	Thousands of tons	3528	7678
Non-containerized general cargo	Thousands of tons	1719	1943
Liquid bulk	Thousands of tons	1721	3438
Solid bulk	Thousands of tons	3081	3520
Passengers	Thousands of passengers	774	1424
Area under concession	Square meters	1149420	979078
Rental fee	Thousands of euros	8443	8708
Price of labor	Thousands of euros	39.424	4.733
Price of intermediate input	Euros	0.219	0.071
Labor	Number of employees	199	107
Intermediate input	Thousands of euros	31156	27484
Linear meters of docks	Meters	7328	4600
Total surface area	Square meters	2992187	3411660
Price per linear meter of dock	Thousands of euros/meter	1.351	0.538
Price of total surface area	Thousands of euros/m^2	0.004	0.003

Source: Annual Statistical and Management Reports for State-Owned Ports, published by Puertos del Estado.

4. Results

The solution to the linear programming problems contained in expressions (2), (5) and (7), which correspond to the dynamic model assuming variable returns to scale, yields the levels for optimal cost [$\hat{C}(\bar{k}_0)$], static efficiency [$\hat{C}_{SE}$] and technical efficiency [$\hat{C}_{TE}$] for each of the PAs in the Spanish port system. With these results from the dynamic model, we can calculate the overall, static technical, static allocative and dynamic efficiency indices using expressions (3), (8), (9) and (6), respectively. The efficiency indices for each PA are shown in Table 2.

Table 2. Efficiency indices based on dynamic model

PORT	Technical efficiency (TE)	Allocative efficiency (AE)	Static efficiency (SE)	Dynamic efficiency (DE)	Overall efficiency (OE)
ALICANTE	0.928	0.982	0.912	0.709	0.646
ALMERIA	0.887	0.976	0.866	0.791	0.685
AVILES	0.963	1.000	0.963	0.994	0.957
B. ALGEGIRAS	1.000	1.000	1.000	1.000	1.000
B. CADIZ	0.988	0.987	0.975	0.811	0.791
BALEARES	1.000	1.000	1.000	1.000	1.000
BARCELONA	0.893	1.000	0.893	1.000	0.893
BILBAO	0.988	1.000	0.988	0.982	0.970
CARTAGENA	1.000	1.000	1.000	1.000	1.000
CASTELLON	0.979	1.000	0.979	0.853	0.835
CEUTA	1.000	1.000	1.000	1.000	1.000
FERROL	1.000	1.000	1.000	1.000	1.000
GIJON	0.971	0.999	0.970	0.998	0.968
HUELVA	1.000	1.000	1.000	1.000	1.000
LA CORUÑA	1.000	1.000	1.000	0.913	0.913
LAS PALMAS	0.996	1.000	0.996	0.984	0.980
MALAGA	0.977	0.983	0.961	0.777	0.746
MARIN-PONT	0.898	0.996	0.894	0.801	0.716
MELILLA	0.943	1.000	0.943	1.000	0.943
PASAJES	1.000	1.000	1.000	1.000	1.000
SANTACTFE	1.000	1.000	1.000	1.000	1.000
SANTANDER	0.868	0.982	0.853	0.777	0.663
SEVILLA	0.990	0.978	0.968	0.844	0.817
TARRAGONA	0.915	0.996	0.911	0.903	0.823
VALENCIA	1.000	1.000	1.000	1.000	1.000
VIGO	0.942	0.986	0.928	0.727	0.675
VILLAG. AROSA	0.914	1.000	0.914	1.000	0.914
AVERAGE	**0.964**	**0.995**	**0.960**	**0.921**	**0.887**

The results show a relatively high average overall efficiency of 88.7% for the period from 2000 to 2007. This means that the improper use of the variable and quasifixed inputs has resulted in an average cost overrun of 11.3%. The decomposition of this overall inefficiency highlights the importance of the dynamic component, since the overuse of quasifixed inputs is responsible for an average inefficiency of 7.9%. This result points to the fact that the infrastructure investment process undertaken by the PAs was not optimal during the period, and evidenced excessive levels of these quasifixed inputs. As for the remaining components of overall efficiency, we should note that the proportion in which the variable inputs were combined is close to optimal, as indicated by an allocative efficiency index value close to unity. Finally, the overuse of both labor and intermediate inputs generated an average increase in costs equal to 3.6%.

A more detailed analysis of the results at the PA level reveals that the rankings for overall efficiency and for each of its components are very similar, there being no common pattern among those ports with higher levels of efficiency. There are 12 efficient ports, among them most of the large ports within Spain's port system, such as Algeciras, Baleares, Barcelona, Santa Cruz de Tenerife and Valencia, some intermediate size ports like Cartagena and Huelva, and smaller ports like Ceuta, Ferrol, Melilla, Pasajes and Villagarcía. There is also no empirical evidence that allows us to draw any conclusions regarding the effect that the traffic type may have on efficiency. We see that among the most efficient PAs, there are ports with high passenger traffic, like Algeciras, Santa Cruz de Tenerife and Baleares, and others with high container traffic, like Algeciras, Barcelona and Valencia, or with significant levels of liquid bulk traffic as is the case with the port of Cartagena.

There is another group of four ports, Avilés, Bilbao, Gijón and Las Palmas, whose efficiency level is very close to unity. Only the ports of Alicante, Almería, Santander and Vigo show efficiency indices below 70%, the value of this index being conditioned by the dynamic efficiency. Thus, the correlation coefficient between the dynamic and total efficiency is 0.987, while for the static and overall efficiency it is 0.833.

So as to obtain the results that would be yielded using a static DEA model, the programming problems presented in expressions (11) and (12) were solved. Then, using the cost estimates $\hat{C}^S(\bar{k}_0)$ and $\hat{C}^S_{TE}$, the static indices for overall (OE^S), technical (TE^S) and allocative (AE^S) efficiency were calculated using expressions (3), (8) and (9). The results are shown in Table 3. We should note that in this case, an intertemporal frontier was estimated in order to be able to interpret the difference between the results of the dynamic and static models correctly.

Table 3.- Efficiency indices based on static model

PORT	Static technical efficiency (TE^S)	Static allocative efficiency (AE^S)	Static overall efficiency (OE^S)
ALICANTE	0.683	0.855	0.584
ALMERIA	0.696	0.936	0.651
AVILES	0.963	0.968	0.932
B. ALGEGIRAS	1.000	1.000	1.000
B. CADIZ	0.982	0.790	0.776
BALEARES	1.000	1.000	1.000
BARCELONA	0.833	1.000	0.833
BILBAO	0.988	0.952	0.941
CARTAGENA	1.000	1.000	1.000
CASTELLON	0.875	0.812	0.710
CEUTA	1.000	1.000	1.000
FERROL	1.000	1.000	1.000
GIJON	0.971	0.920	0.893
HUELVA	1.000	1.000	1.000
LA CORUÑA	1.000	0.902	0.902
LAS PALMAS	0.983	0.874	0.859
MALAGA	0.850	0.769	0.654
MARIN-PONT	0.621	0.882	0.547
MELILLA	0.774	0.983	0.761
PASAJES	1.000	1.000	1.000
SANTACTFE	1.000	1.000	1.000
SANTANDER	0.827	0.801	0.662
SEVILLA	0.802	0.844	0.677
TARRAGONA	0.902	0.868	0.783
VALENCIA	1.000	1.000	1.000
VIGO	0.775	0.850	0.659
VILLAG. AROSA	0.845	1.000	0.845
AVERAGE	**0.902**	**0.927**	**0.836**

The results highlight how the static view of port activity overestimates the overall inefficiency, which in this case is equal to 16.4% on average, or 5.1 percentage points above that calculated using the dynamic model. The same thing occurs with the technical and allocative inefficiencies, which are overestimated by 6.2 and 6.8 percentage points, respectively.

A port-level analysis reveals the most important aspects of the comparison between the two models. First, all of the ports that are efficient in the static model are also efficient in the dynamic and vice versa. Second, the efficiency underestimate using the static model is exhibited for every non-efficient port. This result extends to every efficiency component, meaning that not only is the overall efficiency underestimated in the static model, but also the technical and allocative efficiencies. In the case of technical efficiency, the underestimate results from the fact that the dynamic model shown in (7) only allows for the reduction of the variable inputs, which do not include the quasifixed inputs, while in the static model given in (12), the reduction coefficient is applied to all of the inputs, since the static conception of the problem means that all of the inputs are regarded as variable. In order to facilitate a comparative analysis, we included Table 4, whose columns show the ratio of the efficiency indices obtained using both models.

Table 4.- Comparison of efficiency indices in both models

PORT	TE/TE^S	AE/AE^S	OE/OE^S
ALICANTE	1.358	1.149	1.106
ALMERIA	1.275	1.043	1.052
AVILES	1.000	1.033	1.027
B. ALGEGIRAS	1.000	1.000	1.000
B. CADIZ	1.006	1.249	1.019
BALEARES	1.000	1.000	1.000
BARCELONA	1.072	1.000	1.072
BILBAO	1.000	1.050	1.032
CARTAGENA	1.000	1.000	1.000
CASTELLON	1.119	1.232	1.176
CEUTA	1.000	1.000	1.000
FERROL	1.000	1.000	1.000
GIJON	1.000	1.086	1.084
HUELVA	1.000	1.000	1.000
LA CORUÑA	1.000	1.109	1.012
LAS PALMAS	1.013	1.144	1.141
MALAGA	1.149	1.278	1.141
MARIN-PONT	1.446	1.129	1.308
MELILLA	1.218	1.017	1.239
PASAJES	1.000	1.000	1.000
SANTACTFE	1.000	1.000	1.000
SANTANDER	1.050	1.226	1.000
SEVILLA	1.235	1.159	1.208
TARRAGONA	1.014	1.147	1.051
VALENCIA	1.000	1.000	1.000
VIGO	1.215	1.160	1.025
VILLAG. AROSA	1.082	1.000	1.082
AVERAGE	**1.083**	**1.082**	**1.066**

It is obvious that ports that are efficient under both models yield a result for this index that is equal to unity. For the remaining ports, the index is greater than unity. From a quantitative standpoint, the average underestimate of the technical efficiency index is 8.3%. But a port-level analysis shows very significant differences. Such is the case for the ports of Alicante, Almería, Marín-Pontevedra, Melilla, Sevilla y Vigo where the static model reports a technical efficiency of 35.8%, 27.5%, 44.6%, 21.8%, 23.5%, and 21.5%, respectively, below that obtained using the dynamic model. In this sense, Nemoto and Goto (2003) in the Japanese electric utilities, and Wang and Huang (2007) in the commercial banking sector provide a result similar to ours. Likewise, Geymueller (2009) provides evidence from American electrical transmission system operators that shows how efficiency measures calculated using the static DEA methodology are underestimated in comparison to the results obtained using a dynamic DEA model. It is important to note that differences also emerge along the same lines among the measures of allocative efficiency, as is the case with 60% of the ports, and significantly in the case of the ports of Cadiz, Castellón, Malaga and Santander. As a result, the overall efficiency index is underestimated in the static model. This distortion could be significant, as seen in the ports of Marín-Pontevedra, Melilla, Sevilla and Castellón. These results highlight how the static model's failure to capture the dynamic inefficiency leads to distortions in both the technical and allocative components of efficiency.

Next, in keeping with the procedure described in Section 2, we compare the technical efficiency components obtained from the static and dynamic models. Table 5 shows the pure technical and scale efficiency components, as well as the returns to scale under which each port is operating, for both the dynamic and static models.

Focusing first on the results of the dynamic model, we see that in addition to the pure technical inefficiency noted earlier (obtained using the model that assumes variable returns to scale), there is an average scale inefficiency in Spain's port system of 2%, with the highest levels present in the ports of Barcelona, Marín-Pontevedra and Villagarcía de Arosa. There is a group of ports (Barcelona, Castellón, Gijón, Melilla and Villagarcía de Arosa) where, despite the technically efficient use of production resources, the scale at which they are operating is not optimal, which is an additional cause of inefficiency. Finally, we note that based on the results, there is no common pattern to the distribution of the pure technical and scale efficiencies. Specifically, neither the predominant type of traffic at each port nor the port's size provides an explanation for the decomposition of technical efficiency.

Table 5.- Decomposition of technical efficiency and type of returns to scale in both models

PORT	Dynamic model			Static model		
	Pure Technical Efficiency	Scale Efficiency	Returns to Scale	Pure Technical Efficiency	Scale Efficiency	Returns to Scale
ALICANTE	0.954	0.973	DRS	0.756	0.904	IRS
ALMERIA	0.910	0.975	IRS	0.733	0.949	IRS
AVILES	0.993	0.970	IRS	0.993	0.970	IRS
B. ALGEGIRAS	1.000	1.000	CRS	1.000	1.000	CRS
B. CADIZ	0.992	0.996	DRS	0.991	0.991	DRS
BALEARES	1.000	1.000	CRS	1.000	1.000	CRS
BARCELONA	1.000	0.893	CRS	1.000	0.833	DRS
BILBAO	0.988	1.000	CRS	0.988	1.000	CRS
CARTAGENA	1.000	1.000	CRS	1.000	1.000	CRS
CASTELLON	1.000	0.979	IRS	0.995	0.879	IRS
CEUTA	1.000	1.000	CRS	1.000	1.000	CRS
FERROL	1.000	1.000	CRS	1.000	1.000	CRS
GIJON	1.000	0.971	IRS	1.000	0.971	CRS
HUELVA	1.000	1.000	CRS	1.000	1.000	CRS
LA CORUÑA	1.000	1.000	CRS	1.000	1.000	CRS
LAS PALMAS	1.000	0.996	CRS	0.987	0.996	DRS
MALAGA	0.987	0.990	IRS	0.947	0.898	IRS
MARIN-PONT	0.982	0.914	IRS	0.873	0.711	IRS
MELILLA	1.000	0.943	IRS	1.000	0.774	IRS
PASAJES	1.000	1.000	CRS	1.000	1.000	CRS
SANTACTFE	1.000	1.000	CRS	1.000	1.000	CRS
SANTANDER	0.888	0.978	DRS	0.850	0.973	IRS
SEVILLA	0.992	0.998	IRS	0.829	0.967	DRS
TARRAGONA	0.941	0.972	DRS	0.928	0.972	DRS
VALENCIA	1.000	1.000	CRS	1.000	1.000	CRS
VIGO	0.955	0.986	DRS	0.803	0.965	DRS
VILLAG. AROSA	1.000	0.914	IRS	1.000	0.845	IRS
AVERAGE	**0.985**	**0.980**	**-**	**0.951**	**0.948**	**-**

Comparing the technical efficiency indices obtained from the models that assume CRS, VRS and NIRS allowed us to identify the type of returns to scale for each port authority. We see that 13 of the 27 ports analyzed are operating under constant returns to scale, while nine are doing so under increasing returns to scale. This result confirms prior findings for this same sector (Núñez et al. (2011) and Jara-Díaz et al. (2002)), which indicate that the existence of increasing returns to scale converge to constant returns as traffic levels increase.

Following the same procedure as in the dynamic case yielded the pure technical and scale efficiencies for the static model. In this case, an average scale inefficiency of 5% was identified. The effect on inefficiency of operating at a non-optimal size exceeded 10% in the ports of Barcelona, Castellón, Málaga and Villagarcía de Arosa, and 20% at the ports of Marín-Pontevedra and Melilla.

Finally, a comparison of the results obtained using the dynamic and static models reveals, first of all, that not considering the existence of quasifixed (indivisible and long service life) inputs leads to underestimating both components of efficiency; in other words, the measures of pure technical and scale efficiency calculated using the static model are lower for every port than those obtained using the dynamic model. This result highlights the importance of distinguishing between the variable and quasifixed inputs in the model, since not doing so will exaggerate both the pure technical and scale inefficiencies. Secondly, we should also underscore that the type of returns to scale changed in 20% of the ports analyzed, which reinforces the idea that not considering the presence of quasifixed inputs can significantly alter the results, and could call into question the suitability of any decisions that are made based on this characteristic of technology.

5. Conclusions

The indivisibilities and long service life of port facilities result in this production factor being regarded as a quasifixed input, meaning that it cannot be immediately adjusted to actual production and that it contributes to the production of services over several consecutive periods. These characteristics of port technology require formulating a dynamic model for measuring efficiency that acknowledges the existence of an intertemporal relationship between the inputs used and the resulting outputs.

In this paper we have calculated the efficiency of the provision and utilization of the infrastructure of Spanish ports applying a dynamic DEA model to a database compiled for the period from 2000 to 2007. The measure of overall efficiency at Spanish port authorities shows an average inefficiency of 11.3%. The decomposition of this inefficiency shows that it is determined primarily by the improper use of quasifixed inputs, which increases costs on average by 7.9%. This highlights how the infrastructure investment process undertaken by Spanish port authorities was not optimal during the period analyzed, with excessive levels of docks and port surface area. Moreover, the overuse of both labor and intermediate inputs caused by the technical inefficiency generated an average cost increase of 3.6%. With respect to the contribution from allocative inefficiency, the proportion in which the variable inputs were combined is close to optimal.

Failing to consider the dynamic nature of the technology used by port authorities leads to an improper estimate of their efficiency. By ignoring the interrelationship in time among the technologies used in each period, the measures for overall, pure technical, scale and allocative inefficiency under a static view of port activity will be overestimated if the quasifixed inputs are used inefficiently. The difference between the results of the dynamic and static models emphasize the importance of acknowledging and modeling the presence of quasifixed inputs, whose use cannot be immediately adjusted and whose contribution to the production of port services extends over time. What is more, ignoring the dynamic aspects imposed by the use of quasifixed inputs, such as an infrastructure, can have a significant effect on the type of returns to scale under which the port is assumed to be operating.

An erroneous inefficiency calculation can lead to faulty policy or business management decisions. If a system for setting prices based on recovering total costs is followed, as is the case with Spain's port system, the port's inefficiency is transferred to the user. In addition, the use of a dynamic model lets us to measure the inefficiency caused by the inadequate use of quasifixed inputs and obtain a correct measure of the production scale with the implications that this has on investment decisions. Finally, the evaluation of the productive performance is also affected by the improper choice of model, as evidenced by the underestimate in the efficiency that results from the use of a conventional static approach.

References

Banker, R.D., Charnes, A. and Cooper, W.W. (1984) Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, 30 (9), 1078-1092.

Bichou, K. and Gray, R. (2005) A critical review of conventional terminology for classifying seaports. *Transportation Research Part A*, 39, 75-92.

Castillo-Manzano, J, López-Valpuesta, L. and Pérez, J. (2008) Economic analysis of the Spanish port sector reform during the 1990s. *Transportation Research Part A*, 42.

Charnes, A., Cooper, W.W. and Rhodes, E. (1978) Measuring the efficiency of decision makings units. *European Journal of Operational Research* 2, (6), 429-444.

Cooper, W.W., Seiford, L.M. and Tone, K. (2000) *Data Envelopment Analysis. A Comprehensive Text with Models, Applications, References and DEA-Solver Software*. Kluwer Academic Publishers.

Cullinane, K.P.B. and Song, D. (2002) Port privatization policy and practice. *Transport Reviews*, 22, 55-75.

Cullinane, K.P.B., Song, D.-W., Ji, P. and Wang, T. (2004) An application of DEA Windows analysis to container port production efficiency. *Review of Network Economics*, 3(2), pp. 186–208.

Cullinane, K.P.B., Wang, T., Song, D.-W., Ji, P. (2006) The technical efficiency of container ports: Comparing data envelopment analysis and stochastic frontier analysis. *Transportation Research Part A*, 40, 354-374

Cullinane, K.P.B and Wang, T. (2007) Data Envelopment Analysis (DEA) and improving container port efficiency. Devolution, Port Governance and Port Performance. *Research in Transportation Economics*, 17, 517-566.

De Mateo, F., Coelli, T. and O´Donnell, C. (2006) Optimal paths and costs of adjustment in dynamic DEA models: with application to Chilean department stores. *Annals Operations Research*, 145, 211-227.

Emrouznejad, A. and Thanassoulis, E. (2005) A mathematical model for dynamic efficiency using data envelopment analysis. *Applied Mathematics and Computation*, 160, 363–378.

Emrouznejad, A. and E. Thanassoulis (2010) Measurement of productivity index with dynamic DEA. *International Journal of Operational Research* 8(2), 247-260.

Färe, R. and Grosskopf, S. (1996) *Intertemporal Production Frontiers: with Dynamic DEA*. Kluwer Academic Publishers.

Färe, R., Grosskopf, S. and Lovell, C. (1985) *The measurement of Productive Efficiency*. Kluwer Academic Press.

Färe, R., Grosskopf, S. and Lovell, C. (1994) *Production Frontiers*. University of Cambridge Press

Farrell, M.J. (1957) The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society*, Serie A, General, 120, Part 3, 253-81.

Geymueller, P. (2009) Static versus dynamic DEA in electricity regulation: the case of US transmission system operators. *Central European Journal of Operations Research* 17, 397-413.

González, M. and Trujillo, L. (2008) Reforms and infrastructure efficiency in Spain´s container ports. *Transportation Research Part A*, 42, 243-257.

Jara-Díaz, S., Martínez-Budría, E., Cortés, C. and Basso, L. (2002) A Multioutput cost function for the services of Spanish Ports' infrastructure. *Transportation*, 29 (4), 419-437.

Jara-Díaz, S., Martínez-Budría, E., and Díaz-Hernández, J.J. (2006) Multiple output in port cost functions. *Port Economics. Research in Transportation Economics*,16, eds K. Cullinane and W.K. Talley, pp. 67-84, Elsevier.

Limao, N. and Venables, A. (2001) Infraestructure, geographical disadvantage, transport cost and trade. *The World Bank Economic Review*, 15 (3), 450-479.

Márquez Ramos, L. Martínez Zarzoso, I., Pérez García, E., and Wilmsmeier, G. (2007) Determinantes de los costes de transporte marítimos. El caso de las exportaciones españolas. *Información Comercial Española. Revista de Economía*, 834, 79-93.

Nemoto, J. and Goto, M. (1999) Dynamic Data Envelopment Analysis: modelling intertemporal behaviour of a firm in the presence of productive inefficiencies. *Economics Letters*, 64, 51-56.

Nemoto, J. and Goto, M. (2003) Measurement of dynamic efficiency in productions: an application of Data Envelopment Analysis to Japanese electric utilities. *Journal of Productivity Analysis*, 19, 191-210.

Núñez-Sánchez, R., Jara-Díaz, S. and Coto-Millán, P. (2011) Public regulation and passengers in port infraestructure costs. *Transportation Research Part A*, 45, 653-666.

Ouellette, P. and Vierstraete, V. (2004) Technological change and efficiency in the presence of quasi-fixed inputs: A DEA application to the hospital sector. *European Journal of Operational Research*, 154, 755-763.

Ouellette, P. and Vierstraete, V. (2010) Malmquist indexes with quasi-fixed inputs: an application to school districts in Quebec. *Annals Operations Research*, 173, 57-76.

Ouellette, P. and Yan, L. (2008) Investment and dynamic DEA. *Journal of Productivity Analysis*, 29, 235-247.

Panayides, P., Maxoulis, C., Wang, T. and Ng, K. Y. A. (2009) A critical analysis of DEA. Applications to seaport economic efficiency measurement. *Transport Reviews*, 29:2, 183-206.

Sengupta, K. (1995) *Dynamics of Data Envelopment Analysis: Theory of System Efficiency*, Kluwer Academic Publishers, Dordrecht, London.

Wang, M. and Huang, T (2007) A study on the persistente of Farrell´s efficiency measure under a dynamic framework. *European Journal of Operational Research*, 180, 1302-1316.

Woo, S., Pettit, S., Kwak, D. and Beresford, A. (2011) Seaport research: A structured literature review on methodological issues since the 1980s. *Transportation Research Part A*, 45, 667-685.