MEASURING THE RELATIVE EFFICIENCY OF EUROPEAN PORTS: THE ROLE OF REGULATION AND OTHER NON DISCRETIONARY FACTORS. A MULTI-STEP APPROACH.

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SOMMARIO

This paper provides an estimation of the impact of exogenous factors - such as governance regimes and local socio-economic conditions – and managerial capacity, cleared of statistical noise, on the efficiency of ports. We implement a three stage DEA procedure following the approach of Fried et al. (2002), using a panel of European ports, observed over a ten year period. Using a mixed DEA and SFA approach, we are able, thus, to identify the determinants of input-specific efficiency differentials across ports. The outcome shows that, in general, governance related factors and other external elements predominates on the managerial skills in determining efficiency conditions of ports. The third step of the analysis is to rerun the DEA calculations with the adjusted factors to determine efficiency scores cleared of exogenous factors. The procedure helps to gain further insights on the evolution of the port industry in the EU and to propose strategies for improving operational performance of ports, passing through governance and regulatory framework. Results show, in fact, that there are significant variations in efficiency levels across the ports in the sample and that performances change significantly by controlling for factors considered outside direct ports’ managers control.
1. INTRODUCTION

The port sector plays an important role in the economic development of a country and public sector involvement, although, to a varying degree in the different EU countries, is still quite significant. Economic conditions, globalisation and technological innovations have increased the competitive pressures on the overall industry. This situation has stimulated increasing interests on the capacity of ports to respond effectively to the increasingly growing requirements of shipping lines, the hinterland, local authorities and, in general, final users. Information of ports’ efficiency and its evolution is pivotal for the evaluation of both managerial strategies and port planning, at local and national level. This is the more so in the presence of policy changes that might influence the governance structure of ports. Many countries, especially in Europe, have, in the last decades, adapted their port-related legal framework in order to give ports more flexibility in all aspects related to management, commercial strategies and financing (De Monie (1996); Suykens and Van de Voorde (1998), Trujillo and Nombela (2000), Noteboom and Winkelmans (2001), Bergantino (2002), Tovar et al. (2004), Castillo-Manzano et al. (2008), Musso (2008)).

Researchers have, thus, focussed increasing attention on the measurement of efficiency in the port industry\(^1\). Although a number of different approaches have been adopted, there is a general consensus on either DEA or SFA related measures\(^2\). They represent two alternative methods to measure efficiency based on frontier models. Both techniques allow derivation of relative efficiency within a group of units of analysis.

It is well known that DEA is a non-parametric mathematical programming technique used for estimating the relative efficiency and return to scale of decision making units that perform the same or similar tasks in a production system, through the construction of a best practice frontier. Since it was first developed by Charnes et al. (1978) and extended

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\(^2\) For a general overview of DEA approach the reader is referred to Charnes et al. (1978), Banker et al (1984) and Cooper et al. (2000). In addition, for a comparison of the two methods, see: Coelli et al. (2005) and Fried et al (2008).
by Banker at al. (1984), various DEA approaches have been widely applied for the efficiency evaluation throughout different industries, including public and private sectors. SFA, on the other hand, is an econometric technique which involves imposing a particular functional form and specific distribution assumptions for the one-sided error term associated with technical efficiency. Both have advantages and disadvantages. In particular, DEA, contrary to SFA which allows to include the term explicitly in the model, seemed to be unable to give insights on the role played by the operating environment focussing on internal factor.

The role played by non-discretionary characteristics in affecting performances, however, has been gaining momentum in the literature investigating the determinants of production inefficiency in sectors with relevant involvement of the public sector. Efficiency gaps, in fact, might be due to, besides managerial lack of capability, either the high degree (or the form) of government involvement (i.e. alternative governance regimes might give rise, ceteris paribus, to inefficiency differentials across operators) or the different operating conditions, that are not controlled by operators. These considerations fit well the transport sector in general and the port industry in particular. Port and terminal efficiency are the main drivers of port selection by shippers and shipping companies.\(^\text{3}\)

On the basis of these considerations, for a long time, the SFA has been favoured in the dedicated literature. Stochastic frontier models allow to analyse directly the impact of these factors on the absolute efficiency of the sample. The widespread result is that the predictions from incentive theory do, indeed, explain productive efficiency differentials. With reference to the maritime industry, Cullinane et al (2002) and Cullinane and Song (2006) estimated the efficiency of terminal operators dealing with the role played by different administrative and ownership structures in the industry as exogenous factors affecting inefficiency differentials. They also find a significance influence of external factors on the overall terminal’s efficiency. Also Trujillo and Tovar (2007) results point in the same direction.

These studies although shading light on the relevance of the operational and institutional environment of ports in influencing ports’ efficiency outcome, show only “aggregated” efficiency results. In fact, while stochastic methods provide extremely valid insights in identifying the importance of the relationship between factors external to companies’ control and their performance, they do not yield indications on how to narrow the

\(^{3}\) For a review of the port selection criteria and their evolution the reader is referred to, for instance: Murphy and Daley (1994); Bergantino and Coppejans (2000); Cullinane et al. (2001) and Tongzon (2002).
efficiency-gaps nor on which inputs are majorly affected by the operating conditions. They fall short of distinguishing the impact of external factors and noise from the effects of managerial skills on efficiency, on an input-by-input base. As a matter of fact, inputs employed by ports can be rationalised to different extents. Hence, changes in regulation and/or non-discretionary characteristics may induce higher efficiency in the use of more controllable inputs compared to less controllable ones: capital and labour, for instance, might be influenced differently by different forms of regulation or different economic conditions. Their overall effect on the technical efficiency of the port might differ, independently of the managerial capacity of the authorities.

On this account, in recent years, there have been some developments in DEA-based models. In particular, starting from the work of Fried et al. (1999 and 2002), operating environment and statistical noise have been introduced in the DEA-framework through a multi-stage procedure combining DEA and SFA.

This current analysis presents a number of advantages and integrates well the existing literature. Building on previous literature it aims at verifying the extent to which both governance and other non-discretionary factors affect input inefficiencies in the port sector, across countries, using a combination of DEA and SFA. Ports’ relative efficiency has been, in fact, calculated without imposing any ex-ante assumption on the functional form as, instead, it would have been necessary, should SFA have been adopted and it has been possible to quantify, input by input, the contribution to a port’s efficiency level of three main factors: exogenous factor (outside the managers’ control but modifiable by regulators and policy-makers), managers’ abilities and statistical noise. The outcome of the study allows the assessment the efficiency enhancing effect of different forms of governance of the port authorities across countries and regions and complements the SFA in the capacity of identifying the source of inefficiencies input by input. The third stage reruns the DEA using inputs that are adjusted to reflect differences in the nature of ports’ exogenous conditions. What is left is a set of rankings that more accurately reflects differences in ports’ relative efficiency.

The rest of the paper is organised as follows. Section 2 briefly reviews the mixed DEA-SFA methodology used by Fried et al. (2002) to take account of input-by-input sources of slacks, while, section 3 details the implementation to our case study with the identification of the variables and the data description. The results of the three step procedure are presented in Section 4. Section 5 concludes the paper with a brief outline of the main implications of the analysis and some suggestions for future research.
2. ESTIMATION METHODOLOGY

The purpose of this section is to detail the estimation approach used in identifying the true managerial performance of ports once the playing field has been levelled by taking account of input-by-input sources of slacks. As stated in the introduction, our approach is based on Fried et al. (2002)’s three step methodology.

2.1. Inclusion of external factors

The two main limitation of DEA, i.e. assumption that data is free of measurement errors and that it cannot take explicitly into account environmental factors, have lead to the flourishing of different solutions aiming to overcome these limits. There are at least two main approaches to incorporating uncontrollable or non-discretionary inputs in DEA. The first approaches were based on a single step procedure, where uncontrollable inputs were included in DEA as a constraint in linear programming (Banker and Morey, 1986). However, for all those case for which it is preferable to test the direction of the impact of discretionary factors on efficiency, this approach is not appropriate (Avkiran and Rowlands, 2008) and the multiple step approach comes in. This approach entails a number of methods. However, a common practice is to run DEA where all the inputs are treated as controllable and then, in stage two, regress the emerging efficiency scores on non-discretionary inputs and run the DEA using the adjusted inputs. Fried et al (2002) implemented this procedure.

2.2 Three step procedure

Fried et al (2002)’s procedure to clear producers’ performance evaluation of environmental effects an statistical noise consists of a three stage analysis that starts with DEA. The second stage is a SFA. It serves to explain the variation in organisational performance measured in the first stage in terms of operating environment, statistical noise and managerial efficiency. Global input inefficiencies determined in stage one are regressed on a set of regressors relating to regulatory and to other exogenous factors. The third stage concludes with a new DEA of organisational performance. The analysis is carried out using adjusted data from the second stage that have been purged of the influence of the operating environment and statistical noise. The re-evaluation of performance allows for a better assessment of the role played by managerial skills as the evaluation emerging from stage three DEA represents managerial efficiency only.
2.2.1 First step

Consider $i$ Decision Making Units (DMUs), with $i = 1, \ldots, I$, each of them employing $N$ inputs ($n = 1, \ldots, N$) to produce $M$ outputs ($m = 1, \ldots, M$). Using data on observed inputs and outputs, a standard input-oriented variable returns to scale envelopment problem is solved for each $i_{th}$ DMU in the sample (Banker et al. 1984). In stage 1 an input oriented variable return to scale DEA with the conventional BCC model is used. The Linear programming problem outlined by the authors is:

$$\begin{align*}
\text{Min} & \quad \theta \\
\text{s.t.} & \quad \theta x_i \geq X\lambda \\
& \quad \lambda Y \geq y_i \\
& \quad \lambda \geq 0 \\
& \quad e \lambda = 1
\end{align*} \tag{1}$$

where $x_i$ is a DMUs $N \times 1$ non-negative vector of inputs; $y_i$ is a DMUs $M \times 1$ non-negative vector of outputs; $\lambda = [\lambda_1, \ldots, \lambda_I]$ is an $I \times 1$ vector of intensity variables; $X = [x_1, \ldots, x_I]$ is an $N \times I$ matrix of input vectors in the comparison set; $Y = [y_1, \ldots, y_I]$ is an $M \times I$ matrix of output vectors in the comparison set; $e = [1, \ldots, I]$ is an $I \times 1$ vector.

The optimal solution to emerge from equation (1) are the preliminary performance evaluation scores. The total slacks - radial plus non radial -, for each input are calculated as the following non-negative scalars$^4$:

$$S_{ni} = x_{ni} - X_n\lambda \tag{2}$$

DEA-based measures of the $i^{th}$ producer performance, relative to the best-practise nonparametric frontier, however, has the limitation of neglecting two possible sources of inefficiency:

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$^4$ The input slack represents the overall input excess with respect to the optimal use under best practice conditions.
i) DEA models are solely based on input and output data while external and operation factors might have, instead, a significant role in affecting overall efficiency levels of the various DMUs;

ii) omitted variables are ruled out from the performance evaluation since the DEA framework is deterministic.

Not accounting for either of these non-discretionary differentials across firms belonging to the sample might lead to over or under evaluated performances and misleading rankings. A solution to such a limitation is given by adopting SFA to decompose DEA input slacks into exogenous effects, managerial inefficiency and statistical noise.

### 2.2.2 Second step

In stage two, using SFA input slacks are regressed on observable non-discretionary regulatory and environmental variables and a composite error term that captures statistical noise due to measurement errors and managerial inefficiency. The aim is to clear slacks of external effects and statistical noise not accounted for in stage one, letting each of the exogenous characteristics produce a different impact across the SFA equations.

The N separate SFA regressions take the following form:

\[
s_{ni} = f_n(z_i, \beta_n) + \nu_{ni} + u_{ni} \tag{3}\]

where \( s_{ni} \) is stage 1 slack for the \( n \)th input and the \( i \)th DMU, \( z_i = [z_{1i}, \ldots, z_{Ki}] \) is a vector of K exogenous variables, \( \beta_n \) are unknown parameters to be estimated and \( (\nu_{ni} + u_{ni}) \) is a composite error term. The component \( \nu_{ni} \sim (0, \sigma^2_{\nu n}) \) represents statistical noise, while the one-sided truncated-normal error term \( u_{ni} \sim N+(\mu_n, \sigma^2_{un}) \) reflects pure managerial inefficiency, with mean \( \mu_n \) and variability \( \sigma^2_{un} \) across observed slacks of the \( n \)th input. For the alternative assumption of half-normal distributed managerial inefficiency, the latter is, instead, \( u_{ni} \sim N+(0, \sigma^2_{un}) \).

The SFA regression model does not require specification of the direction of the impact of the non-discretionary variables: it can be read by the sign of the estimated coefficients.
Each of the \( N \) regressions [3] can be estimated by maximum likelihood (ML) techniques. In each regression the parameters to be estimated are \( \beta_n, \mu_n, \sigma^2_{\text{un}}, \) if the inefficiency error term is assumed to be truncated or \( \beta_n, \sigma^2_{\text{un}}, \sigma^2_{\text{un}} \) if the error term is assumed to be half-normally distributed. All parameters are allowed to vary across the \( N \) input slack regressions, which allows all of the three elements (the non-discretionary variables, statistical noise and managerial inefficiency) to exert, each, a different impact across inputs.

The *deterministic* feasible slack frontier term \( f_n(z_i, \beta_n) \) captures the impact of observable external factors (regulation and environmental characteristics) on the stage one slacks, while the *stochastic* feasible slack frontiers is given by the expression \( f_n(z_i, \beta_n) + \nu_{ni} \), which indicates the minimum achievable slack in a noisy context since \( \nu_{ni} \geq 0 \). Any slack in excess of the stochastic feasible slack frontier are attributable to managerial inefficiency because the effect of non-discretionary variables and statistical noise have been netted out. The managerial inefficiency component of the slacks is captured by the non negative error components \( \nu_{ni} \), with the parameters \( (\mu_n, \sigma^2_{\text{un}}) \) reflecting the variability of managerial inefficiency across both DMUs and inputs.

Parameter estimates obtained from SFA regressions are used to predict input slacks attributable to the operating environment and to statistical noise. Thus, observed inputs can be adjusted for the impact of the environment and statistical noise using the resulting estimates for \( \beta_n \) and \( \nu_{ni} \):

\[
x_{ni}^{\text{Adj}} = x_{ni} + [\max_i(z_i \hat{\beta}_n) - z_i \hat{\beta}_n] + [\max_i(\nu_i) - \nu_i]
\]

(4)

where \( (x_{ni}^{\text{Adj}}) \) is the adjusted quantity of the \( nth \) input in the \( ith \) DMU.

The terms in brackets represent the adjustments and are used to create, “artificially”, a level playing field for the DMUs in the sample: the first term in square brackets places all firms in the least favourable environment observed in the sample, while the second term in square brackets forces all firms to operate in the worst situation observed in the sample. By doing so, distortions from the efficient usage of each input due to external factors and random noise, which are not under the control of DMUs, are removed. Econometric computer programmes such as LIMDEP and FRONTIER can be used to estimate the parameters of the SFA regression.
In order to assess true performance it is necessary to distinguish between statistical noise \((\nu_{ni})\) due to the inputs used from managerial inefficiency \((u_{ni})\) in the composed error term of the SFA regression. Once \(\nu_{ni}\) has been estimated [4] can be implemented and observed input usage adjusted\(^5\). The statistical noise attached to an input usage, which is conditional on the composite error structure, is estimating by subtracting from the input slack calculated in step 1 the estimate of the input slack for a given DMU attributed to non-discretionary factors and the conditional estimate of managerial inefficiency for the same input and DMU.

### 2.2.3 Third step

In the third step DEA is repeated replacing the observed input data with adjusted input data in order to reflect differences in DMUs exogenous conditions. The outcome represent DMUs performance due to managerial efficiency only. Comparison between initial and final DEA efficiency measures gives, thus, an understanding of the extent to which non-discretionary variables affect efficiency differentials, other things being equal.

### 3. THE SPECIFICATION OF THE MODEL

The current section describes the implementation of this methodology to our case study, focusing on the specification of nonparametric deterministic reference technology and on the modelling of regulatory schemes and other environmental variables involved in the subsequent SFA. One might, in principle, try to estimate the efficiency conditions in either a demand or a supply-related framework. However, as Cullinane and Wang (2006) point out, supply-related output indicators of port services might be considered under greater managerial control than demand. Although regulatory constrains (both institutional and financial) influence strongly the service level provision and supply in general, it is reasonable to think that such constraints are the outcome of some negotiation process with the regulatory authorities. Thus, the analysis is carried out adopting an input-oriented DEA framework.

\(^5\) The method used to separate the composed error term into its components has been developed by Jondrow et al (1982).
3.1 Variables selection

Port activity is complex and involves a number of functions and stakeholders. Ports are “factories designed to receive and dispatch cargo that arrives in many different forms” (Jara-Diaz et al. 2006, p. 68) and, depending on which feature of the port operations are being valued, there are a number of different measures of port output. The movement of cargo is one of the most widely used ones and can take many different forms. Since the scope of the current analysis is to test efficiency of ports across various EU countries, notwithstanding their specific vocation, port output is identified as “port throughput expressed in total tonnes of cargo handled per annum”. Although the selected measure has been subject to some criticism when the analysis was focussed on container terminal, its use in this framework might be justified in the light of the wider scope of the present study. In this case, in fact, the more commonly used measure of TEUs or of the number of containers handled, although it would improve the precision of the estimates by considering a more homogeneous product, it would limit the extent of the analysis to only one of the port activities. As stated earlier, we considered each port with all its transport related activities, a single unit of analysis.

The services produced by the port require a large variety of inputs. Based on the production framework, port inputs can be generalised as: land, labour and capital, which can be grossly redefined as space, employees, facilities and equipment, respectively. In the light of the difficulties in obtaining reliable direct data and information on labour inputs, this variable is generally considered pre-determined and it is excluded from the estimation.

Following the literature flourished in this field, thus, the choice of inputs has fallen on those related to physical factors: dimension of quay, number of terminals, area of the port

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6 For a detailed analysis of the variable selection the reader is referred to Cullinane and Song (2006).
7 A number of authors consider that port activities should be specified in a multiple output form, however, the aggregate output approach, on account of data availability, has been favoured in many studies. For a detailed review of the issue, see, for instance, Jara-Diaz et al., 2006.
8 A number of authors point out that labour information can be determined as a function of the facilities of a port and that, thus, they can be excluded from the estimation (see for instance; Tongzon, 1995; Notteboom et al., 2000; Turner et al, 2004; Trujillo and Tovar, 2005; Gonzales and Trujillo, 2008). In particular, Notteboom et al (2000), report no statistical significance for this input and attribute the result to the co-linearity of the variable with that related to equipments. As Cullinane et al (2004) point out, however, it should be emphasised that there are a number of caveats linked to this assumption which should be clearly stated. For instance, they refer to technological progress, which might induce dramatic changes in any pre-determined relationship between terminal facilities and the absolute number of workers or to the differences in the use of labour in ports of different sizes, with different clients, or, and this is particularly relevant for this study, for different governance regimes. For greater details, Cullinane et al. (2002).
used for handling freight, cargo handling equipment (cranes, lifters, link-belt). Table 1 reports descriptive statistics on outputs and inputs used in the analysis.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Average</th>
<th>St. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total movements (tons)</td>
<td>57.206,50</td>
<td>86.921,86</td>
</tr>
<tr>
<td>Dimension of quay (sqm)</td>
<td>103.587,64</td>
<td>410.879,00</td>
</tr>
<tr>
<td>Number of terminals (units)</td>
<td>17</td>
<td>20,069</td>
</tr>
<tr>
<td>Area of the port for Handling (sqm)</td>
<td>1.636.037,393</td>
<td>2.580.033,952</td>
</tr>
<tr>
<td>Handling equipment (units)</td>
<td>315,928</td>
<td>359,697</td>
</tr>
</tbody>
</table>

As previously illustrated, in order to take account the external conditions that might influence ports’ efficiency scores, a number of exogenous variables, beyond management control, have been considered. The exogenous variables used in the second stage are of two types: environmental, non-discretionary, variables and policy variables. The former, take account of the impact of the different characteristics of the area where the port is located, thus control for heterogeneity among ports. The latter, relates to the governance set-up and, more specifically, it aims to pin-point the potential changes in the economic environment that occurs after the introduction of new regulatory framework. This variable, vary across country and time, but is not differentiated for ports belonging to the same country, since, in general, port regulation is determined at national level.

This set of variables have been selected with a twofold objective: on the one side to capture additional sources of inefficiency not accountable by managerial efforts; on the other side, to identify their specific effects on each of the inputs considered in the analysis and thus highlight possible specific policy intervention measures.
Non-discretionary characteristics include variables linked to the operating context of each port and to other external factors outside management control. Considering the need to identify variables that would be able to account differentials both among ports of different countries and ports of the same country, the choice has fallen on: regional GDP, employment rate, population density, accessibility. Gross domestic product (GDP) to capture the derived nature of the port service and maritime transport demands from economic activity. It is expected that as GDP grows the throughput of a port increases. Also regional employment rate (EMPL) and population density per square kilometre (POPDENS) is considered a proxy for local demand and it is reported as a ratio to EU average values in order to signal the differences to the other areas involved in the analysis.

Accessibility, to the mind of the authors, should have been included as the effective level of surface accessibility (rail/road) to the origin/destination market of the freight, considering the country import/export flows. Difficulties in gathering data sufficiently homogeneous among the different areas involved, has induced us to define the variable as the presence of a direct link to the national rail arteries from within the port. The variable (ACCESS) takes the value of 0 and 1, with 0 for the ports which do not have a direct link to the main rail network. This data has been collected from published data and also through direct interviews.

In relation to port legislation and ports’ governance framework, the last twenty years have been characterised by significant changes. A number of measures were implemented aiming at increasing the autonomy of individual ports in the management, financing and organisation of its activities. Most ports in the sample experienced a change in the regulation during the period under investigation. Since identifying the extent of the implementation of each subsequent measure at port level is an extremely complex task, the regulatory context has been approximated by a dummy (REG), taking the value of one after the introduction of a relevant policy measure aiming at increasing the autonomy of the port with respect to the central government in all aspects related to management, commercial strategies and financing. In the footsteps of previous studies related to terminal operations and to other transport sectors, especially public transport, it is expected that the introduction of greater autonomy will increase the level of efficiency and reduce the slacks in the use of the resources, at least for those inputs that are more suitable for rationalisation.
The expectation is that all these exogenous variables should have a positive effect on technical efficiency through a reduction of the slacks for the selected capital and space related inputs.

A time trend (TREND) has also been included to account for any technological changes. Given the structure of the second stage estimation, the time trend variable captures only technological shifts, and not, instead, changes in managerial performances which are embodied in the one-sided distributed error component\(^9\). Although technical progress is a usual hypothesis, there are no \textit{a priori} forecasts on its impact, especially within an input-by-input framework. However, it wouldn’t be surprising if technological progress was encouraged by the increasingly competitive situation of the European port industry.

Finally, two dummies have been defined to verify if results generally observed can be confirmed by our exercise: a dummy segmenting ports by size (DDIM) and a dummy separating ports accordingly to their involvement in container traffic (DCONTRATE).

\subsection*{3.2 Data description}

The dataset used in the following analysis consists of a balanced panel of 30 European ports. Observations cover the ten year period 1995-2005. The database is assembled with data referring to 1995, 1997, 2000, 2002, 2005 for a total of 150 pooled observations.

Our sample is fairly representative of the European port system: 40\% of the sampled ports are specialised in the container service while the remaining 60\% mostly operate in the international, long distance, traffic and can be defined as multi-service ports. Twelve operators are located in the Northern Range and eighteen provide services in Central and Southern Mediterranean.

The information for the construction of the database was gathered from different sources, although the bulk of information were extracted from Lloyds Port of the world, Containerisation International Yearbook and Port Authority Reports and websites. Disaggregated information concerning specific aspects have been obtained thought direct telephone interviews with port authority representatives. The environmental, non discretionary variables, related mainly to macro-economic indicators, used in the second

\footnote{Changes in managerial performance due to experience are embodied in the one-sided distributed inefficiency component as specified in the Battese and Coelli (1992) SFA approach.}
stage of the estimation, are taken from the Eurostat database, integrated, when necessary, with national statistical office information. The information on the governance practice for the European port industry was gathered from both indirect sources (mainly ministries websites) and direct interviews aiming at classifying the governance mechanism adopted by the competent authority and its recent evolution.

4. ESTIMATION RESULTS

4.1 Step 1

The output of the first stage is reported in Table 2. The unadjusted DEA has been run on two separate groups of ports, identified on the basis of the containerisation rate: “high” if more than 60% of the total throughput is due to container traffic, “low” if the incidence of container traffic is lower. This has been done in order to take account of potential differences in service characteristics (Jara-Diaz et al., 2006).

The DEA efficiency scores are higher for the ports belonging to the first group. Obviously cross-group results are not comparable as they depend on separate frontiers, however, the lower variance of the efficiency scores for the container ports implies that they are closer to their own efficiency frontier than the multiservice ports and that differentials among ports in the former category are less marked. This can be expected as the activity carried out within the port is more homogeneous and, thus, more easily comparable.

<table>
<thead>
<tr>
<th>TABLE 2 – DEA efficiency scores (step 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Containerisation rate “HIGH”</td>
</tr>
<tr>
<td>Mean efficiency</td>
</tr>
<tr>
<td>Minimum</td>
</tr>
</tbody>
</table>
These scores do not provide evidence on the source of the inefficiency. In order to explore the contribution of different factors to each input inefficiency, we run a SFA on each input slack.

4.2 Step 2

Table 3 reports the results from second stage SFA input-by-input regressions. The regression has been carried out on the whole database, stacking the 30 ports. Exogenous regulatory and environmental factors are included as exogenous determinants of input slacks, while the managerial inefficiency component $u_{ni}$, in order to capture the inefficiency trend over time, have been modelled, according to the time-varying inefficiency model defined in Battese and Coelli (1992):

$$u_{ni} = u_{ni0} e^{-\eta(t-T)}$$

where $T$ indicates the final year of the time series for each port, $t$ is the current year, $\eta$ is a parameter to be estimated which indicates the direction and the magnitude of the trend of the $u$-term over time, and the inefficiency term ($u_{ti}^T$) is assumed to be i.i.d. as half-normal random variables $N^+ (0, \sigma u^2)$. A positive value of $\eta$ implies a downward trend in the managerial efficiency term over time while a negative value implies an upward trend. Thus, the trend of the managerial inefficiency for each input, along with its statistical significance, is directly derived from the data once both environmental factors and noise have been removed.

### TABLE 3 – Results of SFA – parameter estimates of slack equations

<table>
<thead>
<tr>
<th>Variable</th>
<th>QUAY</th>
<th>TERM</th>
<th>AREA</th>
<th>EQUIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP</td>
<td>-0.102***</td>
<td>-0.081**</td>
<td>-0.093***</td>
<td>-0.009**</td>
</tr>
<tr>
<td>EMPL</td>
<td>-0.067</td>
<td>0.059</td>
<td>0.038</td>
<td>-0.006</td>
</tr>
</tbody>
</table>
The coefficients of the policy variable REG are, as expected, significant and negative, thus indicating a reduction in the slack as a consequence of the introduction of greater autonomy of port authorities in determining investments and in their financing. The underlying mechanism of the port sector reforms seem to have been successful in most countries. It has induced port authorities to increase the use of the facilities. However, the magnitude of the coefficient for AREA and for EQUIP implies that for these inputs the effect is greater: the rationalisation of the area destined to freight handling and of equipment is easier to carry out than that of other inputs, characterised by greater indivisibilities. This result confirms previous evidence on the effectiveness of new regulatory framework in reducing production inefficiency\(^\text{10}\), while, at the same time, extending the latter by letting regulatory practice changes provide a differentiated impact on the different types of input.

The coefficients for the GDP variable appear to be highly significant for all the inputs and show the expected negative sign. This implies that an increase in the GDP of the area

\(^{10}\) For instance: Cullinane and Wang (2005, 2006); Cullinane et al. (2005); Gonzales and Trujillo (2005, 2008); Castillo-Manzano et al. (2008).
would reduce the input slacks. The dimension of the impact, however, is quite limited. The impact of the \textit{EMPL} variable is generally not statistically significant and shows alternations in signs. It implies, thus, that a higher employment rate does not necessarily stimulate demand for port services and a better usage of fixed inputs – and, thus, a reduction in input slacks - as it had been assumed \textit{a priori}. Also the coefficient of the \textit{POPDENS} have the expected negative sign, but it is significantly different from zero only for the slack regression for QUAY.

The coefficient relating to \textit{ACCESS} is in line with expectations in both magnitude and significance. Indeed, greater accessibility promotes a more efficient use of port infrastructure and equipment which, in turn, leads to an improved performance for those inputs which are more linked to capital utilisation.

The \textit{TREND} coefficient is significant but it alternates signs among regressions. It is positive for QUAY and TERM and negative for AREA and EQUIP. The managerial efficiency for infrastructure related inputs does not show a progressive improvement, as, instead, it is the case for equipment and area of operations.

As expected, the dummy associated with the dimension of the port \textit{DDIM} had a negative and generally significant impact on the input slacks. This means that if the port grows, the efficiency conditions improve. Consistently with previous studies\textsuperscript{11} the result seems to confirm that a large scale of production is more likely to be associated with high efficiency scores and that thus, the efficiency of a terminal is significantly influenced by its production scale. As Cullinane and Wang (2006) point out, this is not surprising considering the fact that large terminals are more likely to utilise more state-of-the-art equipment and sophisticated management than their smaller counterparts. This result has relevant policy implications. For instance, conspicuous investment in port infrastructure should be carried out at ports where traffic flows concentrate in order to exploit economies of scale and scope within the port notwithstanding other logics which often prevail in funding allocation.

Also the coefficient related to the containerisation rate (\textit{DCONTRATE}) is negative and rather significant, thus implying, according to our interpretation, that diversified ports are, in general, more affected by a higher variability in efficiency conditions than ports operating mainly with container traffics. This higher variability means, in turn, higher input slacks. The result of the estimation seems to support the idea that ports with a more

\textsuperscript{11} For instance, Cullinane and Wang, 2006 and De Neufville and Tsunokawa (1981).
homogeneous output tend to be more efficient and, looking at the magnitude and significance of the coefficients across input slacks, that quay length, terminal and equipment seem to be more influenced than the slack relating to the AREA variable.

The last part of this section is devoted to the analysis of the managerial inefficiency component (η). As explained, the term γ represents the proportion in the total error variance that is attributable to managerial inefficiency component. A likelihood ratio (LR) test for this structural parameter has been carried out and its outcome supports the inclusion of the parameter\[12\]. From the results it appears that the effects of pure managerial inefficiency is quite differentiated among input slacks. It accounts for only 3.1\% and 10.3\% for QUAY and TERM inefficiencies, respectively, while it is a significant component of overall inefficiency for AREA and EQUIP, whose values of γ are remarkably higher (79.3\% and 87.7\%, respectively). For the latter inputs, differences among ports efficiency rankings still remains attributable to discrepancies among managerial performances. This implies that, even once exogenous factors are controlled for and all ports are considered as operating in a common playing field without regulatory and time effects, they still manage inputs differently.

For all the regressions, the parameter η is positive and significantly different from zero: the trend of the input-specific technical inefficiency is negative, which implies that managers’ ability to reduce overuse of inputs improved over time. This might be due to the capacity of ports to adapt, especially with respect to more flexible inputs, to the new organisational models required by the reforms. It is worthwhile underlining that this trend of managerial efficiency during the observed years is distinguished from technological change, which is, instead, captured by the time variable TR.

### 4.3 Step 3

After having accounted for the impact of regulatory and environmental factors, the third stage of the process was carried out using algorithm [4] for adjusting the input data. DEA was re-run separately on the two set of ports, those highly containerised and the others. The estimation yielded new adjusted coefficients that are no longer affected by exogenous, non discretionary and controllable factors nor by random noise. The adjusted results are reported in table 4, together with the original output.

\[12\] The test rejects the null hypothesis that γ equals zero in all cases.
From the comparison of the two output a number of considerations can be drawn. First, there is a generalised increase in mean efficiency. The increase is more intense for the highly containerised ports which, from the previous section, appeared the ports most effected by performance variability. The dispersion around the average appears to reduce as a large part of the inefficiency is due to exogenous factors rather than to the capacity or the effort of managers.

5. CONCLUSIONS AND FURTHER RESEARCH

In this paper we extend previous work on port efficiency to take account of a number of issues connected to operating environment which, as we show through the analysis, play a significant role in determining efficiency scores. The main results are encouraging. We provided evidence supporting that greater autonomy granted to ports though governance reforms, has had beneficial effects for the EU port system as a whole. In particular, the effect has been more relevant for AREA and EQUIP: it seems, thus, that space utilisation and capital investment in equipment, variables that can be varied in a shorter time frame, respond more to exogenous shocks caused by policy changes. We find, also, that environmental factors in general do play a role on ports efficiency and that, depending on the specific characteristics of the port, inputs are influenced differently by different factors. In particular, general economic conditions do have a significant, positive effect on ports’ efficiency, although the impact is relatively limited and uniform with respect to input factors’ utilisation. Employment level is, instead, not relevant for all the inputs as it
is the population density of the region with respect to number of terminal, equipment, area of the port used for handling freight. For the remaining input the coefficient, although significantly different from zero, is extremely small. Accessibility does, instead, play a relevant role in determining efficient input utilisation: its coefficient is significant and negative, implying that greater accessibility favour the utilisation of the ports’ production factors. On account of the magnitude of the relevant coefficients, the impact is larger for those inputs directly linked to capital utilisation. We also find that, in relation to the sampled ports, the inefficiency in the use of infrastructure related inputs does not show progressive improvements as, instead, do the ones related to the other inputs. Furthermore, as expected on the basis of the results of previous studies, both ports’ dimension and containerisation rate play a relevant role in determining input efficiency. Bigger ports seem to lead to greater efficiency in input usage so as ports with a more homogeneous production. These results seem to confirm, also at input by input level, the presence of significant economies of scale within a port. No support, instead, can be found for economies of scope within sampled ports. Finally, we show how, once operational environment and regulatory effects have been eliminated, pure managerial efficiency could be elicited, giving a more precise assessment of the change of managers’ incentives over time. The policy implications are relevant. Ports reform that go in the direction of greater managerial autonomy seem to support the drive toward efficiency, especially with respect to inputs under the direct control of ports’ managers and that can respond in the short-medium period to external impulses. Also, the analysis seems to offer renovated support for the idea that larger ports can exploit greater economies of scale and that port specialisation can lead to more efficient utilisation of inputs. The results, however, are based on the sample of ports included in the exercise. There is still a lot to be done in terms of both empirical (enlarging the database, cleaning up the data, ecc.) and methodological research. For the former aspect, the authors are working on developing a larger database with a more refined definition of variables. For the latter aspect, a number of extremely recent integrations to the Fried et al. (2002) approach are developing (for instance, bootstrapping on the basis of the work of Simar and Wilson (2007) or alternative adjustment methods (Tone and Tsutsui (2006)), whose effects would be interesting to test on the same database in order to verify the robustness of both the model and the empirical output.

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6. Bibliografia


