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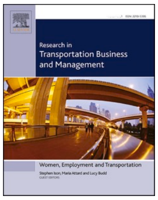

Persistent and transient inefficiency in ports: An application to Spanish port authorities

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ABSTRACT

We estimate technical efficiency using stochastic frontier techniques, distinguishing between persistent and transient inefficiency. Previous studies in the port efficiency literature have accounted for firm heterogeneity and time-varying technical inefficiency. However, no port studies to date have accounted for heterogeneity, time-invariant (persistent) and time-varying (transient) inefficiency. Accounting for both types of inefficiency is important because addressing them requires different types of managerial measures. Using data from a sample of Spanish port authorities observed over the period 1993–2020, we estimate a stochastic output distance frontier with four error components which includes determinants of persistent and transient inefficiency. Port authorities show very low levels of transient inefficiency but higher levels of persistent inefficiency. Overall inefficiency is therefore basically due to persistent inefficiency. We find that port authorities managing more than a single port suffer from greater persistent inefficiency, whereas those located on the Mediterranean seaboard have a structural advantage over their Atlantic seaboard counterparts in terms of persistent inefficiency. The type of output and its share of national output also affect persistent inefficiency.

1. Introduction

Ports play a crucial role in modern economies, whether as gateways that serve hinterlands or hub ports, or ports centred on given sectors such as the energy sector or cruise-based tourism. A steady process of deregulation and privatization combined with a generalised shift towards the landlord model has led to the sector becoming increasingly competitive in recent decades, and this has meant a greater focus from policymakers on port efficiency and productivity. It is not surprising, therefore, that there is a large and fast-growing literature on port technical efficiency. As noted by Yen and Mulley (2023), efficiency is a key research area as it is critical to improving overall performance. This empirical literature typically uses tools from production economics, and in particular production frontiers, where the models used may be non-parametric (e.g., Data Envelopment Analysis) or parametric (Stochastic Frontier Analysis).

Our focus in this work is on stochastic frontier analysis of port technical efficiency. Stochastic frontier models have been commonly used in the literature in both single-output (production frontier) and multi-output (distance function) variants. One of the advantages of the stochastic frontier approach is that researchers can distinguish between unobserved port-specific heterogeneity and technical inefficiency. In particular, the production function error term has been decomposed into a firm-specific effect capturing latent (unobserved) heterogeneity, a firm-specific time-varying inefficiency term and a time-and firm-varying random error term by, among others, Kumbhakar & Wang (2005), Greene (2005a, 2005b), Wang and Ho (2010) and Chen, Schmidt, and Wang (2014). These models have been widely used in the port efficiency literature. However, a drawback of these models is that they consider any producer-specific, time-invariant component as unobserved heterogeneity, thereby ignoring possible time-invariant (or persistent) long-term inefficiency. That is, latent port-specific heterogeneity is confounded with time-invariant inefficiency.

Our contribution in this work is to estimate technical efficiency using stochastic frontier techniques for a sample of Spanish port authorities observed over the period 1993–2020, distinguishing between persistent and transient inefficiency. Transient, or time-varying, inefficiency can be considered as the result of short-term management actions (e.g., reallocation of inputs). Persistent inefficiency, on the other hand, is more long-term and can be considered the result of structural obstacles

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Table 1
Spanish port efficiency: parametric literature.

Study	Model	Function	Measures	Sample	Frontier	Efficiency determinants
Baños-Pino, Coto-Millán, & Rodríguez-Álvarez, 1999	SCF SDF (IO)	Translog with time dummies	TE AE	27 PA (1985–1997) I	FE	NO
Coto-Millán, Baños-Pino, & Rodríguez-Álvarez, 2000	SCF	Translog with time trend	EE	27 PA (1985–1989) I	FE	Port size, type of organization
Rodríguez-Álvarez, Tovar, & Trujillo, 2007	SDF (IO)	Translog (M) with time dummies and SE	TE AE	3 MT (1991–1999) CH	FE with producer-specific time-varying intercept	NO
Díaz-Hernández, Martínez-Budría, & Jara-Díaz, 2008	SCF	Quadratic (M) with time trend	TE AE	19 Port (1992–1998) CH	FE	NO
Gonzalez & Trujillo, 2008	SDF (OO)	Translog (M) with time dummies	TE	9 PA (1990–2002) I	BC88	NO
Núñez-Sánchez & Coto-Millán, 2012	SDF (IO)	Translog (M) with time trend	TE TFP	27 PA (1986–2005) I	BC88	NO
Rodríguez-Álvarez & Tovar, 2012	SCF	Translog (M) with time trend	TE	26 PA (1993–2007) I	TFEM	BC95M with degree of mechanization
Tovar & Hernandez-Deniz, 2015	SCF	Translog (M) with time trend	TE	26 PA (1993–2007) I	TFEM	NO
Tovar & Wall, 2015	SDDF	Quadratic (M) with time trend	TE	20 PA (1993–2012) I	TFEM	NO
Coto-Millán, Fernández, Hidalgo, & Pesquera, 2016	SDF (IO)	Translog (M) without time trend	TE	26 PA (1986–2012) I	TFEM	BC95M with public regulation
Tovar & Wall, 2017a	SDDF SCF	Quadratic (M) with time trend	TE AE	26 PA (1993–2012) I	TFEM	NO
Tovar & Wall, 2018	SDF (OO)	Translog (M) with time trend	TE	26 PA (1993–2012) I	TFEM	CEA95M with specialization and size indicators
Coto-Millán, de la Fuente, & Fernández, 2019	SDF (IO)	Cobb-Douglas (M) with time trend	TE	11 PA (1986–2013) I	TFEM	BC95M with public regulation and economic crisis
Garcia-Alonso, Moura, & Roibas, 2020	SDF (OO)	Translog (M) with time trend	TE	15 PA (1992–2016) I	TFEM	CEAM95 with weather conditions and economic crisis
Hidalgo-Gallego, De La Fuente, Mateo-Mantecón, & Coto-Millán, 2020	SDF (IO)	Translog (M) with time trend	TE	26 PA (1986–2015) I	TFEM	BC95M with specialization indices by cargo, deposit area and total cargo
Perez, Trujillo, & González, 2020	SDF (OO)	Translog (M) with time dummies	TE	27 Port (2001−2011) CH	BC88M	BC95M with specialization indices by cargo and size
Hidalgo-Gallego, Núñez-Sánchez, & Coto-Millán, 2022	SDF (IO)	Translog (M) with time trend and SE	TE AE	26 PA (1992–2016) I	Quantile regression	Recession, specialization, complexity, multiple ports and regulation
Tovar & Wall, 2022	SDF (OO)	Translog (M) with time trend	TE	16 PA (2006–2016) I	TFEM	CEA95M with connectivity, output concentration and specialization.
Present paper	SDF (OO)	Translog (M) with time dummies	TE	26 PA (1993–2020) I	GTFEM	Output concentration, relative specialization, structural characteristics (location, multiport)

Note: SPF = Stochastic Production Function, SCF = Stochastic Cost Function; SDF = Stochastic Distance Function; SDDF = Stochastic Directional Distance Function; IO = Input Orientation; OO = Output Orientation; TE = Technical Efficiency; AE = Allocative Efficiency, TFP = Total Factor Productivity; M = Multiproduct, PA = Port Authorities; MT = Multipurpose Terminals; I = Infrastructure; CH = cargo Handling; BC88M = Battese and Coelli (1988) Model; BC95M = Battese and Coelli (1995) Model; CEA95M= Caudill, Ford, and Gropper (1995) Model; TFEM = True Fixed Effects Model; TREM = True Random Effects Model; Generalised True Fixed Effects Model = GTFEM.

to efficient management (e.g., regulatory framework or local environmental conditions that make management more difficult). In the context of ports, the economic dynamism of the hinterland and the local entrepreneurial culture may have structural effects on efficiency. Also, the level of collaboration between the different public and private stakeholders involved in the port's business (export/import) processes, namely the port logistics community or cluster (Ascencio & González-Ramírez, 2016), would also be expected to affect persistent efficiency. Previous studies in the port efficiency literature in general have accounted for firm heterogeneity and time-varying technical inefficiency but none to date has accounted for heterogeneity, time-invariant (persistent) and time-varying (transient) inefficiency. The literature on Spanish port efficiency is no exception to this.[1] A summary of the stochastic frontier literature for Spain in presented in Table 1, where it can be seen that the distinction between persistent and transient inefficiency has been ignored.

Accounting for both types of inefficiency is important because addressing them will require different types of management responses. It is also important if benchmarking exercises comparing the performance of ports are carried out to identify best practices. Ignoring the possibility of persistent inefficiency may lead to incorrect estimates of technical inefficiency and provide a distorted picture of port performance.

To estimate port technical inefficiency, we use a version of the four-error term model that permits separate identification of transient and persistent inefficiency, time-invariant unobserved firm-specific heterogeneity, and statistical errors, introduced by Kumbhakar, Lien, and Hardaker (2014), Colombi, Kumbhakar, Martini, and Vittadini (2014) and Filippini and Greene (2016). We find evidence of persistent (time-invariant) inefficiency and identify determinants of this.

The paper is structured as follows. In Section 2 we discuss the econometric model to be estimated. The data are presented in Section 3. In Section 4, we present the results of our empirical estimation and Section 5 concludes.

2. Measuring technical efficiency and specialization in a multi-output setting

Given the multi-output nature of port activity, to estimate technical efficiency we use an output-oriented distance function (Perez et al., 2020; Tovar & Wall, 2022). Given N inputs and M outputs, the starting point is the production set, defined as

$$\mathscr{P} = \left\{(x,y) \in R_{+}^{N+M} \left| x\ can\ produce\ y \right.\right\} \tag{1}$$

For the input-output combination $(x_0, y_0) \in R_{+}^{N+M}$ technical efficiency[2] can be defined as:

$$D_0(x,y) = min\{\delta|(x,y/\delta) \in \mathscr{P}, \delta > 0\} \tag{2}$$

It should be noted that $\delta \leq 1$ when $(x_0, y_0) \in \mathscr{P}$.

One of the properties of the output distance function is homogeneity of degree one in outputs, which implies that

$$D_0(x,\theta y) = \theta D_0(x,y) \text{ for any } \theta > 0 \tag{3}$$

Following Coelli and Perelman (2000), we impose this property by normalizing the distance function by the Mth output, y_M. Setting $\theta = 1/y_M$ in (3) we have

$$D_0(x, 1/y_M) = D_0(x,y)/y_M \tag{4}$$

To get to an estimable panel data econometric model with the conventionally-used translog (TL) functional form using panel data, we write

$$ln(D_{0it}(x_{it}, y_{it})/y_{Mit}) = TL(x_{it}, y_{it}/y_{Mit}, \beta) \tag{5}$$

where β represents parameters to be estimated. (5) can be written as

$$lnD_{0it}(x_{it}, y_{it}) - lny_{Mit} = TL(x_{it}, y_{it}/y_{Mit}, \beta) \tag{6}$$

Rearranging:

$$-lny_{Mit} = TL(x_{it}, y_{it}/y_{Mit}, \beta) - lnD_{0it}(x_{it}, y_{it}) \tag{7}$$

To express as this as an estimable stochastic distance frontier that takes account of individual firm effects (unobserved time-invariant heterogeneity), time-invariant inefficiency and time-varying inefficiency, we write:

$$-lny_{Mit} = TL(x_{it}, y_{it}/y_{Mit}, \beta) + \mu_i + v_{it} - \eta_i - u_{it} \tag{8}$$

where μ_i represents unobserved firm-specific time-invariant heterogeneity ('individual effects'); v_{it} is a symmetric random disturbance term, assumed to be distributed as $iid\,N(0, \sigma_v^2)$; and we have set $ln\ D_{oit}(x_{it}, y_{it}) = \eta_i + u_{it}$, where $\eta_i \geq 0$ is the time-invariant technical inefficiency term and $u_{it} \geq 0$ is the time-varying technical inefficiency term.

To arrive at the actual expression of the model to be estimated, we substitute for $TL(x_{it}, y_{it}/y_{Mit}, \beta)$ in (8). This gives us:

$$\begin{aligned} -lny_{Mit} = {} & \alpha_0 + \sum_{m=1}^{M-1} \alpha\beta_m ln(y_{mit}/y_{Mit}) + \frac{1}{2}\sum_{m=1}^{M-1}\sum_{n=1}^{M-1}\beta_{mn} ln(y_{mit}/y_{Mit}) ln(y_{mit}/y_{Mit}) \\ & + \sum_{k=1}^{K}\beta_k lnx_{kit} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K}\beta_{kl} lnx_{kit} lnx_{lit} + \sum_{k=1}^{K}\sum_{m=1}^{M-1}\beta_{kl} lnx_{kit} ln(y_{mit}/y_{Mit}) \\ & + \mu_i + v_{it} - \eta_i - u_{it} \end{aligned} \tag{9}$$

Estimation of this model can be carried out in several different ways. Following Kumbhakar, Lien, & Hardaker (2014); Kumbhakar, Parmeter, & Zelenyuk (2022), rewrite (9) as:

$$\begin{aligned} -lny_{Mit} = {} & \alpha_i + \sum_{m=1}^{M-1} \beta_m ln(y_{mit}/y_{Mit}) + \frac{1}{2}\sum_{m=1}^{M-1}\sum_{n=1}^{M-1}\beta_{mn} ln(y_{mit}/y_{Mit}) ln(y_{mit}/y_{Mit}) \\ & + \sum_{k=1}^{K}\beta_k lnx_{kit} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K}\beta_{kl} lnx_{kit} lnx_{lit} + \sum_{k=1}^{K}\sum_{m=1}^{M-1}\beta_{kl} lnx_{kit} ln(y_{mit}/y_{Mit}) \\ & + \varepsilon_{it} \end{aligned} \tag{10}$$

where $\alpha_i = \alpha_0 - \eta_i$ and $\varepsilon_{it} = v_{it} - u_{it.}$

Note here that the error term ε_{it} has mean zero. In line with Kumbhakar, Parmeter, & Zelenyuk (2022), (10) is a standard panel data model with firm-specific heterogeneity. As such, we can estimate the model by generalised least squares, under a random effects (RE) framework, or by the within transformation under the fixed effects (FE) framework. To control for possible correlation between the explanatory variables and unobserved firm-specific heterogeneity, we opt for a FE approach. In this FE setting, the stochastic output distance frontier model can be estimated using a simple step-wise procedure.

Step 1. Use the within transformation to estimate $\widehat{\beta}$. This procedure provides predicted values of α_i and ε_{it}, which we denote by $\widehat{\alpha}_i$ and $\widehat{\varepsilon}_{it}$.

Step 2. Use the predicted values of $\widehat{\varepsilon}_{it}$ from Step 1 to estimate time-varying technical inefficiency. Assuming $u_{it} \sim iid\,N^{+}(0, \sigma_{uit}^2)$ and $\sigma_{uit}^2 = g(z_{it}; \delta)$, we can apply standard stochastic frontier techniques permitting heterogeneity to account for inefficiency determinants. Thus, the inefficiency terms are assumed to follow non-negative half-normal distributions where their variances depend on a series of explanatory variables, z (Caudill, Ford, & Gropper (1995); Kumbhakar, Lien, &

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[1] In a recent themed volume on transport efficiency where a wide range of approaches and models were covered, it is interesting to note that none of the studies distinguished between persistent and transient inefficiency (see Yen and Mulley (2023)).

[2] This is the Shephard (1970) output distance function.

Hardaker, 2014; Kumbhakar, Parmeter, & Zelenyuk, 2022).

Step 3. Use the predicted values of $\hat{\alpha}_i$ from Step 1 to estimate time-invariant technical inefficiency. Similarly to Step 2, by assuming $\eta_i \sim iid\, N^+(0, \sigma^2_{ui})$ and $\sigma^2_{ui} = h(w_i; \gamma)$ we can apply standard stochastic frontier techniques permitting heterogeneity to account for inefficiency determinants, w.

From Step 2 we obtain an estimate of time-varying or transient technical efficiency as $TTE = exp(-\hat{u}_{it})$, and from Step 3 an estimate of time-invariant or persistent technical efficiency as $PTE = exp(-\hat{\eta}_{it})$. Overall technical efficiency (OTE) is obtained as the product of these terms; $OTE = TTE^{*}PTE$.

3. Data

The data we use correspond to the Spanish port system. We have balanced panel data on 26 port authorities covering the period 1993–2020, for a total of 728 observations.[3] The data has been gathered from the annual reports of the port authorities and the accounts and reports provided annually by the Spanish Public State Ports Body (EPPE). While most port authorities manage a single port, some of them manage multiple ports.

Data on inputs and outputs are needed to estimate the distance function technology. We have three inputs: expenditure on labour (x_1), intermediate consumption expenditures (x_2), and the expenditure on capital asset services (x_3). The outputs comprise merchandise and passenger transport. The merchandise outputs, measured in tons, are liquids (y_1), solid bulk (y_2), containerised cargo (y_3), and general non-container cargo (y_4). Passenger output (y_5) is measured by number of passengers.

To explain transient and persistent port inefficiency, we use a series of control variables capturing different characteristics of the port authorities and their ports. Following the previous literature (see, for example, Tovar & Wall, 2017b, 2017c, 2022) we use an output concentration index, a set of relative specialization indices, and relevant structural characteristics.

To measure output concentration, we focus on merchandise and use the (normalised) Herfindahl-Hirschman Index (HHI) (Al-Marhubi, 2000). For port authority i producing M cargo services, this can be defined as:

$$HHI_i = \frac{\sum_{m=1}^{M} s^2_{mi} - \frac{1}{M}}{1 - \frac{1}{M}} \tag{11}$$

where $s_{mi} = \frac{y_{mi}}{\sum_{m=1}^{M} y_{mi}}$ is the share of cargo m in total cargo. The values of the normalised HHI range from 0 (complete diversification) to 1 (perfect specialization) and values closer to 0 represent greater diversification. In order to have common units of measurement for outputs, we calculate the HHI for cargo traffic only.

To capture relative specialization ($RELSPECy_{mi}$) in each merchandise we use the so-called Bird Index (Frémont & Soppé, 2007). For merchandise m in port authority i, y_{mi}, this is defined as:

$$RELSPECy_{mi} = \frac{y_{mi}/Y_i}{y_{mSYS}/Y_{SYS}} \tag{12}$$

where Y_i is total merchandise output of the port authority i, y_{mSYS} is the total output of merchandise m in the system as a whole, and Y_{SYS} is the total overall merchandise output (grand sum of all merchandise outputs) of the system as a whole. A port authority is relatively more (less) specialised in a merchandise compared to the system as a whole when the value of the relative specialization index is greater (less) than 1.

While the HHI and Bird Indexes provide information about the level of concentration/diversification of port authority cargo and the cargoes they are relatively specialised in, these do not provide information on the relative importance of the port authority's cargo within the system as a whole, i.e., they provide no information on the size or relative weight of the port authority. To control for this, we include the shares of each output m of port authority i in total system output, which we label $NATSHARE_{mi}$:

$$NATSHARE_{mi} = \frac{y_{mi}}{y_{mSYS}} \tag{13}$$

where y_{mi} and y_{mSYS} are defined as above.

The preceding variables were all used to explain transient inefficiency. Regarding persistent inefficiency, as this is time-invariant we include the average of the *NATSHARE* variables to capture the structure of port output. These output shares change very slowly over time and may be the source of structural advantages or disadvantages. We also include two other determinants that capture location and management aspects of port authorities.

The first is the seaboard on which the port authority operates. In recent decades, Spain has experienced a growth in the relative importance of trade with Asia at the expense of trade with the Americas. As trade with Asia tends to go largely through the Mediterranean, this may provide an advantage for ports on this seaboard compared to those on the Atlantic seaboard. Complementing this is the increasing spatial concentration of economic activity in the North-Eastern corner of the Peninsula and the Mediterranean corridor in comparison to the Atlantic regions, which may provide advantages to the Mediterranean ports and/or be indicative of a more dynamic entrepreneurial or managerial culture in those regions.[4] Moreover, preoccupation about the performance of EU Atlantic ports is reflected in the introduction of the European Commission's Maritime Strategy for the Atlantic Ocean Region and the Atlantic Action Plan where the importance of developing trade with the America's is highlighted (European Commission, 2011, 2013). We therefore include a dummy variable, *Mediterranean*, that takes value 1 when the port authority operates on the Mediterranean seaboard, and 0 otherwise.

Another issue to be taken into account is that some of the port authorities manage more than one port, which may also be expected to affect performance. In particular, we would expect the management of multiple ports, some of which are relatively small in terms of volume of traffic, to negatively affect the productive performance of port authorities. To capture this possibly negative effect, we include, as a determinant of persistent inefficiency, a dummy variable *Multiport*, which takes the value 1 if the port authority manages more than one port, and 0 otherwise.[5]

Descriptive statistics of the output and input variables and the determinants of inefficiency by type (persistent and transient) are presented in Table 2, where all monetary variables have been expressed in real terms (2020 euros).

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[3] The port authorities included are A Coruña, Alicante, Avilés, Bahía de Algeciras, Bahía de Cádiz, Baleares, Barcelona, Bilbao, Cartagena, Castellón, Ceuta, Ferrol-San Cibrao, Gijón, Huelva, Las Palmas, Málaga, Marín y Ría de Pontevedra, Melilla, Pasajes, Sta. Cruz de Tenerife, Santander, Sevilla, Tarragona, Valencia, Vigo and Vilagarcía.

[4] Another possible source of structural disadvantage of Atlantic ports is identified by García-Alonso, Moura & Roibas (2020), who find that the relatively worse weather conditions of the Atlantic seaboard generates a greater need for some overcapacity to deal with demand peaks, making Atlantic ports less efficient than those located on the Mediterranean coast.

[5] We also estimated a version of the model including a dummy variable for insular port authorities but this variable was not significant, probably due to the fact that these are all multiport authorities and this is already captured by our *Multiport* variable.

Table 2
Descriptive statistics of variables.

Variable	Description	Mean	Std. Dev.	Min.	Max.
Outputs and inputs in frontier					
y_1	Liquid bulk (tons)	5,519,946	7,295,689	0	31,763,061
y_2	Solid bulk (tons)	3,226,558	3,465,098	3425	19,658,167
y_3	Container (tons)	4,452,821	11,063,737	0	65,434,203
y_4	General non-container (tons)	1,959,111	2,491,505	77,496	14,585,870
y_5	Passengers (units)	1,587,912	6,195,483	0	76,011,953
x_1	Labour (€ deflated)	7,780,846	5,533,600	1,309,605	34,519,000
x_2	Supplies (€ deflated)	8,498,128	9,680,258	339,895	65,435,000
x_3	Capital expenditure (€ deflated)	24,744,454	23,932,109	884,473	157,311,880
Variables used to explain inefficiency					
Transient inefficiency					
HHI	Normalised Herfindahl-Hirschman Index	0.2907	0.1691	0.0047	0.8007
$RELSPEC_{LIQ}$	Relative specialization in output y_1	0.7913	0.7252	0.0000	2.3823
$RELSPEC_{SOLID}$	Relative specialization in output y_2	1.5009	1.1614	0.0160	4.3210
$RELSPEC_{CONT}$	Relative specialization in output y_3	0.6192	0.6988	0.0000	2.6979
$RELSPEC_{GC}$	Relative specialization in output y_4	1.6288	1.4018	0.0371	6.5757
$NATSHARE_{LIiQ}$	Share of output y_1 in system output	0.0385	0.0493	0.0000	0.1843
$NATSHARE_{SOLID}$	Share of output y_2 in system output	0.0385	0.0405	0.0000	0.2106
$NATSHARE_{CONT}$	Share of output y_3 in system output	0.0385	0.0813	0.0000	0.3577
$NATSHARE_{GC}$	Share of output y_4 in system output	0.0385	0.0429	0.0019	0.1912
$NATSHARE_{PASS}$	Share of output y_5 in system output	0.0385	0.0661	0.0000	0.2923
Persistent inefficiency					
Mediterranean	Mediterranean Seaboard (Dummy)	0.4231	0.4944	0	1
Multiport	Multiple ports (Dummy)	0.2308	0.4216	0	1
$AVNATSHARE_{LIQ}$	Mean share of output y_1 in system output	0.0385	0.0394	0.0005	0.1825
$AVNATSHARE_{SOLID}$	Mean share of output y_2 in system output	0.0385	0.0476	0.0000	0.1519
$AVNATSHARE_{CONT}$	Mean share of output y_3 in system output	0.0385	0.0799	0.0000	0.3156
$AVNATSHARE_{GC}$	Mean share of output y_4 in system output	0.0385	0.0409	0.0044	0.1348
$AVNATSHARE_{PASS}$	Mean share of output y_5 in system output	0.0385	0.0615	0.0003	0.2014

4. Empirical specification and results

In this section we present the results of the estimation of the generalised true fixed effects output distance frontier (9). In the presentation of the data, it was seen that zero values exist for certain types of cargo (in particular, liquids, containers and passengers). In order not to lose these especially interesting observations due to the fact that the output distance frontier has a translog functional form, we follow Battese (1997) by replacing the output variables with $y^*_{mi} = Max\left(y_{mi}, D_{mi}\right)$, and $D_{mi} = 1$ if $y_{mi} = 0$ and $D_{mi} = 0$ if $y_{mi} > 0$.

The final model to be estimated, using the step-wise procedure, is therefore the following version of (10):

$$
-lny^*_{Mi} = \alpha_i + \sum_{m=1}^{M-1}\alpha_m ln\left(y^*_{mi}/y^*_{Mi}\right) + \frac{1}{2}\sum_{m=1}^{M-1}\sum_{n=1}^{M-1}\alpha_{mn} ln\left(y^*_{mi}/y^*_{Mi}\right) ln\left(y^*_{mit}/y^*_{Mi}\right)
$$

$$
+\sum_{k=1}^{K}\beta_k lnx_{ki} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K}\beta_{kl} lnx_{ki} lnx_{li} + \sum_{k=1}^{K}\sum_{m=1}^{M-1}\beta_{kl} lnx_{ki} ln\left(y^*_{mi}/y^*_{Mi}\right)
$$

$$
+\sum_{t}^{T-1}\varnothing_t D_t + \sum_{m}^{M}\gamma_m D_{mi} + \varepsilon_{it} \tag{14}
$$

where $\alpha_i = \alpha_0 - \eta_i$ and $\varepsilon_{it} = v_{it} - u_{it}$; $u_{it} \sim iid\, N^+\left(0, \sigma^2_{uit}\right)$ and $\sigma^2_{uit} = g(z_{it}; \delta)$; and $\eta_i \sim iid\, N^+\left(0, \sigma^2_{ui}\right)$ and $\sigma^2_{ui} = h(w_i; \gamma)$. A set of time dummy variables have been included to capture technical change and therefore separate this from technical inefficiency.

The estimated parameters of the output distance function are presented in Table 3.[6]

Most of the estimated parameters are statistically significant, pointing to a well-behaved model. As basic properties, the output distance frontier should be decreasing in inputs and increasing in outputs. Given that we have expressed the variables in terms of deviations from their means, these properties can be checked from the first-order conditions. All the first-order output parameters, with the exception of passenger output, are positive and significant. While the estimated coefficient on passenger (y_5) is negative, it is not significant and the hypothesis that the coefficient is positive cannot be rejected. All the first-order input coefficients are negative. The coefficient on supplies (x_2) is not significant, but the hypothesis that it is negative cannot be rejected.

We now turn to the estimates of transient (time-varying) and persistent (time-invariant) inefficiency. The estimates for transient inefficiency are presented in Table 4. It should be kept in mind that negative (positive) coefficients represent a reduction (increase) in inefficiency and hence an increase (decrease) in efficiency. The coefficient on *HHI* is negative and highly significant, showing that port authorities that are more concentrated in terms of outputs tend to be more efficient. This is in line with previous findings in the literature (e.g., Tovar & Wall, 2017b, 2022). Size also matters, with port authorities that are important national players in liquids (without necessarily being specialised in this) are more efficient, whereas those that are more important in solids are less efficient. The signs on the interaction variables *HHI*NATSHARE* are of particular interest. The negative sign on $HHI*NATSHARE_{CONT}$ and the positive sign on $HHI*NATSHARE_{GM}$ tell us that for a given level of output concentration, port authorities that are important in container traffic are more efficient whereas those that are more important in non-container general merchandise are less efficient. In other words, output concentration is positively related to efficiency, but it makes a difference which outputs the port authorities are important national players in. Generally speaking, port authorities that are important players on in liquids and container traffic tend to be more efficient, as evidenced by the signs of the coefficients on the *NATSHARE* variables and the interaction variable *HHI*NATSHARE.* Similar results were found by Gonzalez & Trujillo (2008) and Perez et al. (2020), who found that having an oil refinery near the port improves productivity. Those that are important in solids and general non-containerised merchandise, on the other hand, tend to be less efficient. This is also the story told by the sizes of the

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[6] To save space, we do not report the estimates of the individual effects and time dummies.

Table 3
Output-oriented stochastic distance frontier.

Variable	Estimate	Std. Err.	p-value	Variable	Estimate	Std. Err.	p-value
y_1	0.0581	0.0122	0.000	$y_4 \bullet y_5$	*−0.0042*	*0.0030*	*0.160*
y_2	0.5018	0.0191	0.000	$x_1 \bullet x_2$	−0.0379	0.1049	0.718
y_3	0.0597	0.0075	0.000	$x_1 \bullet x_3$	−0.0544	0.1241	0.661
y_4	*0.3878*	*0.0186*	*0.000*	$x_2 \bullet x_3$	0.0482	0.0731	0.510
y_5	−0.0074	0.0071	0.297	$y_1 \bullet x_1$	−0.0208	0.0168	0.217
x_1	−0.4845	0.0713	0.000	$y_1 \bullet x_2$	−0.0087	0.0089	0.327
x_2	−0.0120	0.0340	0.724	$y_1 x_3$	−0.0346	0.0171	0.044
x_3	−0.0846	0.0438	0.054	$y_2 \bullet x_1$	0.1353	0.0314	0.000
$y_1 \bullet y_1$	0.0147	0.0022	0.000	$y_2 \bullet x_2$	−0.0578	0.0164	0.000
$y_2 \bullet y_2$	0.1166	0.0087	0.000	$y_2 x_3$	0.0229	0.0261	0.382
$y_3 \bullet y_3$	0.0057	0.0016	0.000	$y_3 \bullet x_1$	0.0414	0.0098	0.000
$y_4 \bullet y_4$	*−0.0882*	*0.0111*	*0.000*	$y_3 \bullet x_2$	−0.0118	0.0055	0.034
$y_5 \bullet y_5$	0.0010	0.0023	0.653	$y_3 \bullet x_3$	0.0061	0.0073	0.404
$x_1 \bullet x_1$	0.2865	0.2088	0.171	$y_4 \bullet x_1$	−0.1159	0.0336	0.001
$x_2 \bullet x_2$	−0.0426	0.0799	0.595	$y_4 \bullet x_2$	0.0565	0.0191	0.003
$x_3 \bullet x_3$	−0.1999	0.1201	0.097	$y_4 \bullet x_3$	−0.0174	0.0322	0.590
$y_1 \bullet y_2$	−0.0082	0.0051	0.110	$y_5 \bullet x_1$	−0.0399	0.0099	0.000
$y_1 \bullet y_3$	0.0017	0.0008	0.040	$y_5 \bullet x_2$	0.0217	0.0063	0.001
$y_1 \bullet y_4$	*−0.0056*	*0.0049*	*0.256*	$y_5 x_3$	0.0231	0.0080	0.004
$y_1 \bullet y_5$	−0.0027	0.0006	0.000				
$y_2 \bullet y_3$	−0.0216	0.0033	0.000	D_1	−0.0326	0.0909	0.720
$y_2 \bullet y_4$	*−0.0936*	*0.0087*	*0.000*	D_3	−0.1056	0.0693	0.128
$y_2 \bullet y_5$	0.0068	0.0025	0.006	D_5	−0.0787	0.1051	0.454
$y_3 \bullet y_4$	*0.0151*	*0.0033*	*0.000*				
$y_3 \bullet y_5$	−0.0009	0.0005	0.083	*Constant*	−0.1982	0.0556	0.000
Number of observations: 728							

Note: figures in italics represent parameter estimates recovered from homogeneity restrictions. Individual port authority-specific effects and time dummy coefficients have been included in the model but are not reported in order to save space.

Table 4
Determinants of transient inefficiency.

Variable	Estimate	Std. Err.	p-value
HHI	−41.079	16.816	0.015
$NATSHARE_{LIiQ}$	−314.698	129.552	0.015
$NATSHARE_{SOLID}$	204.711	66.161	0.002
$NATSHARE_{CONT}$	−2.128	38.228	0.956
$NATSHARE_{GC}$	95.182	51.705	0.066
$NATSHARE_{PASS}$	12.599	11.414	0.270
$HHI{*}NATSHARE_{LIQ}$	139.639	178.765	0.435
$HHI{*}NATSHARE_{SOLID}$	45.033	84.132	0.592
$HHI{*}NATSHARE_{CONT}$	−465.877	176.553	0.008
$HHI{*}NATSHARE_{GC}$	930.189	282.569	0.001
$RELSPEC_{LIQ}$	−139.953	95.721	0.144
$RELSPEC_{SOLID}$	−96.130	55.863	0.085
$RELSPEC_{CONT}$	−123.078	76.828	0.109
$RELSPEC_{GC}$	−67.860	33.243	0.041
t	0.363	0.444	0.413
t^2	−0.015	0.015	0.301
Constant	418.683	261.886	0.110
No of observations. 728			

Table 5
Determinants of persistent inefficiency.

Variable	Estimate	Std. Err.	p-value
Mediterranean Seaboard	−0.7001	0.3228	0.030
Multiport	2.4432	0.3951	0.000
$AVNATSHARE_{SOLID}$	20.6140	3.2632	0.000
$AVNATSHARE_{LIQ}$	33.6892	3.7587	0.000
$AVNATSHARE_{CONT}$	−3.7966	1.7911	0.034
$AVNATSHARE_{GC}$	28.0350	4.6753	0.000
$AVNATSHARE_{PASS}$	−5.6069	2.3393	0.017
Constant	−6.0323	0.7011	0.000
No of observations. 728			

coefficients of the *RELSPEC* variables. Their negative signs show that being relatively specialised works in favour of efficiency, as found by Tovar and Wall (2017b, 2022), but the sizes of the coefficients show that this is particularly true of liquids and container cargo. Finally, a time trend and its square were also included in the model but these did not turn out to be significant.

The estimates of persistent inefficiency are presented in Table 5. Location on the Mediterranean seaboard is found to put port authorities at an advantage in terms of efficiency. In light of the structural disadvantage of Atlantic port authorities uncovered by our model, the European Commission's Maritime Strategy for the Atlantic Ocean Region policy initiative appears more justified than ever. One of the four pillars of the recent Action Plan proposed by the Commission is *Ports as gateways and hubs for the blue economy* whose two goals are to promote ports as gateways for trade in the Atlantic and as catalysts for business (European Commission, 2020). The Action Plan calls for increased cooperation among ports to mobilise financing for smart infrastructures and to develop capacity with the aim of accommodating trade growth. It also aims at intensifying short-sea Atlantic shipping routes. These initiatives should go some way towards addressing the imbalance between Atlantic and Mediterranean ports.

On the other hand, persistent inefficiency is greater for port authorities that manage multiple ports. This result would appear to confirm our hypothesis that the management of multiple ports, which may vary substantially in size, output mix and specialization, negatively affects the productive performance of port authorities as manifested by higher levels of persistent inefficiency. The type of output that the port authority has a large presence in is also found to have an impact on efficiency. In particular, port authorities that are important in terms of container cargo are structurally more efficient than those with a large presence in the other cargoes. Port authorities with a large presence in passenger traffic are also found to be more efficient.

Table 6
Distribution of persistent efficiency scores.

	Number of port authorities
$0.9 \le eff < 1.0$	11
$0.7 \le eff < 0.9$	4
$0.5 \le eff < 0.7$	5
$0.3 \le eff < 0.5$	6

Table 7
Summary of estimated efficiency scores.

	Persistent	Transient	Overall
Mean	0.753	0.987	0.744
Min.	0.352	0.941	0.341
Max.	0.972	1.000	0.972
S.D.	0.218	0.016	0.217
Inefficient port authorities	26	14	26

The distribution of the estimated persistent efficiency scores is presented in Table 6, and summaries of persistent, transient and overall efficiencies are presented in Table 7. From Table 7 we can see that all port authorities were found to be persistently inefficient to some extent, with quite a large range of scores: the lowest estimated persistent efficiency corresponded to the Atlantic seaboard port authority of Gijón (0.353) whereas the highest corresponded to Melilla (0.972). It can be seen that 11 of the port authorities had quite high persistent efficiency (over 0.90), with 6 port authorities having very low scores (< 0.50). The 6 most inefficient port authorities include, apart from some Atlantic seaboard ports, the large port authorities of Valencia and Bahía de Algeciras, which, it should be noted, manage multiple ports.

The situation with transient efficiency is quite different. Transient efficiency scores are quite high, with port authorities generally proving to be highly efficient. Thus, 12 of the 26 port authorities were found to be efficient, and of the 14 inefficient port authorities, all of these had estimated efficiency scores greater than 0.94. Thus, once specialization, output concentration and the importance of the port authority's cargo in the national system are taken into account, the port authorities were basically found to be highly technically efficient.

Finally, given that estimated transient efficiency is quite high (> 0.94) for all port authorities, overall efficiency, which is the product of transient and persistent efficiency, mainly reflects persistent inefficiency.

5. Conclusions

This is the first paper to estimate port efficiency by distinguishing between persistent (time-invariant) and transient (time-varying) technical efficiency. While there is a large and growing literature devoted to the important issue of port efficiency, none of these have contemplated accounting for unobserved heterogeneity, time-invariant efficiency and time-varying efficiency. This distinction is important as the nature of efficiency calls for different policy management responses from port authorities. Our results for the Spanish port system covering the last three decades indicate that time-varying (or short-term) inefficiency is relatively low. Persistent (time-invariant) inefficiency, on the other hand, was found to be much larger. We find that the type of output matters. For example, port authorities with larger national shares of container cargo are systematically more efficient. Port authorities with ports located on the Mediterranean seaboard are found to be at an efficiency advantage over those on the Atlantic seaboard. Importantly, we find that port authorities managing several ports are persistently more inefficient than those that manage only a single port. Addressing persistent inefficiency, which is structural in nature, is not easy and will depend to a large degree on national and European-level initiatives to address structural disadvantages rather than on the immediate managerial action of individual port authorities, which seems to be achieving high short-run efficiency levels.

Overall, our results show that care should be taken when comparing the productive performance of port authorities. For example, in the Spanish case, any benchmarking exercise comparing the performance of port authorities should take into account whether these entities manage more than a single port, as failure to do so would overestimate their inefficiency. Similarly, the location of the ports matters, with ports on the Atlantic seaboard at a structural efficiency disadvantage over those on the Mediterranean. The type of cargo that port authorities are specialised in should also be taken into account when comparing performance, as those with a large presence in general non-containerised cargo are found to be at a disadvantage in terms of both persistent and transient efficiency.

While these results are of interest in themselves, one of our main aims in this work is to encourage researchers in the field of port efficiency – and in particular those working with stochastic frontiers – to take account not only of time-varying efficiency but also persistent efficiency, as these call for different policy responses from authorities. We have estimated these efficiencies with a simple multiple-step approach using a fixed effects framework, and for a given country and time period. A random effects framework could also be used, which can be combined with a Mundlak adjustment to facilitate the inclusion of time-invariant variables. Other more efficient estimation methods than our three-step approach, such a one-step maximum likelihood, can be used. It is also possible to model unobserved heterogeneity as a function of determinants, and models also exist which account for possible endogeneity issues. In the case of Spain, it would be interesting to see whether the results we have found hold if different estimators were used or if different time periods were contemplated. It would also be interesting to compare results for different countries to check whether the underlying causes of persistent efficiency are repeated. As can be seen, the incorporation of persistent as well as transient efficiency into port productive performance studies provides a wealth of possibilities for future research with different methods and samples, and we hope our work encourages researchers to explore these possibilities in the future.

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CRediT authorship contribution statement

Beatriz Tovar: Conceptualization, Investigation, Formal analysis, Methodology, Supervision, Writing – review & editing, Project administration, Funding acquisition. **Alan Wall:** Conceptualization, Investigation, Formal analysis, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

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