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When It Comes to Container Port Efficiency, Are All Developing Regions Equal?

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Abstract

This paper develops a port productivity and efficiency analysis of all developing regions between 2000 and 2010, using both parametric and nonparametric approaches. From a unique dataset – our sample covers 70 developing countries, 203 ports, and 1,750 data points–, we carry out an analysis of the evolution and drivers of productivity and efficiency changes across developing regions. We show that productivity growth rates between 2000 and 2010 vary significantly and that this heterogeneity is explained by pure efficiency changes rather than scale efficiency of technological changes. Therefore, we carry out a detailed efficiency analysis to determine the drivers of port efficiency. Time series results show an upward trend for port efficiency in developing regions, as it increased from 47 percent in 2000 to 57 percent in 2010. Our analysis indicates that private sector participation, the reduction of corruption in the public sector and improvements in liner connectivity and the existence of multimodal links increase the level of port efficiency in developing regions.

JEL Classification: L51, L91, L92, O18.
Key-words: productivity; technical efficiency; ports; developing regions; benchmarking.

1. Introduction

About 80 percent of world trade is carried via maritime transport and consequently the performance of ports, being the most important gateways for international trade, is a key determinant of countries' competitiveness. Assessments of the level and evolution of port performance, if able to influence the adoption of public policies, can bring about sizable reductions in logistics costs. The need to reduce logistics costs is more acute in developing countries which as a group have a significant cost gap when compared to OECD countries. According to the World Bank' Logistics Performance Indicators (World Bank, 2014a) developing countries had a score of 2.41 in 2014 on a scale from 1 to 5, compared with 3.70 for OECD countries.

The last decades have witness a radical transformation of the shipping market with the emergence of the container as increasingly important transportation equipment. Even though containerized commercial services date from the 1950s, containerization only started to seriously affect global trade patterns and manufacturing strategies in the 1990s (Rodrigue, 2013). The changes have been so profound that by 2009, over 90 percent of nonbulk maritime trade was shipped in containers across the world, shaping international trade among countries in all regions (Ebeling, 2009). In recent years, developing countries have increased their role in the container maritime shipping market. These countries moved 35.7 percent of the world's container traffic in 2000 while ten years after their share reached 47.5 percent, despite accounting for 29 percent of the gross world product (World Bank, 2014b). This growth was the result of deeper integration of supply chains, a notable increase in commodities trade, and higher volumes of import demand for capital and consumer goods. Although most of this expansion is a product of fast development in larger developing countries, such as China, India, Russia, and Brazil, small and medium-sized developing economies experienced a similar expansion. As an example, from 2000 to 2010, Bangladesh and Peru had container traffic growth rates of 197 percent and 233 percent, respectively, rates that rival those of China (217 percent) and Brazil (237 percent).

The impressive growth of container traffic handling in ports of developing countries coexisted with a large gap in the perception of port quality between developed and developing countries. According to the port quality perception indicator prepared by the World Economic Forum (2014), developed countries outperform developing countries by 5.5 to 3.7 on a scale from 1 to 7 based on a country average comparison, being Singapore (6.8) and Hong Kong (6.6) the top performers.

The evidence shows a strong negative link between port efficiency and transport costs. In Latin America, Wilmsmeier et al (2006) calculates that doubling port efficiency in a pair of ports has the same impact on international transport costs as halving the distance between them. Similarly, Clark et al (2002) found that improving port efficiency from the 25th to 75th percentile reduces shipping costs by 12% in this region. When it comes to shipping costs, the World Bank' Doing Business report (2013) shows much higher costs for exports by container in developing regions: USD1,283 in Latin America; USD1,787 in South Asia and USD2,108 in Sub-Saharan Africa, compared to USD1,070 in OECD high income countries (World Bank, 2013). The cost comparison is similar for imports with values of USD1,676, USD1,968, USD2,793 and USD1,090, respectively. It is reasonable to assume that one port performance is a likely candidate to explain the observed cost differential.

Considering both the impressive traffic growth and the higher costs associated to ports in developing regions – together with the perception of a lower service quality–, it seems surprising the little knowledge available on the port performance in the developing world. The adoption of cost-effective policies aimed at improving port competitiveness requires good quality information in the form of benchmarks of performance indicators. Unfortunately, there are very limited comprehensive studies of the productivity and efficiency of container ports in developing countries, and what little is available is focused mostly on single countries or small geographic regions.

Relying on a unique dataset that covers the entire developing world between 2000 and 2010, this paper calculates the drivers of productivity changes among developing regions and identifies determinants of port efficiency. To the best of our knowledge, there is no study that analyzes the level of port performance, their differences and potential determinants across all the developing regions.

This paper first looks briefly at port performance theory, including efficiency and productivity analyses. It then presents the available data and provides a detailed review of descriptive statistics by region, before turning to an examination of the productivity of container terminals in developing regions. The sources of differences in productivity between regions are then examined and an efficiency analysis is conducted. Finally, the paper puts forth some conclusions and policy recommendations.

2. Benchmarking Port Performance

Several port performance indicators have been used with the aim of improving port operations and providing useful information for port development planning and strategy. Talley (2006) defines these indicators as choice variables – i.e., variables that can be controlled by port management – for optimizing economic objectives. These indicators may assess port operations from different viewpoints (UNCTAD, 1976). Some examples of the broad taxonomy used to measure performance include efficiency, productivity, utilization, and effectiveness indicators.

The port industry has mostly relied on the use of partial performance indicators because these metrics are simple to understand and easy to calculate.[1] These indicators describe waiting times,

[1] Partial performance indicators have been in use in the port industry for more than four decades. UNCTAD (1976) is the first in the literature that summarizes and explains partial performance indicators in the port sector.

service or turnaround time, labor expenditure, capital equipment expenditures per ton of cargo, tons/TEUs[2] per ship hour in port or at berth, berth occupancy, and cargo handling revenues per ton of cargo, among other industry metrics. However, a port production function requires from multiple outputs and inputs. For this reason, the economic literature has evolved and increasingly focuses on total measures of port performance, that account for a mix of inputs used, technology to transform inputs into outputs, and the firm's productive scale. In this field, two different concepts stand out: efficiency and productivity.

2.1. Port Efficiency

Efficiency has been addressed by port-related literature from many different perspectives. Essentially, port efficiency analyzes established relationships between inputs (mainly a port's physical facilities and its labor force) and outputs (such as quantities or movements in ports). To that purpose, it is necessary to estimate a production or cost frontier – i.e., the set of maximum outputs given different levels of inputs or the set of minimum inputs given the different levels of outputs. In this context, the production frontier represents the optimal combination of inputs in a certain industry. Thus, a producer is considered inefficient if it operates beneath the frontier.

According to this literature, efficiency can be estimated as the gap between the position assigned to each observation – which depends on the relationship between its inputs and outputs – and the estimated best practices located on the production frontier. The construction of an efficient frontier has been addressed from two different approaches: parametric, with Stochastic Frontier Analysis (SFA), and nonparametric, with Data Envelopment Analysis (DEA).[3] Both methodologies have proven to be useful for conducting efficiency studies in that they provide valuable information on whether a port or terminal is employing its inputs appropriately, and thus making proper use of investments (Suárez-Alemán et al, 2014).

As a nonparametric estimation, DEA revolves around a programming approach that does not assume a statistical function underpinning the data.[4] Table A1 in the Appendix reviews recent applications of the DEA method to port or terminal efficiency estimations. For its part, SFA represents a parametric approach that assumes the existence of a statistical function and allows for hypothesis testing. Since the initial works by Farrel (1957), Aigner et al (1977), and Meeusen and van den Broeck (1977), this methodology has been constantly updated.[5]

[2] The TEU – twenty-foot equivalent unit – is a unit of cargo capacity of containers based on the volume of a 20-foot-long intermodal container.
[3] Coelli et al (2003) includes a detailed review of their different methodologies.
[4] DEA was first developed by Charnes, Cooper, and Rhodes (CCR) (1978). The authors assumed constant returns to scale, that is, all observed combinations can be scaled up or down proportionally (DEA-CCR model). After that, Banker, Charnes, and Cooper (BCC) (1984) allowed for variable returns to scale (DEA-BCC model).
[5] Morales et al. (2013) explain the evolution of SFA methodology together with recent applications in the port sector.

Briefly, the equation that characterizes the technical efficiency within the SFA methodology is given by:

$$y_{it} = \exp(\alpha + x'_{it}\beta + v_{it} + u_{it}) \text{ for } t \in \tau(i); i = 1,2,\ldots,T,$$

where y_{it} is output and x_{it} is a vector of inputs for each observation i and time period t. β is a vector of unknown parameters and α is a constant. The term τ(i) is a set of T time periods among existent time periods for which observations are available for the ith port. The term u_{it} captures technical inefficiency and is assumed to be a one-sided independent and identically distributed random variable, while v_{it} captures measurement error and random effects, and is assumed to be a two-sided independent and identically distributed normal $N(0,\sigma_v)$ variable. Following Battese and Coelli (1995), a one-stage model may incorporate the explanatory factors of technical efficiency by fitting a conditional mean model to u_{it} in the estimation:

$$u_{it} = exp(z_{it}\delta + w_{it}),$$

where z_{it} is a set of explanatory variables associated with technical inefficiency over time, δ is a vector of unknown parameters, and w_{it} is defined by the truncation of a normal distribution with mean zero and standard deviation σ^2. Once the assumptions are set, technical efficiency in each observation can be computed by comparing the observed output in each firm against the output if there were no inefficiencies of production. These estimates are calculated with the following equation:

$$TE_{it} = exp(-z_{it}\delta - w_{it}).$$

TE_{it} or technical efficiency is a variable ranging between 0 and 1, with the maximum value representing the technical efficiency frontier. Although the application of frontier analysis in the port sector is relatively recent, there are numerous studies that analyze port efficiency using SFA. Table A2 in the Appendix lists notable applications of the SFA method to port or terminal efficiency estimations over recent decades.

2.2. Port Productivity

The concept of productivity, used frequently to measure and compare the performance of firms, refers to the ratio of outputs over inputs. It analyzes how well a firm employs its input endowment to produce its outputs. Although productivity and efficiency oftentimes are used interchangeably, the former is comprised of a broader concept. Port efficiency, on the one hand, analyzes the ability of a port to obtain the maximum output under a given amount of inputs or through the use of the minimum amount of inputs under a given amount of outputs. Efficiency gains, therefore, represent a movement to a situation closer to optimal. On the other hand, changes in port productivity may be derived from efficiency gains or from changes in technology. In a production frontier context, this could be represented by an upward shift in the frontier over time, for example.

Ports commonly have different outputs (handling of containers, liquid, solid or break bulk, general cargo, etc.) and inputs (cranes, labor, terminal facilities, etc.). Thus, a simple ratio of an output over an input may not properly represent the reality of a port. We have to employ methodologies that account for all inputs required to produce one or more outputs, which is known as total factor productivity (TFP). A wide range of methodologies to determine TFP have been implemented in recent decades, mainly based on the use of market prices (e.g., price-based index numbers) or on the estimation of a production frontier.[6] This latter methodology allows for the decomposition of TFP into different components through panel data on different firms.

Malmquist DEA TFP decomposition – first implemented by Färe et al (1992) based on the productivity measure developed by Caves (1982) in the context of efficiency theory – represent a sound example in the estimation of a production frontier. These indices have been widely employed in port-related literature during the last decade. Table 1 shows a list of recent academic papers that cover several regions of the world.

Table 1: Malmquist Index in Recent Port Studies

Author	**Region/Country**	**Period**
Martín Bofarrul (2003)	Spanish ports (theoretical)	–
Estache et al. (2004)	Mexican industrial ports	1996–1999
Díaz-Hernández et al. (2008)	Spanish ports	1994–1998
Bo-xin et al. (2009)	Chinese container ports	2001–2006
Guerrero and Rivera (2009)	Mexican ports	2000–2007
Al-Eraqi et al. (2009)	Middle East and East African container terminals	2000–2005
Lozano (2009)	Spanish port authorities	2002–2006
Cheon et al. (2010)	Worldwide ports	1991–1994
Haralambides et al. (2010)	Middle East and East African ports	2005–2007
Choi (2011)	Chinese container ports	2003–2008
Barros et al. (2012)	Brazilian seaports	2004–2010
Halkos and Tzeremes (2012)	Greek ports	2006–2010
Mokhtar and Shah (2013)	Major container ports in Peninsular Malaysia	2003–2010
Song and Cui (2013)	Chinese container terminals	2006–2011
Wilmsmeier et al (2013)	Latin America and the Caribbean and Spain	2005–2011
Chang and Tovar (2014)	Peruvian and Chilean ports	2004–2010

Source: Prepared by the authors.

Although there are several examples of studies that follow a multi-country approach (Wilmsmeier et al, 2013; Cheon et al, 2010; Al-Eraqui et al, 2009), to our knowledge there is no

[6] Coelli et al. (2003) provides a detailed review of these methodologies.

research that analyzes the productivity growth and its determinants of container terminals across all developing regions.

2.3. Malmquist Decomposition Index

Briefly, this index estimates TFP changes by calculating the ratio between the distances from two input combinations in two different time periods with a common technology. The Malmquist TFP change index between periods 0 (the base year) and 1 (the reference technology) is given by

$$\frac{TFP_1}{TFP_0} = \frac{D_1(Y_0,X_0)}{D_1(Y_1,X_1)},$$

where $D_1(Y_0, X_0)$ represents the distance from the period 0 observation to the period 1 technology (Coelli et al., 2003).[7] According to Färe et al (1992), an alternative Malmquist TFP index is defined as the geometric mean of indexes referred to in these two different periods (reference technologies). That is,

$$\frac{TFP_1}{TFP_0} = \left[\frac{D_1(Y_0,X_0)}{D_1(Y_1,X_1)}\frac{D_0(Y_0,X_0)}{D_0(Y_1,X_1)}\right]^{\frac{1}{2}}.$$

Alternatively, we could write the previous expression as follows:

$$\frac{TFP_1}{TFP_0} = \frac{D_0(Y_0,X_0)}{D_1(Y_1,X_1)}\left[\frac{D_1(Y_0,X_0)}{D_0(Y_0,X_0)}\frac{D_1(Y_1,X_1)}{D_0(Y_1,X_1)}\right]^{\frac{1}{2}},$$

where the expression in brackets represents the shift in technology between the two periods, and the ratio outside the brackets measures technical efficiency change. Thus, we may separate both components of productivity to better determine the source of TFP changes.

The DEA method allows for estimating the distance functions required for the abovementioned Malmquist TFP analysis. Moreover, the implementation of both constant returns to scale (CCR, from Charnes, Cooper, and Rhoades, 1978) and variable returns to scale (BCC, from Banker, Charles, and Cooper, 1984) allows not only for disentangling technology and efficiency changes, but, within the latter, disentangling pure technical efficiency and scale efficiency. In order to account for these two effects, the previous expression is modified by introducing BCC distance functions to obtain

$$\frac{TFP_1}{TFP_0} = \frac{{D_0}^{BCC}(Y_0,X_0)}{{D_1}^{BCC}(Y_1,X_1)}\left[\frac{{D_1}^{BCC}(Y_1,X_1)}{{D_0}^{BCC}(Y_0,X_0)}\frac{{D_0}^{CCR}(Y_0,X_0)}{{D_1}^{CCR}(Y_1,X_1)}\right]\left[\frac{{D_1}^{CCR}(Y_0,X_0)}{{D_0}^{CCR}(Y_0,X_0)}\frac{{D_1}^{CCR}(Y_1,X_1)}{{D_0}^{CCR}(Y_1,X_1)}\right]^{\frac{1}{2}}.$$

Thus, TFP change is finally formed as the multiplication of technological, scale, and pure technical efficiency changes:

[7] This analysis could also be done by considering period 0 as the reference technology.

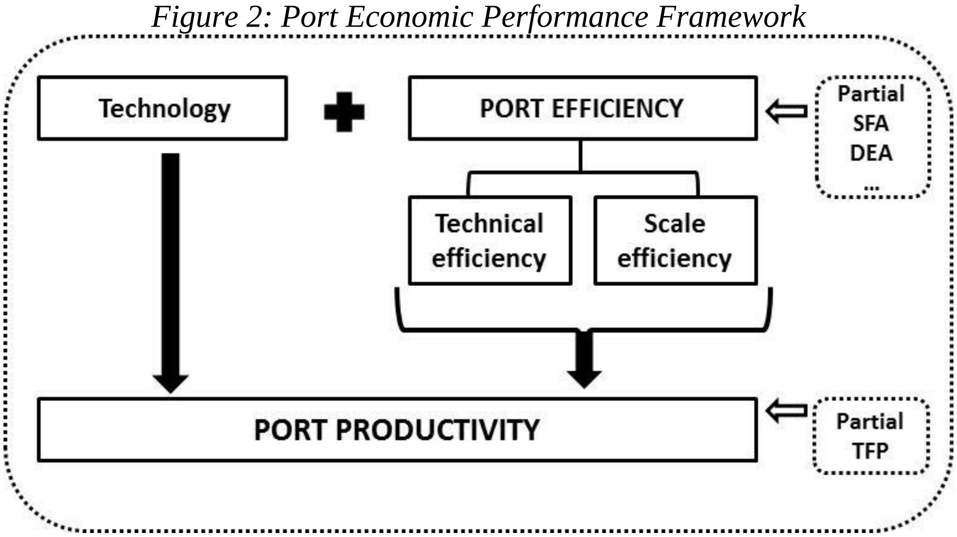
$$TFPCH = EFFCH \cdot TECHCH ; \quad EFFCH = PECH \cdot SECH,$$

where

- *TFPCH* = total factor productivity change and represents the overall change that may vary over time because of *EFFCH* or *TECHCH*;
- *EFFCH* = efficiency change and represents the part of the productivity change due to the level of efficiency in performance, and may be decomposed into *PECH* and *SECH*;
- *TECHCH* = technical change and represents the part of the productivity change due to technological modifications (a shift in the production frontier over time);
- *PECH* = pure efficiency change and represents the part of the efficiency change due to pure efficiency considerations, once scale efficiency is removed;
- *SECH* = scale efficiency change and represents the part of the efficiency change due to size: the scale efficiency is a measure of the degree to which a firm is optimizing the size of its operations (Coelli et al., 2003).

To summarize, Figure 2 schematically shows the theoretical framework of the analysis.

Figure 2: Port Economic Performance Framework



Note: DEA = Data Envelopment Analysis; SFA = Stochastic Frontier Analysis; TFP = total factor productivity.
Source: Prepared by the authors.

3. Data

This paper uses port data collected from various editions of the Containerisation International Yearbook (2002-2012), a publication that provides a detailed description of container terminal assets worldwide. The information is used to construct a database that spans 11 years, from 2000 through 2010, covering 70 developing countries,[8] 203 ports, and 1,750 data points. To construct the database, we omitted ports that did not reach an annual container throughput of 50,000 TEUs over the 11-year period (representing 0.2% of total throughput in the sample). Moreover, terminal-level data were aggregated at the port level for comparative purposes. Altogether, our database is an unbalanced panel including most major ports in the developing world, representing roughly 95 percent of total container traffic in the developing regions.

We gathered port information on (1) annual container throughput, (2) total terminal area, (3) total length of berths, (4) number of mobile cranes with container-handling capacity,[9] and (5) number of ship-to-shore (STS) gantry cranes.[9] For each time period, we also identified ports that were privately operated, ports that had access to rail, and ports that were major transhipment hubs. In addition, we included country-level data that may affect port performance, including (1) data from the World Bank's World Development Indicators on per capita income (in constant U.S. dollars), GDP (in constant U.S. dollars), and trade openness (imports and exports as a share of GDP); (2) data from the United Nations Commission for Trade and Development (UNCTAD) on liner shipping connectivity, an index that measures the degree to which countries are connected to the global maritime shipping network; and (3) data from Transparency International for a measure of public sector corruption ranging from 0 (highly corrupt) to 10 (highly clean).

The developing world is far from being a homogenous group of countries with similar development challenges. Countries have different income levels, geography, and institutions, among many other different characteristics. We classified ports geographically according to the World Bank criterion to group developing regions based on income levels and location: Latin America and the Caribbean (LAC), Europe and Central Asia (ECA), the South Asia Region (SAR), sub-Saharan Africa (SSA), East Asia and the Pacific (EAP), and the Middle East and North Africa (MENA).[10] However, we also considered China as a separate region because of its large number of ports and their different characteristics relative to ports in other East Asian countries. A breakdown of ports by countries and regions is provided in Table A3 in the Appendix.

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[8] For a country to be considered as "developing," we used a threshold of US$20,000 gross national income per capita in 2010, as calculated by the World Bank atlas method.

[9] Cranes with capacity equal to or over 15 tons.

[9] Our inputs choice follows the traditional approach in port efficiency and productivity studies. However, the introduction of some other non-physical indicators such as crane moves per hour, waiting or dwell time would improve the analysis. Unfortunately, to the best of our knowledge there is no reliable data at this level for the whole developing world.

[10] See Table A3 in the Appendix for a list of the countries that correspond to each region, and the ports considered in each country.

Table 2: Port Traffic Growth, by Region

	Throughput 2010 (thousands of TEUs)	Compound Annual Growth Rate, 2000–2010 (percent)	Growth Rate 2008–2009 (percent)
LAC	39,931	9	-8
ECA	12,332	17	-27
SAR	17,323	13	2
SSA	9,221	9	-3
EAP	45,129	11	-2
MENA	25,273	14	5
CHINA	130,290	12	-6
Total	**279,499**	**12**	**-5**

Note: TEU = twenty-foot equivalent unit; LAC = Latin America and the Caribbean; ECA = Europe and Central Asia; SAR = South Asia Region; SSA = sub-Saharan Africa; EAP = East Asia and the Pacific; MENA = Middle East and North Africa.

Source: Prepared by the authors.

Comparing total container traffic by region, China clearly dominates in terms of volume, having handled more than 130 million TEUs in 2010 (Table 2), which represents 47 percent of the total TEUs moved in the developing world in that year. EAP follows with 45 million TEUs (16 percent). The smallest regions in terms of container traffic are SSA and ECA. However, in terms of the regions whose throughput grew over 2000–2010, ECA stands out with a compound annual growth rate of 17 percent. Despite ECA's strong throughput growth over the period, however, it was the developing region that clearly was most affected by the international financial crisis in 2008–2009, as reflected in the decline in its throughput growth rate during those years by 27 percent.

Table 3: Port Descriptive Statistics by Region, Average over 2000–2010

Region	Ports	Statistic	Annual Throughput (TEUs)	Terminal Area (square meters)	Berth Length (meters)	Mobile Cranes (units)	Ship-to-Shore Gantry Cranes (units)
LAC	64	Average	440,103	266,398	1,114	2.4	2.4
		Maximum	2,758,506	1,580,000	5,380	38	19
		Minimum	3,721	12,000	140	0	0
ECA	20	Average	394,639	468,030	1,187	6.3	4.0
		Maximum	2,540,353	2,634,000	6,000	33	38
		Minimum	6,902	16,248	155	0	0
SAR	14	Average	758,812	301,152	1,148	2.9	5.7
		Maximum	4,269,811	2,140,000	3,749	23	26
		Minimum	8,593	3,200	168	0	0
SSA	23	Average	351,855	335,482	1,053	3.5	2.9
		Maximum	2,642,559	2,475,000	4,484	78	25
		Minimum	26,225	11,000	180	0	0
EAP	35	Average	1,082,733	592,609	1,724	4.1	7.3
		Maximum	8,870,000	10,100,000	10,300	47	81
		Minimum	17,781	3,600	100	0	0
MENA	25	Average	758,976	655,371	1,329	5.7	6.8
		Maximum	3,830,857	4,400,000	6,070	50	45
		Minimum	1,089	45,000	110	0	0
CHINA	22	Average	4,438,505	880,995	1,886	3.4	12.0
		Maximum	29,100,000	8,569,837	9,142	39	113
		Minimum	19,000	11,000	180	0	0

Note: TEU = twenty-foot equivalent unit; LAC = Latin America and the Caribbean; ECA = Europe and Central Asia; SAR = South Asia Region; SSA = sub-Saharan Africa; EAP = East Asia and the Pacific; MENA = Middle East and North Africa;

Source: Prepared by the authors.

Table 3 shows port statistics by region. Data patterns of note include China being a leader in stock of port infrastructure and in container throughput. China has average container traffic by port that is four times that in EAP and 12 times that in SSA. Moreover, a typical port in China has the highest number of STS gantry cranes, the longest berths, and the largest terminal areas.

Table 3 also reveals significant port heterogeneity among the six remaining developing regions. EAP has more port infrastructure and annual throughput than ports in other regions. In part, this is driven by container transhipment hubs in countries such as Malaysia, Indonesia, and Thailand, but also by strong import/export traffic in a region that relies heavily on maritime transportation.

The average ports in SAR and MENA are quite similar in terms of container traffic (with roughly 750,000 TEUs). While MENA's transhipment around the Suez Canal helps increase its container traffic, a large share of its output is due to maritime trade from large economies such as

Saudi Arabia and Iran. In turn, SAR is mostly represented by ports in India (10 of its 14 ports), along with ports in Pakistan, Sri Lanka, and Bangladesh. Even though SAR and MENA have comparable average throughput, SAR ports are smaller in area and have fewer berths and cranes.

LAC has the highest number (64) of ports in the sample and a variety of port sizes. Larger ports are located not only in the largest economies such as Brazil and Mexico, but also in transhipment hubs such as Panama and Jamaica. In LAC, average container traffic is comparable to that of ECA and SSA. However, in terms of assets, LAC lags behind the average port in ECA, which has a typical stock of port infrastructure that is twice as large. In this regard, LAC is in fact closer to SSA, a region that also has a variety of port sizes, with the largest in Nigeria and the smallest in Mozambique.

Table 4: Private-Sector-Operated Ports and Other Descriptive Statistics by Region (Percent of total)

Region	Private-Sector-Operated[1]	Rail Link	Transshipment Traffic
LAC	61	47	13
ECA	40	50	0
SAR	43	71	7
SSA	17	61	0
EAP	46	23	14
MENA	64	44	20
CHINA	73[2]	32	5
Total	**52**	**44**	**10**

[1] Limited-liability companies.
[2] As we define private-sector-operated ports as those where the operator is a limited-liability company, this figure includes purely private companies in China, as well as listed state-owned enterprises.
Note: LAC = Latin America and the Caribbean; ECA = Europe and Central Asia; SAR = South Asia Region; SSA = sub-Saharan Africa; EAP = East Asia and the Pacific; MENA = Middle East and North Africa.
Source: Prepared by the authors.

Developing regions are also heterogeneous in terms of private sector ports operations. Table 4 shows that China has the highest share of ports that are operated by private sector or state-owned enterprises, followed by MENA and LAC. Roughly two-thirds of the ports in all three regions operate under a landlord port ownership model. SSA has the smallest proportion of private participation, at only 17 percent, while the overall developing world average is 52 percent.

Another aspect of port operations relevant to port productivity is rail access within a container terminal. Table 4 shows that SAR and SSA are better endowed in this regard, which can be in part explained by a historical tradition of rail infrastructure investment in former British colonies such as India, Sri Lanka, South Africa, and Nigeria, among other countries. Conversely, EAP has the least amount of ports with rail connections. With respect to transhipment hubs in the developing world, Table 4 reveals that most of these international hubs are concentrated in MENA, EAP, and LAC.[11] In fact, most are located in countries such as Malaysia, Indonesia, Sri Lanka, Egypt, and Oman, and in Caribbean countries. In contrast, no port in ECA or SSA was a major transhipment hub over the 2000–2010 period.

4. Productivity Analysis of Container Terminals is Developing Regions

This section analyzes TFP changes in container terminals in developing regions. In order to use a required balanced panel for DEA estimations, we have considered ports with input and output data over the period from 2000 to 2010. Following the theoretical framework introduced in Section 2, Table 5 shows the results derived from a DEA Malmquist analysis of TFP changes by region.

Table 5: A Data Envelopment Analysis Malmquist Decomposition of Total Factor Productivity Changes from 2000 to 2010, by Region

Region	Descriptive	TFPCH	EFFCH	TECHCH	PECH	SECH
CHINA	Mean	1.3157	1.4386	1.0314	1.5154	0.9248
	Median	1.9902	1.8102	1.0905	1.6549	1.0493
EAP	Mean	1.9746	1.7653	1.0692	1.6852	1.0492
	Median	0.7613	0.8948	0.9972	0.7130	0.9786
ECA	Mean	1.6044	1.2585	1.2756	1.0051	1.3204
	Median	1.5070	1.3055	1.2483	0.9187	1.1977
LAC	Mean	1.2426	1.3237	1.0128	1.1497	1.0802
	Median	1.0544	1.0000	0.9848	1.0000	0.9974
MENA	Mean	1.7531	1.7735	1.0148	1.6925	1.0166
	Median	1.9317	1.8333	1.0256	1.3879	1.0560
SAR	Mean	1.8626	1.6118	1.2254	1.5299	1.1218
	Median	1.3855	1.0511	1.1037	1.0000	1.0000
SSA	Mean	1.8637	1.9498	1.0437	1.3948	1.2543
	Median	1.3857	1.4502	1.0749	1.4496	1.0004

Note: LAC = Latin America and the Caribbean; ECA = Europe and Central Asia; SAR = South Asia Region; SSA = sub-Saharan Africa; EAP = East Asia and the Pacific; MENA = Middle East and North Africa; TFPCH = total factor productivity change; EFFCH = efficiency change; TECHCH = technical change; PECH = pure efficiency change; SECH = scale efficiency change.
Source: Prepared by the authors.

Table 5 shows the TFP changes and their components. The analysis is carried out in terms of means and medians in order to account for possible heterogeneity within regions' TFP changes. Indeed, this heterogeneity is certainly observed in EAP, where the mean differs widely from the median. According to the mean, the region improved its productivity by 97.46 percent during the decade, while the median shows a decrease in productivity of 13.87 percent. This is

[11] Table A3 in the Appendix includes detailed descriptive statistics for 2000 and 2010 in order to compare the evolution not only in terms of outputs but also in terms of port facilities.

explained by the Tanjung Pelepas port (Malaysia), which is recognized as the world's fastest growing port, with close to 1 million TEUs in its first operational year (from October 1999) and with growth of about 770 percent over the period.[12] Thus, the analysis in terms of median seems the most appropriate in terms of taking into account the existence of such cases.

Taking into consideration the median container terminal, there is a wide variation between regions. It is clear that developing regions did not behave similarly over the last decade. We go from cases with remarkable productivity gains – such as China (99.02 percent), MENA (93.17 percent), ECA (50.70 percent), SAR (38.55 percent), and SSA (38.57 percent) – to regions with practically zero growth (LAC, 5.44 percent) or even declining growth (EAP, –13.87 percent). The results for these two latter regions improve significantly if accounting for the mean instead of the median terminal, pointing again to the high level of heterogeneity among those regions, with some ports advancing far more than others.

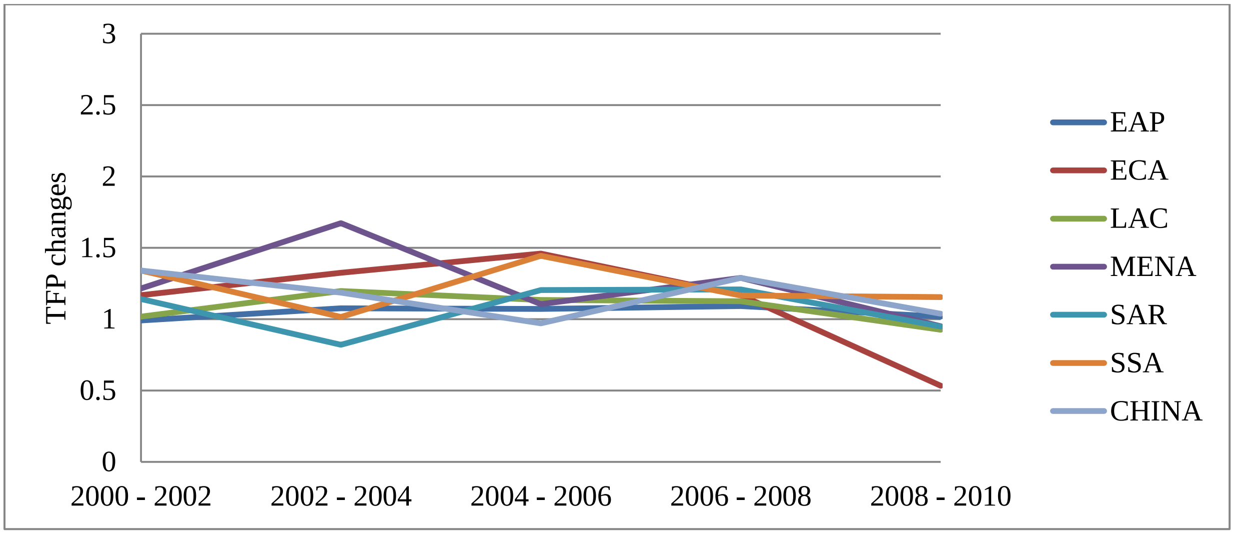
With respect to the TFP decomposition of the median terminal, we could distinguish between Asian terminals (EAP and SAR), where the main source of productivity is technical change, and other regions where efficiency constitutes the main driver of productivity changes. Among the latter category, there are regions where pure efficiency change is the main force (China, LAC, MENA, and SSA) and those where efficiency changes are explained by the scale efficiency component (ECA).

5. The Source of Differences in Productivity

According to results above, it is clear that regions are different in terms of productivity. Considering these remarkable differences between regions, it is reasonable to analyze the evolution of TFP over the 2000–2010 period. Moreover, the decade was marked by an economic crisis that reduced the level of world throughput and might have affected the productivity of developing regions and their ports differently. In this section, we carry out a disaggregated analysis of the productivity changes. In order to account for timeframes that allow for productivity changes in terms of efficiency or technical changes, we have accounted for five different subperiods over the decade. Figure 3 graphically shows TFP evolution of the median terminal by region.

[12] For more information about the Tanjung Pelepas port, see the port's official website at http://www.ptp.com.my

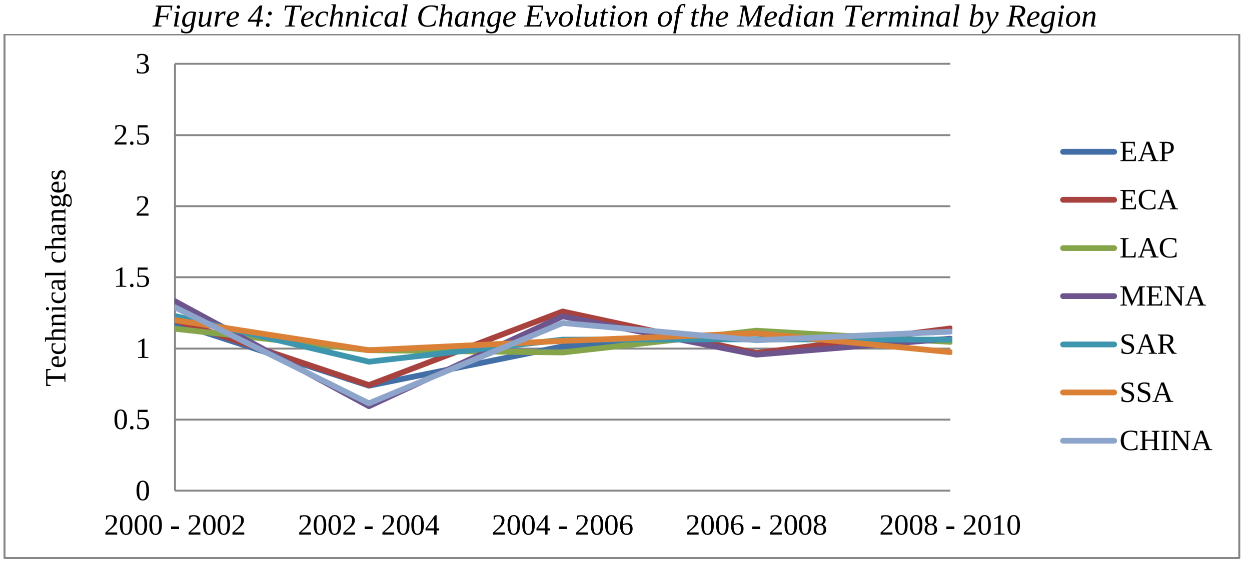
Figure 3: Total Factor Productivity Evolution of the Median Terminal by Region



Note: LAC = Latin America and the Caribbean; ECA = Europe and Central Asia; SAR = South Asia Region; SSA = sub-Saharan Africa; EAP = East Asia and the Pacific; MENA = Middle East and North Africa.
Source: Prepared by the authors.

The evolution of TFP clearly shows two different trends: pre- and post-crisis. Although some regions performed better than others after the 2008 downturn, they all experienced a decline. In general, most regions are above the number 1, which means productivity gains. However, the high level of heterogeneity among regions is quite clear, with productivity gains differing greatly. Since TFP may be decomposed into technical changes and efficiency changes, our empirical strategy is to analyze trends in these two components. Figure 4 and Figure 5 plot the evolution of technical change and efficiency change, respectively.

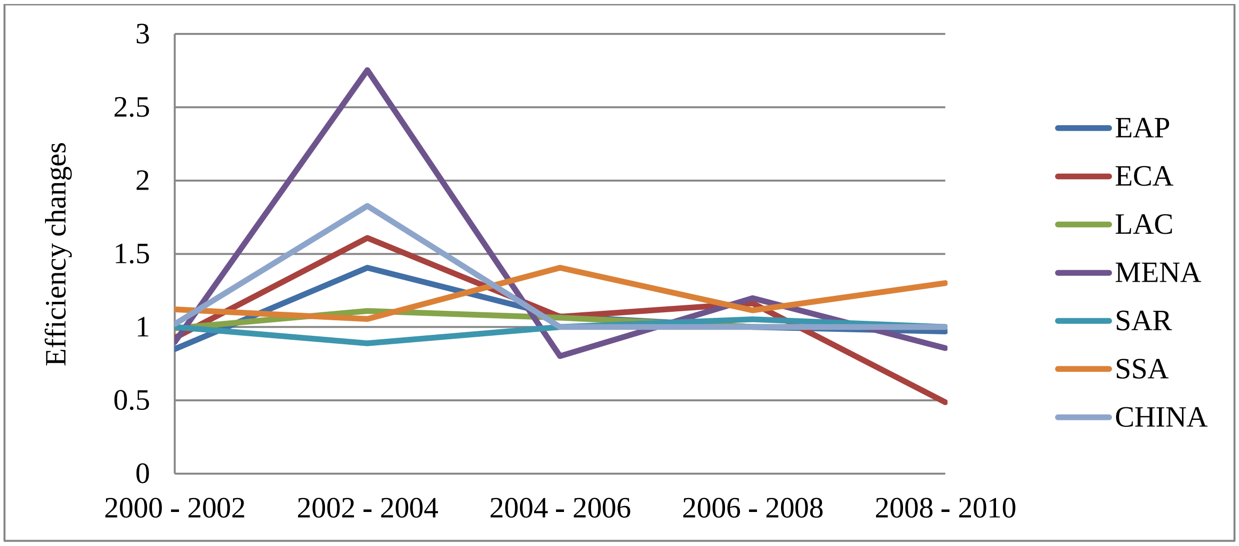
Figure 4: Technical Change Evolution of the Median Terminal by Region



Note: LAC = Latin America and the Caribbean; ECA = Europe and Central Asia; SAR = South Asia Region; SSA = sub-Saharan Africa; EAP = East Asia and the Pacific; MENA = Middle East and North Africa.
Source: Prepared by the authors.

The technical change in the median terminal by region shows that regions followed similar patterns. This result discards technical change as the main driver of productivity differences between developing regions. In this sense, all regions have experience similar technological changes, so productivity variances have to be necessarily explained by the efficiency component. This result highlights the importance of carrying out an analysis of efficiency changes as well as their determinants.

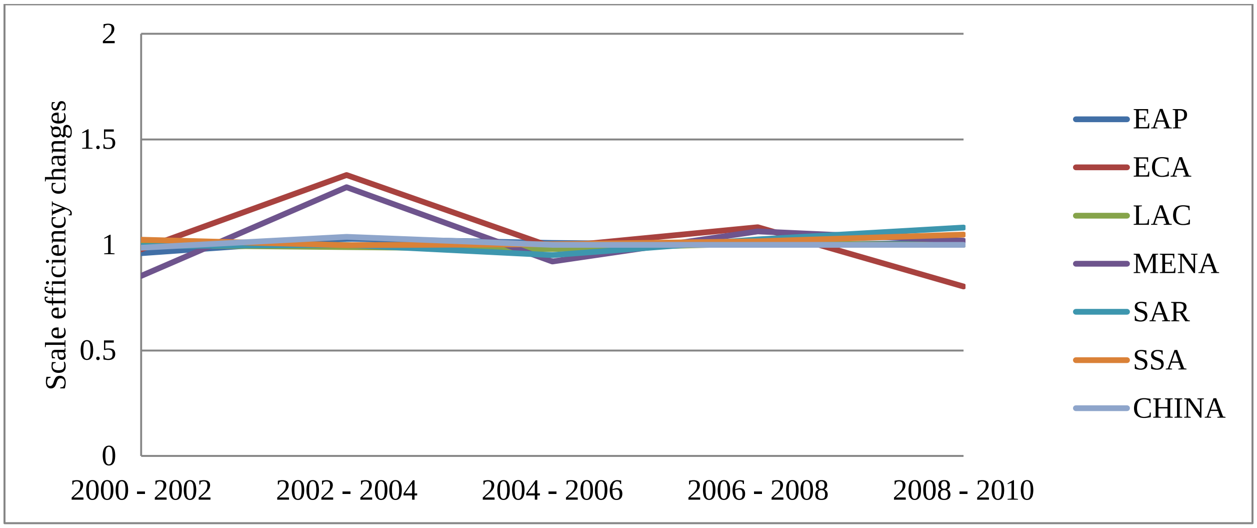
Figure 5: Efficiency Change Evolution of the Median Terminal by Region



Note: LAC = Latin America and the Caribbean; ECA = Europe and Central Asia; SAR = South Asia Region; SSA = sub-Saharan Africa; EAP = East Asia and the Pacific; MENA = Middle East and North Africa.
Source: Prepared by the authors.

The evolution of efficiency shows that the trends at the beginning of the 2000–2010 period are similar to that of productivity. The case of MENA is notable. The region experienced a great increase from 2000–2004, explained by the enormous increase in throughput of Saudi Arabian and Omani ports, without further infrastructure expansion. By the end of the decade, some regions had efficiency gains while others incurred losses. Since there is a relevant heterogeneity in the changes in efficiency over time, the differences in productivity shown in Figure 2 are explained mostly by efficiency rather than technical change. Therefore, assessing efficiency becomes crucial to determining the evolution of the productivity in container terminals in developing regions. To this end, Figure 6 and Figure 7 show the evolution of the two components of efficiency (scale efficiency and pure technical efficiency) by region over 2000–2010.

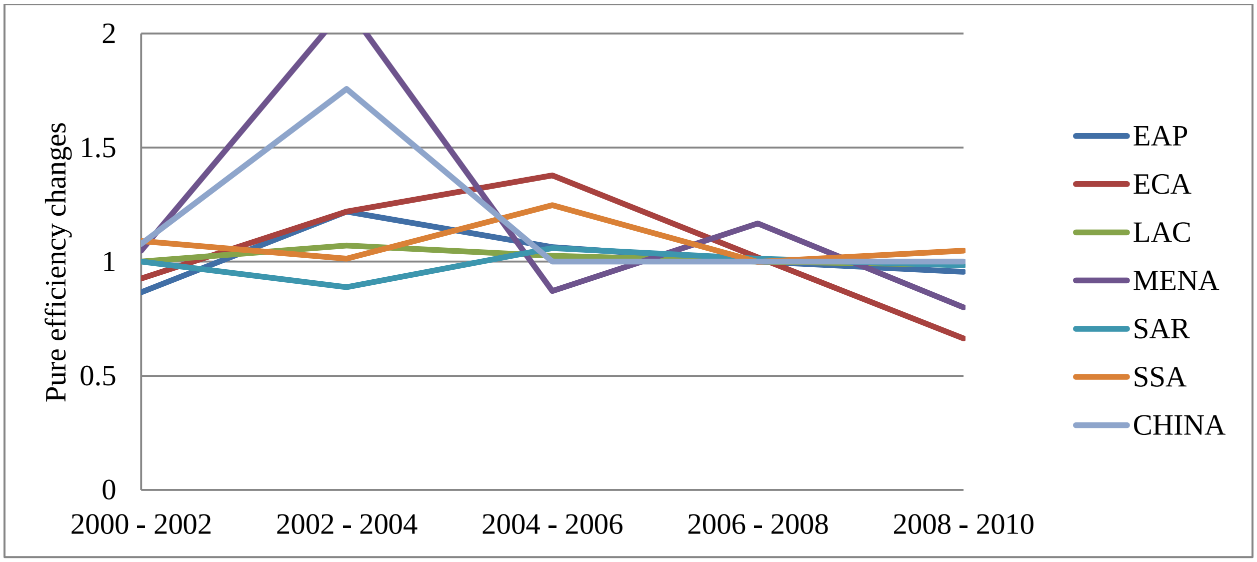
Figure 6: Scale Efficiency Evolution of the Median Terminal by Region



Note: LAC = Latin America and the Caribbean; ECA = Europe and Central Asia; SAR = South Asia Region; SSA = sub-Saharan Africa; EAP = East Asia and the Pacific; MENA = Middle East and North Africa.
Source: Prepared by the authors.

With respect to scale efficiency, Figure 6 reveals two patterns converging into similar results (except for ECA, which underperforms at the end of the decade). The figure shows a certain level of homogeneity among container terminals in the developing regions. Therefore, scale efficiency may not be the most significant determinant of the variation in productivity.

Figure 7: Pure Efficiency Evolution of the Median Terminal by Region



Note: LAC = Latin America and the Caribbean; ECA = Europe and Central Asia; SAR = South Asia Region; SSA = sub-Saharan Africa; EAP = East Asia and the Pacific; MENA = Middle East and North Africa.
Source: Prepared by the authors.

Finally, Figure 7 shows the evolution of pure efficiency over 2000 to 2010, revealing it as the real driver of productivity in developing regions. We find a high level of heterogeneity between changes in pure efficiency over the period.

The decomposition of the productivity changes enables us to acknowledge the key role of efficiency in explaining differences between regions. In other words, there have been productivity changes over the decade because efficiency changed. And efficiency varied among regions because of the pure efficiency component. Thus, by identifying the drivers of technical efficiency, we will be able to explain an important part of port productivity and the differences in that productivity between developing regions. This more detailed analysis of efficiency and its determinants is important for a clearer understanding of port productivity that can provide a foundation for port policy decisions by public authorities. To this end, the next section shows the results of a SFA that determines technical efficiency by port with the estimation of a production function controlling for variables that drive port demand and other port-specific variables.

6. Efficiency Analysis: The Stochastic Frontier

The Stochastic Frontier Analysis allows for a parametric estimation of technical efficiency in ports, as highlighted in Section 2. We used the SFA model to account for institutional and demand-side variables and to single out efficiency, and also to explain the impact of port and country characteristics on determining technical efficiency.

As a starting point for a container port production function specification, we base our model on Morales-Sarriera et al. (2013), Trujillo et al. (2013), Cullinane and Song (2006), and Liu (1995). We assume that terminal area, berths, cranes, and gantries are infrastructure inputs required to handle containers. Moreover, we control production with a series of variables that determine maritime shipping demand:

$$
\begin{aligned}
ln(Q_{it}) = \alpha &+ \beta_1 ln(A_{it}) + \beta_2 ln(B_{it}) + \beta_3 ln(MC^*_{it}) + \beta_4 ln(GC^*_{it}) + \beta_5[ln(A_{it})^2/2] \\
&+ \beta_6[ln(B_{it})^2/2] + \beta_7[ln(MC^*_{it})^2/2] + \beta_8[ln(GC^*_{it})^2/2] + \beta_9 ln(A_{it}) ln(B_{it}) \\
&+ \beta_{10} ln(A_{it}) ln(MC^*_{it}) + \beta_{11} ln(A_{it}) ln(GC^*_{it}) + \beta_{12} ln(B_{it}) ln(MC^*_{it}) \\
&+ \beta_{13} ln(B_{it}) ln(GC^*_{it}) + \beta_{14} ln(MC^*_{it}) ln(GC^*_{it}) + \beta_{15} DMC_{it} + \beta_{16} DGC_{it} \\
&+ \gamma_1 Ships'Cranes_{it} + \gamma_2 Tranship_{it} + \gamma_3 Railway_{it} + \gamma_4 ln(Connectivity_{it}) \\
&+ \gamma_5 ln(Trade_{it}) + \gamma_6 \Delta\ln(GDP_{ti}) + \gamma_7 T_t + v_{it} + u_{it}
\end{aligned}
$$

These variables are defined as follows:

$$\forall \mathrm{i} = 1, \ldots, N \text{ and } t = 1, \ldots, T.$$

Q_{it} is the container throughput (in TEUs) handled by port *i* in period *t*, which is the single output in the equation. As for the infrastructure inputs, A_{it} is the total area (in square meters) of the container terminals in port *i* in period *t*; B_{it} is the total length (in meters) of berths used for container handling in port *i* in period *t*; MC_{it} is the number of mobile cranes owned by port *i* in period *t*; and GC_{it} is the number of STS gantry cranes owned by port *i* in period *t*.

In this model, MC_{it} and GC_{it} are nonessential inputs, i.e., variables that can assume a value of zero, since container terminals might use a combination of mobile cranes, STS gantry cranes, or ships' cranes to move containers (i.e., only one of the three crane types needs to assume a positive value). In that case, a Cobb-Douglas production function does not have a solution, since the log of zero is unidentified. In our sample in 2010, 108 ports did not own either mobile cranes or STS gantry cranes, and 22 ports had no container cranes whatsoever. We employ the methodology proposed in Battese (1997) to estimate unbiased parameters in such cases: first, we created the variable $GC_{it}*$ defined such that $GC_{it}*=Max\ (GC_{it}, DGC_{it})$, where $DGC_{it}=1$ if $GC_{it}=0$ and $DGC_{it}=0$ if $GC_{it}>0$. This modified variable and its dummy that identifies the ports that own no cranes are used in the estimations. The procedure was repeated for MC_{it}.

The equation also considers other variables affecting port throughput that are exogenous to ports (e.g., a demand-side variable). To this end, the production equation has the following other independent variables: $\Delta ln(GDP_{ti})$ represents real GDP growth in period *t* in the country in which port *i* is located; $Connectivity_{it}$ is a liner shipping connectivity index in period *t* in the country in which port *i* is located; and $Trade_{it}$ is trade openness (as a share of GDP) in period *t* in the country in which port *i* is located. These variables are known as proxies of the demand for port services in a country.

Two variables in our specification are binary variables that identify ports that operate as transshipment hubs and ports that have direct railway connections. First, $Tranship_i$ captures the transshipment effect: offloading and loading containers in transit at higher speeds using less port resources such as yard infrastructure, storage, and customs, and optimizing transit speeds. Second, $Railway_i$ controls for the productivity effect of a multimodal link within the port, reducing container yard time and improving container arrival and departure from the terminal.

Finally, we considered the variable $Ships'Cranes_{it}$ to control for those ports that use cranes mounted directly on ships to load and offload containers. According to Morales Sarriera et al. (2013), the use of ships' cranes must be taken into account in port efficiency estimations because these cranes represent a port-exogenous asset that is fundamental for the productivity of terminals with little infrastructure (i.e., container ports that do not have any crane, or have just a few, but have a relatively high level of throughput). Therefore, we created the binary variable $Ships'Cranes_{it}$ that identifies whether port *i* at time *t* has throughput in excess of the highest possible capacity predicted by the use of all its cranes combined, and therefore uses ships' cranes for its additional container traffic.[13]

[13] We based our calculation on industry averages that indicate that a mobile crane does not exceed 25 TEUs handled per hour and the productivity of a STS gantry crane does not exceed 40 TEUs handled per hour. We assume that

Moreover, we also introduced independent explanatory variables for the efficiency term. Therefore, in our model, u_{it}, the error term that explains inefficiency, is determined by the following equation:

$$u_{it} = \delta_1 Landlord_{it} + \delta_2 Corruption_{it} + \delta_3 ln(GDPpc_{it}) + \delta_4 T_t + w_{it},$$

where $Landlord_{it}$ is a dummy that takes the value 1 if port *i* used a landlord ownership model in period *t*; $Corruption_{it}$ is the corruption index in period *t* in the country in which port *i* is located; and $GDPpc_{it}$ is income per capita in period *t* in the country in which port *i* is located (in constant U.S. dollars).

6.1. Estimation Results

Table 6 summarizes the maximum likelihood estimations of the equations described in the previous section. We estimated four different specifications: (1) a full translog model with control variables and an explanatory model for technical efficiency; (2) a translog that calculates the frontier without modeling the determinants of technical efficiency; (3) a reduced-form translog that only includes significant quadratic or interaction terms; and (4) a Cobb-Douglas model estimated with control variables.

these cranes operate 16 hours a day, 365 days a year, and we consider that an upper bound of productivity in ports with less than 1.5 million TEUs in container traffic.

Table 6: Results of Maximum Likelihood Estimations

		Specifications			
Variables		**Translog (1)**	**Translog (2)**	**Translog (3)**	**Cobb-Douglas (4)**
β_1	Ln(Area)	0.19 (0.29)	0.05 (0.29)	0.11** (0.02)	0.07** (0.02)
β_2	Ln(Berth)	-1.39** (0.32)	-1.31** (0.32)	-1.00** (0.27)	0.34** (0.03)
β_3	Ln(MobileCrane)	0.69** (0.27)	0.92** (0.27)	0.97** (0.21)	0.15** (0.02)
β_4	Ln(GantryCrane)	1.24** (0.34)	1.33** (0.34)	0.86** (0.16)	0.49** (0.03)
β_5	$[Ln(Area)]^2$	-0.03 (0.02)	-0.02 (0.02)		
β_6	$[Ln(Berth)]^2$	0.20** (0.05)	0.16** (0.05)	0.20** (0.04)	
β_7	$[Ln(MobileCrane)]^2$	0.01 (0.04)	-0.01 (0.04)		
β_8	$[Ln(Gantry Crane)]^2$	0.07 (0.06)	0.07 (0.06)		
β_9	Ln(Area)*Ln(Berth)	0.03 (0.02)	0.05* (0.02)		
β_{10}	Ln(Area)*Ln(MobileCrane)	-0.04 (0.02)	-0.06** (0.02)	-0.05** (0.02)	
β_{11}	Ln(Area)*Ln(GantryCrane)	-0.02 (0.03)	-0.03 (0.03)		
β_{12}	Ln(Berth)*Ln(MobileCrane)	0.02 (0.03)	0.02 (0.03)		
β_{13}	Ln(Berth)*Ln(GantryCrane)	-0.07** (0.03)	-0.06* (0.03)	-0.04* (0.02)	
β_{14}	Ln(MobileCrane)*Ln(GrantryCrane)	-0.13** (0.02)	-0.11** (0.02)	-0.11** (0.02)	
β_{15}	Mobile Crane Dummy	-0.12** (0.05)	-0.17** (0.05)	-0.16** (0.04)	-0.08* (0.04)
β_{16}	STS Gantry Cranes Dummy	-0.38** (0.06)	-0.41** (0.06)	-0.43** (0.05)	-0.27** (0.05)
β_{17}	Linear Trend	0.02** (0.01)	0.03** (0.01)	0.03** (0.00)	0.03** (0.01)
γ_1	Ships' Cranes	0.99** (0.05)	0.94** (0.05)	0.95** (0.05)	0.74** (0.05)
γ_2	Transshipment	0.49** (0.06)	0.50** (0.06)	0.50** (0.05)	0.52** (0.06)
γ_3	Railway	0.06* (0.03)	0.06 (0.03)	0.06* (0.03)	0.11** (0.03)
γ_4	Connectivity	0.17** (0.02)	0.20** (0.02)	0.20** (0.02)	0.22** (0.02)
γ_5	Trade	-0.05 (0.03)	-0.04 (0.03)		
γ_6	GDP growth	0.01** (0.00)	0.01** (0.00)	0.02** (0.00)	0.02** (0.00)
α	Constant	13.87** (2.11)	14.03** (2.13)	12.48** (0.90)	8.42** (0.24)
δ_1	Landlord	-1.43** (0.38)			
δ_2	Corruption	-0.70* (0.37)			

δ_3	GDPpc	0.11 (0.07)			
δ_4	Linear Trend	-0.11** (0.05)			
σ^2_u		1.43** (0.16)	2.15** (0.68)	2.32** (0.80)	2.01** (0.54)
σ^2_v		0.35** (0.02)	0.38** (0.03)	0.38** (0.02)	0.41** (0.03)
λ		4.05** (0.15)	5.63** (0.67)	6.02** (0.79)	4.93** (0.53)
Log-likelihood		**-1,790**	**-1,822**	**-1,827**	**-1907**
LR Test. H_0: Specification Nested in (1)			**63****	**73****	**232****
Observations		**1,733**	**1,733**	**1,733**	**1,733**
Number of Ports		**203**	**203**	**203**	**203**

Note: Standard errors in parentheses. *p<0.10, **p<0.05.
Source: Prepared by the authors.

Specifications (1) and (2) reveal the 14 coefficients associated with a translog production function. The direct impact of inputs on container throughput can be calculated with the marginal effect of adding a new unit of input; however, because of the quadratic and interaction terms, this effect cannot be interpreted directly from the estimation results. Due to variable returns to scale, the marginal effect also depends on input combination. We calculated the marginal effect for a port with an average input combination (Table 7).

Table 7: Output Elasticity of Inputs in a Translog Specification, at Means

Variables	Elasticities at Means
Terminal Area	0.03 (0.02)
Berth Length	0.31** (0.03)
Mobile Cranes	0.20** (0.03)
Ship-to-Shore Gantry Cranes	0.54** (0.04)

* Elasticities from full translog specification at means.
** Standard errors in parentheses calculated using delta method.
Source: Prepared by the authors.

Table 7 reveals that, for the average port, increasing berth length or the number of mobile or STS gantry cranes has a positive and statistically significant effect on production. The largest elasticity is associated with STS gantry cranes, which is significantly larger than the elasticity associated with mobile cranes – confirming that the higher productivity of the former is fundamental for large increases in output. The results also show that total length of berths is another fundamental variable for production because it is associated with a sizable elasticity. Total terminal area has a relatively lower and not statistically significant impact on container throughput. These results calculated for an average port are on the same order of magnitude as the constant elasticities in a Cobb-Douglas production function, shown in specification (4).

Two control variables associated with port demand used in specification (1) are positive and significant: economic growth and liner shipping connectivity. First, the coefficient associated with economic growth shows that countries with faster economic growth also demand more maritime shipping services in each port. Second, the variable connectivity controls for the total shipping lines connecting ports with other countries. The model reveals that this variable has a direct impact on port container throughput.

On the other hand, the variable trade openness is not significant in specifications (1) and (2), showing that total trade as a share of GDP does not translate into bigger ports in the countries in LAC, possibly because countries that are more open to trade have to rely on a network of big, medium, and small ports. Finally, another variable used in all the specifications is the linear trend (positive and significant), revealing an improvement in port productivity over time.

Another interesting analysis derives from adding the binary variable ships' cranes to the model, which has a positive and significant effect. The interpretation of the coefficient in terms of the log transformed independent variable reveals that, in smaller ports with little infrastructure, ships' cranes accounts for over 60 percent of their container throughput. According to Morales-Sarriera et al. (2013), disregarding this dummy would cause a potential omitted variable bias in the model, affecting the estimated parameters and the efficiency results, especially in ports that rely heavily on the use of ships' cranes.

A similar analysis that uses a binary variable to identify ports that operate mainly transshipment traffic indicates that this type of traffic increases the productivity of a port by 65 percent due to the expedited nature of container transshipment. The coefficient is positive and statistically significant across specifications. In a similar analysis, the results reveal that multimodal ports (those that have a railway link) are also more productive. The positive and significant coefficient indicates that these ports can be 7 percent more productive, on average.

The full translog specification also shows the results obtained with a conditional mean model on technical inefficiency involving a set of explanatory variables. Among the four variables that we included, three were significant: port ownership type, corruption in the public sector, and time trend. The country-level variable of GDP per capita did not turn out to be significant.

The negative and significant relationship between technical inefficiency and landlord ownership shows that ports that operate in a landlord model – i.e., ports managed and operated by a limited liability company – tend to be more efficient. Second, the significance of the variable related to the perception of public sector corruption also indicates that ports located in less corrupt countries tend to be relatively more efficient. Third, the negative and significant relationship with a time trend means that ports in developing countries are becoming more technically efficient over time. Finally, the relationship with GDP per capita is non-significant, meaning that efficient and inefficient ports can be located in richer or poorer countries in the developing world.

All models estimated had a desirable higher variance of the disturbance term associated with technical efficiency than the variance of the random error (σ^2_u = 1.43 and σ^2_v = 0.35 in specification (1)). Therefore, the statistically significant lambda (λ) indicator reveals that most of the variation in production is due to technical inefficiencies, while a smaller portion of this variation is due to random external factors. Moreover, a likelihood ratio test comparing the fit of specification (1) with specifications (2) to (4) reveals that the latter specifications are nested within model (1), as shown in Table 6. This is a strong indication that the unrestricted translog model fits the data better than the other three estimated models.

In summary, the results show a good overall fit of the estimation, showing that all inputs have positive effects on container throughput. The elasticity of STS gantry cranes in an average port is the largest among inputs. The most important control variables in the production function are liner shipping connectivity and economic growth, as well as the positive effect on productivity of transshipment traffic and multimodal accessibility. The model also included a significant and positive binary variable that controls the effect of port-exogenous input ships' cranes, still used in several ports in the developing world. Finally, the estimations revealed that private ownership of ports and corruption in the public sector are two institutional variables that drive technical efficiency.

6.2. Efficiency Analysis

A technical efficiency frontier was constructed with the results from specification (1). It reveals the distance between technical efficiency in each port and the frontier over the period 2000–2010 (the results are presented in percentage points of the highest achievable efficiency in Table A4 in the Appendix). The average over the 11-year period is 54 percent and the standard deviation is 20 percentage points. The highest average efficiency in the sample is 85 percent, meaning that even the most efficient port has room to improve in terms of asset utilization. On the other end, the lowest efficiency ports achieved only 7 percent with respect to the frontier.

Table 8: Average Technical Efficiency: Descriptive Statistics by Region, 2000–2010 (Percent)

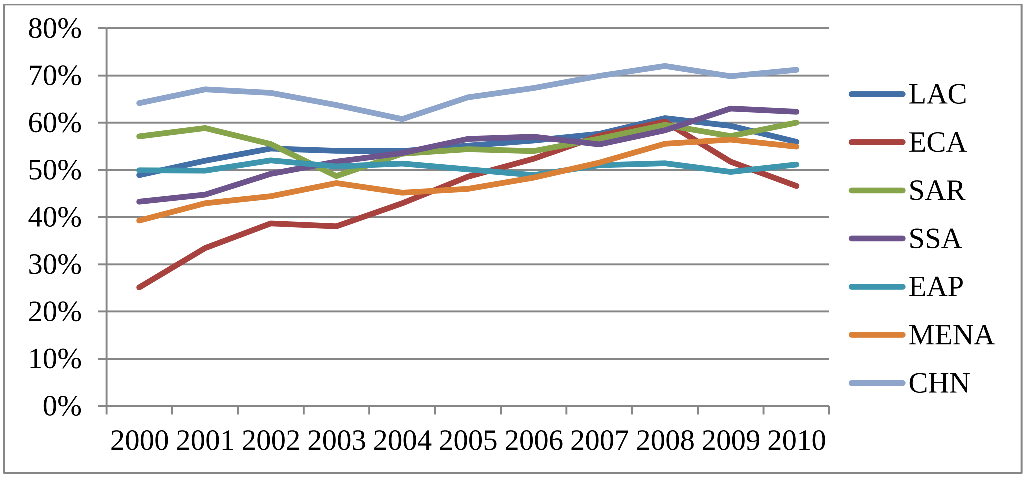
Region	Average	Median	Minimum	Maximum	Standard Deviation
LAC	55	59	8	85	19
ECA	46	45	20	73	17
SAR	55	57	16	80	20
SSA	54	60	16	78	21
EAP	50	55	7	79	23
MENA	49	46	11	79	18
CHINA	67	73	21	85	15
Total	54	58	7	85	20

Note: LAC = Latin America and the Caribbean; ECA = Europe and Central Asia; SAR = South Asia Region; SSA = sub-Saharan Africa; EAP = East Asia and the Pacific; MENA = Middle East and North Africa.
Source: Prepared by the authors.

Based on a regional analysis, Table 8 shows that technical efficiency ranged, on average, between 46 percent in ECA and 67 percent in China. Other than China, whose ports are significantly more efficient than those in the rest of the sample, technically efficient and inefficient ports can be found anywhere in the developing world. The least efficient port in each region ranges from 7 to 21 percent in average technical efficiency, while the more efficient port ranges between 73 and 85 percent.

LAC and SAR have average port technical efficiency of 55 percent, the second highest after China. The regions with the lowest average efficiency are ECA and MENA. The results also show the largest variation in port efficiency in EAP, with a standard deviation of 23 percent, explained by the big difference in efficiency between local ports and large transshipment ports.

Figure 8: Evolution of Average Technical Efficiency by Region
(Percent)



Note: LAC = Latin America and the Caribbean; ECA = Europe and Central Asia; SAR = South Asia Region; SSA = sub-Saharan Africa; EAP = East Asia and the Pacific; MENA = Middle East and North Africa; CHN = China.
Source: Prepared by the authors.

Figure 8 shows that technical efficiency over the period 2000–2010 followed an upward trend in all regions: the overall compound annual growth rate reached 1.8 percent. In China, the leader over the entire period, there was a technical efficiency increase from 64 percent in 2000 to 71 percent in 2010. Two other regions with noteworthy increases in efficiency over the period were SSA and ECA, with increases of 22 and 19 percentage points, respectively. SAR and EAP had the lowest efficiency gains during the period (3 and 1 percentage points, respectively).

Figure 8 also reveals the significant effect of the international financial crisis on worldwide container traffic in 2009. EAC was the hardest hit: port technical efficiency dropped from 60 percent in 2008 to 47 percent in 2010, explained by the decline in container traffic in countries such as Turkey and Russia coupled with an overall expansion in container port assets. However, other developing regions did not experience sizable losses in technical efficiency, although LAC saw a significant drop of 5 percentage points between 2008 and 2010.

7. Conclusions

Container traffic in developing regions experienced annual growth rates close to 12 percent, on average. As the main gateways for international trade, ports are directly associated with competitiveness, integration, and logistics costs. The literature has demonstrated how improving port productivity has a direct impact on reducing port-related logistics costs, and therefore on trade and global competitiveness.

Using a TFP decomposition, this paper has shown that productivity growth rates over the 2000–2010 period varied widely in the developing regions. One might expect these differences to be due to the reliance on alternative technologies to handle container traffic. However, this paper has shown that technology is not the driver of the observed variance in productivity growth. We have observed how all the developing regions have experienced very similar behaviour patterns with respect to technological changes. In addition, the paper has revealed that developing regions behaved similarly in terms of scale efficiency – that is, the ability of ports to optimize the size of their operations – even during the international financial crisis. The most important determinant of port productivity, according to our results, was pure efficiency. This finding reinforced the need to carry out a detailed efficiency analysis to pinpoint technical efficiency per port and determine the drivers of port efficiency in the developing world.

The Stochastic Frontier Analysis production function estimation results reveal that infrastructure inputs (particularly berth length, mobile cranes, and STS gantry cranes) are important to predict the level of container throughput, but that the highest elasticities are associated with STS gantry cranes and berth length. In addition, a binary variable employed to identify ports that use ships' cranes was also significant in the results, revealing the importance of this exogenous asset to productivity in smaller ports. Most control variables related to port demand and other port characteristics had significant and positive coefficients in the estimations. These variables indicate that container ports in countries with faster economic growth and with higher liner connectivity have higher levels of predicted output. Moreover, ports that operate as transhipment hubs and have multimodal links also show higher rates of productivity.

The estimation of the efficient frontier reveals that no port in the sample of developing economies has reached an efficient input combination. The highest ranked port reached a technical efficiency score of 85 percent over 2000–2010. The results also revealed that there are ports that are very far from the frontier, with container traffic efficiencies lower than 10 percent. On average, ports in the sample had an efficiency level of 54 percent with respect to the frontier. Time series results show an upward trend for technical efficiency in developing countries, as it increased from 47 percent in 2000 to 57 percent in 2010. The cross regional analysis of results indicate differences in the level and evolution of technical efficiency, where some regions have substantially improved their efficiency ratios – such as ECA (a 73 percent increase), MENA (a 20 percent increase) or SSA (a 24 percent increase) – while some others have experienced moderate efficiency growth ratios – LAC, with a 14 percent increase –, low growth ratios – EAP, with a 3 percent increase – or even negative ratios – SSA, with a 2 percent decrease. It is worth highlighting that port technical efficiency within regions is highly heterogeneous, with notable standard variations: 22 percent in EAP, 17 percent in ECA, 20 percent in LAC, 21 percent in MENA, 18 percent in SAR and 20 percent SSA.

Analysis of the determinants of technical efficiency indicates that ports that are operated and managed by private companies are more efficient than those operated and managed by the public sector. Also, the perception of corruption in the public sector is a significant variable for determining port efficiency in each country. On the other hand, per capita income did not have any significant impact on the determination of efficiency.

In conclusion, the results show that ports in the developing world have varying levels of productivity and efficiency, regardless of the region or country in which they are located. Thus, ports in the developing world, and within countries themselves, should not be considered as homogenous units of production. Moreover, greater efficiency, which translates into higher productivity, is not directly linked to a single characteristic. We believe that a more thorough examination of the determinants of efficiency – especially by introducing variables related to port management and governance – is necessary to provide clearer policy recommendations. That said, the results of this paper provide evidence that some variables have sizable effects on ports technical efficiency: private sector participation in ports, the reduction of corruption in the public sector, and improvements in liner connectivity or multimodal links.

Appendix

Table A1: Recent Applications of Data Envelopment Analysis to Port or Terminal Efficiency Estimation

Article	Scope of Analysis	Time Series
Wilmsmeier et al (2013)	Latin America and Spanish ports	20052011
Mokhtar (2013)	Container terminal in Peninsular Malaysia	2003–2010
Lu and Wang (2013)	Major Chinese and Korean container terminals	2010
Li, and Pian (2013)	Coastal container terminals in China	
Suárez-Alemán et al (2014)	African ports	2010
Schoyen and Odeck (2013)	Norwegian container ports	2002–2008
Niavis and Tsekeris (2012)	South-Eastern European ports	2008
Bichou (2011)	Container terminals	2002–2008
Wanke et al. (2011)	Brazilian port terminals	2009
Hung, Lu and Wang (2010)	Asian container ports	2007
Cullinane and Wang (2010)	25 of the world's top container ports in 2001	1992–1999
Liu (2008)	10 Asia-Pacific ports	1998–2001
Wang and Cullinane (2006)	European container terminals	2003
Cullinane, Ji, and Wang (2005)	European container terminals	2003
Rios and Gastaud Maçada (2006)	Container terminals in the Mercosur region	2002–2004
Barros (2006)	Italian ports	2002–2003
Cullinane et al. (2005)	World's top 30 container ports	2001
Barros and Athanassiou (2004)	Portuguese and Greek seaports	1998–2000
Bonilla et al. (2004)	Spanish port system	1995–1998
Park and De (2004)	Korean ports	1999
Turner et al (2004)	North American ports	1984–1997
Estache et al (2004)	Mexico's main ports	1996–1999
Barros (2003, 2004)	Portuguese port industry	1999–2000
Itoh (2002)	Japan's international container ports	1990–1999
Valentine and Gray (2001)	31 of the top 100 container ports	1998
Tongzon (2001)	Australian and other international container ports	1996
Martínez-Budría et al. (1999)	Spanish port authorities	1993–1997

Source: Updated from Suárez-Alemán, et al (2014).

Table A2: Recent Applications of Stochastic Frontier Analysis to Port or Terminal Efficiency Estimation

Article	Scope of Analysis	Time Series
Morales-Sarriera et al. (2013)	Latin America and Caribbean ports	1999–2009
Trujillo et al. (2013)	African ports	1998–2007
Wanke et al. (2011)	Brazilian port terminals	2009
Yan et al. (2009)	World's major container ports	1997–2004
González and Trujillo (2008)	Spanish container ports	1990–2000
Cullinane and Song (2003)	European container ports	2003
Barros (2005)	Portuguese ports	1990–2000
Tongzon and Heng (2005)	World container terminals	2000
Cullinane and Song (2003)	Korean and UK container terminals	1979–1996
Cullinane, Song, and Gray (2002)	Major container ports in Asia	1989–1998
Estache et al (2002)	Mexican ports	1996–1999
Coto-Millán et al (2000)	Spanish ports	1985–1989
Notteboom et al (2000)	European container terminals	1994
Baños-Pino et al (1999)	Spanish container ports	1985–1997
Liu (1995)	UK ports	1983–1990

Source: Updated from Suárez-Alemán et al (2014).

Table A3: List of Ports

Region	Country	Ports
China	China	Dalian, Fuzhou, Gaolan, Guangzhou, Jiangmen, Jiuzhou, Kaohsiung, Keelung, Lianyungang, Longkou, Nanjing, Ningbo, Qingdao, Qinhuangdao, Shanghai, Shantou, Taichung, Tianjin, Xiamen, Yantai, Yingkou, Zhangjiagang
East Asia and Pacific (EAP)	Cambodia	Sihanoukville
	Indonesia	Banjarmasin, Belawan, Makassar, Semarang, Tanjung Perak, Tanjung Priok
	Malaysia	Bintulu, Kota Kinabalu, Kuantan, Kuching, Pasir Gudang, Penang, Port Klang, Sibu, Tanjung Pelepas
	Myanmar	Thilawa
	Papua New Guinea	Lae, Port Moresby
	Philippines	Cagayan de Oro, Cebu, Davao, General Santos, Iloilo, Manila, Subic Bay, Zamboanga
	Thailand	Bangkok, Laem Chabang
	Vietnam	Cai Mep, Danang, Haiphong, Ho Chi Minh, Qui Nhon, Vung Tau
Europe and Central Asia (ECA)	Bulgaria	Varna
	Georgia	Poti
	Romania	Constantza
	Russia	Kaliningrad, Novorossiysk, St. Petersburg, Vladivostok, Vostochniy
	Turkey	Ambarli, Antalya, Borusan, Diliskelesi, Evyap, Gemlik, Haydarpasa, Izmir, Mersin, Nemport
	Ukraine	Illichivsk, Odessa
Latin America and the Caribbean (LAC)	Argentina	Buenos Aires (excluding Exolgan), Exolgan, Rosario, Ushuaia, Zarate
	Bahamas	Freeport
	Barbados	Bridgetown
	Brazil	Belém, Fortaleza, Itajaí, Manaus, Paranaguá, Pecém, Rio De Janeiro, Rio Grande, Salvador, Santos, São Francisco Do Sul, Sepetiba, Suape, Vitoria
	Chile	Antofagasta, Arica, Iquique, Lirquén, San Antonio, San Vicente, Valparaíso
	Colombia	Barranquilla, Buenaventura, Cartagena, Santa Marta
	Costa Rica	Puerto Caldera, Puerto Limón
	Cuba	Havana
	Dominican Republic	Caucedo, Rio Haina
	Ecuador	Guayaquil
	El Salvador	Acajutla
	Guatemala	Puerto Barrios, Puerto Quetzal, Santo Tomás de Castilla
	Honduras	Puerto Castilla, Puerto Cortés
	Jamaica	Kingston
	Mexico	Altamira, Ensenada, Lazaro Cardenas, Manzanillo, Progreso, Veracruz
	Nicaragua	Corinto
	Panama	Balboa, Colon CT, Puerto Manzanillo
	Peru	Callao, Paita
	Puerto Rico	San Juan
	Saint Lucia	Vieux Fort
	Trinidad & Tobago	Point Lisas, Port of Spain
	Uruguay	Montevideo
	Venezuela	La Guaira, Puerto Cabello

Table A3: List of Ports (continued)

Middle East and North Africa (MENA)	Algeria	Port de Bejaia
	Djibouti	Port of Djibouti
	Egypt	Alexandria Port Authority, Damietta Port Authority, El Dekheila Port Authority, Port Said, Sokhna Port Development Co.
	Iran	Iman Khomeini, Shahid Rajaee
	Jordan	Aqaba
	Lebanon	Beirut
	Libya	Benghazi, Tripoli
	Morocco	Casablanca, Tanger Med
	Oman	Port Sultan Qaboos, Salalah, Sohar
	Saudi Arabia	Dammam, Jeddah, Jubail
	Syria	Tartous
	Tunisia	Rades
	Yemen	Aden, Hodeidah
South Asia Region (SAR)	Bangladesh	Chittagong
	India	Chennai, Jawaharlal Nehru, Kandla, Kochi, Kolkata, Mumbai, Mundra, Pipavav, Tuticorin, Visakhapatnam
	Pakistan	Karachi, Port Mohammad Bin Qasim
	Sri Lanka	Colombo
Sub-Saharan Africa (SSA)	Benin	Port Autonome de Cotonou
	Cameroon	Port Authority of Douala, Port Autonome d´Abidjan
	Côte d'Ivoire	Port Autonome de San Pedro
	Gabon	Owendo
	Ghana	Takoradi, Tema
	Kenya	Mombasa
	Madagascar	Toamasina
	Mauritius	Port Louis
	Mozambique	Beira, Maputo
	Namibia	Walvis Bay
	Nigeria	Lagos, Onne
	Senegal	Port Autonome de Dakar
	South Africa	Cape Town, Durban, East London, Ngqura, Port Elizabeth
	Sudan	Port Sudan
	Tanzania	Dar es Salaam

Source: Prepared by the authors.

Table A4: Technical Efficiency Ranking of Container Ports, 2000–2010

No.	Port - Country	Average (percent)	No.	Port - Country	Average (percent)	No.	Port - Country	Average (percent)
1	San Juan - Puerto Rico	85	**37**	Durban - South Africa	73	**73**	Ambarli - Turkey	61
2	Nanjing - China	85	**38**	Port Mohammad Bin Qasim - Pakistan	73	**74**	Colon CT - Panama	61
3	Puerto Limón - Costa Rica	83	**39**	Bangkok - Thailand	73	**75**	Point Lisas - Trinidad and Tobago	61
4	Puerto Cortés - Honduras	81	**40**	Manila - Philippines	72	**76**	Kaohsiung - China	61
5	Jawaharlal Nehru - India	80	**41**	Tianjin - China	72	**77**	Port Sudan - Sudan	60
6	Rades - Tunisia	79	**42**	San Vicente - Chile	71	**78**	St. Petersburg - Russia	60
7	Montevideo - Uruguay	79	**43**	Karachi - Pakistan	71	**79**	Casablanca - Morocco	59
8	Itajai - Brazil	79	**44**	Puerto Barrios - Guatemala	71	**80**	Odessa - Ukraine	59
9	Ho Chi Minh - Vietnam	79	**45**	Salalah - Oman	70	**81**	Port of Spain - Trinidad and Tobago	59
10	Pasir Gudang - Malaysia	79	**46**	Tanjung Pelepas - Malaysia	70	**82**	Cartagena - Colombia	59
11	Santos - Brazil	79	**47**	General Santos - Philippines	70	**83**	Yantai - China	59
12	Port Autonome d´Abidjan - Côte d'Ivoire	78	**48**	La Guaira - Venezuela	69	**84**	Valparaiso - Chile	59
13	Davao - Philippines	77	**49**	Paranagua - Brazil	69	**85**	Alexandria Port Authority - Egypt	59
14	Santo Tomás de Castilla - Guatemala	77	**50**	Balboa - Panama	69	**86**	Pecem - Brazil	58
15	Guangzhou - China	77	**51**	Exolgan - Argentina	69	**87**	Puerto Manzanillo - Panama	58
16	Port Autonome de Dakar - Senegal	77	**52**	Haiphong - Vietnam	69	**88**	Colombo - Sri Lanka	58
17	Manzanillo - Mexico	76	**53**	Belawan - Indonesia	68	**89**	Fuzhou - China	58
18	Freeport - Bahamas	75	**54**	Sao Francisco Do Sul - Brazil	67	**90**	Port Louis - Mauritius	57
19	Ningbo - China	75	**55**	Penang - Malaysia	67	**91**	Dammam - Saudi Arabia	57
20	Dalian - China	75	**56**	Havana - Cuba	67	**92**	Port Klang - Malaysia	57
21	Chittagong - Bangladesh	75	**57**	Rio Haina – Dom. Rep.	67	**93**	Iquique - Chile	57
22	Xiamen - China	75	**58**	Toamasina - Madagascar	67	**94**	Bridgetown - Barbados	57
23	Veracruz - Mexico	74	**59**	Callao - Peru	67	**95**	Port Elizabeth - South Africa	57
24	San Antonio - Chile	74	**60**	Buenaventura - Colombia	67	**96**	Kingston - Jamaica	56
25	Shanghai - China	74	**61**	Shahid Rajaee - Iran, Islamic Rep.	66	**97**	Cape Town - South Africa	56
26	Mombasa - Kenya	74	**62**	Dar es Salaam - Tanzania	66	**98**	Mumbai - India	56
27	Guayaquil - Ecuador	74	**63**	Kota Kinabalu - Malaysia	65	**99**	Tanjung Perak - Indonesia	55
28	Puerto Quetzal - Guatemala	74	**64**	Tanjung Priok - Indonesia	64	**100**	Salvador - Brazil	55
29	Lianyungang - China	74	**65**	Port Autonome de Cotonou - Benin	64	**101**	Jeddah - Saudi Arabia	55
30	Lirquen - Chile	74	**66**	Izmir - Turkey	64	**102**	Bintulu - Malaysia	54
31	Qingdao - China	74	**67**	Taichung - China	63	**103**	Lae - Papua New Guinea	53
32	Poti - Georgia	73	**68**	Tuticorin - India	62	**104**	Sokhna Port Development Co. - Egypt	51
33	Yingkou - China	73	**69**	Rio Grande - Brazil	62	**105**	Kandla - India	51
34	Chennai - India	73	**70**	Port Authority of Douala - Cameroon	62	**106**	Mundra - India	51
35	Aqaba - Jordan	73	**71**	Gemlik - Turkey	62	**107**	Keelung - China	49
36	Zhangjiagang - China	73	**72**	Manaus - Brazil	61	**108**	Altamira - Mexico	49

Table A4: Technical Efficiency Ranking of Container Ports, 2000–2010 (continued)

No.	Port - Country	Average (percent)	No.	Port - Country	Average (percent)
109	Puerto Caldera - Costa Rica	49	**145**	Fortaleza - Brazil	32
110	Rio De Janeiro - Brazil	49	**146**	Makassar - Indonesia	30
111	Lazaro Cardenas - Mexico	48	**147**	Haydarpasa - Turkey	30
112	Caucedo - Dominican Republic	48	**148**	Kuantan - Malaysia	29
113	Kolkata - India	48	**149**	Corinto - Nicaragua	28
114	Vitoria - Brazil	47	**150**	Varna - Bulgaria	28
115	Port Said - Egypt	46	**151**	Walvis Bay - Namibia	27
116	Illichivsk - Ukraine	46	**152**	Kuching - Malaysia	26
117	Damietta Port Authority - Egypt	45	**153**	Progreso - Mexico	26
118	Constantza - Romania	45	**154**	Belem - Brazil	25
119	El Dekheila Port Authority - Egypt	44	**155**	Iloilo - Philippines	24
120	Zamboanga - Philippines	44	**156**	Novorossiysk - Russia	23
121	Port de Bejaia - Algeria	44	**157**	Ensenada - Mexico	22
122	Mersin - Turkey	44	**158**	Maputo - Mozambique	22
123	Buenos Aires (excluding Exolgan) - Argentina	44	**159**	Shantou - China	21
124	Sepetiba - Brazil	43	**160**	East London - South Africa	20
125	Arica - Chile	43	**161**	Antalya - Turkey	20
126	Barranquilla - Colombia	42	**162**	Pipavav - India	19
127	Port of Djibouti - Djibouti	41	**163**	Subic Bay - Philippines	19
128	Kaliningrad - Russia	41	**164**	Sibu - Malaysia	16
129	Suape - Brazil	41	**165**	Beira - Mozambique	16
130	Puerto Cabello - Venezuela	40	**166**	Visakhapatnam - India	16
131	Onne - Nigeria	40	**167**	Zarate - Argentina	14
132	Laem Chabang - Thailand	39	**168**	Qui Nhon - Vietnam	14
133	Sihanoukville - Cambodia	39	**169**	Ushuaia - Argentina	13
134	Aden - Yemen, Rep.	37	**170**	Iman Khomeini - Iran, Islamic Rep.	12
135	Kochi - India	36	**171**	Jubail - Saudi Arabia	11
136	Port Moresby - Papua New Guinea	36	**172**	Rosario - Argentina	8
137	Beirut - Lebanon	36	**173**	Danang - Vietnam	7
138	Port Sultan Qaboos - Oman	36			
139	Vostochniy - Russia	35			
140	Vieux Fort - Saint Lucia	35			
141	Acajutla - El Salvador	35			
142	Puerto Castilla - Honduras	34			
143	Antofagasta - Chile	33			
144	Paita - Peru	33			

Source: Prepared by the authors.

References

Aigner, D. J., Lovell, C. A. K., Schmidt, P. (1977) "Formulation and Estimation of Stochastic Frontier Production Function Models". *Journal of Econometrics* 6(1): 21–37.

Al-Eraqi, A., Khader, A. and Mustafa, A (2009) "DEA Malmquist Index Measurement in Middle East and East African Containers Terminals". *International Journal of Shipping and Transport Logistics* 1(3): 249–59.

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): 1078–092.

Baños-Pino, J., Coto-Millán, P. and Rodríguez-Álvarez, A. (1999) "Allocative efficiency and over-capitalization: an application". *International Journal of Transport Economics*. Vol. 26(2), pp. 181–199.

Barros, C.P. (2003) "Incentive Regulation and Efficiency of Portuguese Port Authorities". *Maritime Economics and Logistics* 5(1): 55–69.

Barros, C.P. (2004) "The Measurement of Efficiency of Portuguese Sea Port Authorities with DEA". *International Journal of Transport Economics* 30(3): 335–54.

Barros, C.P. (2005) "Decomposing Growth in Portuguese Seaports: A Frontier Cost Approach". *Maritime Economics and Logistics* 7(4): 297–315.

Barros, C.P. (2006) "A Benchmark Analysis of Italian Seaports Using Data Envelopment Analysis". *Maritime Economics and Logistics* 8(4): 347–65.

Barros, C.P., and Athanassiou, M. (2004) "Efficiency in European Seaports with DEA: Evidence from Greece and Portugal". *Maritime Economics and Logistics* 6(2): 122–40.

Barros, C.P., Felício, J.A. and Fernandes, R.L. (2012). Productivity Analysis of Brazilian Seaports. *Maritime Policy and Management* 39(5): 503–23.

Battese, G. E. (1997) "A note on the estimation of Cobb-Douglas production functions when some explanatory variables have zero values." *Journal of Agricultural Economics* 48.1-3: 250-252.

Battese, G.E., and T.J. Coelli. (1995) "A Model for Technical Inefficiency in a Stochastic Frontier Production Function for Panel Data". *Empirical Economics* 20(2): 325–32.

Bichou, K. (2011)"A Two-stage Supply Chain DEA Model for Measuring Container/Terminal Efficiency". *International Journal of Shipping and Transport Logistics* 3(1): 6–26.

Bonilla, M., Casasus, T. Medal, A. and Sala, R. (2004) "An Efficiency Analysis of the Spanish Port System". *International Journal of Transport Economics* 31(3): 379–400.

Bo-xin, F., Xiang-qun, S. and Zi-jian, G. (2009) "DEA-based Malmquist Productivity Index Measure of Operating Efficiencies: New Insights with an Application to Container Ports". *Journal Shanghai Jiaotong University* 14(4): 490–96.

Caves, D., Christensen, L. and Diewert, W.E.(1982) "The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity". *Econometrica* 50: 73–86.

Chang, V., and Tovar, B. (2014) "Efficiency and Productivity Changes for Peruvian and Chilean Ports Terminals: A Parametric Distance Functions Approach". *Transport Policy* 31(C): 83–94.

Charnes, A., Cooper, W.W. and Rhodes, E.L. (1978) "Measuring the Efficiency of Decision Making Units". *European Journal of Operational Research* 2(6): 429–44.

Cheon, S., Dowall, D. and Song, D.W. (2010) "Evaluating Impacts of Institutional Reforms on Port Efficiency Changes: Ownership, Corporate Structure, and Total Factor Productivity Changes of World Container Ports." *Transport Research (Part E)*: 546–61.

Choi, Y. (2011) "The efficiency of major ports under logistics risk in Northeast Asia". *Asia-Pacific Journal of Operational Research*, 28(01), 111-123.

Clark, X., Dollar, D. and Micco, A. (2000) "Maritime transport costs and port efficiency". *Mimeo*, World Bank.

Coelli, T.J., Estache, A. Perelman, S. and Trujillo, L. (2003) "A Primer on Efficiency Measurement for Utilities and Transport Regulators". Washington, DC: World Bank.

Containerisation International (2002-2012) "*Containerisation International Yearbook*". London: Lloyd's List International.

Coto Millán, P., Baños Pino, J. and Rodríguez Álvarez, A. (2000) "Economic Efficiency in Spanish Ports: Some Empirical Evidence". *Maritime Policy and Management* 27(2): 169–74.

Cullinane, K.P.B., and Wang, T. (2010) "The Efficiency Analysis of Container Port Production Using DEA Panel Data Approaches". *OR Spectrum* 32(3): 717–38.

Cullinane, K. and Song, D.W. (2006) "Estimating the relative efficiency of European container ports: A Stochastic Frontier Analysis". *Port Economics: Research in Transportation Economics*, 16(1): 85–115.

Cullinane, K.P.B., Ji, P. and Wang, T. (2005) "The Relationship between Privatization and DEA Estimates of Efficiency in the Container Port Industry". *Journal of Economics and Business* 57(5): 433–62.

Cullinane, K.P.B., Song, D.W. and Gray, R. (2002) "A Stochastic Frontier Model of the Efficiency of Major Container Terminals in Asia: Assessing the Influence of Administrative and Ownership Structures". *Transportation Research Part A* 36(8): 743–62.

Díaz-Hernández, J.J., Martínez-Budría, E., and Jara-Díaz, S. (2008) "Productivity in Cargo Handling in Spanish Ports during a Period of Regulatory Reforms". *Networks and Spatial Economics* 8(2-3): 287–95.

Ebeling, C.E. (2009) "Evolution of a Box". *Invention and Technology* 23(4): 8–9.

Estache, A., Tovar, B. and Trujillo, L. (2004) "Sources of Efficiency Gains in Port Reform: A DEA Decomposition of a Malmquist TFP Index for Mexico". *Utilities Policy* 12(4): 221–30.

Farrel, M.J. (1957) "The Measurement of Productive Efficiency". *Journal of the Royal Statistical Society* 120(3): 253–90.

Färe, R.,Grosskopf, S., Lindgren, B., and Roos, P. (1992) "Productivity Changes in Swedish Pharmacies 1980–1989: A Non-parametric Malmquist Approach". *Journal of Productivity Analysis* 3(1–2): 85–101.

González, M., and Trujillo, L. (2008) "Reforms and Infrastructure Efficiency in Spain's Container Ports". *Transportation Research Part A* 42(1): 243–57.

Guerrero, C., and Rivera, C.(2009) "Mexico: Total Productivity Changes at the Principal Container Ports". *CEPAL Review 99* (December): 173–85.

Halkos, G., and Tzeremes, N. (2012) "Measuring Seaports' Productivity: A Malmquist Productivity Index Decomposition Approach". *MRPA* No. 40174, University of Munich.

Haralambides, H., Hussain, M., Barros, C.P., and Peypoch, N. (2010) "A New Approach and Benchmarking Seaport Efficiency and Technological Change". *International Journal of Transport Economics* 37(1): 77–96.

Hung, S-H., Lu, W.M. and Wang, T.P. (2010) "Benchmarking the Operating Efficiency of Asia Container Ports". *European Journal of Operational Research* 203(3): 706–13.

Itoh, H. (2002) "Efficiency Changes at Major Container Ports in Japan: A Window Application of Data Envelopment Analysis". *Review of Urban and Regional Development Studies* 14(2): 133–52.

Li, D., Luan, W., and Pian, F. (2013) "The Efficiency Measurement of Coastal Container Terminals in China". *Journal of Transportation Systems Engineering and Information Technology* 13(5): 10–15.

Liu, C-C. (2008) "Evaluating the operational efficiency of major ports in the Asia-Pacific region using data envelopment analysis". *Applied Economics*, Vol. 40(13), pp. 1737-1743.

Liu, Z. (1995) "The Comparative Performance of Public and Private Enterprise: The Case of British Ports". *Journal of Transport Economics and Policy* 29(3): 263–74.

Lozano, S. (2009) “Estimating Productivity Growth of Spanish Ports Using a Non-radial, Non-oriented Malmquist Index”. *International Journal of Shipping and Transport Logistics* 1(3): 227–48.

Lu, B, and Wang, X. (2013) “A Comparative Study on Increasing Efficiency of Chinese and Korean Major Container Terminals”. *Springer Berlin Heidelberg*. 163-168.

Martín Bofarull, M. (2003) “Avances de productividad en el sistema portuario español.” VI encuentro de Economía aplicada. Granada. Junio.

Martínez-Budría, E., Díaz-Armas, R., Navarro-Ibañez, M., and Ravelo-Mesa, T. (1999) “A Study of the Efficiency of Spanish Port Authorities Using Data Envelopment Analysis”. *International Journal of Transport Economics* 26(2): 237–53.

Meeusen, W., and Van den Broeck, J. (1977) “Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error”. *International Economic Review* 18(2): 435–44.

Mokhtar, K. (2013) “Technical Efficiency of Container Terminal Operations: A DEA Approach”. *Journal of Transportation Systems Engineering and Information Technology* 6(2): 1–19.

Mokhtar, K., and Shah, M.Z.. (2013) “Malmquist Productivity Index for Container Terminal”. *European Journal of Business and Management* 5(2): 91–106.

Morales-Sarriera, J., T. Serebrisky, G. Araya, C. Briceno, C. Garmendia, and Schwartz, J. (2013) “Benchmarking Container Port Technical Efficiency in Latin America and the Caribbean”. *IDB Working Paper* No. 474. Washington, DC: Inter-American Development Bank.

Niavis, S, and Tsekeris, T. (2012) Ranking and causes of inefficiency of container seaports in South-Eastern Europe. *European Transport Research Review* 4.4: 235-244.

Notteboom., T., C. Coeck, and Van den Broeck, J. (2000) “Measuring and Explaining the Relative Efficiency of Container Terminals by Means of Bayesian Stochastic Frontier Models”. *International Journal of Maritime Economics* 2(2): 83–106.

Park, R-K, and De, P.(2004) “An Alternative Approach to Efficiency Measurement of Seaports”. *Maritime Economics and Logistics* 6(1): 53–69.

Rios, L.R., and Gastaud Maçada, A.C. (2006) “Analysing the Relative Efficiency of Container Terminals of Mercosur Using DEA”. *Maritime Economics and Logistics* 8(4): 331–46.

Rodrigue, J.P. (2013) “The Geography of Transport Systems”. Third Edition. New York: Routledge.

Schoyen, H., and Odeck, J. (2013). “The Technical Efficiency of Norwegian Container Ports: A Comparison to Some Nordic and UK Container Ports Using Data Envelopment Analysis (DEA)”. *Maritime Economics and Logistics* 15(2): 197–221.

Song, B., and Cui, Y. (2013) "Productivity Changes in Chinese Container Terminals 2006-2011". In International Forum on Shipping, Ports and Airports (IFSPA) 2013: Trade, Supply Chain Activities and Transport: Contemporary Logistics and Maritime Issues. Hong Kong: Cassandra.

Suárez-Alemán, A., Trujillo, L., and Cullinane, K.B.P. (2014) "Time at Ports in Short Sea Shipping: When Timing Is Crucial". *Maritime Economics and Logistics*, 16, 399-417.

Talley, W. K. (2006) "Port performance: an economics perspective". *Research in Transportation Economics* 17: 499-516.

Tongzon, J. (2001) "Efficiency Measurement of Selected Australian and Other International Ports Using Data Envelopment Analysis". *Transportation Research Part A* 35(2): 107–22.

Tongzon, J., and Heng, W. (2005) "Port Privatization, Efficiency and Competitiveness: Some Empirical Evidence from Container Ports (Terminals)". *Transportation Research Part A* 39(5): 405–24.

Turner, H., Windle, R., and Dresner, M. (2004) "North American Container Port Productivity: 1984/1997". *Transportation Research Part E* 40(4): 339–56.

Trujillo, L., González, M.M. and Jiménez, J.L. (2013) "An overview on the reform process of African ports". *Utilities Policy* 25: 12-22.

United Nations Conference on Trade and Development (1976) "Port Performance Indicators". UNCTAD, New York.

Valentine, V.F., and Gray, R. (2001) "The Measurement of Port Efficiency Using Data Envelopment Analysis". Paper presented at the Ninth World Conference on Transport Research Proceedings, 22–27 July, Seoul, South Korea.

Wang, T. and Cullinane, K.P.B. (2006) "The Efficiency of European Container Terminals and Implications for Supply Chain Management". *Maritime Economics & Logistics*, Vol. 8(1), pp. 82-99.

Wanke, P. F., Barbastefano, R. G., and Hijjar, M. F. (2011) "Determinants of efficiency at major Brazilian port terminals". *Transport Reviews*, 31(5), 653-677.

Wilmsmeier, G., Tovar, B., and Sanchez, R. (2013) "The Evolution of Container Terminal Port Productivity and Efficiency under Changing Economic Environments". *Research on Transport Business and Management* 8: 50–66.

Wilmsmeier, G., Hoffmann, J. and Sánchez, R. (2006) "The Impact of Port Characteristics on International Maritime Transport Costs". *Research in Transportation Economics*, Vol. 16(1), pp. 117-140.

World Bank (2013) "Doing business database". http://www.doingbusiness.org/data/.

World Bank (2014a) "Logistic Performance Index". http://lpi.worldbank.org/

World Bank (2014b) "Gross Domestic Product database". http://data.worldbank.org/.

World Economic Forum (2014) "Quality of Port Infrastructure. In Global Competitiveness Report". http://data.worldbank.org/indicator/IQ.WEF.PORT.XQ.

Yan, J., Sun, X., and Liu, J. J. (2009) "Assessing container operator efficiency with heterogeneous and time-varying production frontiers". *Transportation Research Part B: Methodological*, 43(1), 172-185.