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Efficiency container ports in Brazil: A DEA and FDH approach

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Abstract:

Aim: This study aims to evaluate the technical efficiency of 44 Brazilian port terminals that handled containers in 2016. The evaluation will first proceed by identifying the main benchmarks. It will then provide an analysis of variables that may have an effect on technical efficiency as well as the nature of their relationship with the latter – namely: container movement and specialized terminals.

Design / Research methods: In this work, we apply the techniques of Data Envelopment Analysis and Free Disposal Hull. Output-oriented models were constructed, using three inputs – berth depth, berth length and number of berths; and three outputs – number of containers handled, medium board measured in container handled per hour of mooring, and medium consignment rate measured in container throughput per ship.

Conclusions / findings: The main results show that half of the terminals have an inefficient infrastructure, with a capacity larger than necessary to meet current demand for transportation of containers. In addition, there is a strong relationship between the efficiency and size of a terminal port and between the efficiency and degree of specialization. Moreover, the private use terminal (TUP) of Itacal and the public quay of OCRIM can serve as benchmarks for most of the terminals.

Originality / value of the article: Relatively few studies in the literature have tried to measure technical efficiency for developing countries. Moreover, none of the studies found regarding Brazilian ports have shown the scenario after promulgation of the Port Law in 2013, and only a few have used container cargo as their focus. This article is of interest for scientists in the transportation sector, exporters/importers, and Brazilian Government officers interested in observing the effects of public policies aimed at the sector. We also suggest future work concerning the sector's improvements, which can follow from our findings.

Key words: DEA, FDH, container terminal, Brazilian ports, port efficiency, technical efficiency.
JEL: R42, O18, L95, N76

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1. Introduction

Disseminated and efficient infrastructure is crucial for ensuring the effective functioning of the economy. It is a substantial factor in selecting the location of economic activity and the types of business or sectors that can develop within a country. Well-developed infrastructure minimizes the effect of distance between regions, integrating the national market and connecting it at low cost to markets in other nations and regions. Moreover, the quality and vastness of infrastructure networks significantly influence economic growth and reduce income inequalities and poverty in a variety of ways. A well-developed transport and communications infrastructure network is a prerequisite for the access of less-developed communities to core economic activities and services (World Economic Forum 2014: 135).

Also, efficient modes of transport – including quality railroads, roads, ports, and air transport – allow managers to get their goods and services to market in a secure and timely manner and facilitate the movement of workers to the most suitable jobs.

In this sense, reducing the inefficiency of port logistics, either through the expectation of greater participation of the private initiative in port operations or through public investments, is something expected by economic agents in Brazil.

Brazilian ports are far from the world references of efficiency and productivity. In a ranking of 144 countries by the World Economic Forum, Brazil ranks 122th in the item on quality of ports in a report released for 2014-2015 (World Economic Forum 2014: 135).

The Brazilian government is concerned about the problems faced by the port sector. In 2013, it sanctioned the Law of Ports (Brazil 2013), which has been causing profound changes in the sector, allowing the private sector to operate ports, offering a better service and cheaper rates.

The debate about the importance and efficiency of ports is not new. In Brazil, 98.6% of Brazilian exports were shipped by Brazilian ports in 2015 (MDIC 2015), and there are numerous bottlenecks in this sector.

This particularity and others indicate the need for Brazil to have an excellent port infrastructure, as the ports are the only access route to the international market for most products exported by Brazil.

In Brazil, the total cargo movement in 2016 amounted to 998 million tonnes, of which 63% was dry bulk cargo, 22% was liquid bulk, 10% was container cargo, and 5% was general cargo (ANTAQ 2016).

In the last decade alone, the global traffic of containerized cargo has grown at a rate of 7.3% per year, from 69 million TEUs[1] in 2000 to 139 million in 2010. Between 2000 and 2010, the proportion of international shipping in tonnes of loaded containers carried increased from 10.5% to 16%, with an estimated growth rate for this segment of approximately 6.6% per year until 2015. In all, approximately 1.3 billion tonnes were transported by containers in 2010 and that loading showed a gain of 12.9% over 2009; i.e., one of the strongest growth rates in the history of containerization (UNCTAD 2011: 213).

In the case of container cargo, Brazilian ports and private use terminals (TUP) handled 8.8 million TEUs in 2016. The port of Santos itself accounted for 31.5% of the total, and the five largest ports accounted for 64.9% of the total, or 5,719,158 TEUs. In terms of weight, 100 million tonnes in containerized cargo were shipped in 2016 compared with 74.1 million tonnes in 2010, a growth of 35% (ANTAQ 2016).

A retrospective analysis shows that maritime transport is not only the most widely used means of cargo transport worldwide but also the fastest growing in recent years, indicating an overall trend of increased participation in the transport matrix of exports.

The purpose of this study is, therefore, to measure and evaluate the technical efficiency of the Brazilian port terminals that facilitated movement of containerized cargo in 2016. To conduct this study, we employed the technique of Data Envelopment Analysis (DEA) and the Free Disposal Hull approach (FDH), using information provided by ports and TUPs and data provided by the National Waterway Transportation Agency (ANTAQ). The work was restricted to terminals that handled the movement of containers in 2016 and that participated in research on port performance by ANTAQ's accountability board in that year.

Although several studies have tried to calculate the technical efficiency of Brazilian ports, none of them have shown the scenario after promulgation of the Port

[1] One TEU is the load capacity of a standard shipping container: 20 feet long by 8 feet wide by 8 feet high. It is a standard measurement used to calculate its volume.

Law in 2013. In 2012, for example, there were only 06 TUPs and 20 ports with container movement. In 2016, we noted the presence of 12 TUPs and 18 ports. These 12 TUPs (all constructed outside Port's area) were responsible for all the increases in container cargo in 2012–2016. We have also noted that several ports are renting their areas to private players to improve their efficiency and competitiveness. Therefore, it is very important to follow all the changes in this sector.

This article is of interest for scientists of the transportation sector, exporters/importers, and the Brazilian Government, which can observe the effects of public policies aimed at the sector.

Future work needs to be done to look at the sector's behavior and identify the ports that either deserve greater investment input or need to be restructured internally.

2. Methodology

The non-parametric DEA model allows for a comparative analysis of processes characterized by different scales, with the aid of a production frontier that enables ranking of processes according to a predetermined performance criterion. The objective of DEA is to identify Decision Making Units (DMUs) as either efficient or inefficient and to determine procedures that can be used to adjust the inputs and outputs of inefficient DMUs to achieve efficiency.

The DEA technique has been widely used to evaluate the technical efficiency of ports. Technical efficiency is used to evaluate relative productivity over time, space, or both. It is a measure that can be improved through better allocation and use of different inputs to produce desired outputs (Itoh 2002).

Wang and Cullinane (2006) analyzed the efficiency of 104 container ports in 29 countries in Europe using DEA. Their main conclusions were that inefficiency permeates most of the ports and that large-scale production tends to be associated with high efficiency.

DEA models had already been used by other authors, such as Roll and Hayuth (1993), who worked with a hypothetical numerical example of twenty ports;

Martinez-Budria, Diaz-Armas, Navarro-Ibanez, and Ravelo-Mesa (1999) and Díaz-Hernández, Martínez-Budría, and Jara-Díaz (2008), who worked with Spanish ports; Tongzon (2001), who focused on four Australian ports and 12 other international container ports; Valentine and Gray (2001), who studied 31 container ports from a list of the top 100 container ports worldwide for 1998; Itoh (2002), who studied the eight major Japanese ports in the 1990s; Barros (2003), who analyzed the technical efficiency and technological change of Portuguese seaports; Barros and Athanassiou (2004), who compared the efficiency of Greek and Portuguese seaports; Park and De (2004), who examined the applicability of DEA to seaport efficiency measurement using eleven Korean seaport as DMUs; Barros (2006) who evaluated the performance of Italian seaports from 2002 to 2003, combining operational and financial variables; Simões and Marques (2010) who studied congestion and technical efficiency of 41 European seaports for 2005; and Wu, Yan, and Liu (2010) who performed a sensitivity analysis in the input and output variables of 77 global container ports.

Studies of Brazilian ports include Sousa Junior (2010) and Bertoloto (2010), who used as inputs the total length of berths (in meters) and maximum draft (in meters) of ports; Acosta (2008), who included “total port storage area” as an additional input; Fontes (2006), who worked only with the extent of the quay as an input; Wanke, Barbastefano, and Hijjar (2011), who analyzed the technical efficiency of 25 Brazilian terminals for 2008 using terminal area (in square meters), size of parking lot for incoming trucks (in number of trucks), and number of shipping berths as inputs; and Rios and Maçada (2006), who measured the technical efficiency of container terminals of Mercosul from 2002 to 2004.

The latter authors included the largest number of variables in their model, with a total of seven variables, as follows: number of cranes, number of berths, number of employees, terminal area, and the quantity of equipment in yard as inputs; and TEUs handled and average number of containers handled by hour/vessel as outputs. Their work stands out because it was the only one that focused exclusively on Brazilian container terminals, while other Brazilian authors used aggregate data to the input (entirely port, not specific terminals) and outputs (sum of two or more types of cargo).

Pallis, Vitsounis, and De Langen (2010) reviewed 395 relevant journal papers on ports that were published during 1997-2008. As one of the results, their work showed that only two articles involving Brazilian ports were published. This underscores the importance of our article on port research.

DEA models may admit constant returns to scale (DEA-CCR) or variable returns to scale (DEA-BCC and FDH); they can also be either input-oriented or output-oriented. Briefly, input-oriented models minimize the resources used without changing the production level, and output-oriented models aim to improve products without modifying the resources used.

The DEA-CCR model was designed by Charnes, Cooper, and Rhodes (1978), while the DEA-BCC model was conceived later, in 1984, by Banker, Charnes, and Cooper (1984). By assuming a convex border, the BCC model allows DMUs that operate with low levels of inputs to have increasing returns of scale and those that operate with high levels of inputs to have decreasing returns of scale.

Measures of technical efficiency derived from DEA-CCR and DEA-BCC are frequently used to obtain measures of scale efficiency, as shown in equation (1) (Cooper et al. 2007):

$$SE_j = \frac{\theta^*_{CCR\_j}}{\theta^*_{BCC\_j}} \; or \; \frac{1/\varphi^*_{CCR\_j}}{1/\varphi^*_{BCC\_j}} \tag{1}$$

where SE_j represents the scale efficiency of the jth DMU, while $\theta^*_{CCR\_j}$ and $1/\varphi^*_{CCR\_j}$ are the technical efficiencies obtained by DEA-CCR (for input-oriented models and output-oriented models, respectively). $\theta^*_{BCC\_j}$ and $1/\varphi^*_{BCC\_j}$ are obtained by DEA-BCC models. If $SE_j = 1$, the jth DMU has scale efficiency, i.e., constant returns to scale prevail for the jth firm. If $SE_j < 1$, then the jth DMU has variable returns to scale (increasing or decreasing).

The non-parametric FDH model, designed by Deprins, Simar, and Tulkens (2006), excludes the condition of local convexity, i.e., only actual existing observations (not linear combinations of observations) are taken into account in the efficiency comparisons (Panayides et al. 2009). This model maintains only the assumption of free disposal and is, therefore, less constrained than are the other models (Da Conceição, Ramos 1999).

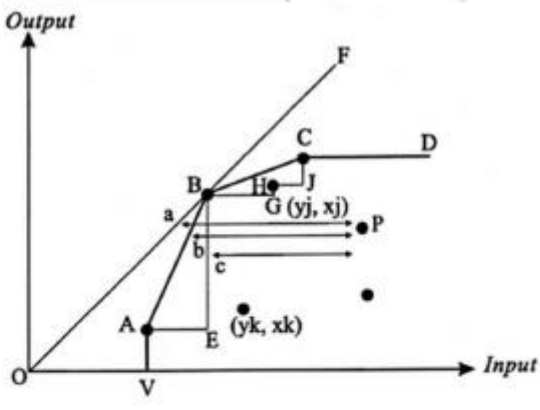
Formally, the efficiency measurement used in FDH models is obtained from:

$$\psi^* = \max_{\lambda} \min_{r=1,2,..s} \left\{ \frac{\sum_{j=1}^{n} \lambda_j y_{rj}}{y_{ro}} \right\}, \text{ such that } \sum_{j=1}^{n} \lambda_j = 1,\ \lambda_j \in (0,1). \qquad (2)$$

The production frontier is obtained under this method by comparing inputs and outputs to establish the dominant DMUs. It is obtained by observing a dominant firm that produces a greater quantity of output using either a smaller or an equal quantity of inputs than used by other firms. An observation is declared inefficient if it is dominated by at least one other observation.

Figure 1 shows the boundaries DEA-CCR, DEA-BCC and FDH, clearly in accord with the hypothesis of convexity. The boundary of the production set linked to the DEA-CCR is given by the segment OF. Excluding the origin, the boundary of the production set is given by the VABCD segment corresponding to the DEA-BCC variant incorporating variable returns to scale. Finally, the FDH frontier is given by the segment VAEBGHJCD.

Figure 1. Alternative forms of construction of the non-parametric production frontier



Source: Tulkens (1990).
Note: P_a = DEA-CCR; P_b = DEA-BCC; P_c = FDH.

Note that point E would not be efficient under the DEA-CCR or DEA-BCC approach, but it represents a point of technical efficiency according to FDH. This allows us to assert that a relationship exists between these boundaries, making possible an ordering of the indices of efficiency associated with the DEA and FDH methods, such that $0 < \theta^*_{CCR\_j} < \theta^*_{BCC\_j} < \psi^*_{FDH\_j} < 1$ (inequality FGL with the FDH index, ψ, included) (Da Conceição, Ramos 1999).

Thus, a DMU considered efficient under the DEA-CCR method would be efficient under all other methodologies. At the same time, a DMU deemed inefficient under the technical FDH would also be deemed inefficient under all other methodologies.

3. Construction of the DEA and FDH models for port efficiency analysis

Depending on the type of cargo moved in a port, different combinations of inputs would be needed to obtain a given output; i.e., the need for a given input may be either larger or smaller depending on the type of load handled: liquid bulk, dry bulk, general cargo, containerized or not. This is the first difficulty that one encounters in formulating a production function for each scenario. Other problems could also be enumerated; for example, the relevant information is not always available, a problem that is even worse if one wishes to compare ports in different countries.[2]

If we consider studies of Brazilian researchers, it will be noted that they have tried to adapt available information from websites of port authorities for the chosen inputs and have used secondary research on Brazilian official sources for outputs. Unfortunately, Brazil does not have uniform information available to the general public. Indeed, it is common to find that data sets on port terminals are insufficiently detailed.

Given the available information, the inputs and outputs selected are shown in Tab. 1. The first output relates to the unit amounts of containers handled at given

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[2] In some cases, an indicator that exists for one country is unavailable for another country, making comparison impossible.

terminals. Almost all previous studies have included this variable in their models, because it is closely related to the need for facilities for cargo handling. In addition, this variable is the main basis for comparison of container terminals, especially in relation to their size (scale), the magnitude of investments made by the port, and the activity levels practiced. Some authors view this variable as the most appropriate and most analytically tractable indicator of the productive efficiency of a port.

Table 1. Input and output variables

Variables	Description	Source
Outputs		
Throughput (units of Containers)	In amounts of units of 20' and 40' containers per terminal, indicating intensity of use of each terminal	ANTAQ
Medium board (units of Containers/h)	Average productivity of the terminal with respect to berthing time of ships	ANTAQ
Medium consignment rate (units of containers/ship)	Indicates the characteristic size of ships that frequent the port, for each type of cargo or goods at each terminal	ANTAQ
Inputs		
Berth length (m)	Total length of berth(s) belonging to a particular terminal that features container handling	Ports' Website
Berth depth (m)	Average depth of berth(s) that moves containers from a particular port terminal	Ports' Website
N. of berths (units)	Number of berths that move containers at a particular port terminal	Ports' Website

Source: Authors' elaboration.

The medium board, the second output of the model, indicates the average productivity of each terminal compared to the time of berthing of ships, taken as service time. It is expected that this indicator will be as large as possible because both a decrease in berthing time and an increase in cargo handled imply a reduction in costs for ships and enables port agents to increase the number of vessels berthed, generating more revenue for the port.

This work additionally uses a third output, the medium consignment rate, which indicates the characteristic size of a ship that arrives at the container terminal. As it represents a measure of the total number of units of containers moved by the number of ships, the higher the rate, the lower the cost of port services for a higher capacity ship. This is because less time would be spent by the agent port and vessels on paperwork, and less time would be used for berthing and loading/unloading of goods for a given quantity of goods that are distributed between two ships instead of just one.

It is important to emphasize that only ports with deep access channels can be used for larger vessels. This is a way of optimizing the port infrastructure and increasing the amount of cargo handled by making better use of all berths. There is, therefore, a gain on both sides (port and client) at these terminals, and it is thus very important to include the final output (medium consignment rate) of the model if one wishes to measure the efficiency of a particular terminal.

The data source for the output variables is ANTAQ. We had access to the available baseline information in the last official report of the Port Services Operational Performance. This report provides various operational and statistical indicators based on data and information obtained from the Administrations of Organized Ports and Private Use Terminals about vessels operations – loading and unloading – that take place in each of the port facilities in Brazil. The reference year 2016 was the last to be provided by ANTAQ. It is important to emphasize that the DMU in this work is not the port as a whole but specific terminals in each port that operate with containers and that have provided ANTAQ with information about such operations.

Regarding port operation facilities, a variety of inputs are needed. A priori information about manpower, capital goods, and land would be needed. However, given that reliable data on manpower are not always available, information about this input may be obtained from a pre-determined relationship, given the strong correlation between manpower and terminal facilities. Specifically, the number of cranes and berths and the amount of terminal area can be used to estimate the number of employees (Wang et al. 2003).

Thus, we created a database with the input variables “terminal berth depth”, “terminal berth length”, and “terminal berth number”. These inputs were found for most of the terminals in the sample, using the terminals’ websites as the data source.

It is worth commenting that none of the previously constructed models for Brazilian ports/terminals included these three inputs simultaneously. Bertoloto

(2010) is the only one that uses length of berth and depth of berth as inputs; however, the focus of this work was not restricted to containerized cargo.

Some terminals had to be removed from the sample because it was not possible to obtain input data for them. In addition, the Tecon and the TEV terminals (both belonging to the port of Santos) had to be aggregated because we did not find disaggregated information for them. However, removed terminals accounted for only 0.02% of containers handled, which does not represent a significant loss for our analysis.

Altogether, the sample included 44 Brazilian port terminals belonging to 17 ports and 11 TUPs, responsible for approximately 99,98% of containers handled in Brazil in 2016, with six variables in total. So, we followed the recommendations in the literature with regard to sample size, that says: it is advised to have a sample at least three and preferably four times the total number of inputs and outputs. (Sarkis 2007).

4. Proposed models

DEA models can be distinguished by their orientation. Input-oriented models are closely related to operational and management issues, while output-oriented models are more closely related to planning and macroeconomic strategies. Both orientations have their uses in the context of the container port industry (Cullinane et al. 2006).

The decision to work with an output-oriented model was made because our focus was on discovering the following: a) whether Brazilian terminals' existing facilities are fully utilized, and b) whether production (outputs) at these terminals is maximized, given the available resources (Cullinane et al. 2006). The results may show the need to either build a new terminal or increase the capacity of ports such as the port of Santos (SP) and other large Brazilian ports operating near their production capacity.

In this work, we chose to develop three non-parametric models: DEA-CCR, DEA-BCC, and FDH. All three are output-oriented, in view of increasing growth rates observed in intermodal container shipping. The choice of the DEA-CCR and DEA-BCC models is justified because it is unknown whether there are a priori economies of scale at the terminals in the sample. Thus, these models can also determine which terminals are the most efficient of all terminals. The FDH model, in turn, will indicate which terminals are the most inefficient among all the terminals.

It is important to emphasize that, although there have been several studies of Brazilian ports, none follow the FDH approach in their modelling, which further reinforces the importance of this study.

5. Empirical results and analysis

To calculate the efficiency index of terminals and their benchmarks, we used the EMS software, version 1.3. To determine returns, efficiencies of scale, and slacks, and to perform some statistical tests, we used the software R. Without prior knowledge of the existence of economies of scale in the production function of the terminals analyzed, it was necessary to work with the DEA-CCR model initially. If it was verified that constant returns applied to certain terminals, the efficiency scale would be unity.

The DEA-CCR model was found to be the one with the smallest number of port terminals considered efficient, with only six (06) terminals, a consequence of the restrictive assumptions assumed under this approach. The DEA-BCC and FDH approaches found 7 and 22 terminals, respectively, to be efficient. Considering that a terminal regarded as effective in the DEA-CCR approach is effective for any other approach, it may safely be said from the results that these terminals have a performance superior to the others. In contrast, terminals found to be inefficient under the FDH methodology would undeniably have poor performance. Both the more efficient and the most inefficient terminals are shown in Tab. 2.

Table 2. Terminal Efficiency under the DEA-CCR, DEA-BCC, and FDH models (efficient terminal = 1; inefficient terminal <1)

DMU – Port/TUP	Terminal	DEA		FDH	Scale Efficiency	Returns of scale
		CCR	BCC			
Fortaleza-CE	Commercial quay	**1.00**	**1.00**	**1.00**	1.00	CTE
Fortaleza-CE	Oil tanker pier	**1.00**	**1.00**	**1.00**	1.00	CTE
Santos-SP	BTP	**1.00**	**1.00**	**1.00**	1.00	CTE
Santos-SP	Tecon + TEV	**1.00**	**1.00**	**1.00**	1.00	CTE
TUP Embraport-SP	Embraport	**1.00**	**1.00**	**1.00**	1.00	CTE
TUP Itacal-AM	Itacal	**1.00**	**1.00**	**1.00**	1.00	CTE
TUP Chibatão-AM	Chibatão	0.86	**1.00**	**1.00**	1.57	INCR
Vitoria-ES	Peiu	0.05	0.06	**1.00**	0.83	DECR
Rio de Janeiro-RJ	Rollon/off Terminal	0.12	0.12	**1.00**	1.00	CTE
Belem-PA	Public Quay	0.33	0.38	**1.00**	0.43	DECR
Belem-PA	Public Quay of Ocrim	0.41	0.52	**1.00**	0.72	DECR
TUP J. F. de Oliveira - AM	J F of Oliveira Manaus	0.53	0.53	**1.00**	1.00	CTE
Salvador-BA	Tecon	0.58	0.59	**1.00**	0.86	DECR
Rio de Janeiro-RJ	Libra T1	0.60	0.61	**1.00**	0.94	DECR
Itaguai-RJ	Tecon	0.78	0.78	**1.00**	0.95	DECR
TUP Itapoa Terminais Portuarios-SC	Itapoa	0.83	0.84	**1.00**	1.03	INCR
TUP Portonave Terminais Portuarios de Navegantes-SC	Portonave	0.87	0.88	**1.00**	0.96	DECR
Itajai-SC	Leased pier	0.85	0.89	**1.00**	1.26	INCR
Vitoria-ES	TVV	0.88	0.90	**1.00**	1.20	INCR
Santos-SP	Libra Terminal S/A	0.91	0.91	**1.00**	0.99	DECR
Imbituba-SC	Public Quay	0.93	0.96	**1.00**	0.77	DECR
Paranagua-PR	TCP	0.94	0.96	**1.00**	0.84	DECR
São Francisco do Sul-SC	Public Quay	0.64	0.74	0.99	1.90	INCR
Rio de Janeiro-RJ	Multi-Rio T2	0.64	0.64	0.93	0.95	DECR
Rio Grande-RS	Tecon	0.60	0.60	0.82	1.06	INCR

Suape-PE	Tecon Suape	0.55	0.58	0.77	1.10	INCR
Vila do Conde-PA	Multiple use terminal 1	0.42	0.47	0.69	1.85	INCR
Natal-RN	Commercial Quay	0.50	0.56	0.69	1.72	INCR
Santos-SP	Public Quay Saboo	0.27	0.28	0.48	0.73	DECR
TUP Super Terminais Comercio e Industria-AM	Super Terminais Commerce and Industry	0.21	0.37	0.42	2.00	INCR
TUP Terminal Portuario de Pecem-CE	Pecem	0.36	0.39	0.40	1.57	INCR
Belem-PA	Outeiro	0.05	0.05	0.30	0.78	DECR
São Sebastiao-SP	Public Quay	0.02	0.02	0.25	1.00	CTE
TUP Intermoor of Brazil-RJ	Intermoor of Brazil	0.04	0.04	0.25	1.00	CTE
Paranagua-PR	Public Quay	0.01	0.01	0.21	0.80	DECR
TUP Terminal Portuario da Gloria-TPG-ES	TPG	0.02	0.03	0.21	0.41	DECR
Rio de Janeiro-RJ	Public Quay	0.02	0.02	0.17	1.21	INCR
Salvador-BA	Public Quay	0.05	0.05	0.12	1.26	INCR
TUP Teporti-SC	Teporti	0.01	0.01	0.09	0.84	DECR
Vitoria-ES	Capuaba	0.02	0.02	0.08	0.59	DECR
Santos-SP	Ecoporto Santos S/A	0.04	0.04	0.07	0.88	DECR
Vitoria-ES	Commercial Quay	0.03	0.03	0.04	1.12	INCR
Itaqui-MA	Public Quay	0.00	0.01	0.02	1.28	INCR
Rio Grande-RS	Public Quay	0.01	0.01	0.01	1.93	INCR
AVERAGE		0.48	0.50	0.68	1.08	

Source: Authors' calculations.
Note: TUP = Private Use Terminal, CTE = constant, INCR = increasing, DECR = decreasing

Once the efficiencies were determined, we applied a nonparametric test, the Wilcoxon Rank Sum Test (Cooper et al. 2007), to examine whether there are significant differences between efficiencies calculated in two different situations (Díaz-Hernández et al. 2008): a) terminals with above-average traffic *versus* terminals with below-average traffic, and b) specialized terminals *versus* unspecialized ones.

The null hypothesis of this test was rejected at the 0.01 significance level in both scenarios. This suggests that the medians are not statistically equal in both cases; i.e., there are significant differences in the efficiencies of the terminals, according to either size or level of expertise. In other words, terminals with great container movement tend to be more efficient than are other terminals that work with diverse types of cargos, and specialized terminals tend to be more efficient than are multiple use terminals.

We also applied the Spearman rank correlation test to see if there was any relationship between cargo moved and the efficiencies calculated by the all three models. The results obtained were 0.77, 0.77, and 0.61 for the DEA-CCR, DEA-BCC, and FDH models, respectively, all statistically significant at the 0.01 significance level. The high values for the Spearman correlation coefficients suggest that the efficiency of a terminal is significantly affected by its size. This may indicate that ports that benefit from economies of scale are necessarily more efficient than are those with low volumes of movement of containerized goods.

6. Economies of scale, slacks, and projection values

Of the 22 inefficient terminals shown in Table 2, only two exhibit constant returns to scale, twelve show increasing returns, and only eight have decreasing returns to scale. This means that it is possible achieve efficiency in fourteen terminals, getting better their productivity indicators and/or more containers movement.

Under the FDH approach, most of the slacks are found in the variables number of berths, berth length, number of containers handled, and medium board. In other words, at most of the terminals, only a portion of the quay and/or berth was necessary and a smaller depth is really required; even then, their best use would allow for increased cargo handling (number of containers) with faster loading/unloading times to achieve efficiency.

Tab. 3 shows all slacks pointed by the FDH approach. TUP Pecém, located in the state of Ceará, while moving other types of non-containerized cargo, can be efficient if it captures six times more than its actual number of containers movement, and increases its productivity from 26.8 to 34.2 containers/hour. For that, this terminal does not even need to use all 04 berths (03 of them would be enough) with a draft that exceeds its needs by 1 meter, and a quay extension that is 2 meters more than necessary.

Table 3. Targets for an inefficient terminal become efficient (FDH approach)

DMU - Port/TUP	Terminal	Score FDH	INPUTS			OUTPUTS			SLACKS					
			NB	EXT	BD	C	MB	CR	NB	EXT	BD	C	MB	CR
São Francisco do Sul-SC	Public Quay	0.99	3	605	14	4,222	20	704	1	158	3	143,544	13	0
Rio de Janeiro-RJ	Multi-Rio T2	0.93	2	550	15	123,761	51	403	0	10	0	1,601	7	0
Rio Grande-RS	TECON	0.82	3	900	13	427,045	41	615	0	0	2	0	38	57
Suape-PE	Tecon Suape	0.77	4	935	16	245,425	49	448	2	305	0	0	8	15
Vila do Conde-PA	Multiple use terminal 1	0.69	3	577	12	22,232	10	494	1	130	1	115,810	19	0
Natal-RN	Commercial Quay	0.69	6	759	16	115,934	33	504	4	202	1	0	8	127
Santos-SP	Public Quay Saboo	0.48	3	526	11	17,859	16	182	1	79	0	110,974	0	336
TUP Super Terminais Comercio e Industria-AM	Super Terminais Commerce and Industry	0.42	2	720	35	37,063	17	399	1	395	18	323,684	48	0
TUP Terminal Portuário do Pecem-CE	Pecém	0.40	4	1,110	14	105,363	27	439	1	2	1	610,106	7	0
Belem-PA	Outeiro	0.30	1	255	10	58	2	29	0	55	3	0	2	98
São Sebastiao-SP	Public Quay	0.25	1	150	9	6	1	6	0	139	7	1,897	0	9
TUP Intermoor-do-Brazil-RJ	Intermoor of Brazil	0.25	1	90	10	237	1	2	0	79	8	973	0	25
Paranagua-PR	Public Quay	0.21	1	122	9	7	0	7	0	111	7	1,888	4	0
TUP Terminal Portuario da Gloria-TPG-ES	TPG	0.21	1	70	5	147	0.3	7	0	59	3	1,228	3	0
Rio de Janeiro-RJ	Public Quay	0.17	2	450	10	33	0	17	1	250	3	0	9	95
Salvador-BA	Public Quay	0.12	3	510	9	153	2	38	1	50	5	49,553	0	148
TUP Teporti-SC	Teporti	0.09	1	150	9	7	0	3	0	139	7	1,844	4	0
Vitoria-ES	Capuaba	0.08	1	204	10	4	1	4	0	4	3	16	0	16
Santos-SP	Ecoporto Santos S/A	0.07	3	704	13	336	3	31	1	44	2	19,385	13	0
Vitoria-ES	Commercial Quay	0.04	2	465	8	92	0	18	0	5	4	48,446	17	0
Itaqui-MA	Public Quay	0.02	2	446	12	12	0	2	1	321	0	0	25	613
Rio Grande-RS	Public Quay	0.01	4	1,115	9	145	0	7	2	655	5	41,097	17	0

Source: Authors' calculations.
Note: EXT = berth extension (m); BD = Depth of berth (m); NB = Number of berths (units); C = number of containers handled (container units); MB = Medium board (containers / hour); TC = Consignment rate (containers / ship)

Also in Tab. 3, Tecon Suape terminal, which is located in the state of Pernambuco and is specialized in container handling, needs small changes to improve its productivity indicators if it wants to achieve maximum efficiency. The "average board" indicator needs to increase from 49.2 to 56.7 container/hour (15% growth), and its consignment rate should increase from 448 to 463 per container/ship, an approximate increase of only 3%.

Therefore, in general, for inefficient terminals under the FDH approach, it is possible to raise production by approximately 134% of the number of containers handled, using only a portion of their infrastructure and achieving better use of their facilities. As for the rest – 22 efficient terminals – it may be necessary to review their production capacity, in the case of higher container demand, once their facilities have been fully utilized.

7. Benchmarks

Under the DEA-BCC model, the main benchmarks were the TUP Embraport, TUP Itacal, and the Tecon + TEV terminals (both in Port of Santos/SP), with 35, 31, and 22 citations, respectively. All benchmarks are specialized terminals and were responsible in 2016 for 1.346.289 units of containers, or 22.902.634 tons of container cargo.

Under the FDH approach, the Itacal terminal emerges as dominant for twelve inefficient terminals (Tab. 4). The public quay OCRIM of the port of Belém/PA emerges as the second most important benchmark, dominating the other seven terminals.

It is important to emphasize that FDH methodology is more suitable for identifying the most obvious cases of inefficiency than for identifying cases of efficiency, as already noted (Da Conceição, Ramos 1999). Therefore, the DEA-BCC methodology is better for identifying benchmarks than is the FDH methodology.

Tab. 4 is self-explanatory when it is easily observed that the main benchmark identified by the FDH methodology presents either equal or smaller values for the inputs than for the other terminals dominated by it. At the same time, it achieves better results for all outputs than do the other terminals listed in the table.

Table 4. TUP Itacal as benchmark and dominated terminals

Location	Terminal	FDH	INPUTS			OUTPUTS		
			EXT	BD	NB	C	MB	CR
TUP	**ITACAL**	**1.00**	**11**	**2**	**1**	**1,921**	**4**	**33**
Port of Belém/PA	Outeiro	0.30	255	10	1	58	2	29
Port of Itaqui/MA	Public quay	0.02	446	12	2	12	0	2
Port of Paranagua/PR	Public quay	0.21	122	9	1	7	0	7
Port of Rio de Janeiro/RJ	Public quay	0.17	450	10	2	33	0	17
Port of Rio Grande/RS	Public quay	0.01	1,115	9	4	145	0	7
Port of Santos/SP	EcoPort Santos S/A	0.07	704	13	3	336	3	31
Port of São Sebastiao/SP	Public quay	0.25	150	9	1	6	1	6
Port of Vitoria/ES	Commercial quay	0.04	465	8	2	92	0	18
Port of Vitoria/ES	Capuaba	0.08	204	10	1	4	1	4
TUP Intermoor of Brasil/RJ	Intermoor of Brasil	0.25	90	10	1	237	1	2
TUP Teporti/SC	Teporti	0.09	150	9	1	7	0.04	3
TUP da Gloria/ES	TPG	0.21	70	5	1	147	0.3	7

Source: Authors' calculations.
Note: EXT = berth extension (m); BD = Depth of berth (m); NB = Number of berths (units); C = number of containers handled (container units); MB = Medium board (containers / hour); TC = Consignment rate (containers / ship)

8. Concluding remarks

This article analyses the technical efficiency of 44 maritime terminals using information provided by ANTAQ about the movement of cargo containers in 2016. The approach taken was to verify whether such terminals were prepared to handle increased demand for their services. To this end, we investigated whether current infrastructure is being fully utilized and whether production (output) indicators have been maximized, given the existing resources.

The main results show that half of the terminals in the sample have an inefficient infrastructure, one that is larger than necessary to meet the current demand for transportation of containers. In other words, if containers were handled only at these terminals (some terminals also handle other types of load), capacity would exist to handle a larger movement of containers than is currently handled –

approximately 134% of the volume handled in 2016 – using only a portion of their infrastructure.

We also observed that there is a strong relationship between efficiency and the size of a terminal port. Putting together all the 22 efficient terminals, they were responsible for 81% of all container movement (5.7 million of units) in 2016. In contrast, the other half of the container terminals accounted for only 19% of the remaining cargo.

Nevertheless, a strong relationship between the technical efficiency of terminals and their degree of specialization was identified in containerized cargo.

In this study, two terminals have excelled, serving as a benchmark for most of the terminals, according to the DEA-BCC and FDH models. These are the TUP Embraport (DEA-BCC approach) and TUP Itacal (FDH approach), both of which are specialized terminals.

It is important to investigate port efficiency using a more realistic model that may include the handling of other types of loads at the same terminals. Perhaps this new type of analysis allows a better verification of the use of inputs and ports and gets to the conclusion that slacks were fully fulfilled and poised to capture the non-containerized cargo.

The DEA-BCC and FDH approaches allow researchers to identify ports that either deserve greater investment input or need to be restructured internally. Furthermore, it is necessary to observe the sector's behavior since the Port Law opened the market for private players.

The Federal Government has been carrying out important public investments in partnership with the private sector (agents responsible for the maintenance and operation of port terminals). The Growth Acceleration Plan (PAC) foresaw many of the port infrastructure bottlenecks, including the construction/expansion of access channels for goods disposal, dredging, and dock works, and the management of surveillance, security, and logistics intelligence services.

The PAC was created in 2007, but, unfortunately, it has been practically stopped since 2016. Among the dredging works planned for 2015-2018 (from a total of 11), only one was completed by June/2017 (Brazil 2017).

Without the resumption of PAC's investments, it is expected that the port inefficiency will not decline, pushing Brazil even further away from the countries that are better positioned in the ranking created by the World Economic Forum (World Economic Forum 2014: 135).

Therefore, we must continue to observe the technical efficiency of the ports in the next few years, as a subsidy for the implementation of new public policies aimed at the sector and the contribution of new investments.

We can also suggest another kind of investigation using other inputs: number of RTG cranes and PT cranes, total storage area, number of reach stackers, terminal tractors, and forklifts for loaded and empty containers. Unfortunately, it is very difficult to find this type of information for Brazilian terminals.

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