Original Article

# On measuring the efficiency of Brazilian ports and their management models

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**Abstract** Brazil is currently encumbered with various logistical inefficiencies, some of which related to the port logistics chain, affecting the competitiveness of the country's exporters and importers. Given this context, it is important to assess the efficiency of ports as strategic links in this chain. The article evaluates and compares the efficiency of the main Brazilian ports using data envelopment analysis. The inputs used are cargo capacity, quay length and maximum draft. Outputs considered are cargo throughput and the number of shipping calls. Owing to the diversity of the Brazilian port system, the main goal of this article, in addition to identifying the most efficient port, is an attempt to assess whether the nature of cargo handled, or the management model adopted, affect significantly efficiency. Outcomes indicate that the port of Paranaguá is the most efficient port of Brazil and could therefore be considered as a benchmark. Our analysis did not find significant efficiency differences based on different management models or nature of cargo handled.

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## Introduction

In an environment of global competition, companies must manage various factors such as quality, price and agility to remain profitable. Logistical efficiency may affect all these factors and is a key aspect for many companies under the current economic conditions (Brooks *et al*, 2011; Woo *et al*, 2011; Barros *et al*, 2012; Gutiérrez *et al*, 2014).

According to a recent study on the logistical efficiency of various countries published by the World Bank (BIRD, 2014), Brazil decreased 20 positions between 2010 and 2014. Among the various aspects considered in the study, Brazil had very poor performance regarding customs administration, ranking 94th among 160 countries, and it was tied with Mali at 81st with regard to international deliveries of goods. Regarding logistics infrastructure, Brazil was ranked 54th, showing a performance inferior to countries with a much lower GNP such as Chile, Lithuania and Bulgaria.

Because of these inefficiencies in logistics, caused by institutional barriers (Padilha and Ng, 2012), the laws governing the port industry have been modified. Among these changes in the law, the Ports Modernization Act (Act 8.630/93) was significant because it ended two monopolies operating in this sector: (i) the monopoly on port operations by the Government, mainly through the 'Companhias de Docas' (docks companies), which were mixed-capital companies with the federal government as the major shareholder; and (ii) the stevedores (that is, longshoremen or dock workers) monopoly, which was dominated by port workers' unions. Act 8.630/93 allowed the concession of port operations to private companies through lease contracts, and it created the Manpower Management Agencies to manage all unionized workers.

Although Act 8630/93 brought change to the industry, after some years it stopped producing the desirable increases in efficiency. For this reason, and to attract new investment to the industry, a new regulatory framework was created with Act 12.815/2013 (Brasil, 2013), which established new criteria for the operation of port facilities and their lease to the private sector. The main objectives of this act were the licensing of investments, and the development and operation of existing port facilities by the private sector. Another important difference from the previous legislation was the inclusion of a performance criterion for awarding concessions for port services: the winner must offer greater efficiency at lower fees.

Within this context, the present study attempts to evaluate and compare the efficiency of the main ports in Brazil. data envelopment analysis (DEA) is used to measure comparatively the efficiency of each port (Cook and Seiford, 2009). Unlike other applications of DEA to Brazilian ports (Wanke *et al*, 2011; Cortez *et al*, 2013; Wanke, 2013), we here address the handling of bulk and containerized goods in a unified manner, using three inputs and two outputs, and study the relationships between port efficiency, management models and predominant nature of cargo.

The next section presents a review of port operations, DEA, DEA models and port efficiency analysis through DEA. Then, the methodology is presented, including the data collection procedures and the data analysis. The results, including a comparison with other studies, are analyzed and discussed subsequently. Finally, a summary of the results and suggestions for further research are given.

## Theoretical Background

### Ports management models and types of cargo in the Brazilian port system

Ports are complex and dynamic elements of a transport system that moves mainly cargo but also passengers. According to Cullinane *et al* (2005), ports perform three functions: (i) regulatory, by monitoring activity and enforcing regulations, often through a port authority; (ii) landowning (landlord), by managing the property in the port area; and (iii) operational, by transferring passengers and cargo. In addition, because of their importance in a competitive global market, ports must demonstrate greater efficiency in their operations, and provide more value-added services (Verhoeven, 2010; Da Silva and Rocha, 2012).

According to the World Bank (2007), four main models of port management have been used to achieve these objectives: (i) public service port, in which the port is predominantly managed by the government; (ii) landlord port, in which the government performs the regulatory and landowning functions while the private sector carries out the operational function; (iii) tool port, which is similar to the previous model except that the government provides the infrastructure *and* superstructure in addition to being the landowner; and (iv) private service port, in which the port is completely private.

The Brazilian port system was opened to friendly nations in 1808. Since then, the system has undergone various institutional changes. In 1963, the National Department of Ports and Waterways ('Departamento Nacional de Portos e Vias Navegáveis' – DNPVN) under Decree Law no. 200/67, instituted the administration of ports by government agencies, which resulted in the formation of the docks companies (Companhias de Docas) (Acosta, 2008).

According to Wilmsmeier and Monios (2016), until the 1990s, Brazilian ports were administered at government level by Portobrás (created in 1975 with the elimination of the DNPVN to improve port management through national policies), and at local level by the docks companies, private and government concessionaries. However, to decentralize and ensure autonomy and flexibility in the port sector, publicly administered ports, known as 'organized ports' (OPs), were instituted during the 1990s.

The dissolution of Portobrás in March 1990, and Decree 99.475 in August 1990, initiated the decentralization of the Brazilian port sector. According to Ng *et al* (2013), Act 8.630/93, the Ports Modernization Act, created institutional reforms under a new legal and regulatory framework that enabled new investment possibilities.

The Ports Modernization Act, which was passed on 25 February 1993, established a new legal framework for the industry, decentralized its administration and promoted the participation of the private sector in port activities (Brasil, 1993). The legislation also regulates the delegation of port administration to states and municipalities and the concession of port operations to the private sector.

In 2013, a new regulatory framework for the port sector was sanctioned by the Brazilian president. Act 12.815/2103 included a performance criterion for awarding concessions for port services. Thus, concessions are no longer given to the operator with the highest bid but to the operator that can offer the highest efficiency and the lowest fees. The objective of this criterion is to maximize cargo movement and to minimize the price per moved ton (Brasil, 2013).

According to the National Agency of Water Transportation (Agência Nacional de Transportes Aquaviários) (ANTAQ, 2013), the Brazilian port system consists of 234 ports, of which 134 are seaports and 100 are river ports.

These ports can be classified as either OPs or private use terminals (PUTs). Brazil has 100 OPs and 134 PUTs (ANTAQ, 2013). An OP is a set of port facilities, defense infrastructure and water access provided by public administration. The operation of these facilities can be managed directly by the government or through concessions to the private sector, or to states and cities, and involve the movement and storage of goods transported by water (ANTAQ, 2014a). PUTs are facilities built and managed by private firms or government institutions. The latter do not belong to the government administration, and move and/or store goods originating from their own economic activities, or those of third parties (ANTAQ, 2014a).

Generally, only two of the four models of port management are currently in use in Brazil. Public service ports were eliminated by Act 8.630/93, and the OPs, both those owned by the federal government and those delegated to states and cities, became landlord ports. Several tool ports still exist, but they are exceptions and will become landlord ports as new investment becomes necessary. PUTs are essentially private service ports. Figure 1 shows the port management models found in Brazil.

Regarding cargo types, Jaccoud and Magrini (2014) identified four main categories: (i) bulk solids (dry bulk); (ii) bulk liquids; (iii) general cargo; and (iv) containerized cargo. Iron ore, coal, salt, wheat and soy are examples of bulk solids. Bulk liquids include oil and oil-derived products. General cargo refers to

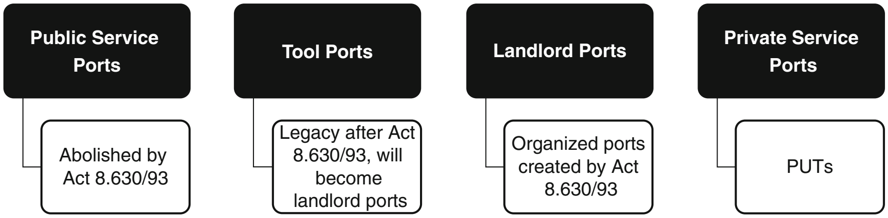

**Figure 1:** Port management models found in Brazil.

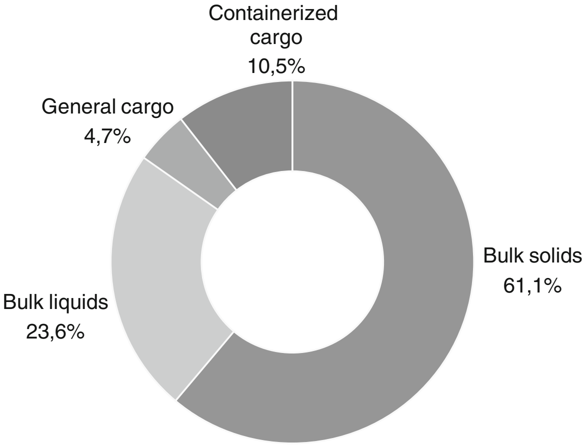

**Figure 2:** Cargo-type distribution in Brazil.

products such as cars, industrial machinery and stone blocks. Containerized cargo refers to products transported in standardized shipping containers. According to ANTAQ (2014d), the predominant cargo type in Brazil is bulk solid, followed by bulk liquids. Figure 2 shows the cargo-type distribution in Brazil.

## Data envelopment analysis

DEA is a linear programming method designed to measure the efficiency of decision-making units (DMUs) in a comparative manner using DMU input and output data. The two main DEA models are the Charnes–Cooper–Rhodes (CCR) model and the Banker–Charnes–Cooper (BCC) model.

The CCR model was the first DEA model and is one of the more basic models (Charnes *et al*, 1978; Cooper *et al*, 2000). There are many studies on mathematical programming with the CCR model; however, this study is based on

Cooper *et al* (2000) and Cook and Seiford (2009). One of the main characteristics of the model is the assumption of constant returns to scale, that is, there are no scale effects. The CCR model can be input-oriented to minimize the inputs or output-oriented to maximize the output level (Charnes and Cooper, 1962; Cooper *et al*, 2000).

The BCC model is an extension of the CCR model that allows variable returns to scale. In the study in which they introduced the BCC model, Banker *et al* (1984) defined a rule for the numbers of inputs and outputs that can be used relative to the number of DMUs to be analyzed. This rule is shown in equation (1).

$$\text{number of inputs} + \text{number of outputs} \leqslant \frac{\text{number of DMUs}}{3} \tag{1}$$

## DEA of ports

Several studies of port efficiency using DEA have been conducted in various countries including Brazil in recent years. In this method, it is fundamental that the inputs and the outputs reflect actual DMU conditions because they directly influence the results. Table 1 shows studies performed from 2010 to the present with applications of DEA in the port industry.

Certain inputs and outputs are common in most earlier studies. Mainly, inputs used are the port area (terminal, storage or total), the quay length and the number of cargo-handling equipment (for internal movement or at the quay). Output variable have been the volume of cargo, expressed in either tons or Twenty-foot Equivalent Units (TEUs). Most of the earlier studies are on container ports. For example, Rios and Maçada (2006) studied the relative efficiency of ports from different countries (Mercosur) using DEA. Wu *et al* (2010) identified the most sensitive measures impacting performance (number of berths and capital deployed). However, few studies have considered general cargo and containers in a unified manner, a problem that is addressed in the present study.

In addition to these studies, Panayides *et al* (2009) provided a thorough review and critical analysis of the major DEA applications and highlighted some problems and limitations in the application of the technique in the seaport context. Moreover, Markovits-Somogyi (2011) reviewed the state of the art of applying DEA in the transport sector. Finally, Odeck and Bråthen (2012) presented the first attempt to use meta-analysis to examine efficiency in the context of seaports.

In the case of Brazilian ports, Rios and Sousa (2014) concluded that even with obsolete equipment, a terminal can be efficient, and that only studies such as DEA could provide this type of information. Likewise,

**Table 1:** Recent studies of the port industry using DEA

| *Authors* | *Inputs* | *Outputs* | *Sample* |
|---|---|---|---|
| Hung *et al* (2010) | Number of berths; terminal area in m$^2$; number of cranes on the quay (ship–shore container gantry); quay length in meters | Annual movement in TEUs | 31 ports in Asia |
| Sharma and Yu (2010) | Terminal area in m$^2$; quay length in meters; number of cranes; number of transfer cranes; number of reach stackers; number of straddle carriers | Annual movement in TEUs | 70 container ports |
| Wu and Goh (2010) | Total terminal area in m$^2$; quay length in meters; number of pieces of equipment | Annual yield in TEUs | Major ports in 2005, including 21 ports on various continents |
| Lozano *et al* (2011) | Terminal area in m$^2$; quay length in meters; number of cranes; number of tugs | Annual movement in TEUs; cargo traffic in tons/year; number of vessels per year | Spanish ports |
| Oliveira and Cariou (2011) | Draft in meters; quay length in meters; storage stack in meters | Loading rate (ton/h); movement | 122 worldwide iron ore and coal ports in 2005 |
| Wanke *et al* (2011) | Number of berths | Loaded shipments | 26 Brazilian ports |
| Barros (2012) | Total terminal area in m$^2$; quay length in meters; number of workers | Annual movement in TEUs; bulk solids in tons; bulk liquids in tons; number of days to move the cargo | African ports |
| Niavis and Tsekeris (2012) | Quay length in meters; number of berths; number of cranes | Annual movement in TEUs | 30 ports in the southeast of Europe |
| Bichou (2013) | Total terminal area in m$^2$; quay length in meters; number of gates; number of wharf and yard cranes, pieces of cargo-handling equipment, conveyor belts, trucks, tractors and other internal vehicles | Annual movement in TEUs | 420 container terminals |
| Cortez *et al* (2013) | Number of workers; operational cost | Revenue; annual movement in tons | 24 Brazilian ports |
| Schøyen and Odeck (2013) | Total berth length in meters; total terminal area in m$^2$; number of cranes; number of carriers | Number of handling trucks; annual movement in TEUs | 24 Norwegian container ports |

**Table 1:** (Continued)

| *Authors* | *Inputs* | *Outputs* | *Sample* |
|---|---|---|---|
| Trujillo *et al* (2013) | Total terminal area in $m^2$; total berth length in meters; number of cranes | Annual movement in TEUs | African ports |
| Wanke (2013) | Number of berths; warehouse area in $m^2$; yard area in $m^2$ | Annual movement in TEUs; annual yield of bulk solids in tons | 27 Brazilian ports |
| Yuen *et al* (2013) | Terminal area in $m^2$; quay length in meters; number of berths; number of quay cranes; number of yard cranes | Annual movement in TEUs | Chinese ports |
| Güner (2015) | Terminal area in $m^2$; quay length in meters; number of berths; number of tugs; number of cranes; number forklifts; number of workers; total expenditures | Freight handled; number of shipments | 13 Turkish ports |

Bergantino and Musso (2011) and Bergantino *et al* (2013) investigated the impact of variables and evaluated the relative efficiency of port management across countries. The authors established that efficiency, and thus performance of ports, is influenced by a number of contextual variables, such as local availability of manpower and port accessibility, however, operational environment and regulatory effects are the most significant variables and, therefore, must be considered in the analysis. Analyzing possible efficiency factors, as the Brazilian port sector is under a unified regulatory system, it is expected that port efficiency must be widely affected by the operational environment. Therefore, the present article intends to cover this context by studying management models and nature of cargo handled.

## Methodology

Our cross-sectional study consists of three stages: (i) sampling and data collection; (ii) efficiency analysis using DEA; and (iii) evaluation of results and discussion.

The selected variables cover major port activities and nature of cargo. Three input variables related to infrastructure were selected: (i) cargo capacity (*t*); (ii) quay length (m); and (iii) maximum draft of berths (m). The cargo capacity reflects the infrastructure of the port, the quay length represents the number of vessels that can berth simultaneously and the maximum draft can reflect the tonnage of the vessels that call at the port. The port area was not used in this study to avoid distortions caused by data patterns, because that information was not available in a standardized form from any government agency, study or report. The number of cranes was not used because the equipment can be used to move different types of cargo and therefore can have different specifications. Thus, the cargo capacity (*t*) was chosen as an input. Output variables were: (i) cargo throughput in 2013 (*t*); and (ii) the number of shipping calls in the same year (dimensionless).

Only secondary information from government agencies was used to collect the data. The cargo capacity was approximated by multiplying the highest monthly volume of cargo handled in 2013 by 12 to create an annual base. The information was obtained from the Management Information System of ANTAQ (ANTAQ, 2014b). The quay length and maximum draft values were collected from the infrastructure files available online from ANTAQ (ANTAQ, 2014c). The output data were obtained from the 2013 Annual Cargo Movement Report of the National Water Transportation Agency (ANTAQ, 2014d).

The initial sample included the 34 largest Brazilian ports according to ANTAQ (2014c): Angra dos Reis (RJ), Antonina (PR), Aratu (BA),

**Table 2:** Input and output data for the 15 main Brazilian ports

| *Port* | *Inputs* | | | *Outputs* | | |
|---|---|---|---|---|---|---|
| | *Movement capacity (t)* | *Quay length (m)* | *Maximum draft (m)* | *Cargo throughput (t)* | *Number of shipping calls* | *Percentage of cum. cargo throughput* |
| Santos | 117 627 516 | 13 091 | 17.50 | 99 808 300 | 5166 | 29.50 |
| Itaguaí | 72 267 576 | 2200 | 17.80 | 58 327 912 | 872 | 46.75 |
| Paranaguá | 49 339 164 | 2943 | 13.30 | 41 912 263 | 2075 | 59.14 |
| Rio Grande | 25 908 564 | 4144 | 14.50 | 20 534 639 | 2310 | 65.21 |
| Itaqui | 18 463 272 | 2608 | 19.00 | 15 291 910 | 739 | 69.73 |
| Vila do Conde | 16 682 652 | 1541 | 20.00 | 14 405 206 | 758 | 73.99 |
| São Francisco do Sul | 15 812 580 | 1530 | 14.50 | 13 029 826 | 633 | 77.84 |
| Suape | 16 019 088 | 3571 | 15.50 | 12 853 885 | 1364 | 81.64 |
| Rio de Janeiro | 9 553 764 | 6740 | 14.50 | 8 858 836 | 1138 | 84.26 |
| Aratu | 7 588 536 | 895 | 12.00 | 5 825 663 | 567 | 85.98 |
| Fortaleza | 6 738 396 | 1260 | 13.00 | 5 160 708 | 568 | 87.50 |
| Vitória | 7 708 656 | 2510 | 10.67 | 5 065 852 | 1344 | 89.00 |
| Santarém | 5 623 332 | 560 | 18.00 | 4 434 997 | 1728 | 90.31 |
| Itajaí | 5 865 924 | 1035 | 10.50 | 4 112 998 | 303 | 91.53 |
| Salvador | 5 639 376 | 2085 | 15.00 | 3 986 204 | 672 | 92.71 |

Areia Branca (RN), Belém (PA), Cabedelo (PB), Estrela (RS), Forno (RJ), Fortaleza (CE), Ilhéus (BA), Imbituba (SC), Itaguaí (RJ), Itajaí (SC), Itaqui (MA), Maceió (AL), Manaus (AM), Natal (RN), Niterói (RJ), Paranaguá (PR), Pelotas (RS), Porto Alegre (RS), Porto Velho (RO), Recife (PE), Rio de Janeiro (RJ), Rio Grande (RS), Salvador (BA), Santana (AP), Santarém (PA), Santos (SP), São Francisco do Sul (SC), São Sebastião (SP), Suape (PE), Vila do Conde (PA) and Vitória (ES).

The sample was refined according to the importance of each port in the Brazilian port industry. The first refined sample included 13 ports that represent 90 per cent of the total cargo throughput in tons (2013). This resulted in fewer DMUs than required (equation (1)), so the number of ports was increased by including the next two ports in the list. The final sample, shown in Table 2, had 15 ports representing 92.71 per cent of the Brazilian port industry, which satisfied the condition of equation (1).

The CCR and BCC models were used here, because they are the best-known and most-used models. The CCR and BCC models can be either input- or output-oriented; the output-oriented model was used in the present study. The decision support software SIAD was used to execute the models (Meza *et al*, 2005). This software calculates the normalized composed efficiency, where one DMU is assigned 1 point to improve accuracy and resolve equal scores among DMUs. Equation (2) gives the definition of the composed efficiency, obtained from the classic efficiency (CCR or BCC) method and the inverted efficiency, which is a measure of inefficiency (Entani *et al*, 2002). Subsequently, the composed efficiency is normalized to obtain a final value between 0 and 1.

$$\text{Composed efficiency} = \frac{\text{classic efficiency} + (1 - \text{inverted efficiency})}{2} \qquad (2)$$

Three result evaluations were performed: (i) sensitivity analysis; (ii) analysis of the effect of port management model on efficiency; and (iii) analysis of the effect of the predominant nature of cargo on efficiency. The DEA sensitivity analysis, which is used to determine the robustness of the model, was performed by removing one variable and re-computing the efficiency (Pahwa *et al*, 2002). This analysis was performed only for the classic efficiency of the CCR model because the CCR model is the most frequently used model in the literature. The analysis of the dependence of efficiency on port management models determines whether a certain model (federal, state or municipal OP or PUT) is the most efficient. The same is true for the analysis of the dependence of efficiency on the predominant nature of cargo (bulk solids, bulk liquids, general cargo or containerized cargo). Both analyses used the Kruskal–Wallis approach, included in Minitab 17 (Minitab Inc., State College, PA, USA), to test for significant differences between the groups, classified according to ANTAQ data (ANTAQ, 2014c, d).

## Results

This section presents the results of the study. Those are shown in the three stages: (i) sampling and data collection; (ii) efficiency analysis using DEA; and (iii) evaluation of the results and discussion.

### Sampling and data collection

The final sample included the 15 largest Brazilian ports and was obtained after the initial sample (34 ports) was refined to cover at least 90 per cent of the total cargo and the minimum number of DMUs, satisfying equation (1). Table 2 shows the final sample with the values of the inputs, the outputs and the percentages of cargo throughput for each port.

### Efficiency analysis using DEA

To compare the efficiency of the sample ports, the output-oriented CCR and BCC models were used. The complete results are shown in Appendices A and B.

**Table 3:** Normalized composed efficiency using DEA with the CCR and BCC models

| *Port* | *CCR (output)* | *BCC (output)* | *Average (position in the ranking)* |
|---|---|---|---|
| Santos | 0.985 | 0.944 | 0.965 (3) |
| Itaguaí | 0.871 | 0.944 | 0.907 (8*) |
| Paranaguá | 0.982 | 0.996 | **0.989 (1)** |
| Rio Grande | 0.982 | 0.944 | 0.963 (4) |
| Itaqui | 0.897 | 0.903 | 0.900 (13) |
| Vila do Conde | **1.000** | 0.944 | 0.972 (2) |
| São Francisco do Sul | 0.920 | 0.982 | 0.951 (5) |
| Suape | 0.924 | 0.881 | 0.902 (12) |
| Rio de Janeiro | 0.871 | 0.944 | 0.907 (8*) |
| Aratu | 0.863 | **1.000** | 0.932 (6) |
| Fortaleza | 0.851 | 0.999 | 0.925 (7) |
| Vitória | 0.871 | 0.944 | 0.907 (8*) |
| Santarém | 0.871 | 0.944 | 0.907 (8*) |
| Itajaí | 0.702 | 0.944 | 0.823 (15) |
| Salvador | 0.706 | 0.944 | 0.825 (14) |

Table 3 shows the normalized composed efficiency from each method and the average of the two values, which was used to rank the ports.

According to the CCR model, the efficiency of two ports, Itajaí and Salvador, was significantly lower (approximately 0.7) than this of the other ports, and the ports of Santos, Paranaguá, Rio Grande and Vila do Conde were the best, with an efficiency greater than 0.98. According to the BCC model, the port of Suape was the only port for which the efficiency was less than 0.9, and the ports of Paranaguá, São Francisco do Sul, Aratu and Fortaleza were the best, with an efficiency greater than 0.98.

The ports can be classified by the average of the composed efficiencies of the two methods. According to this criterion, the port of Paranaguá was the most efficient at 0.989, followed by the ports of Vila do Conde, Santos, Rio Grande and São Francisco do Sul, all of which presenting values greater than 0.95. The least efficient ports were Itajaí and Salvador, both revealing values less than 0.9. Those are high levels of efficiency, but it should be remembered that only the most important Brazilian ports were studied, and that DEA efficiency is comparative, and not absolute.

## Evaluation of the results and discussion

Three tests were performed to evaluate the results. The first test, sensitivity analysis, evaluated the effects of changes in the inputs or the outputs of the model on efficiency. For this analysis, the efficiency obtained from the CCR model was used. Table 4 shows the efficiency for each port and the difference when an input or output is removed.

**Table 4:** Sensitivity analysis with the CCR model (classic efficiency)

| *Port* | *Classic CCR* | *Without movement capacity* | *Without quay length* | *Without maximum draft* | *Without cargo throughput* | *Without number of shipping calls* | *Average variation* |
|---|---|---|---|---|---|---|---|
| Santos | 1.000 | 1.000 | 1.000 | 0.980 | 1.000 | 1.000 | 0.004 |
| Itaguaí | 1.000 | 1.000 | 0.945 | 1.000 | 0.391 | 1.000 | 0.133 |
| Paranaguá | 1.000 | 1.000 | 0.993 | 1.000 | 1.000 | 1.000 | 0.001 |
| Rio Grande | 1.000 | 1.000 | 1.000 | 0.924 | 1.000 | 0.919 | 0.032 |
| Itaqui | 0.956 | 0.353 | 0.921 | 0.954 | 0.317 | 0.956 | 0.256 |
| Vila do Conde | 1.000 | 0.463 | 0.950 | 1.000 | 0.347 | 1.000 | 0.248 |
| São Francisco do Sul | 0.957 | 0.466 | 0.923 | 0.954 | 0.373 | 0.957 | 0.223 |
| Suape | 0.931 | 0.595 | 0.908 | 0.924 | 0.657 | 0.919 | 0.130 |
| Rio de Janeiro | 1.000 | 0.521 | 1.000 | 1.000 | 0.647 | 1.000 | 0.166 |
| Aratu | 0.897 | 0.459 | 0.828 | 0.897 | 0.440 | 0.886 | 0.195 |
| Fortaleza | 0.888 | 0.377 | 0.826 | 0.888 | 0.406 | 0.877 | 0.213 |
| Vitória | 1.000 | 1.000 | 1.000 | 0.778 | 1.000 | 0.740 | 0.096 |
| Santarém | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.913 | 0.017 |
| Itajaí | 0.806 | 0.267 | 0.756 | 0.806 | 0.265 | 0.804 | 0.227 |
| Salvador | 0.810 | 0.366 | 0.783 | 0.810 | 0.445 | 0.792 | 0.171 |
| Average variation (input/output) | | 0.292 | 0.027 | 0.022 | 0.331 | 0.032 | |

The average variation in efficiency when an input or output was removed differed among the ports. The differences were small for some ports such as Santos, Paranaguá, Rio Grande and Santarém, indicating less sensitivity. Other ports such as Itaguaí, Suape, Rio de Janeiro, Vitória and Salvador had average variations ranging from 0.09 to 0.17. The ports of Itaqui, Vila do Conde, São Francisco do Sul, Aratu, Fortaleza and Itajaí had average variations greater than 0.19, indicating that the model was more sensitive to certain inputs or outputs for those ports.

To identify the inputs/outputs with the greatest influence on the model, the average variations were calculated. For the removal of the quay length (input), the maximum draft (input) and the number of calls (output) individually, the changes were 0.027, 0.022 and 0.032, respectively. In contrast, the variations for the removal of the movement capacity (input) and the cargo throughput (output) were 0.292 and 0.331, respectively. The magnitudes of these variations indicate that these two variables are the most important in this model. In addition, a high correlation (0.99) between these variables is indicated, demonstrating the importance of analyzing the two variables together.

Finally, for the dependence of efficiency on the port management model and the main nature of cargo, it was necessary to relate the ANTAQ port classifications to these two parameters (ANTAQ, 2014c, d). As mentioned previously, the responsibility for the management of an OP can be federal, state, municipal or PUT, and the predominant nature of cargo of the ports can be bulk solid, bulk

**Table 5:** Classification of the ports according to management model and predominant nature of cargo

| *Port* | *State* | *Management* | *Main nature of cargo* |
|---|---|---|---|
| Santos | SP | Federal OP | Bulk solid |
| Itaguaí | RJ | Federal OP | Bulk solid |
| Paranaguá | PR | State OP | Bulk solid |
| Rio Grande | RS | State OP | Bulk solid |
| Itaqui | MA | State OP | Bulk solid |
| Vila do Conde | PA | Federal OP | Bulk solid |
| São Francisco do Sul | SC | State OP | Bulk solid |
| Suape | PE | State OP | Bulk liquid |
| Rio de Janeiro | RJ | Federal OP | Containerized cargo |
| Aratu | BA | Federal OP | Bulk liquid |
| Fortaleza | CE | Federal OP | Bulk liquid |
| Vitória | ES | Federal OP | Containerized cargo |
| Santarém | PA | Federal OP | Bulk solid |
| Itajaí | SC | Municipal OP | Containerized cargo |
| Salvador | BA | Federal OP | Containerized cargo |

**Table 6:** Efficiency analysis for port management model

*Kruskal–Wallis test: Efficiency versus management*

| *Management* | *N* | *Median* | *Average rank* | *Z* |
|---|---|---|---|---|
| Federal OP | 18 | 0.9440 | 15.2 | −0.21 |
| Municipal OP | 2 | 0.8230 | 9.5 | −1.00 |
| State OP | 10 | 0.9340 | 17.2 | 0.75 |
| Overall | 30 | — | 15.5 | — |
| $H=1.32$ | DF = 2 | $P=0.517$ | | |
| $H=1.36$ | DF = 2 | $P=0.506$ | (Ajusted for ties) | |

*Note*: One or more small samples.

liquid, general cargo or containerized cargo. Table 5 shows the classifications of the 15 main Brazilian ports according to these two criteria.

The port classification can be analyzed if there is a significant difference among the groups according to the Kruskal–Wallis test for both port management models and predominant nature of cargo. The composed efficiencies from the two models (CCR and BCC) were used in both assessments, with a total of 30 elements. Tables 6 and 7 show the results of the tests.

The *P*-value highlighted in Table 6 was used to analyze the effect of port management model on efficiency. The *P*-value is 0.506; therefore, the null-hypothesis (H0: there is no difference among the groups) could not be rejected at the 95 per cent level of significance. It should be noted that for the management model evaluation, no ports were classified as PUT and only one port was municipally managed, which contributed to make it difficult to reject H0.

**Table 7:** Efficiency evaluation according to the predominant nature of cargo

*Kruskal–Wallis test: Efficiency versus nature of cargo*

| *Nature of cargo* | *N* | *Median* | *Average rank* | *Z* |
|---|---|---|---|---|
| Bulk liquid | 6 | 0.9025 | 14.4 | −0.34 |
| Bulk solid | 16 | 0.9440 | 18.2 | 1.77 |
| Containerized cargo | 8 | 0.9075 | 11.0 | −1.69 |
| Overall | 30 | — | 15.5 | — |
| $H=3.64$ | DF = 2 | $P=0.162$ | | |
| $H=3.75$ | DF = 2 | $P=0.153$ | (Ajusted for ties) | |

In the evaluation of the dependence of efficiency on the predominant cargo type, the *P*-value was 0.153 (Table 7); therefore, in this case, the null-hypothesis (H0: there is no difference among the groups) could not be rejected at the 95 per cent level of significance. It should be noted that in this case the number of observations was better distributed among the predominant nature of cargo. This greater uniformity in the number of observations improved the reliability of the analysis and resulted in a lower *P*-value, which was not sufficient, so as to reject H0. Thus, there were no statistically significant differences in port efficiency with regard to port management models or predominant nature of cargo.

In this sense, Bergantino *et al* (2013) highlighted the impact of operational environment on port efficiency and, therefore, this impact has been widely investigated, albeit without consensus. For instance, our article is in line with Liu (1995) and Notteboom *et al* (2000), who established that neither the management model nor ownership have a significant effect on port efficiency. Yuen *et al* (2013) and Cortez *et al* (2013), on the other hand, concluded that the management model might have an effect on port efficiency. Cargo-type impact on port efficiency has been narrowly explored, because the majority of studies just compare the efficiency of ports with the same nature of cargo (see Table 1).

## Conclusions

The objective of this study was to evaluate the efficiency of the main Brazilian ports using DEA. A simple average of the efficiencies obtained from the BCC and CCR models was used to determine the benchmark.

The Kruskal–Wallis test was used to investigate the effect of port management model and predominant type of cargo on port efficiency. In both cases, the test indicated that port efficiency is not affected by these two variables.

The results shown in Table 3 indicate that the Port of Paranaguá is the most efficient Brazilian port. This result is consistent with Wanke (2013), who concluded that Paranaguá has high physical infrastructure and shipment consolidation efficiency levels.

Although the efficiency of Paranaguá has been less sensitive to the elimination of inputs and outputs than the efficiency of the other ports in the sample (see sensitivity analysis presented in Table 4), one of the main factors affecting this efficiency is the quay length. Compared with other ports in the sample, Paranaguá handled a large number of ships and cargo throughput for the available quay length. The high average assignment (port throughput/number of vessels), already mentioned by Wanke (2013), and the berth occupation rate (port throughput/quay length) verified in Paranaguá are only possible because of the existing systems of cargo-handling and the efficient procedures for incoming and outgoing trucks.

With regard to ships loading and unloading, the port has new shiploaders that have allowed high efficiency in handling of agricultural dry bulk, the main type of cargo in Paranaguá. This favors both the increase in the number of vessels and the port throughput.

As regards the access of trucks, this is an important point, since Brazilian transport takes place mainly by road and this is also the main mode of transport in Paranaguá, even for dry bulk. It is important to highlight, in this regard, the implementation of a truck center in Paranaguá, which has reduced the queues of vehicles in the port access, making more efficient the receiving and delivery cargo process.

The two points mentioned above have been highlighted as strengths of Paranaguá in the Master Plan carried out by the SEP/PR. Furthermore, these factors help to explain the efficiency found in DEA.

The main limitation of the present study was the exclusion of the port area as an input in the DEA, the reasons for which were discussed previously. In addition, the small number of observations in certain groups, such as the municipally managed ports, may have affected the results of the Kruskal–Wallis test. There is also an intrinsic limitation in the cross-sectional study method in that data collected in a short period will not capture changes that occur slowly over time.

In future research, the analysis could be expanded with a larger number of ports, and DEA could be used with a sample of ports that have the same main type of cargo and/or management model to identify a benchmark for each category. An investigation of best practices and productivity in benchmark ports is also important in revealing and promoting the Brazilian port sector.

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# Appendix A

**Table A1:** Complete efficiency results of the DEA with the CCR (output) model

| *Port* | *CCR (output)* | | | |
|---|---|---|---|---|
| | *Classic* | *Inverted* | *Composed* | *Normalized composed* |
| Santos | 1.000 | 0.869 | 0.566 | 0.985 |
| Itaguaí | 1.000 | 1.000 | 0.500 | 0.871 |
| Paranaguá | 1.000 | 0.873 | 0.564 | 0.982 |
| Rio Grande | 1.000 | 0.873 | 0.564 | 0.982 |
| Itaqui | 0.956 | 0.926 | 0.515 | 0.897 |
| Vila do Conde | 1.000 | 0.852 | 0.574 | 1.000 |
| São Francisco do Sul | 0.957 | 0.901 | 0.528 | 0.920 |
| Suape | 0.931 | 0.870 | 0.530 | 0.924 |
| Rio de Janeiro | 1.000 | 1.000 | 0.500 | 0.871 |
| Aratu | 0.897 | 0.906 | 0.495 | 0.863 |
| Fortaleza | 0.888 | 0.912 | 0.488 | 0.851 |
| Vitória | 1.000 | 1.000 | 0.500 | 0.871 |
| Santarém | 1.000 | 1.000 | 0.500 | 0.871 |
| Itajaí | 0.806 | 1.000 | 0.403 | 0.702 |
| Salvador | 0.810 | 1.000 | 0.405 | 0.706 |

# Appendix B

**Table B1:** Complete efficiency results of the DEA with the BCC (output) model

| *Port* | *BCC (output)* | | | |
|---|---|---|---|---|
| | *Classic* | *Inverted* | *Composed* | *Normalized composed* |
| Santos | 1.000 | 1.000 | 0.500 | 0.944 |
| Itaguaí | 1.000 | 1.000 | 0.500 | 0.944 |
| Paranaguá | 1.000 | 0.944 | 0.528 | 0.996 |
| Rio Grande | 1.000 | 1.000 | 0.500 | 0.944 |
| Itaqui | 0.956 | 1.000 | 0.478 | 0.903 |
| Vila do Conde | 1.000 | 1.000 | 0.500 | 0.944 |
| São Francisco do Sul | 0.989 | 0.948 | 0.520 | 0.982 |
| Suape | 0.933 | 0.999 | 0.467 | 0.881 |
| Rio de Janeiro | 1.000 | 1.000 | 0.500 | 0.944 |
| Aratu | 1.000 | 0.940 | 0.530 | 1.000 |
| Fortaleza | 0.997 | 0.938 | 0.529 | 0.999 |
| Vitória | 1.000 | 1.000 | 0.500 | 0.944 |
| Santarém | 1.000 | 1.000 | 0.500 | 0.944 |
| Itajaí | 1.000 | 1.000 | 0.500 | 0.944 |
| Salvador | 1.000 | 1.000 | 0.500 | 0.944 |