Public-private partnerships and scale efficiency in Brazilian ports: Evidence from two-stage DEA analysis

Peter F. Wanke a,*, Carlos Pestana Barros b,1

a Center for Studies in Logistics, Infrastructure and Management, COPPEAD Graduate Business School, Federal University of Rio de Janeiro, Brazil
b Instituto Superior de Economia e Gestão, University of Lisbon, Rua Miguel Lupi, 20, 1249-078 Lisbon, Portugal

A R T I C L E   I N F O
Article history:
Available online 25 June 2015

Keywords:
Ports
DEA
Bootstrap
Brazil
Scale efficiency
PPPs

A B S T R A C T
This paper assesses the impacts of public-private partnerships on major Brazilian public ports. It is proposed that these kinds of arrangements with private terminal operators could help achieving higher levels of scale efficiency by enhancing coordination processes, providing more adequate information technologies, and higher connectivity with other transportation modes. Methodology relies on factor extraction of inputs/outputs as a first step to compute DEA efficiency estimates, followed by truncated bootstrapped regression analysis to test different contextual variables. Results indicate a strong positive impact of public-private partnerships on port scale efficiency, corroborating their impacts in relation to the most productive scale size.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

The development of world class infrastructure is a difficult task for governments to pursue alone, especially in light of fiscal constraints and other monitory liabilities. Notwithstanding, and especially in developing countries, reforms to improve and extend infrastructure level and quality have a huge effect on economic growth, mainly in terms of production and provision of goods and services and significantly affect an economy’s productivity, costs and competitiveness [40].

In tune with growing needs vis-à-vis foreign trade and strengthening and supplementing the existing infrastructure facilities, the Public Private Partnerships (PPP) model has emerged as a preferred mode of funding infrastructure [48]. According to Tang et al. [77], there is a global trend for financing public works via PPPs. In Brazil, for instance, port operations were completely controlled by the federal government until the mid-1990s; until then, investment in port infrastructure was performed solely by state-owned companies. However, Brazil’s Ports Act 8630/93 established the path for ports to contract private terminal operators, partially breaking up the state monopoly of the sector and inaugurating the use of PPPs in Brazil [38].

Since then, accelerated growth on foreign trade has increased the demands for port services in Brazil. Between 2006 and 2010, the physical aggregate throughput handled within Brazilian ports — measured in tons/year — grew at an average rate of 10% per year [16]. This increasing demand for reliable services has placed enormous pressure upon the infrastructure of Brazil’s ports. Even though public investments in infrastructure expansion have remained at minimal levels for the last three decades — 2.1% of GDP [53], the capability of addressing the growth of demand for port services by means of PPPs is now being questioned [3,19,73].

In this sense, the Brazilian government recently reopened the debate on the regulatory agenda. Legal barriers to the contracting of private terminal operators still exist, the main one being the bureaucracy faced by the state-owned company Companhia Docas to perform the various steps that precede such contracting; indeed, the entire process can take years [38]. The idea now is to speed up capacity expansion projects to better serve Brazil’s major hinterlands. It is likely that the current model of public-private partnerships will be enhanced to also encompass the funding of private ports. However, the control of crucial decisions on port concession agreements — such as the types of ports and cargoes that should be prioritized within each region and how port connectivity to access

* Research made with support of Calouste Gulbenkian Foundation.
* Corresponding author. Rua Paschoal Lemme, 355, Cidade Universitária, Rio de Janeiro – RJ, CEP 21941-918, Brazil. Tel.: +55 21 2598 9896.
E-mail addresses: peter@coppead.ufrj.br (P.F. Wanke), cbarros@iseg.ULisboa.pt (C.P. Barros).
1 Tel.: +351 213 016 115; fax: +351 213 925 912.

http://dx.doi.org/10.1016/j.seps.2015.06.002
0038-0121/© 2015 Elsevier Ltd. All rights reserved.
channels, highways, and railroads could be improved — will still be held by the federal government.

This paper presents a benchmark and efficiency analysis of 27 major Brazilian ports based on data for 2012, putting their scale efficiencies into perspective in light of current PPPs, where public ports owned by Companhia Docas conceded the administrative rights of their terminals to private operators. Although recognizing the potential of PPP agreements, it is important to consider that some academic findings and empirical observations lead to mixed conclusions about their actual benefits [22]. This opens up opportunities to keep investigating the theme.

Our particular contribution lies in an empirical application, inspired not only by the current debate in the Brazilian port sector concerning the role of private terminal operators, but also by using scale efficiency as a cornerstone measure to assess the impact of PPPs on port operations. Furthermore, according to Ross and Droge [72], scale efficiency is a measure that better fits large-scale investments, such as ports, airports and railroads. Zelenyuk [95] highlights the relevance of scale efficiency, once it combines both the notion of optimal scale and the notion of (relative) production efficiency; also, it is showed how important the analysis of economies of scale has been one of the fundamental subjects in economics, operations research and production management, both in theory and especially in practice. Kao and Hwang [47] show the necessity of the decomposition of scale efficiency into two-stage production systems, such as the case of ports that can be decomposed in physical infrastructure and shipment consolidation stages [90]. It also contributes to the port regulatory agenda in terms of potential empirical application, expanding the literature of transportation analyses from new perspectives, in line with the goals of the Journal.

The empirical results corroborate the evidence that although most of major Brazilian ports are facing capacity constraints PPPs are responsible for achieving a better fit between the physical resources of ports and their respective service demands. More precisely, PPPs seem to be an effective way, under the Brazilian regulatory system, to move port operations towards their most productive scale size. The rationales behind these issues are further discussed over the next four sections.

This paper is structured as follows. The literature review section addresses not only the backgrounds of PPPs and Brazilian port regulation, but also focuses on previous studies on port efficiency, with a particular emphasis on the Brazilian case. Additionally, it explores the relationship between PPPs and scale efficiency, leading to the major proposition of this study. The methodology section deals with data collection related to aspects and the subsidiary steps necessary to perform Data Envelopment Analysis (DEA) properly: variable reduction and bootstrapped regression. The conclusion follows the results and discussion, where policy implications are discussed in light of the findings for the Brazilian case.

2. Literature review

2.1. Background: PPPs and Brazilian port regulation

A PPP can be defined as “an arrangement of roles and relationships in which two or more public and private entities coordinate/combine complementary resources to achieve their separate objectives through joint pursuit of one or more common objectives” [51,62]. It is observed that PPPs are rapidly becoming popular, and one contributing factor for such popularity is their capability to harness the managerial practices, innovative capabilities, and capital from private sector [59,78].

It is relevant to highlight that there is no single definition to PPP. To Grimsey and Lewis [39], generally speaking, PPPs fill a space between traditionally procured government projects and full privatization. Besides, it is a refinement of the private financing initiatives for infrastructure that started in the early 1990s and describe the provision of public assets and services through the participation of the government, the private sector and the consumers.

While PPPs can be created to pursue a variety of activities [51], some empirical evidence suggests that they are most commonly used by governments for infrastructure projects [11], as Grimsey and Lewis [39] emphasized. In the context of infrastructure projects, PPPs are long-term agreements between a public entity and a private partner, with the objective of assuring the financing, construction/renovation, and operation of a public infrastructure service [69].

The Private Participation in Infrastructure Database [94], for example, shows that 139 developing countries are aggressively inviting private participation in infrastructure projects. The trend is also evident in developed countries/areas such as US, UK, EU, Canada, Japan and South Korea. Notably, the number of PPP-related publications in transportation and construction journals increased from 2.9% in 1998 to 5.1% in 2008 [49], further evidence of this global trend to PPPs.

Regarding ports infrastructure, the choices as to the scope of public sector participation in ports range from the strong involvement of governments in the provision of both port services and also of port infrastructure to the total privatization of ports, as in England [81]. Most PPP models in the ports sector sit within a landlord port structure in which a public sector port authority (often autonomous) enters into PPP contracts for a series of individual terminals [36]. In this sense, according to Debie et al. [30], the public authority owns the land and infrastructure and leases these to private operators as a concession, with equipment and operations in the hands of the private sector. This is the most common model found in Latin America, although some fully private port experience can be found in Mexico and some of the Caribbean countries.

In Brazil, the landlord port model was adopted as the cornerstone format of the current PPPs between Companhia Docas and several private terminal operators. Under this scenario, port operations and management of terminals are responsibility of private enterprise, while (as is the case of investment in land and waterway access to ports) the administration of common-use infrastructure is maintained with the public sector [52].

Specifically, a part of the port infrastructure in Brazil — the areas for cargo loading and unloading, and storage areas — was transferred to private operation via leasing under the 1993 Ports Act [26]. Prior to the Ports Act, port authorities were responsible for the majority of ports operations, including cargo loading and unloading from vessels, and transport, storage and handling of cargo. After the port areas had been leased, these activities were, in general, transferred to private operators, and port administrations became managers of the common port areas, being made responsible for construction procurement, renovations, expansion, improvements and conservation of port facilities, including infrastructure for water and land access to ports [52].

According to Goldberg [38], there is little doubt that the expansion of Brazilian port capacity was enabled by the PPP-landlord port model, especially with respect to the handling of containers. More specifically, and still in accordance to Goldberg [38], between 1996 and 2005, total import/export revenue in Brazilian ports grew 6.6% per annum, with the vast majority of this expansion centering around container loads, driven by private terminals contracts established in 1995 for the ports of Santos, São
Francisco do Sul, Rio Grande, Rio de Janeiro, Paranaguá, Vitória, Itajai, Salvador, Itajaí, Vila do Conde, and Imbituba. These are the public ports with PPPs analyzed in this research.

It is important to stress that nowadays there is a new legislation ruling the Brazilian port management and administration; the Brazil’s new Port Law (Law N°. 12.815/13) brings significant changes to Brazil’s port regulatory regime and aims to increase private investment in Brazilian ports, essential to tackling one of the country’s most prominent logistical bottlenecks. The 5th article in section IX of the Law states that “are essential to the concession contracts and lease the rights clauses, warranties and obligations of the contractor and the contracted, including those related to future needs supplementation, modification and expansion of activity and consequent modernization, improvement and expansion of facilities”. Then, the new law settled one of the sector’s main legal disputes concerning the handling by private terminals of cargo belonging to third parties. Law N°. 12.815/13 now clearly states that private terminals outside established ports are authorized to handle any type of cargo, including those of other companies, thus increasing competition among port operators and boosting greenfield site development via new investment, as the new regulations stipulate.

2.2. Studies on port efficiency: the Brazilian case

The literature on efficiency measurement recognizes the need to consider the effects of external factors on efficiency, even though the inclusion of environmental factors in empirical efficiency analyses is often dismissed. In accordance with Cruz and Marques [23]; there are five different origins of these external factors (contextual variables), which follow (i) natural conditions; (ii) customer-related aspects; (iii) institutional framework; (iv) legacy conditions; and (v) market conditions. Those contextual variables will be better analyzed and contextualized in the Methodology section.

Taken this into account, the performance of ports and terminals has been variously evaluated by numerous attempts at calculating and seeking to optimize the operational productivity of cargo handling at the berth and in the terminal area [25]. In recent years, approaches such as DEA (Data Envelopment Analysis), FDH (Free Disposal Hull), and SFA (Stochastic Frontier Analysis) [24,25] have been increasingly utilized to analyze production and performance of ports and terminals. It must be noted, however, that FDH and SFA are less frequently used than DEA, the technique that presents the largest amount of applications in this sector [66]. Within port operations, the use of DEA is increasing, while the application of FDH remains low [74].

There are many authors who also use DEA approach to analyze production and performance of ports and terminal, such as Bracqier et al. [13], Gutiérrez et al. [42], Markovits-Somogyi [58], Yu and Lin [84], Wang et al. [85]. It is noteworthy that Curi et al. [27,28], Gitto and Mancuso [41], Lozano et al. [56], Martín and Román [60,61], Yoshida and Fujimoto [83], and de la Cruz [31] have also been using DEA approach to measure airport efficiency.

The comprehensive literature review presented in Panayides et al. [68] indicates that the number of port/terminals researched in each study usually ranges from 6 to 104 (mean 28). Although DEA obtains a single, dimensionless, overall index of efficiency, its essential differences to parametric approaches, such as Stochastic Frontier Analysis (SFA), are found in the very nature of the analytical approach [60]. As long as SFA is stochastic and parametric, DEA uses linear programming techniques.

Schuyten and Odekk [74] showed that DEA is the most popular approach, it is more recent in applications across studies and it also produces higher efficiency scores in comparison to the Stochastic Frontier Analysis (SFA). These advantages are indeed stressed by the very first DEA hypothetical study by Roll and Hayuth [71]; who also indicates that DEA studies seem to be more current than the SFA studies. In recent years, however, as far as the Brazilian case is concerned, only a few DEA-based studies have appeared in international peer-reviewed journals. All of them addressed the issues of capacity constraints and the impact of contextual variables on efficiency estimates.

Rios and Maçada [70] point out that, at the time of their paper, no studies had thus far been conducted in Brazil. The authors analyzed the relative efficiency of 20 container terminals located in Mercosur during 2002, 2003, and 2004 by means of an input-oriented BCC model (variable return-to-scale). Results indicate that 60% of the terminals were managerially efficient in this three-year period, probably reflecting the fact that the Brazilian terminals had reached record rates of cargo traffic, including higher-value added products such as automobiles. According to these authors, container traffic increased 23.1% during the period, while almost 17% in Argentina. No further international peer-reviewed studies on the efficiency of Brazilian ports/terminals were conducted from 2006 to 2010.

More recently Wanke et al. [91], analyzed a mix of 25 major Brazilian container/bulk terminals (based on 2008 data). The authors found that the vast majority of Brazilian terminals presented increasing returns to scale, and that bulk terminals appeared to be proportionally smaller than container terminals. Additionally, terminals controlled by the private sector tended (although not statistically significant at 0.05) to be more efficient than those controlled by the government. Statistical tests with efficiency levels were also performed against railroad connectivity and labor force qualification, albeit with inconclusive results, despite previous studies, such as Cullinane and Song [24], Turner et al. [82] and Doctor [34].

On the other hand Barros et al. [8], analyzed the productivity of Brazilian seaports over the period 2004–2010, using a Malmquist index with technological bias. During this period, the authors found that Brazilian seaports, on average, became less productive. There were improvements in efficiency derived from better managerial practices — probably due to private operations. Technological change, however, experienced deterioration.

As regards the use of parametric approaches, such as SFA, studies on Brazilian ports are also scarce [37]. For example Wanke et al. [91], also used SFA to cross-check efficiency scores with DEA results, corroborating earlier studies that found that operational inefficiencies are not purely derived from random noise. More recently, [15] used probabilistic decomposition in conjunction with DEA and the ordinal Copeland method in order to choose the most adequate transshipment port within Mercosur.

2.3. Public-private partnerships and scale efficiency

PPPs are viable legal mechanisms to design, develop, and maintain capital-intensive transportation infrastructure systems [4,32,65], while sharing control and administration mechanisms with private entities. The management of these large-scale transportation systems, such as ports and terminals, typically relies on a number of coordination processes and information technologies of various kinds [72].

PPPs arrangements with private terminal operators may engender a favorable business environment that potentially makes more flexible the tailoring of scale (capacity) to the operation (demand). Such tailoring seems to be the result of alternative patterns of resource allocation among port activities, enabled by the choice of the most adequate mix between coordination processes and information technologies [72,88]. This being true, scale
efficiency measurements would reflect the impacts of this favorable business environment and may also indicate opportunities for downsizing (decreasing returns to scale) or consolidation of operations (increasing returns to scale) in light of different coordination processes and/or information technologies [72, 88]. For example, depending on alternative uses of information technologies and coordination processes—such as queue priorities and/or berth allocation policies—to synchronize ship-berth link in port operations [87], there may be situations in which the terminal experiences decreasing (increasing) returns to scale due to its very large (small) size compared to the queue of incoming ships that have been allocated [72, 87].

According to Núñez-Sánchez and Coto-Millán [63]; which present a table summarizing many port efficiency studies, there are three studies using scale efficiency as a measure of port efficiency: Díaz-Hernández et al. [33], Estache et al. [35] and Cheon et al. [18], which respectively analyze Mexican, Spanish and international ports. Cullinane et al. [25] also use DEA and scale efficiency (SE) to compare technical efficiency of container ports; Herrera and Pang [44] provide a SE analysis of container ports, as well as Liu [55], who add the same analysis to terminals.

Therefore, the major proposition of this research regards the positive relationship between PPPs and scale efficiency levels in port operations. In other words, it is proposed here that the underlying coordination processes and information technologies embedded within PPPs in Brazilian ports may engender a more rational allocation of resources (berths, yards) to demand (ships, containers) and, consequently, lead to an operation closer to the most productive scale size.

3. Methodology

3.1. The data

Secondary data regarding a sample of 27 Brazilian ports were obtained from the statistical database provided by the Brazilian National Agency for Waterway Transportation (ANTAQ) website (http://www.antaq.gov.br), encompassing the year of 2011. This sample of 27 Decision-Making Units (DMUs) is comparable to similar DEA applications, as previously discussed. A Brazilian map is given in Fig. 1 in order to illustrate the geographic location of the ports present in the sample.

Readers should note the presence of five riverine ports in this sample: Macapá, Porto Velho, Santarém, Vila do Conde, and Belém. Most of them are specialized in handling and moving soybeans from producers, located at middle-eastern in land states, to foreign markets or to the closest road/rail way in order to reach the major export terminals, located at the ports Santos and Paranaguá. They also serve as hubs to the transport of goods between cities located in the Amazon basin. According to Alderton [4], one major characteristic that should be considered when distinguishing operating advantages/disadvantages between a seaport and a riverine port is...
whether the later is located: on a tidal estuary on a river delta. In many cases, dredging can be one of the major costs and in estuarian ports; in particular any new structure on the riverbanks or within the water may cause serious situation problems. The Amazon river and basin, however, are very peculiar. The width of the Amazon river ranges between 1.6 and 10 km at low stage but expands during the wet season to 48 km or more. The river enters the Atlantic Ocean in abroad delta (about 240 km wide). The mouth of the main stem is 80 km large. Because of its vast dimensions, it is sometimes called “The River Sea”.

The seven inputs originally surveyed from each port are: quay length (m), maximal quay depth (m), number of berths, warehousing area (sq. m), yard area (sq. m), channel width (m), and channel depth (m). With respect to the outputs, six variables were initially surveyed: solid bulk loading hours (per year), container loading hours (per year), solid bulk throughput (tons/year), container throughput (containers/year), solid bulk frequency (shipments/year), and container frequency (shipments/year). Correlation analyses indicate significant positive relationships between the inputs and the outputs, which are, therefore, isotonic and justified to be included in the model [86]. All these data relate to 2012 and their descriptive statistics are presented in Table 1.

Additionally, contextual variables, which are stressed by Cruz and Marques [23] as important factors in the efficiency measurement analysis, were recorded to explain differences in managerial and scale efficiency estimates. The variables are presented in Table 2 and relate to the presence of PPPs (yes = 1, no = 0); the presence of riverine and railroad access, (yes = 1, no = 0); the port hinterland or the area from which products are delivered to a port for shipping elsewhere (in sq. km); the number of highway accesses; the number of accessing channels; and whether the port handles both container and solid bulk cargoes (yes = 1, no = 0). As can be seen, the external factors presented by the same authors are considered in this analysis, in other words, natural conditions (presence of riverine access, and number of accessing channels), and institutional and legal (presence of PPP), and its frequency. Hinterland and whether the port handles both container and solid bulk or not can be considered as legacy factors. According to Bhaumk et al. [10], such “external factors” are identified like “determinants of entry”, which have impacts on productivity.

As a methodological note with respect to the definition of ports with PPPs, only public ports with concession agreements to private terminal operators established in 1995/1996 are considered to qualify. Conversely, public ports without concession agreements to private terminal operators, as well as Vale’s dedicated iron ore ports (Tubarão, Iataí, and Praia Mole), and other private ports prohibited so far by Brazilian legislation to operate third-party cargoes by using their slack capacity are considered not to meet the PPP criteria. If Vale’s ports were included, their remarkable iron ore throughput would certainly bias the analysis towards the beneficial effects of PPPs on scale efficiency. On the other hand, the inclusion of private ports that are forbidden to handle third-party cargoes would possibly imply a negative bias towards PPPs, since there is unused capacity slack.

It is still important to consider that these contextual variables are exogenous, that is, they affect efficiency levels without being affected by them. Here, these contextual variables represent, therefore, decision variables based on external factors rather than endogenous variables generated within the ambit of an efficiency model or a production process [92]. However, endogeneity may be present in the regression. Endogeneity refers to the fact that an independent variable included in the model is potentially a variable correlated with unobservable variables, which are relegated to the error term. Endogeneity may be due to biased

### Table 1
Summary statistics – inputs and outputs.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Coefficient of variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inputs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quay length (m)</td>
<td>2.017.35</td>
<td>2.830.10</td>
<td>1.40</td>
</tr>
<tr>
<td>Maximal quay depth (m)</td>
<td>13.07</td>
<td>3.94</td>
<td>0.30</td>
</tr>
<tr>
<td>Number of berths</td>
<td>9.04</td>
<td>9.66</td>
<td>1.07</td>
</tr>
<tr>
<td>Warehousing area (sq. m)</td>
<td>43.243.41</td>
<td>103.072.01</td>
<td>2.38</td>
</tr>
<tr>
<td>Yard area (sq. m)</td>
<td>108.730.70</td>
<td>215.822.08</td>
<td>1.98</td>
</tr>
<tr>
<td>Channel width (m)</td>
<td>4.363.78</td>
<td>15.211.76</td>
<td>3.49</td>
</tr>
<tr>
<td>Channel depth (m)</td>
<td>12.30</td>
<td>4.56</td>
<td>0.37</td>
</tr>
<tr>
<td>Outputs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid bulk loading hours (per year)</td>
<td>13.341.71</td>
<td>21.188.07</td>
<td>1.59</td>
</tr>
<tr>
<td>Container loading hours (per year)</td>
<td>8.575.29</td>
<td>13.587.31</td>
<td>2.34</td>
</tr>
<tr>
<td>Solid bulk throughput (tons/year)</td>
<td>7.644.492.20</td>
<td>13.587.31</td>
<td>2.69</td>
</tr>
<tr>
<td>Container throughput (containers/year)</td>
<td>199.329.02</td>
<td>403.540.26</td>
<td>2.09</td>
</tr>
<tr>
<td>Solid bulk frequency (shipments/year)</td>
<td>263.49</td>
<td>434.57</td>
<td>1.65</td>
</tr>
<tr>
<td>Container frequency (per year)</td>
<td>689.05</td>
<td>1.028.28</td>
<td>1.85</td>
</tr>
</tbody>
</table>

### Table 2
Summary statistics – contextual variables.

<table>
<thead>
<tr>
<th>Metric variables</th>
<th>Hinterland (sq. km)</th>
<th>Dummy and ordinal variables</th>
<th>Number of highway accesses</th>
<th>Riverine access? (1 = yes/0 = no)</th>
<th>Railroad access? (1 = yes/0 = no)</th>
<th>Number of accessing channels</th>
<th>Both container and solid bulk (1 = yes/0 = no)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>952.264.61</td>
<td>Mean</td>
<td>0.33</td>
<td>2.15</td>
<td>0.41</td>
<td>66.67</td>
<td>1.19</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>941.249.77</td>
<td>Median</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Coefficient of Variation</td>
<td>0.99</td>
<td>Frequency distribution</td>
<td>0.667%</td>
<td>33.33%</td>
<td>0</td>
<td>33.33%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>
omitted variables, measurement errors and simultaneity/reverse causation [92].

The Durbin–Wu–Hausman test for endogeneity can help determine whether or not there is some biased omitted variables in the regression [29]. Then, the Durbin–Wu–Hausman test were made on contextual variables, and its efficiency scores resulted in the following data: PPP with $F(1, 18) = 0.85893$ and Sig. = 0.36630. Both container and solid bulk with $F(1, 18) = 0.73717$ and Sig. = 0.40186. Number of highway accesses with $F(1, 18) = 0.60549$ and Sig. = 0.44660. Riverine access with $F(1, 18) = 2.70665$ and Sig. = 0.11728. Railroad access with $F(1, 18) = 0.05459$ and Sig. = 0.81790. Number of accessing channels with $F(1, 18) = 0.73596$ and Sig. = 0.40224, and Hinterland with $F(1, 18) = 1.22762$ and Sig. = 0.28246. The test indicates that all contextual must be considered as exogenous.

3.2. Data Envelopment Analysis

DEA is a non-parametric model first introduced by Charnes et al. [17]. It is based on linear programming (LP) and is used to address the problem of calculating relative efficiency for a group of DMUs by using a weighted measure of multiples inputs and outputs [89]. Consider a set of $n$ observations on the DMUs. Each observation, $DMU_j$ ($j = 1, ..., n$) uses $m$ inputs $x_{ij}$ ($i = 1, ..., m$) to produce $s$ outputs $y_{ij}$ ($r = 1, ..., s$). $DMU_n$ represents one of the $n$ DMUs under evaluation, and $x_{io}$ and $y_{ro}$ are the $ith$ input and $rth$ output for $DMU_o$, respectively. Eq. (1) displayed in Table 3 presents the envelopment models for both CRS and VRS frontier types, where $\epsilon$ is a non-Archimedean element and $SE = \frac{ccrb}{\theta_{b}}$ and $a$ account, respectively, for the input and output slack variables [9,96].

As presented in the table, there are two different frontier types. The first one is Constant Returns to Scale (CRS), which is also known as CCR [17]; in fact, this frontier reflects what is called "pure efficiency levels". The other one, Varying Returns to Scale (VRS), is also known as BCC [5] and reflects what is called "managerial efficiency levels". Scale efficiency (SE) measures the impact of scale size on the productivity of a DMU and it is computed using the ratio $\epsilon_{j}$, which ranges from 0 to 1 [79]. When it is precisely 1, the VRS and CRS coincide, so the DMU is operating at optimal scale size [12]. On the other hand, if $0 \leq SE < 1$, this means that there is scale inefficiency, which can be determined by inspecting the sum of weights according to the specifications of the CCR model (constant return-to-scale). If this sum is equal to 1, the law of constant returns to scale prevails, but if the sum is less than or greater than 1, then respectively increasing returns to scale and decreasing returns to scale prevail [64].

Although the orientation of the model is not a consensual aspect of the efficiency models in ports [91], an output maximization orientation is adopted here. Port inputs are strictly seen by some authors as fixed assets, long-term investments, which are difficult to demobilize in the short-term [25]. These are the reasons why decision-makers should focus on maximizing outputs for a given level of production inputs.

3.3. Two-stage DEA models

The approaches to the statistical treatment of the variations in the efficiency estimates produced using DEA – CCR, BCC, or SE – have evolved over the course of the years; see, for example, Banker [6] and Simar and Wilson [75]. As a depiction of this evolution Cooper et al. [21], point to the growing number of studies that combine DEA scores obtained in a first stage with those of multivariate data analysis (such as regression analysis) in a second stage, when the scores are incorporated in the form of the dependent variable (see, for instance [45,46,54,57,68,80]).

Simar and Wilson [75] argue that truncated regression combined with bootstrapping as a re-sampling technique best overcomes the unknown serial correlation complicating the two-stage analysis. More recently Simar and Wilson [76], examined this widespread practice where DEA estimates are regressed on some environmental variables. The authors showed that only two statistical models have been proposed in which second-stage regressions are well-defined and meaningful. In the model considered by Simar and Wilson [75]; truncated regression provides consistent estimation in the second stage, where as in the model proposed by Banker and Natarajan [7]; ordinary least squares (OLS) provides consistent estimation. However, second-stage OLS estimation is consistent only under very peculiar and unusual assumptions on the data-generating process that limit its applicability. Besides, the authors showed that in either case, bootstrap methods provide the only feasible means for inference in the second stage. Therefore, in this research, the Simar and Wilson [75] approach is employed and the following regression specification is assumed and tested:

$$SE_{j} = a + Z_{0} \delta + \epsilon_{j}, \quad j = 1, ..., n,$$

which can be understood as the first-order approximation of the unknown true relationship. In eq. (2), $j$ is the constant term, $SE_{j}$ is statistical noise, and $\delta_{j}$ is a row (vector) of observation-specific variables for DMU $\epsilon_{j} \geq 1 - a - \theta_{j}$ that is expected to be related to the DMU’s scale efficiency score, $SE_{j}$.

Specifically, noting that the distribution of $\delta_{j}$ is restricted by the condition $\epsilon_{j} \geq 1 - \theta_{j}$ (since both sides of (2) are bounded by unit) Simar and Wilson [75], is followed here and it is assumed that this distribution is truncated normal with zero mean (before truncation), unknown variance, and (left) truncation point determined by this very condition.

Furthermore, replacing the true but unobserved regress and in (2), $SE_{j}$ by its DEA estimate, $\hat{SE}_{j}$, the econometric model formally becomes:

$$\hat{SE_{j}} \approx a + Z_{0} \delta + \epsilon_{j}, \quad j = 1, ..., n,$$

where

$$\epsilon_{j} \sim N(0, \sigma_{j}^2), \quad \text{such that } \epsilon_{j} \geq 1 - a - \theta_{j}, \quad j = 1, ..., n,$$

which is estimated by maximizing the correspondent likelihood function, with respect to $(\delta, \sigma_{j}^2)$, given the data collected. Parametric bootstrap for regression can be employed to construct the bootstrap confidence intervals for the estimates of parameters $(\delta, \sigma_{j}^2)$, which incorporates information on the parametric

<table>
<thead>
<tr>
<th>Frontier type</th>
<th>Envelopment Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRS or CCR</td>
<td>$\max \delta - \epsilon = \sum_{i=1}^{m} \frac{x_{i}}{\epsilon x_{io}} + \sum_{r=1}^{s} \frac{y_{r}}{\epsilon y_{ro}}$</td>
</tr>
<tr>
<td></td>
<td>$\text{s.t. } \sum_{i}^{m} \lambda_{ij} = \epsilon x_{io}, \forall i$</td>
</tr>
<tr>
<td></td>
<td>$\sum_{r}^{s} \lambda_{ij} y_{r} = \epsilon y_{ro}, \forall r$</td>
</tr>
<tr>
<td></td>
<td>$\epsilon j \geq 0, \forall j$</td>
</tr>
<tr>
<td>VRS or BCC</td>
<td>Add $\sum_{i=1}^{m} \epsilon j = 1$</td>
</tr>
</tbody>
</table>
structure and distributional assumption. For the sake of brevity, readers should refer to [75] for the details of the estimation algorithm, the respective computations of which were carried out with R codes developed by the authors.

4. Results and discussion

4.1. Variable reduction

Since the combination of the inputs and outputs initially collected does not adhere to the convention where the number of DMUs should be at least three times higher than the total number of inputs and outputs [20], this research followed the methodology developed by Adler and Berechman [1] based on Principal Component Analysis (PCA) to reduce the number of input (output) variables used in DEA into factors. PCA explains the variance structure of a matrix of data through linear combinations of variables, which generally describe 70–90% of the variance in the data. This approach and variations thereof are called PCA-DEA [2, 50, 67].

The extraction of factors from the transformation of the seven input variables was conducted by means of PCA-DEA, with Varimax standardized rotation for data collected from 27 ports with respect to the year of 2011. Results are presented in Table 4 only for eigenvalues greater than 1.

Three main factors represent the port inputs, interpreted next. The inputs quay length, number of berths, warehousing area, and yard area make up factor 1, interpreted as the Port Infrastructure Index. This index denotes the infrastructure intensity level of a given port (e.g. lower values would denote a poorly infrastructured port; higher values, the opposite). In turn, the variables quay depth and channel depth make up factor 2, named Depth Accessibility Index, and its interpretation is straightforward. Finally, the variable channel width makes up factor 3, the input factor Width Accessibility Index. Similarly, taking the same steps with respect to the outputs, the production related variables — loading hours, cargo throughput, and shipment frequency — were reduced into two variables: Container Output and Solid Bulk Output.

4.2. DEA efficiency estimates

Before proceeding with the discussion of the results, it is worth mentioning that an outlier analysis was previously conducted to ensure that the different DMUs consist, as matter of fact, of a homogeneous group. In this research we adopted the approach developed by Wilson [93] to identify the most influential observations (outliers) — within the ambit of DEA analysis — with the support of the statistical software R using the function ap from the FEAR library. It is based on the data cloud method, which is briefly described by Bogetoft & Otto [12]. After evaluating the data under analysis, it was concluded that there were no outlier data to be discarded in the analysis. Even the existence of seaport and riverine port did not lead to this conclusion, as already stated by Alderton [4] in the beginning of Methodology section. The efficiency estimates for each DMU are presented in Table 5, together with the returns-to-scale and the PPP status.

**Table 4**
Factor extraction for variable reduction.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Port Infrastructure Index</th>
<th>Depth Accessibility Index</th>
<th>Width Accessibility Index</th>
<th>KMOs and Bartlett’s test of sphericity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inputs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quay_length</td>
<td>0.91</td>
<td>0.04</td>
<td>0.35</td>
<td>Approx. chi-square: df 163.94, Sig. 0.01</td>
</tr>
<tr>
<td>Quay_depth</td>
<td>0.01</td>
<td>0.90</td>
<td>(0.01)</td>
<td></td>
</tr>
<tr>
<td>Number_berths</td>
<td>0.85</td>
<td>0.04</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Warehousing_area</td>
<td>0.98</td>
<td>(0.05)</td>
<td>(0.08)</td>
<td></td>
</tr>
<tr>
<td>Yard_area</td>
<td>0.93</td>
<td>(0.01)</td>
<td>(0.04)</td>
<td></td>
</tr>
<tr>
<td>Channel_width</td>
<td>0.11</td>
<td>(0.07)</td>
<td>(0.06)</td>
<td></td>
</tr>
<tr>
<td>Percent of Variance Explained by Factor</td>
<td>51.46</td>
<td>23.60</td>
<td>15.35</td>
<td></td>
</tr>
</tbody>
</table>

**Table 5**
Efficiency scores (2012).

<table>
<thead>
<tr>
<th>Port</th>
<th>Efficiency scores</th>
<th>Sum of lambda</th>
<th>Returns-to-scale</th>
<th>PPP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BCC</td>
<td>CCR</td>
<td>SE</td>
<td></td>
</tr>
<tr>
<td>Fortaleza</td>
<td>0.822</td>
<td>0.811</td>
<td>0.986</td>
<td>0.83</td>
</tr>
<tr>
<td>Vila do Conde</td>
<td>0.980</td>
<td>0.958</td>
<td>0.977</td>
<td>1.02</td>
</tr>
<tr>
<td>Vitória</td>
<td>0.897</td>
<td>0.795</td>
<td>0.886</td>
<td>1.03</td>
</tr>
<tr>
<td>Salvador</td>
<td>1.000</td>
<td>0.972</td>
<td>0.972</td>
<td>1.18</td>
</tr>
<tr>
<td>Santarém</td>
<td>0.894</td>
<td>0.860</td>
<td>0.962</td>
<td>1.57</td>
</tr>
<tr>
<td>Aratu</td>
<td>0.921</td>
<td>0.912</td>
<td>0.990</td>
<td>0.94</td>
</tr>
<tr>
<td>Area Branca</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>Constant</td>
</tr>
<tr>
<td>Belem</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>Constant</td>
</tr>
<tr>
<td>Colombo</td>
<td>0.513</td>
<td>0.900</td>
<td>0.985</td>
<td>0.96</td>
</tr>
<tr>
<td>Forno</td>
<td>0.998</td>
<td>0.994</td>
<td>0.996</td>
<td>0.98</td>
</tr>
<tr>
<td>Ilhêus</td>
<td>0.857</td>
<td>0.843</td>
<td>0.983</td>
<td>0.9</td>
</tr>
<tr>
<td>Itajaí</td>
<td>0.873</td>
<td>0.823</td>
<td>0.949</td>
<td>0.98</td>
</tr>
<tr>
<td>Macapá</td>
<td>0.975</td>
<td>0.969</td>
<td>0.994</td>
<td>0.99</td>
</tr>
<tr>
<td>Maceió</td>
<td>0.914</td>
<td>0.902</td>
<td>0.987</td>
<td>0.89</td>
</tr>
<tr>
<td>Pelotas</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>Constant</td>
</tr>
<tr>
<td>Porto Alegre</td>
<td>0.717</td>
<td>0.585</td>
<td>0.816</td>
<td>1.01</td>
</tr>
<tr>
<td>Porto Velho</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>Constant</td>
</tr>
<tr>
<td>Praia Mole</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>Constant</td>
</tr>
<tr>
<td>Recife</td>
<td>0.727</td>
<td>0.652</td>
<td>0.898</td>
<td>0.86</td>
</tr>
<tr>
<td>Suape</td>
<td>1.000</td>
<td>0.952</td>
<td>0.952</td>
<td>1.26</td>
</tr>
<tr>
<td>Tubarão</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>Constant</td>
</tr>
</tbody>
</table>
As one would expect, the CCR model yields lower average efficiency estimates than the BCC model, with respective average values of 0.917 and 0.942. Also, the CCR model identifies more inefficient ports (18 vs. 15) than does the BCC model. This result is not surprising, as the CCR model fits a linear production technology whereas the BCC model features variable returns to scale, which are more flexible and reflect managerial efficiency apart from purely technical limits.

4.3. Two-stage bootstrapped regression

R software — package ‘censReg’ [43] — was used to carry out the previously discussed bootstrapped truncated regression on this dataset, testing for significant differences in scale efficiency given a set of context-related variables and controlling for different levels of inputs and outputs. The results presented in Table 6 confirm the positive impact of PPPs on scale efficiency levels. In other words, the establishment of contractual arrangements with private terminal operators can produce a substantial increment in scale efficiency levels, thus corroborating the major proposition of this paper. In summary, according to Table 6, after performing the second-stage model, it is possible to affirm that the group of factors that are affecting performance the most are legacy (PPP) and natural conditions such as riverine access.

Besides PPPs, variables related to connectivity infrastructure also deserve attention. The existence of railroad and riverine accesses present a significant and positive impact on Brazilian ports, allowing them to move towards the most productive scale size operation. These connectivity infrastructure variables may act as scaling drivers, enabling a better fit between port inputs (available infrastructure) and outputs (demands).

An in-depth discussion based on the results presented in Tables 5 and 6 follows. Ports that have not yet established PPPs with private terminal operators form a group of less-infrastructured DMUs (see Table 5), with constraints related to capacity, as suggested by the large percentage of increasing returns-to-scale cases (72% within this group) and lower levels of infrastructure indexes. Their share of the total container/solid bulk throughput volume in Brazilian terminals is marginal, as well as their potential for accommodating future demand growth in the short term via productivity gains — both of which facts are reflected in the current data. The eighteen ports within this group — including Area Branca, Belém, Pelotas, Praia Mole, Forno, Porto Velho, Porto Alegre, and Recife — represent roughly 13% (3%) of the Brazilian solid bulk (container) throughput — except for iron ore. This group is also geared towards solid bulk operations. Within this group, where throughput is low, PPPs could only be feasible if the Brazilian government assured first the required investments to improve accessibility infrastructure. That is, these ports should reach a minimum scale first so that PPPs can be considered as an economic feasible governance instrument. Then, on a second phase, capacity constraints could be attacked by the private terminal operators.

On the other hand, ports that have already-established PPPs with private terminal operators form a group of relatively more-infrastructured DMUs with somewhat weaker capacity constraints, as suggested by the substantial percentage of decreasing returns-to-scale cases (56% within this group) and the higher levels of infrastructure indexes. This is the case of two major ports within this cluster: Paranaguá and Suape. Altogether, they account for approximately 18% (22%) of the Brazilian yearly container (solid bulk, except for iron ore) throughput. Remarkably, however, Santos and Rio Grande, the two largest Brazilian container ports — accounting for almost 65% of the country’s yearly aggregate throughput — are increasing returns-to-scale DMUs. Anecdotal evidence suggests that these two ports are severely compromised in terms of meeting future demand growth unless urgent measures for long-term infrastructure expansion are put on track. Also noteworthy is the fact that Santos and Rio Grande also account for more than 45% of Brazilian solid bulk throughput (except for Brazilian iron ore exports, which are predominantly handled by Vale ports Tubarão and Iquai). Within this group, however, the role of the hinterland area and port throughput in Brazil should be further analyzed, so that more aggressive PPP arrangements could be made in order to stimulate a greater share of private investment in these more competitive ports.

Therefore, action priorities and their course over time should be put in perspective depending on group of ports. With respect to connectivity infrastructure variables, such as railroads and riverine access, physical expansion priorities and improvement of accessibility should be given to increasing returns-to-scale ports currently under PPPs (Santos and Rio Grande, for instance) in order to increase their scale efficiency levels. On the other hand, ports without PPPs could benefit from these arrangements with private terminal operators in order to achieve a better fit between infrastructure resources and current demand levels, again, with the objective of increasing scale efficiency levels. The crucial point is that alternative ways for moving different groups of ports towards the most productive scale size should be considered, given the current port regulatory system in Brazil: (i) physical expansion and accessibility improvement within the ambit of federal government; and (ii) procurement of private terminal operators to manage the cargo flows, within the ambit of PPPs.

5. Conclusions

This study has evaluated the efficiency levels of major selected ports in Brazil in relation to PPPs. The findings presented here corroborate the major research proposition with respect to the role of PPPs in engendering a more flexible operational environment...
where resources meet demands. It was shown that port scale efficiency is higher when there are PPP arrangements with private terminal operators. Due to methodological issues explained before, only public ports with concession agreements to private terminal operators established during the mid-90’s were considered to qualify as PPPs according to the criterion used in this research.

This paper also contributes to the port regulatory agenda in terms of potential empirical application. Brazilian port authorities can benefit not only the current debate on port sector regulation; they can also exploit currently available information regarding the impact of other contextual variables — such as the connectivity of other transportation modes — on scale efficiency levels. More precisely, the findings can help decision-makers with respect to funding port improvement projects, including establishing a list of priorities within each subgroup of ports, that is, those with or without PPPs.

Future research should continue to assess better ways to use the limited resources of Brazilian ports as long as robust investments in physical infrastructure expansion fail to materialize. Differently from several Asian countries, Brazil, since early 1990’s, has seen relatively little investment in new ports, not only because of federal budget constraints, but also because additional capacity could be gained by improving the existing ports via PPP with private terminal operators under the landlord port structure. Now, with the successful implantation of several PPPs under this structure, the time has come to expand the PPP experience to alternative models, allowing a more intense participation of the private sector. This is critical to fostering a more effective expansion of capacity, given that further modernization of existing terminals alone does not appear able to address future growth estimates based on empirical evidence.

References

[18] Chou Jui-Sheng, Tserng Ping H, Lin Chieh, Yeh Chun-Pin. Critical factors and risk allocation for PPP policy: comparison between HSR and general infra-
versidade de São Paulo; 2008.
[31] Grimes P, Lewis M. Are private port partnerships valuable? Evalu-
[34] Henningsen A. Estimating censored regression models in R using the censReg package. 2012. Available at: http://cran.r-project.org/web/packages/censReg/


[65] Pallis AA, Notteboom TE, Langen PW. Airport Benchmarking; 2009.

[66] Peter F. Wanke. Associate Professor of Logistics at The COPPEAD Graduate School of Business at The Federal University of Rio de Janeiro and researcher at the Centre for Logistics Studies. He received his Ph.D. and M.Sc. in Industrial Engineering from the COPPE Graduate School in Engineering at the same university. He conducted part of his doctoral research at The Ohio State University. His research interests are in logistics strategy, supply chain management, inventory management, and network planning. He has published at the International Journal of Physical Distribution and Logistics Management, International Journal of Operations and Production Management, International Journal of Production Economics, Transport Reviews, International Journal of Production Economics, Transport Reviews and the Internationa


