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# Technological drivers of dry port efficiency in Brazil

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## Abstract

**Purpose** – This paper aims to identify the scale efficiency of dry ports in Brazil and its main technological drivers.
**Design/methodology/approach** – This paper uses the Data Envelopment Analysis (DEA) model in two stages. The first stage of the DEA was used to measure the efficiency of the dry ports. In the second stage, the Bootstrap Truncated Regression (BTR) was applied to explore the relationship between efficiency and the factors analyzed. The inputs, outputs and contextual variables for this analysis were extracted from the secondary database provided by Revista Tecnologística.
**Findings** – In the first analysis stage, a high level of idleness was verified in the operations. The contextual variables in the second stage were significant: Certification, Warehouse Management System (WMS), barcode and Radio Frequency Identification (RFID). Results corroborate the positive impact of Information Technology (IT) coordination processes on logistics performance.
**Practical implications** – Results show that dry ports operate below their technical and operational capacity and that the sector's lack of regulation in Brazil can facilitate and encourage the use of ports and marine terminals by importers and exporters.
**Originality/value** – Application of two-stage DEA measures efficiency as a sectoral benchmarking tool.

**Keywords** Dry port, Brazil, DEA, Efficiency, Bootstrap truncated regression
**Paper type** Research paper

## 1. Introduction

Intensified competition has placed increased responsibilities on infrastructures, which systemically impact companies and their supply networks, requiring continuous improvements in transportation and customs systems (Khaslavskaya & Roso, 2020; Miraj, Berawi, Zagloel, Sari, & Saroji, 2020). In the case of international trade, specifically, customs agility and decreasing bureaucracy play a decisive role in stimulating trade between countries, especially emerging economies – such as Brazil, Russia, China, India and South Africa (Abdoulkarim, Fatouma, & Hassane, 2019; Chang, Yang, Wan, & Han, 2019; Korovyakovsky & Panova, 2011; Li, Dong & Sun, 2015; Ng, Padilha, & Pallis, 2013).

In this context, dry ports play a strategic role by promoting better product distribution performance and using available transportation modes (Jeevan, Chen, & Cahoon, 2017;



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Khaslavskaya & Roso, 2020). In Brazil, additionally, the management of dry ports is directly influenced by regulatory instruments and competition with seaports in the provision of services (Moshtari, 2016; Ng *et al.*, 2013; Padilha & Ng, 2012). Furthermore, with the increasing globalization of business activities and the continuous flow of goods in supply chains, all port activities are driven to efficiently perform (Yang, Taudes, & Dong, 2015). Thus, efficiency has decisive participation in the performance of business operations (Chang *et al.*, 2019; Khaslavskaya & Roso, 2020).

One technique to measure efficiency is the Data Envelopment Analysis – DEA (Cooper, Seiford, & Zhu, 2011), which measures unit efficiency, groups units into clusters with similar interests, and designates the top-performing units to identify the efficiency and productivity improvement path. Its main feature is the ability to simultaneously process multiple inputs and outputs, assisting managers in decision-making. The nonparametric model has been widely applied in dry ports efficiency research (Abdoulkarim *et al.*, 2019; Haralambides & Gujar, 2012; Markovits-Somogyi, Gecse, & Bokor, 2011; Yang *et al.*, 2015).

Thus, this study seeks to contribute by extending previous studies on dry ports' competitive situation, strengths and weaknesses (Chang *et al.*, 2019; Khaslavskaya & Roso, 2020), with methodological refinements. Furthermore, the study aims to identify dry ports' technological drivers of scale efficiency (SE). Therefore, after calculating efficiency with DEA technique, Bootstrap Truncated Regression (BTR) was applied to measure contextual variables' impact on the industry's SE.

This paper contributes to the advancement of the field of study in four ways: first, the study demonstrates that coordination processes and Information Technologies (ITs) in Brazilian dry ports can promote a more rational allocation of resources and, consequently, lead to an operation closer to the most productive scale. Second, the study empirically demonstrates that most dry ports operate below their technical and operational capacity, in line with ABEPRA (2015) and Padilha and Ng (2012). Third, it also contributes to reducing the scarcity of dry port efficiency studies by the two-stage approach, called out by Chang *et al.* (2019). Finally, it is possible to use the methodology as a benchmarking tool for developing best practices in the industry.

The remainder of the paper is divided into six sections. Section 2 discusses dry ports in the Brazilian context, ITs that can be adopted and previous studies that have applied DEA to the dry port sector in other countries. In section 3, two-stage DEA modeling is presented in more detail. In section 4, the data are analyzed and the results are discussed. Finally, section 5 presents conclusions, managerial implications and future research recommendations.

## 2. Literature review

### *2.1 Dry ports and the Brazilian context*

Dry ports play a significant role in importing and distributing commodities and import-export trade. However, in Brazil, dry ports focus more on the product movement for international trade (Ng & Liu, 2014; Ng *et al.*, 2013). The dry port emerged as a terminal for the hinterland and changed over time due to the growth of container use, the expansion of terminals, and the diversification of port functions (Khaslavskaya & Roso, 2020; Miraj *et al.*, 2020).

To meet the criteria of a dry port, a terminal facility must satisfy three parameters (Khaslavskaya & Roso, 2020; Miraj *et al.*, 2020): 1) be an extension of a seaport on land; 2) be an inland extension of a seaport and 3) have a connection to a seaport via "large-capacity transport," which often implies rail transport. However, the last item is not typical for many dry ports worldwide, such as Brazil (Ng & Tongzon, 2010) and China (Chang *et al.*, 2019).

Dry port definitions are still relatively vague, and various terminologies appear in the literature (Khaslavskaya & Roso, 2020; Miraj *et al.*, 2020). Thus, there is still no definitive consensus on which term or definition to use for facilities of this nature (Rodrigue, Debrie, Fremont, & Gouvernal, 2010). For example, a freight village was first introduced in the 1990s as an integrated logistics center without a close relationship to port or container terminals (Yang *et al.*, 2015). In the 2000s, researchers widely used the terminology of ports or land transport terminals for further study (Miraj *et al.*, 2020; Rodrigue & Notteboom, 2009). Other definitions can be found in Witte, Wiegmans, and Ng (2019). Rodrigue *et al.* (2010) developed the term “inland port”, which is widely used in the United States. However, the international literature has adopted the term “dry port” as an inland port that connects goods on the mainland to coastal areas (Miraj *et al.*, 2020).

In Brazil, dry ports were introduced in the 1970s by Decree-Law 1,455, which authorized the implementation of customs clearance in secondary areas. The National Privatization Program created by Law 8,031/90 allowed privatization. Since then, dry ports have faced two challenges: (1) competition with ports and (2) lack of a transparent institutional system to regulate the sector (Ng & Liu, 2014; Santos, 2019). Regarding the first challenge, the legislation for port reform represented an institutional change in port competition due to new rules to regulate seaports. The Port Modernization Law 8,630 affected the development of dry ports after 1993 since seaport (and terminal) operators began to compete for business (Santos, 2019). In order to remain competitive, dry ports needed to be more efficient and provide more sophisticated services and were forced to diversify their activities and offer higher value-added services to shippers (Ng & Liu, 2014; Ng *et al.*, 2013). Unfortunately, many dry ports have not been able to face these challenges and have even closed down their activities, such as the dry port of Piracicaba, in São Paulo (Padilha & Ng, 2012).

Regarding the second challenge, dry ports also face considerable uncertainties due to the absence of an adequate legal framework. Until 1995, dry ports were established through a simple authorization process by the Federal Revenue Service. The term dry port was only adopted in 2002 by Decree 4,543, art. 724. In the same year, the use of dry ports for industrial operations was introduced by Normative Instruction 241/02, which waived some taxes for products assembled or produced in dry ports for export. Three attempts to change the current dry ports paradigm have occurred, namely: Provisional Measure (PM) 320/2006 (rejected), Senate Bill 327/2006 (shelved) and PM 612/2013 (validity ended) (Ng *et al.*, 2013). PM 320 was introduced in 2006 to resolve legal disputes involving dry port operators. The purpose was to end the public bidding requirement and allow dry ports to operate through licenses issued by the Federal Revenue Service. This measure also expanded the scope of dry ports – called the Logistics and Industrial Customs Center (CLIA, in the Portuguese acronym) (Santos, 2019). However, this new measure was considered unconstitutional and rejected by the Brazilian Senate (Santos, 2016). The Draft Bill 327/2006, a substitute for PM 320, lost strength during its run through the Senate, maintaining the requirement for bidding to operate dry ports. After Draft Bill 327/2006 was shelved, PM 612/2013 came into force. During its validity, only requests for dry port conversions into CLIAs were approved. Requests for the installation of new centers were not analyzed. With the expiration of PM 612/2013, request evaluations were suspended, pending legal analysis of the effects resulting from its ineffectiveness.

### *2.2 Dry port efficiency studies*

Research on dry ports conducted using the DEA technique is at its early stage, as shown in Table 1. For review, systematic procedures were followed to ensure the quality of the base used in this study (Thomé, Scavarda, & Scavarda, 2016). Articles published on dry port efficiency (from 2000 to 2020) in the three major indexed journal catalogs – Web of Science, Scopus and Dimensions (Singh, Singh, Karmakar, Leta, & Mayr, 2021) - were selected. After removing duplicate articles, 169 unique documents were in the queried databases. We have identified five articles published in journals with DEA evaluation models in dry ports.

| Papers | Study purpose | DMU | Method | Country | Inputs | Outputs |
|---|---|---|---|---|---|---|
| Chang *et al.* (2019) | Investigate the relationship of Chinese dry port factors – such as customs clearance, rail connection, ownership structure, competition – and the efficiency of dry ports | 43 | DEA (CRS and VRS) and Tobit | China | Total area, current assets and fixed assets | General services, container management, transportation services, and freight services |
| Abdoulkari *et al.* (2019) | Evaluate competitiveness through efficiency analysis for selected dry ports in Africa | 5 | DEA (VRS) | Four countries in Africa | Total area, number of reach stackers | Container transfer rate |
| Yang *et al.* (2015) | Measuring the efficiency of European Freight Villages | 20 | DEA (CRS, VRS and SE) | Nine different countries in Europe | Total area, intermodal area, and storage area | Number of jobs, annual load handled, and number of companies installed |
| Haralambides and Gujar (2012) | Dealing with desirable and undesirable outcomes, adjusting efficiency scores and the number of efficient DMUs | 16 | DEA (VRS) | India | Number of equipment, number of employees, and total area | TKU (tons per kilometer) and CO2 emission |
| Markovits-Somogyi *et al.* (2011) | Investigate how DEA can be used for efficiency evaluation of logistics centers | 12 | DEA (CRS, VRS and SE) | Hungary | Total office area, number of employees and surface of available storage space | Total Sales Revenue and TKU |

**Table 1.** Papers from the systematic literature review

The limited number of studies that use DEA in dry ports present a lack of standard models and variables; thus, we understand that there is no single set of efficiency measurements for this type of operation. Furthermore, only one study applied the DEA methodology and identified contextual variables that significantly impact efficiency. Therefore, we propose to analyze Brazilian dry port operators using a two-stage DEA model. Although it introduces DEA as a possible technique for measuring efficiency in dry ports, this line of research is still embryonic.

### *2.3 Information technologies (ITs) and competitiveness of dry port operations*

ITs are essential tools for improving the performance of supply chain management in terms of coordination, control and flow visibility in logistic networks (Khaslavskaya & Roso, 2020; Mirzabeiki, Roso, & Sjöholm, 2016). Transportation and warehousing management information systems are key technologies used to manage the physical flow of goods along the supply chain (Jeevan *et al.*, 2017). Integrated information systems, encompassing transportation management, warehouse management and global inventory visibility via internet, can potentially lead to reduced costs and improved customer service. They promote a better match between resources and demands, with reduced shipping and receiving cycle times, increased shipment accuracy and reduced variability in response times (Jeevan *et al.*, 2017; Wanke, 2012).

Various technologies and tools have been applied to improve the efficiency of ports and terminals by decreasing error rates and increasing loading speed (Jeevan *et al.*, 2017; Miraj *et al.*, 2020; Mirzabeiki *et al.*, 2016). For example, monitoring and identifying the location or condition of transported goods is a core function of logistics operations that ITs support (Giannopoulos, 2004). Information about the location of goods, including products, packages, loading units and vehicles, and the physical condition of these objects during transportation (for particular product types) in different logistic processes, such as transportation or warehousing, are valuable tools enabling better control of the logistical flow (Ross & Droge, 2004).

The use of automatic identification technology, such as Radio Frequency Identification (RFID) and barcode identification, can provide company information systems with the unique identity of each transported good in the supply chain (Miraj *et al.*, 2020; Mirzabeiki *et al.*, 2016), helping to improve operational performance. In addition, RFID has proven crucial in enabling logistics operators to benefit from the technology, resulting in fast, timely and secure port operations (Mirzabeiki *et al.*, 2016).

Nevertheless, the market also values the adoption of certifications, such as those developed by the International Organization for Standardization (ISO). By structuring and implementing standardized procedures, the certification tends to be associated with better service levels. Lo, Yeung, and Cheng (2009) have empirically shown that ISO 9000 improves the performance of logistics operations, delivering results soon after adoption. The performance lies in improved material flows, financial flows and operational performance in manufacturing supply chains (Prajogo, Huo, & Han, 2012).

This study aims to determine the main factors that affect SE in Brazilian dry ports. SE is used to determine each sample dry port's proximity to the most productive scale and to what extent such distance is a consequence of coordination processes in the supply chain: management of information flows, inventory synchronization mechanisms and resource scaling. In large-scale distribution systems, different coordination processes often lead to different resource allocation patterns among activities, potentially adjusting the scale to make the operation more flexible (Rodrigues, Martins, Wanke, & Siegler, 2018; Ross & Droge, 2004; Wanke, 2012). In this case, SE results may indicate downsizing opportunities (diminishing returns to scale) or consolidation of operations (increasing returns to scale). For example, depending on the alternative uses of ITs and mechanisms to synchronize and move inventory in dry ports, there may be situations where the warehouse experiences diminishing (or increasing) returns to scale due to its large (or small) size compared to inventory levels, cargo movement and allocated orders (Ross & Droge, 2004).

## 3. Methodology

In this study, we use the DEA method, which we present in this section in two topics. The first topic presents the classical DEA models: constant returns to scale (CRS) and variable returns to scale (VRS). In addition, the methodology for evaluating SE is presented. The second topic shows the procedures used in the BTR for evaluating the impact of second-stage contextual variables. Finally, variables and sources used in the models are presented.

### *3.1 DEA models*

Introduced by Charnes, Cooper, and Rhodes (1978), the DEA CCR model is a classical model whose set of production possibilities is based on the assumption of CRS, where growth of the input will produce proportional growth of the output. The coefficient is non-negative. The DEA CCR efficiency measurement is known as overall technical efficiency.

$$\begin{aligned} & min_{\theta\lambda}\,\theta \\ & s.t.\theta x_s - X\lambda \geq 0 \\ & Y\lambda \geq y_s \\ & \lambda \geq 0 \end{aligned} \tag{1}$$

Banker, Charnes, and Cooper (1984) refined the DEA CCR model for the assumption of VRS (increasing or decreasing), referring to this new model as DEA BCC, i.e. the DEA model under conditions of VRS. Specifically, a constraint was added to the DEA CCR model in which only convex linear combinations of the production possibilities are on the efficiency frontier, forming a convex envelope that encompasses all the data. The input-driven linear programming model is presented below:

$$\begin{aligned} & min_{\theta\lambda}\,\theta \\ & s.t.\theta x_s - X\lambda \geq 0 \\ & Y\lambda \geq y_s \\ & \lambda \geq 0 \\ & e\lambda = 1 \end{aligned} \tag{2}$$

The efficiency frontier in the DEA BCC reflects the so-called pure technical efficiency, which indicates the ability to implement the best management practices (Cooper *et al.*, 2011). Therefore, the inefficiency measured in the model can be translated as an indicator of managerial inefficiency (Bogetoft & Otto, 2011), that is, the organization's inefficiency in managing its inputs and outputs.

The SE of a DMU (decision-making unit) is given by the ratio between the efficiency scores of the DEA CCR and DEA BCC models, $SE = \frac{\theta_{CCR}}{\theta_{BCC}}$, ranging between 0 and 1. SE measures the impact of scale size on the DMU's productivity or the ability to generate more input for each input (Bogetoft & Otto, 2011; Cooper, Seiford, & Tone, 2007). When the SE ratio equals 1, the efficiency scores of DEA CCR and DEA BCC models coincide (return to scale (RTS) is constant), and the DMU operates at the optimal scale (Bogetoft & Otto, 2011). If $SE < 1$, the scale of operations is inefficient. Scale inefficiency is given by the expression $\left[\frac{(1-SE)}{100}\right]$. The efficiency measured by DEA CCR model (overall technical efficiency) is divided into efficiency measured by the DEA BCC model (pure technical efficiency) and SE (Cooper *et al.*, 2011).

The RTS can be determined by summing the resulting weights from the DEA CCR model for each DMU. If the sum is 1, the returns to scale will be constant; this is called most productive scale size (MPSS). If this sum is less than 1, the RTS will increase – Increase Return to Scale (IRS), and the SE is classified as suboptimal. Conversely, if the sum is greater than 1, the RTS will decrease – Decrease Return to Scale (DRS) and the SE is rated above optimal (Bogetoft & Otto, 2011).

Our paper seeks to determine how close each of the dry ports analyzed is to its corresponding MPSS and how much this is reflected in their supply chain coordination processes: information flow management, inventory control and resource sizing (Ross & Droge, 2004; Wanke, 2012). According to Ross and Droge (2004), in large-scale distribution systems (such as dry ports), distinct coordination processes lead to different patterns of resource allocation. Consequently, they can make scale adaptation to the operation more flexible.

### 3.2 Bootstrap Truncated Regression

The model proposed by Simar and Wilson (2007), BTR, provides a consistent estimate of efficiency scores based on a confidence interval. The results of this regression are called the second stage of DEA model evaluation. The parametric regression proposed by Simar and Wilson (2007) tests the significance of exogenous contextual variables on the efficiency scores assigned by DEA models, using a specific confidence interval. First, the technique simulates a new sample distribution using the DEA model scores through the data generation process. Next, a new data set is created, and the scores are estimated again using it. By repeating the process several times, the technique provides a good approximation of the accurate sample distribution.

For Simar and Wilson (2000), the two-step procedure of alternative approaches fails to account for the underlying data generation process, casting statistical doubt on the significance of the estimates produced to explain technical efficiency. Simar and Wilson (2000) argue that such a flaw is responsible for seriously correlated efficiency scores. They explain that traditional DEA methods produce efficiency estimates that positively distort the level of efficiency within a data sample. When employing the DEA approach in conjunction with statistical resampling, one can reproduce estimates corrected for technical efficiency bias. Simar and Wilson (2011) used the following regression:

$$SE_j = a + z_j\delta + \varepsilon_j, j = 1, \ldots, n \tag{3}$$

In (3), $SE_j$ is the statistical error; $\varepsilon_j$ is the vector of the observation of DMU variables. The distribution of $\varepsilon_j$ is restricted by the condition $\varepsilon_j \geq 1 - a - z_j\delta$ (the two sides of equation (3) are bounded by the value one, $SE \leq 1$. For Simar and Wilson (2011), the distribution of $\varepsilon_j$ is normal, truncated, with a zero mean, unknown variance and truncated with truncation determined by the initial condition. It is expected that $\varepsilon_j$ is related to the SE of the DMUs, $SE_j$. Relocating, in (3), $SE_j$ by the classical DEA model estimates, $SE_j$, the econometric model is:

$$SE_j \approx a + z_j\delta + \varepsilon_j, j = 1, \ldots, n \tag{4}$$

where

$$\varepsilon_j \sim N\left(0, \sigma_\varepsilon^2\right), whereby\, \varepsilon_j \geq 1 - a - z_j\delta, j = 1, \ldots, n \tag{5}$$

which is estimated by maximizing the corresponding likelihood function $(\delta, \sigma^2)$, considering the collected data. Parametric regression BTR is used to construct a confidence interval for the parametric estimates $(\delta, \sigma_\varepsilon^2)$ that incorporates the assumed distribution and information about the parametric structure.

### 3.3 Input, output and contextual variables

Inputs, outputs, and contextual variables used in this study were collected from the special issue of Revista Tecnologística dedicated to the dry port sector in 2015. The secondary data used are the latest published by the source, which is rare in this area of study. Dry ports are logistics infrastructure; this segment's evolution is slow due to the need for high investments and government authorizations. Thus, the 2015 data should mirror the current structure well since there was no significant impetus for the sector's advancement due to the Brazilian economic crisis and the Covid-19 pandemic.

The data collected from Revista Tecnologística are objective measures based on explicit criteria, represented by metrics (inputs and outputs) and nominal scales (most contextual variables, except for age). As single-item indicators of the objective measures, the data can be valid and reliable indicators of the variables under consideration. Although the dataset provided by Revista Tecnologística may not have been collected in the context of a theoretical model, such a model can still be identified and applied.

After purification of the original database, rejecting dry ports that did not present all the variables used in this study, a final sample of 20 dry ports was obtained. Three inputs and one typical output to all the research members were selected for DEA modeling. Based on the literature, chosen measures were those which translated critical resources for achieving dry port operations. Concerning inputs, the following were used: total employees, total storage area and equipment. In addition, the total number of employees involved in strategic and operational activities was employed to translate workforce utilization (Haralambides & Gujar, 2012; Markovits-Somogyi *et al.*, 2011).

In turn, the warehouse infrastructure is where operators perform most of their business (Chang *et al.*, 2019; Yang *et al.*, 2015). Therefore, selecting a measure that translates how dry ports handle warehousing is necessary. In this regard, the total storage area was chosen as an input for the model (Abdoulkarim *et al.*, 2019; Chang *et al.*, 2019; Haralambides & Gujar, 2012; Markovits-Somogyi *et al.*, 2011; Yang *et al.*, 2015).

Another input included was the number of equipment (Abdoulkarim *et al.*, 2019; Haralambides & Gujar, 2012), as forklifts and pallet trucks are necessary for dry port operations (Jeevan *et al.*, 2017). The use of sophisticated equipment can provide essential conditions for effective operations. Regarding outputs, one variable was initially researched: the number of customers. A high number of customers may suggest greater skill in managing different logistics requirements of dry port operators.

Finally, for the second analysis stage, the following contextual variables were selected: certification, warehouse management system (WMS), bar code, RFID and internet consultations. These variables were used as regressors to identify the determinants of SE of the national dry ports.

## 4. Analysis and discussion of the results

This section analyzes and discusses the results of the classical DEA model and the SE of DMUs. In addition, based on the BTR regression, the effects of contextual variables on efficiency scores are also discussed.

### *4.1 Efficiency models analysis*

The efficiency scores of the DMUs analyzed by the classical DEA CCR and DEA BCC models and efficiencies of scale (SE) are in Table 2. As expected, the CCR models return a smaller number of efficient DMUs than that presented by the BCC model. This result is not surprising since the CCR model assumes that production technology has CRS. In contrast, the BCC model suggests VRS, which are more adherent to reality as they reflect the pure technical efficiency of different DMUs. One notices that many dry ports operate below their optimal capacity; that is, they have increasing returns to scale.

The descriptive statistics of the CCR models show considerable asymmetry of the dry port operators, indicated by the gap between the minimum (0.040) and maximum efficiency (1.000). In addition, the overall average technical efficiency is low (0.37) for the group of DMUs analyzed. The results suggest an overall inefficiency of 63% for the system, indicating that dry ports should be incentivized to increase the number of customers to operate at the efficiency frontier.

In the DEA BCC model with varying returns to scale, the average efficiency found (0.61) reflects an average management inefficiency of 39% for production management, based on the inputs used. The management efficiency is higher than the average SE in dry port operations (42%). The results suggest that, on average, scale inefficiency is more critical than

Table 2.
Efficiency scores for CCR, BBC and scale efficiency (SE)

| DMU | CCR | BBC | SE | RTS |
|---|---|---|---|---|
| 1 | 0.1943 | 0.3600 | 0.5397 | Increasing |
| 2 | 0.1442 | 1.0000 | 0.1442 | Increasing |
| 3 | 0.2625 | 1.0000 | 0.2625 | Increasing |
| 4 | 0.0367 | 0.2115 | 0.1736 | Increasing |
| 5 | 0.3362 | 0.5086 | 0.6611 | Increasing |
| 6 | 0.4530 | 0.4742 | 0.9553 | Increasing |
| 7 | 0.2464 | 0.4344 | 0.5672 | Increasing |
| 8 | 1.0000 | 1.0000 | 1.0000 | Constant |
| 9 | 0.3193 | 0.4467 | 0.7148 | Increasing |
| 10 | 1.0000 | 1.0000 | 1.0000 | Constant |
| 11 | 0.1040 | 0.8376 | 0.1241 | Increasing |
| 12 | 0.5319 | 0.7571 | 0.7026 | Increasing |
| 13 | 0.4725 | 0.6493 | 0.7277 | Increasing |
| 14 | 0.2934 | 0.6101 | 0.4809 | Increasing |
| 15 | 1.0000 | 1.0000 | 1.0000 | Constant |
| 16 | 0.2654 | 0.3369 | 0.7878 | Increasing |
| 17 | 0.1639 | 0.5279 | 0.3106 | Increasing |
| 18 | 0.0457 | 0.3730 | 0.1224 | Increasing |
| 19 | 0.5001 | 0.5147 | 0.9715 | Increasing |
| 20 | 0.0938 | 0.2375 | 0.3951 | Increasing |

DMU management inefficiency when trying to explain the average overall technical inefficiency found in the DEA CCR model.

The efficiency scores in this study show a similar pattern to the findings in the literature (Abdoulkarim *et al.*, 2019; Chang *et al.*, 2019; Markovits-Somogyi *et al.*, 2011). Chang *et al.* (2019) point out that less than 50% of Chinese dry ports are efficient in both models (CCR and BCC). Most dry ports are not efficient in studies by Abdoulkarim *et al.* (2019), and Markovits-Somogyi *et al.* (2011). The inefficiency in these models can be attributed to inefficient operation (e.g. small technical efficiency scores), disadvantageous exogenous conditions (corresponding to SE), or both (Yang *et al.*, 2015). Furthermore, the results match the high levels of sectoral idleness of dry ports in Brazil (ABEPRA, 2015). In addition to the factors cited above, the result may indicate a low demand for these operators by importers and exporters due to competition with Brazilian ports and marine terminals (Ng & Liu, 2014; Ng & Tongzon, 2010).

The availability of freight services from the production zone to the seaports via dry ports is an essential support for dry port operations (Jeevan *et al.*, 2017). In Brazil, the low cargo flows to Port of Santos via São Paulo Dry Port result in cargo fragmentation and decreased operational efficiency compared to other dry ports (Padilha & Ng, 2012). While the collaboration between seaports and dry ports is vital for the efficient operation of the two transport nodes within a cargo system (Jeevan *et al.*, 2017), in reality, there is competition between ports and dry ports, limiting the performance of the latter. Ng *et al.* (2013) indicate that dry ports in Brazil face high competition from seaports because the seaport is interested in dominating the inland market.

Diseconomies of scale suggest a lack of incentives for cooperation between seaports and dry ports (Ng & Liu, 2014). This competitive relationship creates a fragmented supply chain, with seaports in dominant positions and serving as storage facilities (rather than transit points) (Jeevan *et al.*, 2017; Ng *et al.*, 2013). In addition, the legal and institutional framework gaps for providing integration stimuli among these actors encourage powerful groups to gain a competitive advantage through vertical integration (Ng & Tongzon, 2010; Padilha & Ng, 2012). For example, the dry port of Betim in Minas Gerais was controlled by Usiminas Group, a major steel producer with strong presence in transportation infrastructure, including port terminals and dry ports.

The integration problem is further compounded by multiple government agencies and regulatory bodies involved in the logistics process (Ng & Liu, 2014). According to Ng and Tongzon (2010), the regulation segmentation of different types of ports affects systemic efficiency due to fragmented and disconnected planning and the lack of integrated coordination between different administrative entities.

*4.2 BTR analysis*

To identify the determinants of SE of dry port operators in Brazil, traditional technologies used by dry port operators were searched in the Revista Tecnologística database. They are the control variables of the study because they are attributes and not inputs or outputs to the operational processes.

The selected dummy control variables were Certification, WMS, barcode, RFID and internet queries. These variables assume the value 1 for cases with the mentioned characteristic and the value 0 otherwise. The need for k-1 dummy variables represents a variable with k categories (Hair, Black, Babin, & Anderson, 2014). The base category is the absence of the character itself.

Table 3 shows the significance and regression coefficients for the contextual variables for a 5% confidence interval and a resampling set of 2,000 interactions. For interpretation of the results, a positive explanatory variable indicates a negative impact on SE, and a negative value indicates a positive impact on the scores (Simar & Wilson, 2000, 2007, 2011).

The results confirm the impact of coordination processes in the supply chain and, in particular, ITs on increasing the SE of dry ports (Mirzabeiki *et al.*, 2016). The following technologies stand out: WMS, barcode and RFID. For collaboration and coordination related to inventory management, the analysis shows that ITs significantly positively impacted efficiency. A possible justification for this effect is that inventory-related coordination processes enable greater integration of customer product flow with dry port operators' transportation and storage resources for proper movement (Jeevan *et al.*, 2017; Mirzabeiki *et al.*, 2016; Ross & Droge, 2004). For example, inaccurate information about the container delivery timing to seaports or lack of traceability can result in delays that affect the operations and inventories of port logistics operators (Jeevan *et al.*, 2017).

Standardizing business processes by ISO certification also favors increased SE for dry port operators (Lo *et al.*, 2009; Prajogo *et al.*, 2012). The excessive bureaucracy and complexity of customs clearance have created an environment where unpredictability can lead to high inventory levels and slow cargo movement (Ng *et al.*, 2013). Structuring and implementing standardized procedures can deliver promises under the time frame conditions agreed upon in terms of faster flows of materials and information (Lo *et al.*, 2009; Wanke, 2012).

| Coefficients | Value | Lower limit (2.5%) | Upper limit (97.5%) |
|---|---|---|---|
| (Intercept) | −11.0837 | −5.6125 | 2.5052 |
| Certification | −107.3048 | −219.3826 | −78.4973* |
| WMS | −13.9644 | −75.9652 | −33.4600* |
| Barcode | −93.0802 | −198.9720 | −65.8092* |
| RFID | −68.3583 | −140.2883 | −31.9925* |
| Internet queries | 303.9590 | −30.6019 | 32.0827 |

**Note(s):** * significant

**Table 3.** Coefficients and confidence interval (5%) of Bootstrap Truncated Regression (BTR) (number of bootstrap interactions 2000)

## 5. Conclusions

The study's objective was to identify dry ports' main technological drivers of SE. A two-stage DEA model was used to evaluate Brazilian dry ports' SE and identify technological contextual variables determining this efficiency to achieve this objective.

In the first analysis stage, results indicate that dry ports operate below their technical and operational capacity, suggesting that the sector's lack of regulation in Brazil may discourage its use by importers and exporters in favor of using maritime ports and terminals. In this scenario, Brazilian dry ports do not participate much in the supply chain strategy.

The findings reflect the impact of dry ports' regulatory landscape. While institutional configurations and reforms have laid the foundation for process structuring and logistics modernization, the regulatory framework does not encourage cooperation between ports and dry ports, placing the former in dominant positions and turning the latter into storage facilities rather than logistic hubs. Furthermore, mechanisms created by the ports, such as restrictive cargo shipment deadlines and procedures, additional fees, and even lobbying to prevent cargo transshipment, strengthen barriers to port and dry port collaboration. As a result, Brazilian importers and exporters tend to use seaports as part of their supply chain to the detriment of dry ports, causing cargo retention in ports and affecting logistic flows.

For importers and exporters to strategically seek dry ports, thus increasing the interlocutors of their supply chain, they must understand and perceive operational and financial gains from the choice. The offer of operations synchronized with the clients' needs can establish increased demand.

In the second stage, results corroborate the evidence in the literature that supply chain coordination mechanisms, such as IT tools, provide a more rational allocation of resources to customer demands. WMS, barcoding and RFID are information reliability technologies for movement and planning production agility and future purchasing needs. Thus, this information readiness implies the operation's efficiency since it inhibits or eliminates rework. Process standardization also favors increased SE for dry port operators in a highly bureaucratic and complex environment. The results indicate that these mechanisms can provide a near-scale operation that is more productive.

This paper has contributed to theoretical advancement in the field of efficiency and supply chain research while identifying logistics arrangements that are more favorable to agents. In the first instance, the efficiency analysis pointed to the provision of coordination processes and ITs as decisive criteria for supplier selection in supply chains. At the same time, it helped to consolidate the two-stage approach to efficiency analysis, making the methodology more consistent as a benchmarking tool for developing best practices in the industry.

The study also brings a managerial contribution to the sector and makes it clear that the applicability of the DEA technique in measuring the efficiency of dry port operators is opportune. Specifically, the result points out IT tools that can promote new levels of efficiency of scale, revealing room for further investments and for the development of future studies to understand the relationship between these factors and the SE of dry ports.

Finally, using secondary data instead of primary data brings certain limitations to the study, especially regarding the set of inputs and outputs used in the analysis that may not cover all relevant aspects for constructing an efficient frontier. Thus, we suggest new studies should be conducted to expand the set of inputs and outputs in the management and operation of Brazilian dry ports.

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