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The efficiency of railway concessions and the regulation of service quality

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Abstract: This study assessed the efficiency of Brazilian railway transport under three distinct aspects: technical efficiency, quality of service efficiency and economic efficiency from 2006 to 2018 using data envelopment analysis - DEA. As a result of the proposed analysis, we verified that the current quality of service indexes established in concession contracts were not able to encourage quality of service improvements. It was also observed that concessionaires with better technical efficiency are those with lower economic efficiency, indicating that there are gains in profitability with the worsening of the service's quality.

Keywords: DEA, Efficiency, Railway, Concession, Service, Brazil

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1. Introduction

In recent years, especially through the road and rail sectors, Brazil was able to export agricultural and iron ore production, which proved to be an exception when compared to the decline presented by several sectors of the economy. However, the growth in demand for freight transportation was not accompanied by major innovations and growth of national logistics infrastructure, especially railways, even though the production of rail transportation has grown more than the GDP, by 4.6% per year from 2006 to 2018 (ANTT, 2022).

As rail transportation service is recognized as a natural monopoly owned by the State and provided by private companies through concession and authorization contracts, the regulation of the sector is concerned above all with the fulfillment of the contracts and with meeting the requirements of adequate service as defined by law 8.987/1995, which are: regularity, continuity, efficiency, safety, correctness, generality, courtesy in its provision, and moderateness of tariffs.

Since these requirements are only undetermined principles (de Aragão, 2021), it is up to the National Agency of Land Transportation (ANTT) to further detail them in regulatory terms. However, there is no specific regulation to date about requirements for adequate service provision beyond the indexes defined in concession contracts. For contracts signed in the 1990s, those are the safety and production indexes. For contracts signed in 2019 onwards, a new set of obligations are stablished, including mandatory investments in traffic capacity and safety, as well as new service quality indexes are defined: railroad saturation index (ISF), average travel speed index (IVMP), serious rail accident index (IAFG) and maximum age of locomotive fleet (IMFL).

In either case, the current regulation has a repressive and *ex-post* character as to non-compliant conducts (Gomes, 2019), and no monitoring parameters are presented that fully comply with the requirements set in the concessions law.

Given the presented context, this paper's main objective is to assess the efficiency of Brazilian railway freight transportation under three different aspects; technical efficiency, quality service efficiency and economic efficiency in order to observe the current state of rail freight transportation in Brazil and the comparative performance of concessions through a data envelopment analysis - DEA for the period ranging from 2006 to 2018. From this analysis, it will be possible to verify whether the established indicators in concession contracts were able to drive quality of service improvements, also observing whether more profitable concessionaires present higher quality of service when considering the growth of transported goods, reduction of the number of accidents and growth of investments.

Furthermore, this article is inserted in the context of research on rail transportation efficiency and evaluates a trade-off between economic efficiency and adequate service provision, adding a distinct perspective to be explored by Brazilian's regulation agency on the need to regulate the private provision of public rail transport services.

In addition to this introduction, the technical literature was consulted to better understand efficiency analysis in rail transportation, its main models, and the most common variables. Then, most adequate model for the purpose of this study was selected and the results were analyzed. At last, the final remarks are presented, along with the conclusion and suggestions for improvement.

2. Literature review

The two most recurrent methods to assess efficiency are: stochastic frontier analysis (SFA) and data envelopment analysis (DEA) (Lampe & Hilgers, 2015). SFA was first introduced by the seminal works from Aigner et al. (1977) and Meeusen and van Den Broeck (1977). Both inspired by the work of Farrell (1957), who introduced the possibility of estimating an efficient frontier with best practices by calculating the distance of productive units to this frontier, estimating relative efficiency. This idea was implemented by specifying a statistical model characterized by a compound error term in which the classical stochastic disturbance, to capture the measurement error and any other classical noise, is complemented with a one-sided non-negative disturbance that represents inefficiency.

DEA stands out as being the most popular (Lampe & Hilgers, 2015). The data envelopment analysis was initially proposed by the seminal work of Charnes et al. (1978) and incorporates the Pareto–Koopmans efficiency or full efficiency assumption and provides a relative efficiency measure between the compared firms, named decision making unit (DMUs). It allows the use of multiple inputs and outputs and does not need a functional relationship between the variables to form an empirical frontier.

For the classic CCR model (Charnes et al., 1978), the frontier is calculated by a linear combination of observations in the data. The efficiency scores can be translated as the Euclidean distance from the frontier estimated at the measured unit, based on a constant return to scale (CRS) assumption and two efficiency measures, an output oriented and an input oriented.

Later, Banker et al. (1984) proposed a different approach, defending that the CCR model is restrictive when dealing with big differences in scale between DMUs. To deal with this limitation, the authors incorporate the property of variable returns to scale in various parts of the frontier and replace the property of proportionality between inputs and outputs with the property of convexity.

From then, several other seminal works developing the classic DEA models were published, as highlighted by Lampe and Hilgers (2015) in a bibliometric analysis of DEA and SFA literature. However, Mahmoudi et al. (2020), in a literature review for DEA applications in transportation systems states that the most common DEA model is still the CCR (Charles, Cooper & Rhodes), which considers constant returns to scale.

In this sense, Growitsch and Wetzel (2009) investigate the efficiency of European railways and carefully evaluate economies of scope in vertical integration and how it affects efficiency. According to the authors, economies of scope are present when cost savings are obtained because of a joint production of goods. In other words, it may be more efficient when a single company produces a defined set of products than when two or more companies produce those same products. Diseconomies of scale are the opposite.

Then, the authors build a set of arguments against and in favor of economies of scale in the railway sector through an extensive literature review, and state that the impact of scale economies on efficiency remains ambiguous. Merkert et al. (2010) also state that the issue of scale economies in rail transportation is still unresolved.

To support the model decision, Growitsch & Wetzel (2009) state that although a variable return to scale approach allows for scale corrected influences, they chose a CRS approach "because an efficiency comparison should consider the long-term perspective, including increasing European deregulation and competition". As such, the authors defend that country-specific regulation and political influence that may hinder scale economies in the short term will diminish overall. Further, a VRS approach can restrict the number of comparable railway companies to a specific size and, at the extreme, identifying an unusually high number of efficient firms.

In a Brazilian context, to explicitly tackle the issue of scale economies, da Silva et al. (2019) use the test proposed by Simar and Wilson (2002) and concludes that the null hypothesis of constant returns to scale cannot be rejected, partially confirming the remarks made by Growitsch and Wetzel (2009) to support choosing the DEA-CCR model.

As this paper also analyses efficiency of Brazilian railway companies, considering the results obtained by da Silva et al. (2019), we also decide for the DEA-CCR model.

Mahmoudi et al. (2020) also propose a literature segmentation in transportation systems with six sections: (1) DEA and highway transportation; (2) DEA and air transportation; (3) DEA, ports and maritime transportation; (4) DEA and railway transportation; (5) DEA, Eco-design, sustainable development and green issues in transportation and (6) DEA and other transportation research.

Regarding railway transportation, the authors surveyed 29 papers and identified the following themes as the most important: (i) performance assessment of railway passenger and freight transportation companies; (ii) performance assessment of railway transport considering environmental issues; (iii) selection and location of urban railway stations; (iv) assessment of the effect of private sector participation, governance structure, policy changes and new investments on performance and efficiency; and (v) performance of rail transportation through time.

The authors also presented the most recurrent variables in DEA applied to railway transportation. In short, those are: (i) labor, appearing especially as the number of employees; (ii) capital, appearing as the total capital or operational expenditure, net revenue, and annual costs of operation; (iii) facilities, such as the number of wagons and locomotives, total track length, number of terminals etc.; (iv) operational products in the form of total number of passengers transported, total freight transported, train km etc.

The literature on efficiency of rail freight transportation dates to the 1990s, when economists assessed the inefficiency of economic regulation to predict the effects of deregulation in railway sector. Recently, the research on rail efficiency using DEA has experienced a rapid growth, where 45% of all papers were published in the period between 2014 and 2018 (Mahmoudi et al. 2020).

Also, some seminal papers with methodological contribution identified by Lampe and Hilgers (2015) were developed with a direct application to the rail sector, such as Coelli et al. (1999), Yu and Lin (2008) and Yu (2008).

Coelli et al. (1999) use a multi-output distance function to assess the technical (in)efficiency of European railways, comparing results from three alternative methods of estimating multi-output distance functions: linear programming parametric frontier; DEA; and corrected ordinary least squares (COLS). For all three approaches, the authors compare input-oriented, output-oriented, and constant returns to scale (CRS) results. As its main conclusion and main methodological contribution, the authors state that there is a strong correlation between the input and output-oriented results, as well as significant correlation between the three methods. In this sense, there does not seem to be a significant difference in choosing to input or output oriented DEA models.

As future research in railway systems, Mahmoudi et al. (2020) highlights the need of studying various perspectives such as environmental, economic, and social sustainability as well as user and quality of service. Thus, in line with the objectives of this paper. However, efficiency analysis of railway operators is primarily observed under the technical aspect of transportation, taking as outputs the ton-kilometer (TKU) or ton (TU) variables, and as inputs, physical resources, and investments (Caldas et al., 2012; Cantos et al., 2012; de Jorge-Moreno & Garcia - Cebrian, 1999; Paixão & Khoury, 2008; Yu and Lin, 2008).

Regarding service quality, Sharma et al. (2016) assessed the performance of rail transport service in India through a DEA-BCC-Malmquist Index to compare relative efficiency of 16 Indian railway zones. Its main difference from earlier literature on rail efficiency is the inclusion of quality of service as an analysis dimension, considering punctuality; safety; and customer satisfaction.

To translate these parameters into variables, the authors chose as inputs working expenses, number of employees, and line extension. As outputs, the authors selected revenue, punctuality, passenger kilometer, number of accidents and public complaints.

As relevant results, Sharma et al. (2016) states that there seems to be an over deployment of input resources. However, a reduction of the number of employees, for instance, may not be possible in the public sector, but a relocation of staff may be feasible. Also, the authors identified an under-utilization of rail tracks and areas where a policy change is needed to address safety issues, as well as client satisfaction issues.

Link (2019) proposes a 12-year panel data analysis to assess the impact of including service quality into an analysis of efficiency differences between the German public transport authorities through a DEA-BCC followed by a tobit regression. As input variables, the authors chose operating subsidy, investment subsidy and infrastructure charges. As output variables, selected train-km, passenger-km as operational variables and punctuality and passenger satisfaction as quality-of-service variables. For the tobit regression, the authors defined the explanatory variables as the share of tendered train-km, the share of train-km under net contracts, the average size of contracts in train-km and the average contract duration for policy variables. As environmental variables, the authors chose population density, car density and GDP per capita.

The main finding of Link (2019) study is that ignoring quality of service when analyzing efficiency and restricting this analysis to conventional output measures might result in misleading policies with eventually counter-productive effects.

Thus, the discussion on service quality as a dimension in efficiency research beyond the financial perspective and its challenges, especially those related to variable definition and the appropriateness of each input, output, and interpretation of the results, is of major importance to countries where rail transport is regarded as a public service, such as in Brazil.

In this context and considering the presented technical literature on the sector, the purpose of this study is to evaluate the efficiency of the railway concessions under three distinct aspects: (i) technical-operational efficiency; (ii) service quality efficiency, from the perspective of the concession contracts; and (iii) economic efficiency of the concessions. From this analysis, it will be possible to draw a comparison to verify whether concessionaires with high technical-operational efficiency scores are also those with high economic efficiency and whether this economic efficiency is reflected in gains for society through relevant efficiency scores in service quality.

The main aspects that differentiate this article from those in the literature of the sector are (i) the use of primary data, obtained directly from the Monitoring and Inspection of freight railway system - SAFF, the main database of Brazilian railway transportation, maintained by ANTT; (ii) the analysis of three different aspects of efficiency, namely: technical, service quality and economic, and (iii) the use of an analysis period longer than that observed in the national literature, from 2006 to 2018.

3. Materials and methods

As presented in the literature review, the two most popular methods to assess efficiency are: stochastic frontier analysis and data envelopment analysis. This study uses a DEA-CCR approach to assess relative efficiency between Brazilian railway concessionaires.

The model is based on observed inputs and outputs and its respective weights, but rather than being fixed in advance, the weights in DEA are derived from the data itself and, for each decision making unit (DMU), a best set of weight is assigned, and they may vary from one DMU to another (Cooper et al., 2007). Mathematically, this linear problem is described by the following equation:

$$\begin{cases} \text{Min:} \, \eta_i = \vartheta_{1i}x_{1i} + \vartheta_{2i}x_{2i} + \cdots + \vartheta_{mi}x_{mi} \\ \text{s.t.}: \omega_{1i}q_{1i} + \omega_{2i}q_{2i} + \cdots + \omega_{si}q_{si} = 1 \\ \quad \omega_{1i}q_{1j} + \omega_{2i}q_{2j} + \cdots \\ \quad \omega_{si}q_{sj} \leq \vartheta_{1i}x_{1j} + \vartheta_{2i}x_{2j} + \cdots \\ \quad\quad +\vartheta_{mi}x_{mj}, \forall j = 1,2,\ldots,n \\ \quad \omega_{1i}, \omega_{2i}, \ldots, \omega_{si} \geq 0 \text{ e } \omega_i \neq \bar{0} \\ \quad \vartheta_{1i}, \vartheta_{2i}, \ldots, \vartheta_{mi} \geq 0 \text{ e } \vartheta_i \neq \bar{0} \end{cases} \tag{1}$$

the DEA-CCR model choice is based on the literature review and in the work of da Silva et al. (2019). As described earlier, the authors use the Simar and Wilson (2002) scale return test and verify that the null hypothesis of constant returns to scale in Brazilian railway sector cannot be rejected.

Regarding model orientation, as stated by the seminal work of Coelli et al. (1999), there does not seem to be a significant difference in choosing input or output oriented DEA models. Nevertheless, this work takes an input-oriented approach, as these variables can be controlled and managed by Brazilian rail concessionaires.

3.1. Data analysis and variable definition

The population considered in the present analysis is composed of 10 Brazilian railway concessions, namely: Estrada de Ferro Paraná Oeste (EFPO), Ferrovia Centro-Atlântica (FCA), Ferrovia Tereza Cristina (FTC), Ferrovia

Transnordestina Logística (FTL), MRS Logística (MRS), Ferrovia Norte Sul Tramo Norte (FNSTN), Rumo Malha Norte (RMN), Rumo Malha Paulista (RMP), Rumo Malha Sul (RMS) and Rumo Malha Oeste (RMO). The analysis period will range from 2006 to 2018.

The SAFF database is used as the main source of information. As exposed by Merkert et al. (2010), previous works related to railway efficiency used secondary and aggregate data, published by ANTT, Ministry of Infrastructure, Union International des Chemins de Fer (UIC), World Bank, etc. This paper distances itself from this problem by using primary and disaggregated data from SAFF.

The concessions managed by the mining company Vale S.A., Estrada de Ferro Vitória Minas, and Estrada de Ferro Carajás, will not be considered in the present study, as they are inserted in a different context from those previously mentioned, especially because Vale is not a specific purpose company (SPE), and generates most of its demand for transportation. Also, both concessions are not subject to the regulatory maximum fare for iron ore transportation. Thus, Vale's concessions would impair the application of DEA given that DMUs are not inserted in the same regulatory regime, violating the principle of DMU homogeneity.

As to variable selection, Cullinane et al. (2004) present an extensive discussion applied to the Port Sector, that can be transported to the railway sector. The authors state that variable selection must reflect the process and objectives of sector production, as the observed performance of a port is closely related to its objective.

Cullinane et al. (2004) also state that the input-output choice may change depending on the perspective, and variables that were considered as inputs in one model can be outputs in another. This is especially important to our paper, as we assess efficiency under three different perspectives and the variable choice must reflect the objectives of each analysis, also considering data limitations.

Thus, for each efficiency analysis, the variables will be discussed to better represent each objective.

3.2. Technical efficiency

From the literature reviewed in Section 2, especially considering Mahmoudi et al. (2020) research, the analysis of the technical aspects of railway operation is well established, with the use of labor and physical assets as inputs and ton-kilometer and passenger-kilometer as outputs. Thus, the proposed analysis aims to update the national bibliography, given the regulatory and economic scenario changes that have occurred since the last efficiency related publication (Pereira et al., 2015), namely: Law No. 13,448/2017; ripening of the FNSTN operation; change in production and safety goals establishment methodology proposed in 2017 for the 2018-2022 five-year period; abandonment of the open access model; among others.

Considering national and international literature, the main input variable in efficiency analysis of railway operation is the number of employees, used in 14 of the 17 consulted papers. The second most recurrent variable is related to rolling stock, used as input in 12 of the 17 consulted papers. Finally, line extension was used as input in 10 of 17 articles consulted.

Therefore, the variables: number of employees; rolling stock (total number of wagons and locomotives) and railway line extension will be used as inputs. As output, the total tonnage transported, in ton-kilometer (TKU), is selected, since it was used in 11 of the 17 consulted papers.

The Table 1 presents the list of authors and the frequency of use of the variables selected for technical efficiency analysis.

Table 1. Authors and frequency of used variables.

Authors	Labour	Extension	R.Stock	TKU
(Caves & Christensen, 1980)	1	0	1	1
(Gathon & Perelman, 1992)	1	1	1	1
(de Jorge-Moreno & Garcia-Cebrian, 1999)	1	1	1	1
(Cantos & Maudos, 2001)	1	1	0	1
(Baños-Pino et al, 2002)	1	0	1	1
(de Jorge & Suárez, 2003)	1	0	0	0
(Yu & Lin, 2008)	1	1	1	1
(Graham, 2008)	1	1	1	0
(Couto & Graham, 2008)	0	0	1	0
(Lim & Lovell, 2009)	1	1	1	0
(Asmild et al., 2008)	0	0	1	1
(Bhanot & Singh, 2014)	1	0	1	1
(Kutlar et al., 2013)	1	1	1	1
(Cantos et al., 2012)	1	1	0	1
(Noroozzadeh & Sadjadi, 2013)	1	1	0	0
(Pereira et al., 2015)	1	1	0	0
(de Oliveira Fontan et al., 2022)	0	0	1	1
Total	14	10	12	11

3.3. Quality-of-service efficiency

From a different point of view, a quality-of-service provision analysis was proposed, aligned with recent research highlighted in the literature review section, considering the limitations on data as described previously.

Thus, for the input-output variable definition, it is important to better understand how railway concession contracts in Brazil address service quality. Through the Clause Five of these contracts, two indexes are presented as a proxy for quality-of-service. These are: minimum percentages of growth in transport production in TKU and the minimum accident index. Both are perceived as a goal that the concessionaires must attain. The mentioned contracts also state that the concessionaires "must provide the investments necessary to attain these goals" (Ministry of Transportation, 1997).

From this clause, it is possible to extract three main variables, namely: TKU, accident index and investments. For the presented analysis, the accident rate in number of accidents per million train-kilometer will be used as an undesirable output and the tonnage transported, in TKU, will be used as a desirable output. To achieve these goals, the investments in Reais (R$) per train km will be the input for the analysis.

The objective of the proposed analysis is to evaluate the minimization of the accident rate from a given level of investment, without reducing rail transportation, in TKU. As the accident rate variable is an undesired output, it requires a different approach, as what is sought is not its maximum value through input reduction, but its minimization.

In recent studies, the most widely used methodology for similar cases has been the change from output to input of the undesirable variable, proposed by Yaisawarng and Klein (1994) and applied in the studies by Guo and Wu (2013), Li et al. (2013), Yang and Pollitt (2009), Hailu and Veeman (2001), and Korhonen and Luptacik (2004).

Therefore, the accident rate variable will be used as an input, along with the investment per train km variable, while the TKU variable will be the only output.

3.4. Economic efficiency

Lastly, we propose an efficiency analysis from a financial perspective. For the input-output definition, considering the limitations on data as described previously, it is important to assess factors that may impact/generate revenue to the concessionaire. The first is freight transportation in TKU, their main source of revenue, considering that the transportation fare is mostly negotiated in R$ per ton-km.

Following, it is also important to consider capital allocation in railway operation, and how it translates into greater profitability. Given the available data, the one that best suits the presented context is Investment per train km.

Thus, the objective of this analysis is to assess which concessionaires can produce a higher level of revenue, with less investment and less ton-km. The net transport revenue will be the main output of this analysis, considering data limitation.

To summarize the above, Table 2 presents the variables selected for each of the efficiency analyses proposed here.

Table 2. Selected variables.

<table>
<tr><th>Efficiency Analysis</th><th>Inputs</th><th>Outputs</th></tr>
<tr><td rowspan="3">1. Technical</td><td>Number of Employees</td><td rowspan="3">TKU</td></tr>
<tr><td>Line Extension</td></tr>
<tr><td>Wagons + Locomotives</td></tr>
<tr><td rowspan="2">2. Quality of Service</td><td rowspan="2">Investments</td><td>Accident Rate</td></tr>
<tr><td>TKU</td></tr>
<tr><td rowspan="2">3. Economic</td><td>Investments</td><td rowspan="2">Operational Net Revenue</td></tr>
<tr><td>TKU</td></tr>
</table>

4. Results

The R programming language (R Core Team, 2018) was used to obtain the results, with the help of the 'rDEA' library (Jaak & Galina, 2016).

4.1. Technical efficiency

From the proposed technical efficiency analysis, as described in Section 3.1, the results show large gaps between concessionaires. Four DMUs were perceived as efficient, with an efficiency score of 1: MRS Logistics in 2012 and 2016; Rumo Malha Norte in 2015 and 2016. The lowest observed efficiency score was 0.021, for Transnordestina Logística railway in 2006. The average efficiency score is relatively low, 0.27, corroborating the findings of Pereira, Pereira et al. (2015) and Marchetti and Wanke (2017). Appendix 1 presents the rankings of technical efficiency.

From 2010 onwards, there is a predominance of the railways managed by MRS and RMN in the first places of the ranking. Also, there is a significant gain in relative efficiency of Rumo Malha Norte over the years of 2006 to 2011, leaving the 4th place and reaching the 1st. It is also worth noting the significant drop in efficiency of Paraná Oeste's railway, from second place in 2006 to ninth in 2016, returning to seventh place in 2018.

Except for Ferrovia Norte Sul Tramo Norte and Rumo Malha Norte, there does not seem to be a gain in relative efficiency over the period of 2010 to 2018. MRS reached the efficiency frontier as early as 2012 and again in 2016, an indication of stagnation since then.

4.2. Quality-of-service efficiency

As for the Quality-of-Service analysis, as presented in Section 3.2, the general result was like the technical efficiency analysis. A large gap between different concessions, with the predominance of the concessions managed by MRS and RMN as the most efficient. The average efficiency score is 0.22, lower than the 0.27 observed in the technical efficiency analysis. Four efficient DMUs were identified: MRS in 2009 and 2016, EFPO in 2007 and RMN in 2018. The lowest efficiency score was Transnordestina Logística railway once again, this time in the year 2011.

Appendix 2 presents the annual ranking of Brazilian railway concessionaires based on the quality-of-service efficiency scores obtained.

Again, MRS is the most efficient rail, losing the first place to RMN in 2018, which showed significant growth in relative efficiency. There is also a significant drop in the relative efficiency of Paraná Oeste railway, leaving the 1st place in the year 2007 and taking the 9th place in the year 2015.

Given the results obtained, excluding Malha Norte Railway, it is not possible to observe relative efficiency gains over the period, with MRS reaching the efficiency frontier in 2009 and then again in 2016.

4.3. Economic efficiency

Lastly, the results from the proposed model in Section 3.4 show a large gap between different concessions. However, the concessionaires with the highest efficiency scores were mostly FTC and EFPO. On average, an average efficiency of 0.19 was observed, even lower than the results from technical efficiency and quality of service efficiency. Five efficient DMUs were identified: EFPO in 2007 and 2011, and FTC in 2011, 2012 and 2013. The lowest observed efficiency score is, once again, from Transnordestina Logística, in 2006.

Appendix 3 presents the annual ranking of Brazilian railway concessionaires based on the economic efficiency scores obtained.

It is interesting to note that there is an inversion in the efficiency ranking when comparing the results obtained from the economic efficiency and technical efficiency. Among Brazilian rail concessions, FTL's relative efficiency leap over the years stands out, reflecting a scenario of complete disinvestment rather than an improvement in capital allocation, with continuous reduction in absolute value invested and a significant reduction in the distance traveled by trains in its rail network. In addition, more than 3 thousand km of its rail network is out of operation.

We also highlight the growth in relative efficiency by FNSTN, not an unexpected scenario. It is the most recent concession with consolidated operation, requiring fewer investments and lower maintenance expenses.

It is also worth noting that FNSTN was the only concessionaire to present a growth in relative efficiency in all the three proposed analyses, indicating that there was an improvement in the quality of service in terms of the concession contract and in its economic efficiency over the analyzed period.

While other concessionaires were stagnant in terms of their relative economic efficiency, RMP fell from fourth to last place in the ranking. Also, an expected scenario, given its annual growth of about 19% in investments per train km from 2006 to 2018; the highest growth recorded among the concessionaires analyzed, without a proportional increase in their profitability. This growth is due to the duplication of the main line, between the Boa Vista Velha and Perequê stations. This investment cannot be immediately translated in higher relative economic efficiency.

4.4. Comparative analysis

A correlation analysis is proposed to assess the results obtained from the three-efficiency analysis presented earlier. Considering that a negative correlation points to an opposite movement of the efficiency scores, this analysis can suggest a trade-off between service quality efficiency and economic efficiency.

In other words, it would be possible to observe whether technical efficiency of a firm is linked with its economic efficiency, or whether quality of service efficiency is associated with technical efficiency.

The Pearson correlation between the resulting efficiency scores from technical and quality of service analysis was 0.72. This is expected, as operational improvements and investments in fixed assets and rolling stock can result in a safer operation and better transportation performance, while lower accident rates can also reduce the number and duration of traffic interruptions, resulting in fewer economic losses and a more consistent operation. Figure 1 shows the dispersion between quality of service and technical efficiency scores.

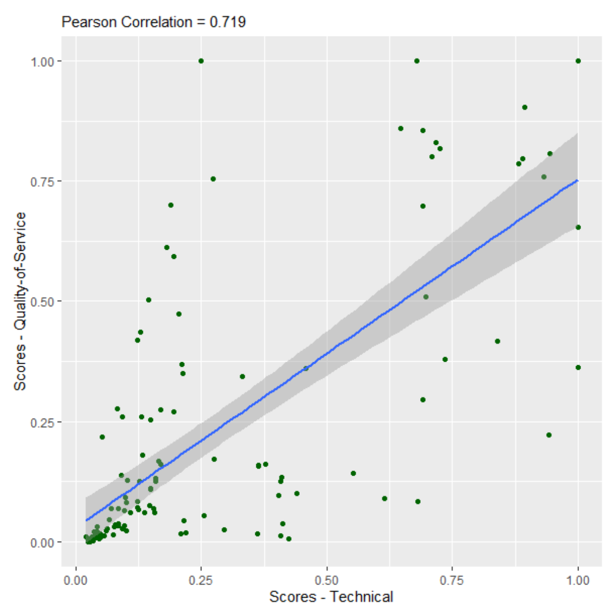

Figure 1. Dispersion between technical and quality-of-service efficiency.

From Figure 1, we can observe a high concentration of efficiency scores between and 0 and 0,25, corroborating the presented results in Sections 4.1 and 4.2 of great inefficiency in Brazilian railway system.

However, when looking at the correlation between the resulting efficiency scores from the technical and economic analysis or quality of service and economic analysis, there is a negative correlation in both cases, of -0.22 and -0.29 respectively. In other words, railways that presented higher efficiency scores in one model showed significant inefficiency in the other.

There is an operational gain in better capital allocation, but a higher economic efficiency occurs at the expense of service quality, indicating a trade- off between the quality of service provided and economic efficiency. Figures 2 and 3 present the dispersions between economic and technical efficiency scores and quality of service and economic scores.

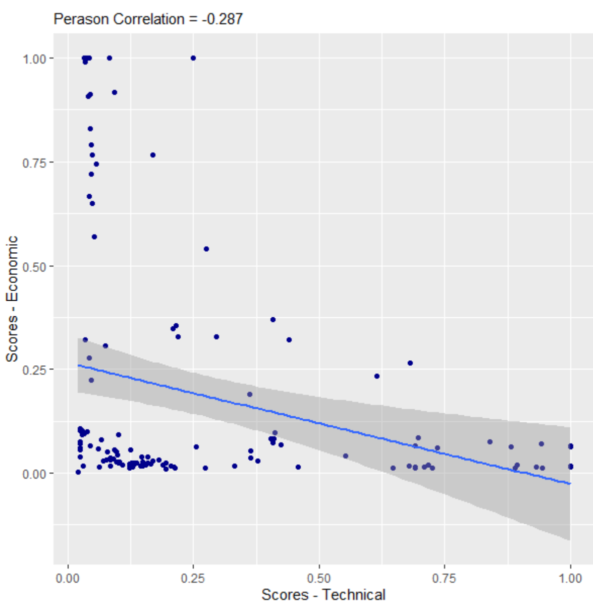

Figure 2. Dispersion between technical and economic efficiency.

From all three proposed analysis, an important result is the low average efficiency scores, consistent with other related works (Marchetti & Wanke, 2016; Pereira et al. 2015). Furthermore, from the analysis of the efficiency scores alone, there does not seem to exist a clear evolution, indicating a stagnation in the sector, except for Ferrovia Norte Sul S.A., the most recent concession with consolidated operation, and Rumo Malha Norte.

Regarding Ferrovia Norte Sul, it was the only concessionaire to present consistent growth in relative efficiency throughout the years in all three proposed analyses, indicating the need for a sector renewal, especially through new concessions projects.

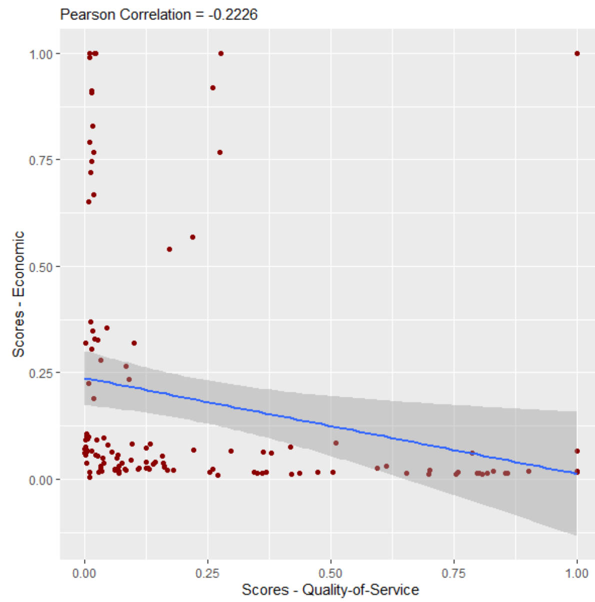

Figure 3. Dispersion between quality-of-service and economic efficiency.

When technical and quality of service aspects are considered, the most efficient concessionaires are those that operate as a "conveyor" for large volumes of commodities heading to the Southeastern ports, with few train crossings along its length. The main one is MRS, which operates in a "carousel" form, where the line called Ferrovia do Aço (Steel Railway) only allows the circulation of trains towards the port complex of Rio de Janeiro and the center line, only the circulation towards the Iron Quadrangle in Minas Gerais. The movement of freight through RMN occurs in a single line, where the transport toward the Port of Santos prevails over the movement of goods toward the interior of Mato Grosso.

However, when efficiency is observed under the perspective of economic efficiency, the most efficient ones are FTC and EFPO, with much different realities. FTC railway is only 162 km long and was built with the sole purpose of serving mineral coal to the Jorge Lacerda thermoelectric complex. This context allows for a long-term transportation contract and predictable revenues, increasing investment security. EFPO, on the other hand, is the only federal concession with public management, by the Paraná State Government. Therefore, investments are scarce and inconsistent, with no investment registered in the years of 2006, 2017 and 2018.

Lastly, considering all the proposed discussion above, it is possible to infer that the concession contracts' Fifth Clause was unable to drive improvements in operational efficiency or the public provided service throughout the analyzed period. On the contrary, the results lead to the interpretation that concessionaires with high technical efficiency are those with lower economic efficiency, indicating that economic efficiency may occur at the expense of service quality.

Therefore, ANTT's initiative to regulate the quality of service beyond the predefined group of indicators presented in the concession contracts seems reasonable, inserting the Agency in a context of regulation by incentive, seeking to reconcile private and public goals, while seeking to benefit the public interest.

5. Conclusions

This paper proposes an assessment of Brazilian railway efficiency through DEA and compares three distinct aspects: technical efficiency, quality service efficiency and economic efficiency. From this analysis, it was possible to observe whether the established indicators in concession contracts were able to drive efficiency improvements in the quality of service, also observing whether economic efficiency is linked to higher quality of service and higher technical efficiency.

The results lead to a set of conclusions:

- For all three proposed analyses, the average efficiency is low, corroborating the preceding literature.
- MRS and RMN are the most efficient in both technical and quality of service analysis, while EFPO and FTC are the most efficient in the economic analysis.
- When technical and quality of service aspects are considered, the most efficient concessionaires are those that operate as a "conveyor" for large volumes of commodities heading to Southeastern ports, with few train crossings in its operation.
- When the economic efficiency is considered, two short railways, with less than 200 km, are the most efficient.
- Railways that presented higher efficiency scores in technical or service quality aspect showed significant inefficiency in the economic analysis as shown by the correlation results.
- Concession contracts' Fifth Clause was unable to drive improvements in operational efficiency or the public provided service throughout the analyzed period.

We believe that the presented paper can provide the National Agency of Land Transportation, Ministry of Transportation, and private investors with relevant and meaningful information about the performance of the rail sector.

As suggestions for future studies and as a development of this one, we present the following: (i) inclusion of stochastic methods for the frontier analysis, as DEA incorporates the Pareto–Koopmans assumption of full efficiency; and (ii) reanalysis of the relative efficiency between concessionaires after relevant regulatory changes.

Conflict of interest

The autors have no conflict of interest to declare.

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Appendix A

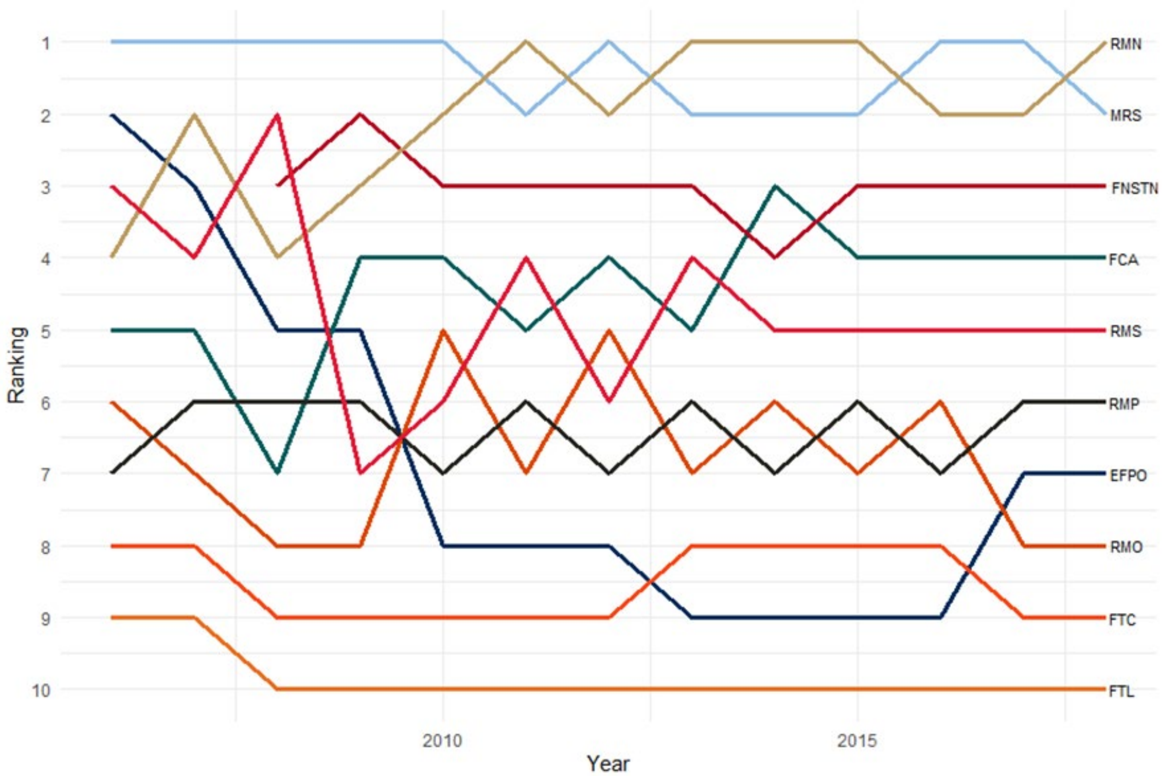

Figure 4. Technical efficiency ranking.

Appendix B

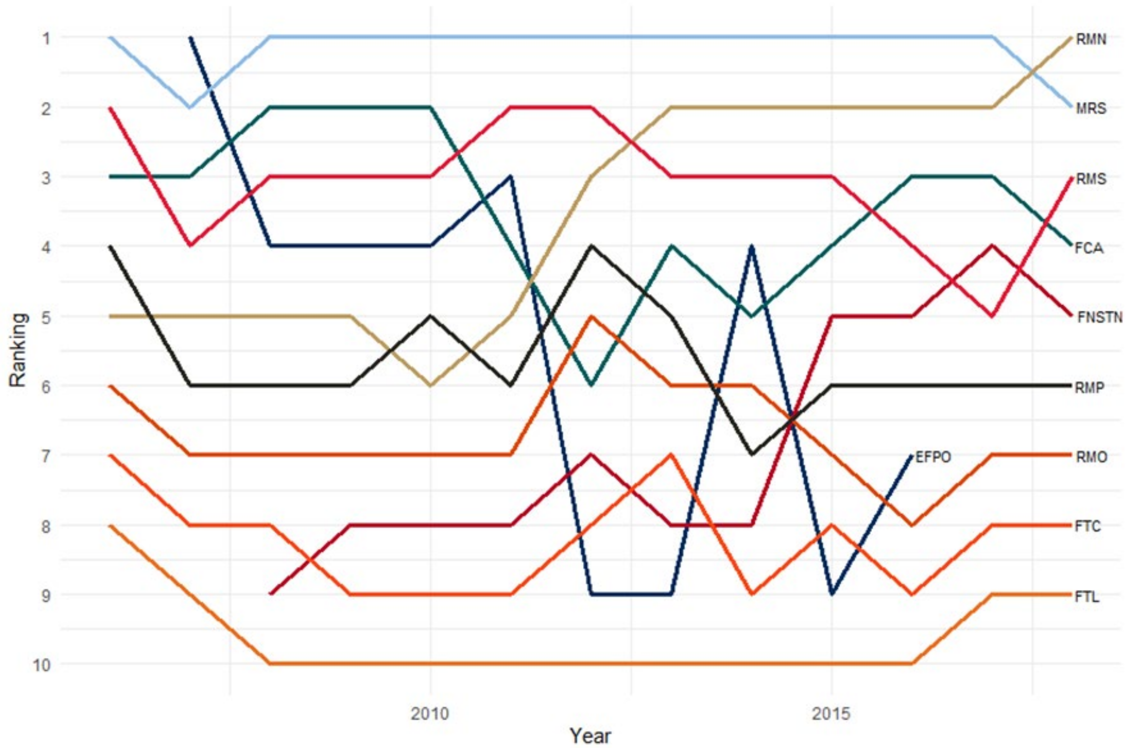

Figure 5. Quality-of-service efficiency ranking.

Appendix C

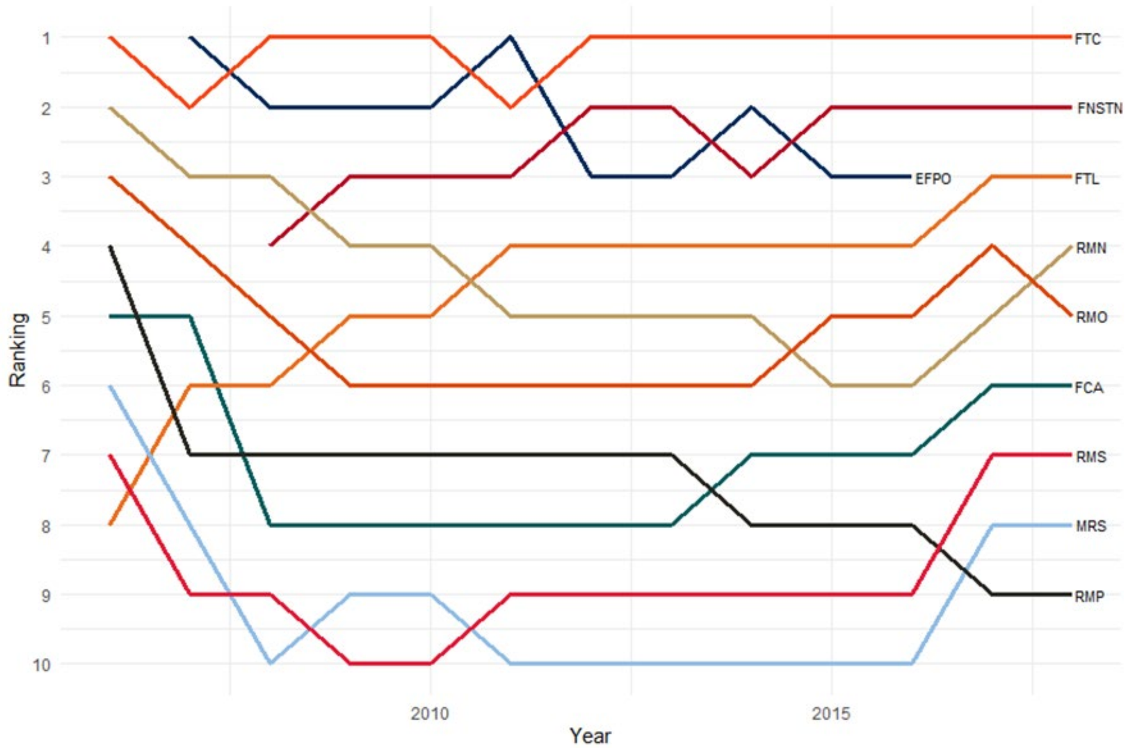

Figure 6. Economic efficiency ranking.