Revista Brasileira de Gestão e Desenvolvimento Regional
G&DR. V. 16, N. 1, P. 369-381, jan-abr/2020. Taubaté, SP, Brasil.
ISSN: 1809-239X

Received: 01/15/2019
Accepted: 04/22/2019

A COMPARATIVE ANALYSIS OF FEDERAL UNIVERSITY EFFICIENCY ACROSS BRAZILIAN REGIONS (2010-2016)

Ariel Gustavo Letti [1]
Mauricio Vaz Lobo Bittencourt [2]
Luis E. Vila [3]

Abstract

Efficiency can be defined as the ratio of a firm's observed output to the maximum output which could be achieved given its input levels and available technology. It became a critical topic when considering the importance of Public Institutions to the Brazilian Higher Education system and its regional idiosyncrasies. Thus, this study applies Data Envelopment Analysis (DEA) to evaluate the relative efficiency of all 56 Brazilian Federal Public Universities for the period of 2010 to 2016 considering some aspects of its regional distribution. The data come primarily from INEP Higher Education Census, CAPES and INPI. The results showed that 26 (47%) of the universities were efficient, with a general mean efficiency of 87%. Although the values by region diverge, they ended up converging to efficiencies between 75% (North) and 90% (Southeast). Through time, the Malmquist index suggests improvements higher than 30% but with different characteristics to the financial and the human resources and among regions. Results also suggest that R$ 2.96 billion by year were wasted due to inefficiency or that an additional 10% of outputs could be obtained.

Keywords: Efficiency. University. DEA. Malmquist index. Brasil.

Introduction

Despite the 200% increase of Brazilian higher education enrollments in the last two decades, in 2013 not more than 16% of the population between 25-34 years of age had an undergraduate degree and only 11% of the population between 55-64 had it (OCDE, 2015). In 2015 the Brazilian population was more than 200 million and the Brazilian Higher Education Institutions (HEIs) overpassed the historic record of 8 million students enrolled (6 in private and 2 in public universities), the same size of the secondary courses system in that year (SAMPAIO, 2017, p. 28). In addition, only recently a great part of the Brazilian young population is taking a secondary course (IBGE, 2010) and potentially will be able to go to universities. In relation to the financial values, in the XXI century the Brazilian public higher education expenditures have increased by a mean of 2.5% a year, representing approximately 0.8% of the GDP in each year and an equivalent value of USD $ 14 billion in 2016 (INEP, 2017).

1 PhD in Economic Development (PPGDE / UFPR). Assistant Professor at the State University of Bahia (UNEB / Senhor do Bonfim). E-mail: ariel_letti@yahoo.com.br.
2 PhD in Agricultural and Development Economics from The Ohio State University. Associate Professor III in the Department of Economics at the Federal University of Paraná (UFPR). E-mail: mbittencourt@ufpr.br
3 PhD Economics and Business from Universidad de Valencia. Full Professor in the Department of Applied Economics at the Universidad de Valencia - Spain. Email: luis.vila@uv.ex

Efficiency can be generalized as the use of the fewest resources to produce the most results. Considering that the monetary and non-monetary benefits from education present strong externality effects overall in the entire society (VILA, 2000) and also that good performance in higher education is believed to produce growth effects, inefficiency in higher education institutions raises a concern among policymakers and institutional administrators (BLANCHARD, 2004). Furthermore, as the institutions can differ in their levels of efficiency, "it is important to study differences in efficiency because this offers lessons about good practice" which "can lead to improvements in the performance of the higher education system as a whole." (JOHNES; JOHNES, 2013, p. 5). In addition to that, these differences can also present regional patterns, which could be specially relevant in the Brazilian case. As an example, Tachibana, Menezes-Filho and Komatsu (2001) show a significant impact of educational distribution and its returns over the regional distribution of Brazilian work. Thus, it could be that this pattern of inequalities is also occurring in the supply of public higher education services and consequently to public HEIs' efficiency.

The findings of Aleskerov, Belousova and Petruschenko (2017) suggested that a major part of pieces of research on HEIs efficiency around the world uses Data Envelopment Analysis (DEA). Then, regarding the Brazilian case, the present study intends to be a contribution and a step forward to previous studies in HEIs efficiency using DEA.

Therefore, the main objective of this study is to evaluate the relative efficiency of all 56 Brazilian Federal Public Universities, for the period 2010 to 2016, considering its regional distribution. This is done by emphasizing the results of three empirical production models: focusing on waste of financial resources (Model 1) and on potential outputs improvements (Model 2 and 3). To each model the results from different returns to scale are considered and also a regional approach is done by comparing the values and their evolution through time (Malmquist index) among the five Brazilian Regions.

Some contributions of this research are mainly in terms of the variables used as inputs and outputs (holding simultaneously the three dimensions of university activities – teaching, research and third mission activities – and innovation, by using registered patents as a proxy), and also due to the period considered – each year from 2010 to 2016. Furthermore, the analysis includes robust techniques to identify and manage outlier observations (Wilson, 1993, 2010).

Keeping in mind what has been presented, this work is organized into five sections of which this introduction is the first. The next section presents the fundamentals of Efficiency and the DEA framework, and a brief review of the most relevant international and Brazilian literature related to universities' efficiency using DEA. The third section presents the methodological procedures used while the fourth section presents and discusses the most relevant results. Finally, conclusions are drawn in the last section.

The background about efficiency and its assessment using DEA

Efficiency is defined, "from an output-oriented[4] perspective (FARREL, 1957), [...] as the ratio of a firm's observed output to the maximum output which could be achieved given its input levels" (JOHNES, 2006, 274)[5]. Charnes, Cooper, and Rhodes (1978) (named CCR) following work by Dantzig (1951) and Farrell (1957), developed a strategy to measure the efficiency of firms by DEA considering constant returns to scale (CRS)[6]. After them, Banker, Charnes and Cooper (1984) modified the DEA model to incorporate variable returns to scale (VRS)[7] keeping the model solvable by using linear programming (JOHNES, 2006). This model was afterwards named BCC. Forsund, Kittelsen and Krivonozhko (2009, p. 1540) affirm that "the three postulates introduced by BCC, convexity, free disposability and tightness of envelopment [...] are the most reasonable assumptions for a production possibility set" and that "researchers in the field universally accept these

4 The output-oriented model measures the efficiency keeping fixed the inputs and maximizing the outputs while the input-oriented model measures the efficency keeping fixed the outputs and minimizing the inputs.

5 Forsund (2018, p. 4) explains that the ratio between the outputs (weighted by type) and the inputs (weighted by type) is termed productivity and a productivity index is closely related to an efficiency index. This way, "If a productivity index for an unit is compared to the productivity index of the most productive unit by forming a ratio, then this ratio is an efficiency index using the most productive unit as a benchmark."

6 CRS occur when, considering a variation in the inputs, the outputs vary proportionally.

7 VRS occur when, considering a variation in the inputs, the outputs vary non-proportionally. They could be increasing returns to scale (IRS, when outputs vary more than proportionally to inputs) or decreasing returns to scale (DRS, when outputs vary less than proportionally to inputs).

conditions". Johnes (2006, p. 274) clarifies that in a multi-output, multi-input production context, DEA provides estimates of the distance function (SHEPARD, 1970), which is a generalisation of the single output production function.

On the other hand, considering practical implications, Johnes (2004, p. 663) presents DEA as a deterministic non-statistical non-parametric technique which "can provide information on realistic targets for an inefficient institution", and also "information on a set of similar (in terms of input and output mix) but better-performing institutions whose practices the inefficient organization can realistically try to emulate."

More information about the background, foundations, advantages and drawbacks of DEA with emphasizes to HEI empirical application could be found in Johnes (2004, 2006) and Forsund (2018). The next paragraphs explain something about the basics of the DEA methodology as a background for the empirical work that follows. Tone (2001, p. 502) emphasizes that "the important characteristic of DEA is its dual side which links the efficiency evaluation with the economic interpretation", in the context of production process and production functions. Then the standard primal problem[8] in contemporary DEA literature using BCC model and output orientation is the one in Eq. A. 1. (FORSUND, 2018, p. 4). Complementarily, Thanassoulis et al. (2011, p. 1297) present both output-oriented and input-oriented models (Eq. A. 1 and Eq. A. 2). According to them, to calculate the efficiency considering that DMUs[9] use m inputs to produce h outputs, under VRS, the following linear programming problem must be solved for each of the n DMUs (k =1,..., n):

Output-oriented (VRS)

Maximise ϕ_k (Eq. A.1)

subject to

$$\phi_k y_{rk} - \sum_{j=1}^{n} \lambda_j y_{rj} \leq 0 \text{ for } r = 1,\dots,h$$
$$x_{ik} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0 \text{ for } i = 1,\dots,m$$
$$\sum_{j=1}^{n} \lambda_j = 1, \lambda_j \geq 0 \forall j = 1,\dots,k,\dots,n$$

Input-oriented (VRS)

Minimise θ_k (Eq. A.2)

subject to

$$y_{rk} - \sum_{j=1}^{n} \lambda_j y_{rj} \leq 0 \text{ for } r = 1,\dots,h$$
$$\theta_k x_{ik} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0 \text{ for } i = 1,\dots,m$$
$$\sum_{j=1}^{n} \lambda_j = 1, \lambda_j \geq 0 \ \forall j = 1,\dots,k,\dots,n$$

The overall efficiency of DMU k is measured by $E_k = 1/\phi_k$in the output-oriented framework or $E_k = \theta_k$in the input-oriented framework ($0 < E_k \leq 1$)[10]. The vector λrepresents the weights to the convex combinations of the HEIs (considering the convexity assumption regarding the technology).

The CRS efficiency score can be calculated simply by deleting the constraint $\sum_{j=1}^{n} \lambda_j = 1$from the model. Complementarily, considering $\sum_{j=1}^{n} \lambda_j \leq 1$, it is possible to calculate the non-increasing returns to scale (NIRS) and use these values to study the scale efficiency (SCE_k). The ratio $E_{k,CRS}/E_{k,VRS}$ [11], results in decomposing the $E_{k,CRS}$ efficiency in pure technical efficiency ($E_{k,VRS}$) and scale efficiency (SCE_k) (THANASSOULIS et al., 2011). Then: if $SCE_k < 1$ and $E_{k,NIRS} = E_{k,VRS}$, the HEI_k is working over the optimal scale (**decreasing** returns); if $SCE_k = 1$ ($E_{k,NIRS} = E_{k,VRS} = E_{k,CRS}$), the HEI_k is working in an optimal scale (**constant** returns); if $SCE_k < 1$ and $E_{k,NIRS} < E_{k,VRS}$, the HEI_k is working under the optimal scale (**increasing** returns).

To complement these analyses it is also important to know how the efficiencies change through time. It can be done using the Malmquist index, which dates back to Malmquist (1953) and

8 Forsund (2018, p. 4) observes that "when using linear program to both estimating the frontier and the efficiency measures we have the fundamental relationship between a primal solution and a dual solution of an optimal solution", and that is natural for economists, "to view the problem called the envelopment problem in operations research for the primal model" (in an input-output space) and "the problem formulated in a shadow price space for the dual problem (the multiplier problem in Operational Research (OR) literature)".

9 Decision Making Unit (DMU) in this context is a synonymous to HEIs, or University.

10 For example, a value equal 0.9 represents 90% of efficiency in relation to the benchmark HEI (or convex combination of HEIs). In an input view, it could reduce in 10% the resources and continue producing the same. In an output view, it would be possible to produce (1.0/0.9 = 1.11) 11% more with the same inputs.

11 The numerator and denominator include efficiency scores calculated under CRS and VRS, respectively.

was made popular by Caves et al (1982)[12]. Let $E_k(s,t)$ be a measure of the performance of firm k in period s against the technology in period t [13]. To better understand the changes, Fare, Grosskopf, Lindgren, Roos (1992), named FGLR, considering only CRS efficiencies, decompose the Malmquist index in two components: technical change (TC, due to general technological shifts) and efficiency change (EC, due to individual catch-up effects). As a way to complement it, and considering also the scale effects (CRS versus VRS measures), Fare, Grosskopf, Norris and Zhang (1994), named FGNZ, decompose that second component in other two, pure technical efficiency change (PEC, due to the catch-up without considering the change size effect) and scale efficiency change (SEC, the catch-up due exclusively to change in the size of DMU) [14]. Then:

$M_k(s,t) = TC_k(s,t).PEC_k(s,t) \cdot SEC_k(s,t) =$ Malmquist index

where

$TC_k(s,t) = \left[\left(\frac{E_{k,CRS}(t,s)}{E_{k,CRS}(t,t)}\right) \cdot \left(\frac{E_{k,CRS}(s,s)}{E_{k,CRS}(s,t)}\right)\right]^{(1/2)}$ = **technical** change index

$PEC_k(s,t) = \frac{E_{k,VRS}(t,t)}{E_{k,VRS}(s,s)}$ = **pure** efficiency change index

$SEC_k(s,t) = \left(\frac{E_{k,CRS}(t,t)}{E_{k,VRS}(t,t)}\right) . \left(\frac{E_{k,CRS}(s,s)}{E_{k,VRS}(s,s)}\right)^{-1}$ = **scale** efficiency change index

The assessment of university efficiency using DEA

In this part of the work are presented some of the existing studies about university efficiencies around the world, with a special emphasis to the Brazilian case. Johnes and Tone (2017, p. 193) point out that the "workhorse analytical framework typically employed" to the studies reviewed by them "is a standard DEA model". Johnes (2004) presents a good review of empirical studies about the efficiency of educational institutions and, focusing specifically on HEIs, Aleskerov, Belousova and Petruschenko (2017) systematized the empirical results on efficiency studies around the world. Their findings suggested that the major part of this type of research uses DEA.

There are university efficiency studies using diverse models of DEA to several countries, the most relevant non-Brazilian works to the context of this study are Agasisti and Salermo (2007) and Agasisti and Dal Bianco (2006), to Italy, which compare the results of CCR and BCC models to analyse the scale efficiency and also do comparisons among Italian regions. Complementarily, and now comparing results between HEIs from England and Italy, Agasisti and Johnes (2009) measure the CCR and BCC efficiencies, calculated the scale efficiencies considering both the data pooled and grouped by country and, then, compare the results. They found that when comparing jointly the England and Italy HEIs, the first presents higher efficiency than the last one. Also, the evolution of these efficiencies present different patterns to each country. Italian universities are improving their technical efficiencies while English universities are obtaining stable scores.

Regarding the Brazilian case, since the 90's Brazilian researchers are involved with measurement of HEIs efficiency using DEA. After some time, a new source of information (data from Federal Court of Audit (Tribunal de Contas da União – TCU) had inspired an increasing group of works. However, the DEA models used by the former considers the 'TCU indices' and not the raw values of the variables. Thus, they could be considered more a type of Multi Criteria Decision Making (MCDM) Analysis using DEA as a tool than actually an efficiency analysis. In that sense, the efficiencies of these pieces of research are considered not comparable with the results from the present work.

On the other hand, it is possible to compare this work with that of Duenhas, França and Rolim (2015), Bittencourt et al (2016), and Letti and Bittencourt (2017), Letti, Vila and Bittencourt (2018) and Villela (2017). Duenhas, França and Rolim (2015) analysed 62 Brazilian public HEIs by using SBM models and Malmquist index. The HEIs were first grouped by size in big (18), medium (22) and small (22) and then the efficiencies were calculated using data from INEP[15] and CAPES[16], and

12 The point is, however, that it is not sufficient for a firm to improve compared to itself. The firm must also improve relative to others, and they have also benefited from general technological progress. Thus, the only way to improve is to catch up to the best, i. e., to get closer to the frontier (BOGETOFT; OTTO, 2011).

13 Note that we now distinguish the technology and the production data depending on the period.

14 To these indexes, the value 1 represents no change, while values >1 represent increase in the efficiency and <1 represents decrease (e. g., the value 1.10 represents 10% of increase and 0.95 represents 5% of decrease).

15 Higher Education Census from the National Institute of Teaching and Educational Research – INEP.

16 Improvement Coordination of People of Higher Education – CAPES.

not data from TCU.[17] They conclude that the Brazilian public universities are inefficient, especially the small and medium ones. Also, they state that small and medium groups increased their productivity among the years 2012 and 2013. These results differ from other Brazilian studies both in terms of static and dynamic analysis. As a conclusion, their findings suggested that if there were improvements in the management of HEIs, it would be possible to increase the number of students in 2,8%, increasing the Brazilian Public HE system in 36 thousands students without increasing the expenditures. Regardless of its positive aspects, there are some aspects in the study that could be improved, such as the consideration of different weights to different types of students (by course and level)[18]. Still, there are other outputs that could be considered, for example the innovation of the HEIs due to its crucial importance for the economic models of development. Also, as the global process of one HEI does not change considerably from one year to another, a period of more years could be advantageous to a dynamic analysis.

In a similar way, but using the raw variables the TCU reports and the Treasury Management System (SIAFI), Villela (2017) applies DEA and Malmquist Index to analyze 55 Brazilian Public Federal Universities to the period 2012-2015. It considers three models named by itself as 'Resource allocation efficiency', 'Target/Quality efficiency' and 'Economic efficiency'. Each one used a different combination of inputs and outputs (financial resources, equivalent professor, equivalent faculty, equivalent student, number of undergraduation degrees, cost by professor and cost by faculty). Its results suggest that 45% of the universities are between 71% and 95% of efficiency level and that the variations were in average 1% through the period. They explain that this variation occurs due to the scale change and not due to pure technical change and emphasize that the recent public policies should be reviewd focusing on more social return.

Moreover, Bittencourt et al. (2016) and Letti and Bittencourt (2017) present some contribution due to using information about registered patents as outputs. However, some limitations from these works are the use of plenty of inputs and outputs to few HEIs (resulted from grouping by size) and the consideration of 'very young' HEIs (lower than 5 years of implementation). Letti, Vila and Bittencourt (2018) partially overcame some of these limitations. Nevertheless, the work could be complemented, as it has been done now, by analyzing the HEIs' efficiencies by regions and using Malmquist index.

Methodological procedures

The focus of this work is on HEIs classified as Public Federal and as University[19].

To the specific case of the DEA Model applications, it was considered only the 56[20] Universities which had worked from 2010 until 2016 and that had some student degree in 2010. The data come primarily from: the Higher Education Census from INEP (2018); CAPES (2018); and National Institute of Industrial Property (INPI, 2018). After some hard work, it results in 9 variables which are presented in Table 1.

17 They use data from CAPES and consider four outputs (number of total students both in under and postgraduate courses, number of services activities, number of theses and dissertations summed up, and a quality index of the courses valid to under and postgraduate courses simultaneously) and two inputs (total income and full time equivalent professor).

18 For example, the structure and process required to 'produce' a medical degree is very different than that for a pedagogical degree or for an engineering degree. The TCU 'student equivalent' tries to overcome it.

19 The analyses did not consider other types of HEIs (State, Municipal and Private, nor Faculties, Federal Institutes and HE centers). All the Public Federal Universities follow the same rules of governmental funding and are enforced by law to attend the three basic HE objectives (teaching, research and third mission). The universities in the sample represent only 2.62 of all Brazilian HEIs, but representing 15.53% of all Brazilian presential undergraduate students, 53.85% of all postgraduate students, 66.28 % of the HEIs' registered patents and 30.58% of the professors engaged in third mission activities. Furthermore, the Public Federal Universities considered in this study represent in general more than half of all public HEIs.

20 Until 2016 there were more 7, 4 completely new ones, and 3 others created by disaggregation.

Table 1: Definition of the variables used in the analysis

Source:

Variable	Description
Inputs	
EXPEND	**Expenditures total (R$ million, constant prices of 2010):** Total expenditures in R$ (including expenditures with professors, staff, operational, investments, research and others) in constant prices of 2010.
PROFES	**Number of full time equivalent professors:** Permanent professors, substitute professor, visiting professors (consider only active ones) – weighted by time of work proportionaly to one professional which works 40h/week (full time = 1, partial time = 0.5), and also weighted by academic degree (doctor = 1, master = 0.6, specialist = 0.4, undergraduate level = 0.2, without undergraduate level = 0.1)
EMPLOY	**Number total of employees:** Number of permanent employees not professors, temporary contract employees not professors (considering only active ones) - it was not possible to weight by time of work due to inexistent information in INEP HE Census
Outputs	
DEGREU	**Number of full time equivalent undergraduate degrees:** Sum of all courses value to each HEI according to the equation: { NDI * (DPC/4) } * [course group weight]; In which: NDI = number of undergraduate degrees in the year; DPC = standard course duration (in years); (see SESu/MEC (2018)); Course group weight = calculated by HE governamental office considering the peculiarities of internal cost structure of each type of course (see SESu/MEC (2018)).
DEGREP	**Number of full time equivalent postgraduate degrees:** Total postgraduate degrees (master academic, master professional and doctorate courses)
THIRDM	**Number of professors enganged in third mission activities:** Number of professors with register of being engaged in third mission activities according to the INEP HE Census, basedata named DM_DOCENTE_[ANO], variable 'IN_ATU_EXTENSAO'.
PATENT	**Number of registered patents and utility models:** Number of registered patents plus number of registered utility model in which the university is the 'first depositor'

constructed from INEP (2010-2016), CAPES(2018), INPI(2018) and SESu/MEC (2018).

The descriptive statistics are presented in Table 2 and it is noticeable the large range in the size of the HEIs by considering both the standard deviation (SD) or max/min values of all variables. Table 2 also shows the representativeness by region. In general, though the variations by regions are diverse, the variables follow the same proportions in each year. The Southeast (SE) region represents almost a third of the national values, the Northeast (NE) and South (S) regions 25% and 20%, and the North (N) and Central-West (CO) near to 12% each one, respectively. In general the proportion to each variable by region is proportional to the number of HEIs, with the exception of the North region which presents lower values. The variation from 2010 to 2016 presents regional patterns different from Brazilian values, specially to variables EXPEND, PATENT and THIRDM.

Table 2: Descriptive statistics of the 56 Brazilian Public Federal Universities - 2016

Source:

	total	mean	SD	max	min	Representativeness by region in 2016 (% of Brazil)					variation from 2010 to 2016 (Δ%)					
						SE	NE	S	N	CO	BR	SE	NE	S	N	CO
N= 56						34	25	16	16	9						
EXPEND	**30.658**	**547**	**471**	**2.529**	**95**	35	25	20	7	13	**15**	2	11	38	19	30
PROFES	**73.444**	**1.311**	**823**	**3.703**	**278**	34	27	19	9	11	**37**	33	40	39	45	36
EMPLOY	**107.855**	**1.926**	**1.700**	**9.445**	**207**	37	31	15	8	10	**25**	20	34	15	30	36
DEGREU	**238.407**	**4.257**	**2.447**	**10.087**	**861**	31	28	15	15	11	**38**	38	46	22	45	41
DEGREP	**41.980**	**750**	**674**	**2.754**	**44**	37	25	21	6	11	**66**	63	62	57	96	88
PATENT	**747**	**13**	**15**	**70**	**0**	32	36	23	3	6	**160**	59	###	###	###	###
THIRDM	**30.290**	**541**	**603**	**3.153**	**1**	39	19	23	6	13	**52**	97	64	32	6	15

INEP (2010-2016), CAPES(2018), INPI(2018) and SESu/MEC (2018).

A synthesis of the evolution of the values can be observed in the third column of Table 2. All variables presented some increase from 2010 to 2016, but in different sizes. PATENT presents the highest variation, 160%, while EXPEND and expenditure with people present the lowest, 14.8% and 14.1%, respectively. The variables related to postgraduate course increased more than 60% while the undergraduate enrollments only 30.3%. On the other hand, the undergraduate degrees increased almost 40%. The total number of professors (not shown in Table 2) and EMPLOY increased similarly at 25%, but the number of PROFES (professor equivalent) increased 37.4, that is, the PROFES increased in work hours and/or in their level of qualification, as well as the number of staff with undergraduate degree (not in Table 2), that increased in 26%.

Previous to the efficiency analysis, robust techniques were used to identify and manage the outlier observations, following the recommendations and procedures of Wilson (1993, 2010) that extended the Andrews and Pregibon's (1978) statistic to the case of multiple outputs and inputs.

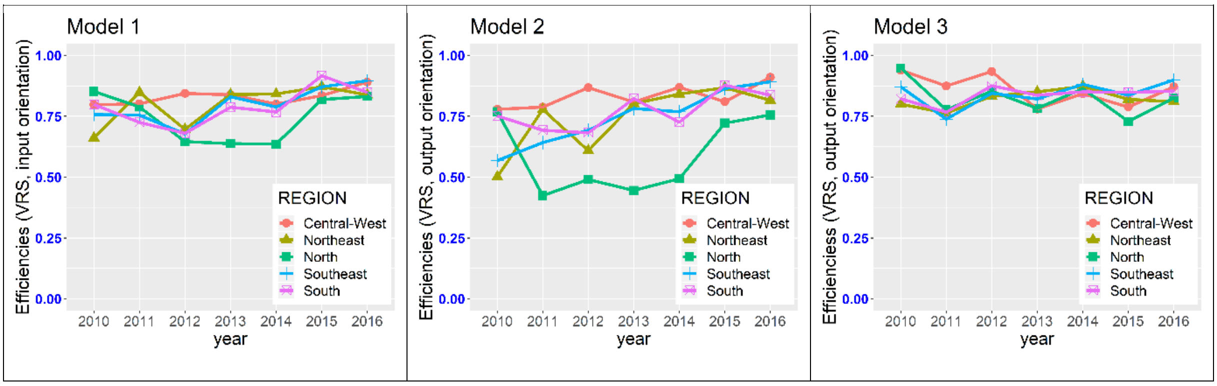
In order to reach the objectives of this research, there were used three different DEA models which consider different characteristics of the production process of higher education services: **Model 1** aims to measure the potential waste of resources and uses EXPEND as input and DEGREU, DEGREP[21], THIRDM and PATENT as output considering VRS and input-orientation; **Model 2**, as a complement, aims to measure the potential improvement in the outputs considering the same variables but with an output orientation; **Model 3** also aims to measure the outputs improvement but now by considering only physical variables as inputs (PROFES and EMPLOY) and the same four outputs. Each model was applied to each year and also to all 7-years-period (with the sum of each variable in the period). This last application was done considering both CRS and VRS. Then it was possible to identify if each universitiy was working under, over or at the optimal scale. The Malmquist index considered the annual values of the initial and the final years of the period (2010 and 2016). The results of DEA application are in the next section.

Results, analysis and discussion

The results from Model 1 showed that, including the 7-year-period as one production cycle, 26 (46.4%) of the universities were efficient. The general mean efficiency was 87.0%, and among the inefficient ones, the efficiency was 75.8%. By region, the mean efficiencies were: Central-West (92.7%), Southeast (87.3%), Northeast (87.3%), South (85.9%) and North (84.1%)[22]. For the entire period (7-year-period), the general results did not differ significantly among the three models[23]. On the other hand, when considering the analysis year by year it is possible to identify some variation among the years in the same model[24], and among the models to the same year[25]. It occurs in special when comparing Models 2 and 3. The North region also presents peculiar visual differences among the results in the Models 1 and 2[26]. The variations through time and region can be visualized in Figure 1 which presents the mean regions values by year to each model. Through regions, different patterns were observed, with the minimum value to the North in 2011 to model 2 (39%) and the maximum to the North region in 2010 to model 3 (95%). Although the values by region diverge through time, they ended up converging to efficiencies between 75% (North, model 2) and 89.7% (Southeast, also in model 2).

21 It presents very strong and statistically significant correlations with all the variables in relation to the research dimension.
22 Kruskal-Wallis test (chi-squared = 1.47, df = 4 , p-value = 0.83) suggests no differences among regions.
23 Friedman rank sum test (chi-squared = 1.39, df = 2, p-value = 0.50) suggests no statiscally significant differences among models' results.
24 Friedman rank sum test results in p-values < 0.02 to each of the three models, suggesting diferences.
25 Friedman rank sum test results in p-values <0.05 to each year with exception of 2015.
26 Nevertheless the Kruskal-Wallis test comparing regions results in p-values > 0.10, suggesting no significant difference. The lower value was found to Model 2 in the year 2013 (p-value = 0.1518).

Figure 1: HEIs efficiency means by region and year to Models 1, 2 and 3



Source: results of the research

These variations could be occurring, at least to Models 1 and 2, due to the fact that the financial values could vary a lot from one year to another for the same universities. Besides, it probably occurs because some funds from one year are accounted in the following year. Thus, the results of the values for each variable added to the 7-year-period seem to be presenting a more plausible situation. In addition, this process avoids us to consider one university as efficient (or outlier) in one year and to consider this same university as extremely inefficient in the following year[27].

Table 3 presents the results (VRS, scale value and type) for the models 1, 2 and 3 to Brazil and to each region. The geometric means of the efficiency (effic.) among the three models are almost the same when considering the entire set, but they vary among regions and, in some cases, by region among the models. The minimum value was observed to the North (0.74) in Model 2 and the maximum to the Central-West (0,94) also in Model 2.

The Malmquist index and its decomposition in the three sources of variation (technological, pure efficiency and scale) are presented in Table 4. Considering the financial inputs (Model 2) the Malmquist index suggests a high improvement in the efficiency (1.46), 1.07 due to technical change, 1.22 due to pure efficiency change, and 1.11 due to scale change. Besides, considering only human inputs (Model 3), the Malmquist value fell to 1.33, but pratically only due to the technological increase (1.29), partially compensated by the pure efficiency decrease (0.98), and with weak influence of scale increase (1.04). It suggested that even though the use of financial resources are becoming more efficient in general (even by changing the scale of values operation), the use of human resources are not increasing proportionally and, more important, are increasing due to the increase of the benchmarkings productivity (change of the technology/frontier) and not all HEI are catching up to this change (pure efficiency decrease). Finally, to human resources the effect of scale change is lower than to financial resources.

27 Because, for example, the financial expenditures from one year were actually registered in the subsequent year (in this case the first year presents quite lower use of resources and the latter year a very high use).

Table 3: Returns to scale - Brazil and regions - Models 1, 2, 3 (2010 to 2016 added)

		Model 1 (VRS, input)					Model 2 (VRS, output)					Model 3 (VRS, output)				
		Efficiency components (geom. means)		number of HEIs presenting			Efficiency components (geom. means)		number of HEIs presenting			Efficiency components (geom. means)		number of HEIs presenting		
Region	**N**	**pure**	**scale**	**IRS**	**CRS**	**DRS**	**pure**	**scale**	**IRS**	**CRS**	**DRS**	**pure**	**scale**	**IRS**	**CRS**	**DRS**
Brazil	**56**	**0,85**	**0,86**	**13**	**15**	**28**	**0,85**	**0,86**	**7**	**14**	**35**	**0,87**	**0,94**	**9**	**25**	**22**
Central-West	**5**	**0,92**	**0,77**	**0**	**0**	**5**	**0,94**	**0,76**	**1**	**0**	**4**	**0,87**	**0,92**	**0**	**1**	**4**
Northeast	**14**	**0,85**	**0,91**	**3**	**3**	**8**	**0,86**	**0,90**	**0**	**5**	**9**	**0,86**	**0,95**	**3**	**7**	**4**
North	**9**	**0,82**	**0,81**	**5**	**1**	**3**	**0,74**	**0,89**	**3**	**2**	**4**	**0,87**	**0,89**	**2**	**3**	**4**
Southeast	**19**	**0,85**	**0,89**	**3**	**9**	**7**	**0,88**	**0,86**	**1**	**6**	**12**	**0,89**	**0,96**	**2**	**9**	**8**
South	**9**	**0,83**	**0,86**	**2**	**2**	**5**	**0,87**	**0,82**	**2**	**1**	**6**	**0,83**	**0,97**	**2**	**5**	**2**

Source: results of the research

This result indicates that despite the improvement in the efficiencies in both models (45% and 33%), the decomposition of this improvement is quite different[28]. Regarding the financial values (Model 2), despite some variation in the technology frontier (7%, due to benchmarks), a lot of improvements were due to individual catch-ups (22% to pure efficiency, and 11% to scale). On the other hand, considering the human resources (Model 3), there was a greater improvement in the technological frontier (29%) but a very small improvement in scale (4%) and a negative variation in pure efficiency (-2%). In general, it could be said that the efficiency of both resources (financial and human) is improving, but due to the different sources, the first is because the universities are near the frontier which are almost static, the second is because the frontier (the benchmark universities) is changing the frontier and the other universities are only accompanying this change.

Considering the Malmquist index results to each region, it is possible to perceive some particularities[29]. First, the means of the Southeast present a pattern and values which are similar to the means of Brazil. As this region represents almost a third part of the nation, it could also be that it is actually influencing the general mean. Second, the Central-West region presents the lower Malmquist values, including the negative (-2%) to Model 3, but even so, there is a strong (21%) technological change to Model 3 and a considerable change by pure efficiency in Model 2. The higher values of scale efficiency occur to the North in both models (42% and 35%, respectively), indicating that the universities of this region are developing to a size nearer to the optimal and they are taking advantage of the scale economies. These values were small or negative to all other regions indicating that the universities, in general, were not taking advantages.

28 The Friedman test to Malmquist index between the models suggests no significant differences (p-value >0.05), despite the results to each component suggest statistically significant differences (p-values < 0.05).

29 The Kruskal-Wallis test to Model 2 (p-value = 0.33), and to Model 3 (p-value = 0.11) suggest no statistically significant diference to Malmquist indexes among regions (considering each component, only technological change in Model 3 presents p-value < 0.06, when comparing among regions).

Table 4: Malmquist index and its decomposition (2010 and 2016) to Models 2 and 3

		Model 2 Financial VRS output orientation				Model 3 Human resources VRS output orientation			
Region	N	Malmquist	Tech. change	Pure efficiency change	Scale change	Malmquist	Tech. change	Pure efficiency change	Scale change
Brazil	56	1,45	1,07	1,22	1,11	1,33	1,29	0,98	1,04
Central-West	5	1,07	0,98	1,17	0,93	0,98	1,21	0,89	0,91
Northeast	14	1,66	1,14	1,37	1,06	1,35	1,37	0,99	0,99
North	9	1,45	1,03	0,99	1,42	1,23	1,04	0,88	1,35
Southeast	19	1,49	1,07	1,31	1,06	1,44	1,39	1,03	1,01
South	9	1,23	1,04	1,10	1,07	1,33	1,32	1,06	0,95

Source: results of the research

Considering the pure efficiency values among the regions, the patterns were diverse to each model. For the financial inputs, only the North region presents no evolution in this component, while considering human resources, only the Southeast and the South present positive values, and, even so, very small ones (3% and 6%). This situation reflects just the national situation presented. Results also suggest that R$ 2.96 billion by year were wasted due to inefficiency, and if they were used efficiently, it would result in an additional 11.6% on undergraduate (23,301 students by year), 8.7% on postgraduate (2,984 students by year), 8.5% on third mission activities (2,249 professors enganged by year), and 7.7% on registered patents (39 registers by year). In addition, by considering only the human resources as inputs, the improvement could be 9.0%, 7.1%, 6.9%, and 5.1%, respectively.

Taking what has been presented into consideration, these results could be calculated and identified to each university and these values could be used as a target by the policymaker or university managers to subsidize their activities. This objective is beyond the scope of this work and it could be focus of future research.

Final remarks

The main objective of this research was to study the relative efficiency of the Brazilian Public Federal Universities for the period of 2010 to 2016 and analyze also the regional patterns of their efficiency. It was done by using DEA models and Malmquist index. Overall, the results showed that, considering the entire period, 26 (46.4%) of the universities were efficient presenting higher mean efficiency (87%) to Brazil and by region: Central-West (93%), Northeast (87%), North (84%), Southeast (87%) and South (86%).

The values were also calculated by year and they presented a lot of variation among years and models when considering each university. Because of this, it was necessary to use and explore in more details the values of efficiencies by considering the entire 7-year period as the same production cycle. In addition, it was also perceived that, in general terms, the efficiency is improving through time and that it seems to occur due to different factors in relation to financial resources and human resources. Regarding the financial resources, the technological frontier is almost static, the universities are actually becoming more efficient, and only the North region is taking advantage from the scale change. On the other hand, for the human resources, it seems that the frontier is changing (the benchmarks are improving) and the majority of the universities are not accompanying these changes.

As a following stage in this research agenda, it would be a great contribution to consider quality and contextual variables, as well as search for potential determinants which might better explain the performance of the institutions.

Aknowledgement

This work received a grant by CAPES, Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil.

References

AGASISTI, T.; DAL BIANCO, A. Data envelopment analysis to the Italian university system: theoretical issues and policy implications. **Int. J. Business Performance Management**, v. 8, n. 4, p. 344-367, 2006. Retrieved from: <https://econpapers.repec.org/article/idsijbpma/v_3a8_3ay_3a2006_3ai_3a4_3ap_3a344-367.htm>. Access on: 20 jun. 2018.

AGASISTI, T.; SALERMO, C. Assessing the cost efficiency of Italian universities. **Education Economics**, v. 15, n. 4, p. 455-471, 2007. Retrieved from: <http://dx.doi.org/10.1080/09645290701273491>. Access on: 20 jun. 2018.

AGASISTI, T.; JOHNES, J. Beyond frontiers: comparing the efficiency of higher education decision-making units across more than one country, **Education Economics,** v. 17, n. 1, 59-79, 2009. Retrieved from: <http://dx.doi.org/10.1080/09645290701523291>. Access on: 20 jun. 2018.

ALESKEROV, F. T.; BELOUSA, V. Y.; PETRUSHCHENKO, V. V. Models of data envelopment analysis and stochastic frontier analysis in the efficiency assessment of universities. **Automation and Remote Control**, v. 78, n. 5, p. 902–923, may 2017. Retrieved from: <https://doi.org/10.1134/S0005117917050125>. Access on: 20 jun. 2018.

ANDREWS, D. F.; PREGIBON, D. Findingt he OutliersT hat Matter, Journal of the Royal Statistical Society, Ser. B, v. 40, p. 85-93, 1978.

BANKER, R. D.; CHARNES, A.; COOPER, W. W. Some models for estimating technical and scale inefficiencies in data envelopment analysis. **Management Science**, v. 30, n. 9, p. 1078–1092, 1984. Retrieved from: <https://doi.org/10.1287/mnsc.30.9.1078 >. Access on: 20 jun. 2018.

BITTENCOURT, M. V. L.; GOMES, L. C.; LETTI, A. G.; BRAGANÇA, R. C.. University and Regional Development: Efficiency of Brazilian Universities. Congress of ***European Regional Science Association (ERSA)*** , *47º*, **Anais**..., Viena, Áustria, 23-26 ago. 2016.

BLANCHARD, O. The economic future of Europe, **National Bureau of Economic Research**, NBER Working Paper, n. 10310, March 2004. Retrieved from: <http://www.nber.org/papers/w10310>. Access on: 20 jun. 2018.

BOGETOFT, P.; OTTO, L. **Benchmarking with DEA, SFA, and R**. International Series in Operations Research and Management Science. Springer, 2011.

CAPES (2018). GEOCAPES – **Sistema de Informaçãoes Georreferenciadas**. Retrieved from: <https://geocapes.capes.gov.br/geocapes/>. Access: 20 jun. 2018.

CAVES, D. W.; CHRISTENSEN, L. R.; DIEWERT, W. E. (1982) The economic theory of index numbers and the measurement of input, output, and productivity. **Econometrica**, v. 50, n. 6, p. 1393–1414, nov. 1982. Retrieved from:<https://aae.wisc.edu/aae741/Ref/Caves%20Econometrica%201982.pdf>. Access on: 20 jun. 2018.

CHARNES, A.; COOPER, W. W.; RHODES, E. Measuring the efficiency of DMUs. **European Journal of Operational Research**, v. 2, n. 6, p. 429–444, 1978. Retrieved from: <https://doi.org/10.1016/0377-2217(78)90138-8>. Access on: 20 jun. 2018.

DANTZIG, G. B. Maximization of a linear function of variables subject to linear inequalities. In T. KOOPMANS, C. (Ed.). **Activity analysis of production and allocation**. New York: Wiley, 1951.

DUENHAS, R. A.; FRANÇA, M. T. A.; ROLIM, C. F. C. A expansão do número de matrículas no ensino superior é possível? Uma análise estática e dinâmica da eficiência na gestão das universidades públicas brasileiras. **Espacios**, Caracas-Venezuela, v. 36, n23, p. E-1, 2015. Retrieved from: <http://www.revistaespacios.com/a15v36n23/153623E1.html>. Access on: 20 jun. 2018.

FARREL, M. The measurement of productive efficiency. **Journal of the Royal Statistical Society**, Series A, v. 120, p. 253–281, 1957.

FÄRE, R.; GROSSKOPF, S.; LINDGREN, B; ROOS, P. (1992). Productivity changes in Swedish pharamacies 1980–1989: A non-parametric Malmquist approach. **Journal of Productivity Analysis**, v. 3, n.1-2, p. 85-101, jun. 1992. Retrieved from:<https://doi.org/10.1007/BF00158770>. Access on: 20 jun. 2018.

FÄRE, R.; GROSSKOPF, S.; NORRIS, M.; ZHANG, S. (1994) Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries, **The American Economic Review**, v. 84, n. 1, p. 66-83, mar. 1994. Retrieved from:<https://www.jstor.org/stable/2117971?seq=1#page_scan_tab_contents>. Access on: 20 jun. 2018.

FORSUND, F. Economic interpretation of DEA. **Socio-Economic Planning Sciences**, v. 61, march 2018, p. 9-15. Retrieved from: <https://doi.org/10.1016/j.seps.2017.03.004>. Access on: 20 jun. 2018.

FORSUND, F. R.; KITTELSEN, S. A. C.; KRIVONOZHKO, V. E. (2009). Farrel revisited – visualizing properties of dea production frontiers. **Journal of the Operational Research Society**, v. 60, p. 1535-1545. Retrieved from: <https://www.tandfonline.com/doi/full/10.1057/jors.2008.185>. Access on: 20 jun. 2018.

IBGE–Instituto Brasileiro de Geografia e Estatística. **Censo Demográfico 2010**. Rio de Janeiro, [2010].

INEP – Instituto Nacional de Pesquisas Educacionais Anísio Teixeira. **Indicadores Financeiros Educacionais**. 2017. Retrieved from: <http://portal.inep.gov.br/indicadores-financeiros-educacionais>. Access on: 20 jun. 2018.

INEP. Censo da Educação Superior. **Microdados**. 2018. Retrieved from: <http://portal.inep.gov.br/web/guest/censo-da-educacao-superior>. Access on: 20 jun. 2018.

INPI (2018). Estatística. Indicadores de Propriedade Industrial. Dowload das tabelas completas. Retrieved from: <http://www.inpi.gov.br/sobre/estatisticas>. Access on: 20 mar. 2018.

JOHNES, J. Efficiency measurement. Cap. 16, 613-742. In: JOHNES, G.; JOHNES, J. **International Handbook on the Economics of Education**. Cheltenham-UK, Edward Elgar Publishing, 2004.

JOHNES, J. Data envelopment analysis and its application to the measurement of efficiency in higher education. **Economics of Education Review**, v. 25, n. 3, p. 273-288, June 2006. Retrieved from: <https://doi.org/10.1016/j.econedurev.2005.02.005>. Access on: 20 jun. 2018.

JOHNES, J.; JOHNES, G. Efficiency in the higher education sector: a technical exploration. **BIS Research Paper,** n. 113, September 2013. Retrieved from: <http://dera.ioe.ac.uk/18264/1/bis-13-918-efficiency-in-higher-education-sector.pdf>. Access on: 20 jun. 2018.

JOHNES, G.; TONE, K. The efficiency of higher education institutions in England revisited: comparing alternative measures. **Tertiary Education and Management**, v. 23, n. 3, p. 191-205, 2017. Retrieved from: <https://doi.org/10.1080/13583883.2016.1203457>. Access on: 20 jun. 2018.

LETTI, A. G.; BITTENCOURT, M. V. L.; Regional development and the relative efficiency of Brazilian Universities. Congress of *European Regional Science Association (ERSA)*, *48º*, **Anais**..., Groningen, Netherlands, 28 ago./01 set., 2017.

LETTI, A. G.; VILA, L. E.; BITTENCOURT, M. V. L.; The relative efficiency of Brazilian Public Universities (2010 - 2016): an analysis through time and space. Congresso da ***European Regional Science Association (ERSA)*** , *49º*, **Anais**..., Cork, Ireland, 28 ago./01 set., 2018.

MALMQUIST, S. Index numbers and indifference curves. **Trabajos de Estatistica**, v. 4, n. 1, p. 209–242, 1953.

OECD. **Education at a Glance 2015**: OECD Indicators. OECD Publishing, 2015. Retrieved from: <www.oecd.org/education/education-at-a-glance-19991487.htm>. Accessed in: 20 jun. 2018.

SAMPAIO, Carlos Eduardo Moreno – **Diretoria de Estatísticas Educacionais**. 26 abril 2017. Retrieved from: <http://www.andifes.org.br/wp-content/uploads/2017/04/INEP-Censo-da-Educa%C3%A7%C3%A3o-Superior-Andifes-16042017.pdf>. Access on: 20 jun. 2018.

SESu/MEC. **Orientações para o cálculo dos indicadores de gestão**. Decisão TCU n. 408/2002-Plenário. Versão revisada em março/2004. 2018. Retrieved from: <http://portal.mec.gov.br/sesu/arquivos/pdf/indicadores.pdf>. Access on: 20 jun. 2018.

SHEPARD, R. W. **Theory of cost and production functions**. Princeton University Press: New Jersey, 1970.

TACHIBANA, T. Y.; MENEZES-FILHO, N.; KOMATSU, B. Ensino superior no Brasil. Insper – Centro de Políticas Públicas. **Policy Paper**, n. 14. Dezembro, 2015.

THANASSOULIS, E.; KORTELAINEN, M.; JOHNES, G.; JOHNES, J. Cost and efficiency of higher education institutions in England: a DEA analysis. **Journal of the Operational Research Society**, v. 62, n. 7, p. 1282–1297, July 2011. Retrieved from: <https://doi.org/10.1057/jors.2010.68 >. Access on: 20 jun. 2018.

TONE, K. A slacks-based measure of efficiency in data envelopment analysis. European Journal of Operational Research, 130, 498-509, 2001.

VILA, L. E. The non-monetary benefits of education. European Journal of Education, 35,1, p. 21-32, 2000. Retrieved from: <https://www.jstor.org/stable/1503615>. Access on: 20 jun. 2018.

VILLELA, J. A. Eficiência universitária: uma avaliação por meio de Análise Envoltória de Dados. 2017. 81 f., il. **Dissertação** (Mestrado Profissional em Economia)—Universidade de Brasília, Brasília, 2017.

WILSON, P. W. Detecting outliers in deterministic nonparametric frontier models with multiple outputs, **Journal of Business and Economic Statistics**, 11, 319–323, 1993.

WILSON. P. W. Detecting Outliers in Deterministic Nonparametric Frontier Models with Multiple Outputs: Correction. **Unpublished working paper**, Department of Economics, Clemson University. 2010. Retrieved from: <http://media.clemson.edu/economics/faculty/wilson/Papers/ap-corrected.pdf>. Access on: 20 jun. 2018.