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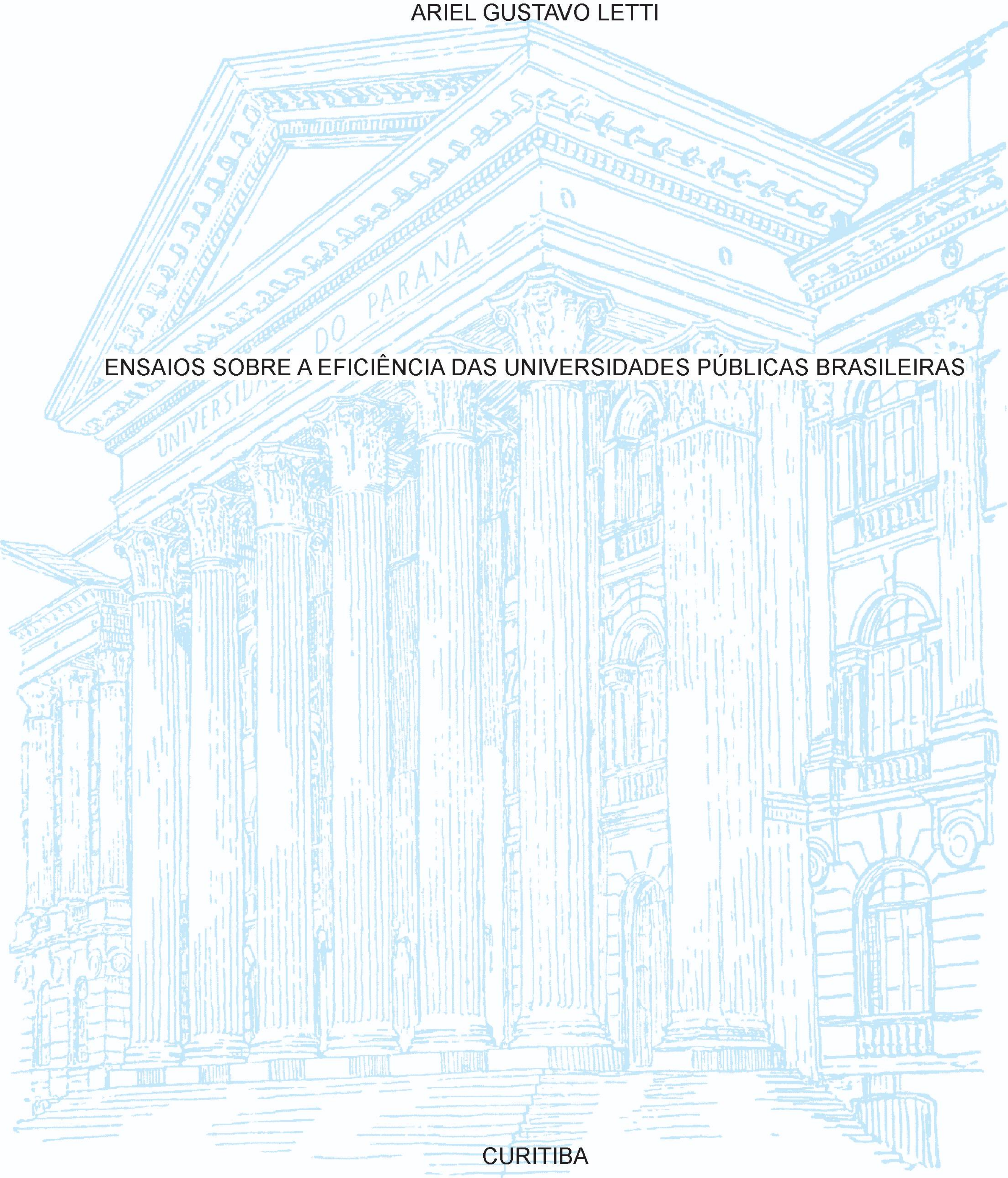

ENSAIOS SOBRE A EFICIÊNCIA DAS UNIVERSIDADES PÚBLICAS BRASILEIRAS

CURITIBA

2019

ARIEL GUSTAVO LETTI

ENSAIOS SOBRE A EFICIÊNCIA DAS UNIVERSIDADES PÚBLICAS BRASILEIRAS

Tese apresentada ao Programa de de Pós-Graduação em Desenvolvimento Econômico, Setor de Ciências Sociais Aplicadas, da Universidade Federal do Paraná, como requisito parcial à obtenção do título de Doutor em Desenvolvimento Econômico.

Orientador: Prof. Dr. Mauricio Vaz Lobo Bittencourt

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Aos meus professores

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“só sei que nada sei”

(atribuído a Sócrates)

“essentially, all models are wrong, but some are useful”

(George E. P. Box apud Luis E. Vila)

RESUMO

Eficiência pode ser entendida como a razão entre a produção atual e a máxima produção possível dados os recursos disponíveis pela unidade produtora. Esse tema torna-se relevante no contexto das instituições públicas de ensino superior no Brasil, considerando o seu recente contingenciamento financeiro e suas idiossincrasias regionais. Assim, utilizou-se da teoria microeconômica a fim de modelar a universidade como uma unidade produtiva, a qual usa recursos (inputs) para obter resultados (outputs). Internacionalmente o tema da eficiência das instituições de ensino superior (IES) tem sido abordado usando tanto análise de fronteira estocástica (SFA) quanto análise envoltória de dados (DEA). Entretanto, esses métodos nem sempre apresentam resultados coincidentes em relação à eficiência das unidades produtivas avaliadas e não existe um critério único para a seleção da abordagem mais adequada. Além disso, para as IES brasileiras existem apenas estudos usando DEA. Nesse contexto, o presente estudo mensura e compara a eficiência das 56 universidades federais brasileiras no período de 2010 a 2016. Primeiramente, são analisados criticamente os trabalhos que tentam avaliar a eficiência das IES brasileiras. Depois, são utilizados modelos DEA e SFA para estimar as eficiências das IES brasileiras considerando a natureza de multi-produtos e multi-recursos característica desse sistema produtivo. Finalmente, foram comparados os resultados e identificadas suas similaridades e discrepâncias. As variáveis utilizadas como produtos e recursos das IES consideram simultaneamente as três dimensões da atividade universitária - ensino, pesquisa e extensão. Foram consideradas diferentes combinações de: i) cinco produtos - alunos graduados, alunos pós-graduados, atividades de extensão, registro de patentes e nota CAPES; e ii) três recursos produtivos - valores financeiros, professores e servidores técnico-administrativos. As fontes dos dados utilizados foram o Censo do Ensino Superior do INEP/MEC, a CAPES, o INPI e os relatórios anuais de gestão entregues pelas IES ao Tribunal de Contas da União (TCU). Assim, essa pesquisa pode ser considerada como inovadora principalmente devido: (i) ao uso de SFA para estimação das eficiências da IES brasileiras; (ii) à comparação entre os resultados dos modelos DEA e SFA; e (iii) ao uso de variáveis para tentar mensurar atividades de extensão e inovação. Os resultados da pesquisa apontam para a existência de ineficiência relativa no sistema federal de ensino superior, sendo que tais ineficiências parecem não mudar ao longo do tempo e parecem estar relacionadas com características das universidades e regiões onde se situam. O valor e o ranking das eficiências estimadas são sensíveis ao método empregado e apresentam correlação fraca e estatisticamente significativa. A abordagem de SFA parece apresentar mais coerência com a realidade das IES brasileiras, pois esta permite considerar variações aleatórias nas variáveis. Entretanto, como já observado em estudos para sistemas de ensino superior de outros países, é preciso muito cuidado quando do uso de um único método para analisar o setor e subsidiar ações de políticas públicas. Deste modo, recomenda-se o uso e comparação de diferentes métodos para obtenção de resultados mais confiáveis.

Palavras-chave: Eficiência. Ensino Superior. Fronteira Estocástica. Análise Envoltória. Brasil.

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. It became a critical topic when considering the importance of Public Institutions in the Brazilian Higher Education system, especially in the context of its current financial stringency and its regional idiosyncrasies. The microeconomic theory is used to model the university as a production unit, which uses resources (inputs) to obtain results (outputs). Frontier production methods such as Stochastic frontier analysis (SFA) and Data envelopment analysis (DEA) have often been used to evaluate efficiency in the context of higher education institutions (HEI). However, according to international investigations, the results of these two approaches are not always uniform and there are no established methods or criteria for choosing one or the other. Regarding Brazilian HEIs, until now, only DEA was used in research. Taking that into consideration, this study aims to compare efficiency scores obtained by SFA and DEA models for all the existing 56 Brazilian federal universities for the period of 2010 to 2016. First, the literature about the application of DEA regarding Brazilian universities is critically analyzed. Then, the efficiencies considering DEA and SFA are calculated using empirical models which consider the multi input and multi output characteristics of the higher education production process. Finally, these results are compared and their similarities and discrepancies are analysed. The variables used as inputs and outputs hold simultaneously the three dimensions of university activities - teaching, research and third mission activities. This study also considers different combinations of: (i) five outputs - under- and postgraduate degrees, professors engaged in third mission activities, registered patents and CAPES index; and (ii) three inputs - financial resources, professors and staff. The data came primarily from INEP Higher Education Census, CAPES, INPI and the reports done by the universities to the Brazilian Federal Court of Audit (TCU). Because of all these elements, this investigation can be considered innovative mainly due to: (i) the estimation of SFA to Brazilian HEIs, (ii) the comparison between results from DEA and SFA models; and (iii) the use of patents and third mission variables. The findings suggest a relative inefficiency in HEI production with no general change through time and with some influence from environmental variables. The values and the ranking of the efficiencies calculated are sensitive to the model or method employed, presenting highly significant but weak correlations. The SFA approach seems to present a higher coherence with the Brazilian HEIs context because this approach allows the existence of noise in the variables. However, as advised by other international comparative analyses, caution is required when applying the results for management and policy purposes, being thus recommended the use and comparison of different methods as a way to reach more trustworthy results.

Keywords: Efficiency. Higher Education. Stochastic Frontier. Data Envelopment. Brazil.

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LIST OF ABBREVIATIONS AND ACRONYMS

AE	number of students equivalent
AIC	Akaike information criterion
ATIPE	full time student by equivalent professor
ATIFECHU	full time student by equivalent employees with HU
BC92	Battese and Coelli (1992)
BC95	Battese and Coelli (1993, 1995)
BCC	Banker, Charnes and Cooper (1984)
BIC	bayesian information criterion
CAPES	Coordination for the Enhancement of Higher Education Personnel
CCAPES	quality index of postgraduate courses
CCCHU	current cost with HU (university hospitals)
CCCHUAE	current cost with HU by equivalent student
CCR	Charnes, Cooper, and Rhodes (1978)
CHU	with university hospital
CO	Center-West
COLS	corrected ordinary last squares
CRS	constant returns to scale
CV	coefficient of variation
DEA	data envelopment analysis
DEGREP	number of full time equivalent postgraduate degrees
DEGREU	number of full time equivalent undergraduate degrees
DMU	decision making unit
DRS	decreasing returns to scale
DSBM	dynamic slack based measure
EC	efficiency change
EMPLOY	number of employees
ENROLP	number of postgraduate enrollments
ENROLU	number of full time equivalent undergraduate enrollments
EXPEND	expenditures total (R$ million, constant prices of 2010)
FECHU	number of full time equivalent employees, with HU
FUNCEQSHU	number of full time equivalent employes, without HU
FGLR	Fare, Grosskopf, Lindgren and Roos (1992)

FGNZ	Fare, Grosskopf, Norris and Zhang (1994)
HEI	higher education institution
HU	university hospital
IRS	increasing returns to scale
INEP	National Institute of Teaching and Educational Research
INPI	National Institute of Industrial Property
IQCD	qualification of teaching staff index
LR	loglikelihood ratio
MCDM	multi criteria decision making
N	North
NE	Northeast
NEWSF	fixed-HEI dummy variable relative to year of federalization
NIRS	non-increasing returns to scale
OLS	ordinary last squares regression
PROFEQ	equivalent full time professors
PROFES	number of full time equivalent professors
PATENT	number of registered patents and utility models
PE	number of full time equivalent professors
PEC	pure technical efficiency change
REGION	dummy variables relative to Brazilian regions
S	South
SD	standard deviation
SE	Southeast
SBM	slack based measure
SCE	scale efficiency
SEC	scale efficiency change
SFA	stochastic frontier analysis
SHU	without university hospital
TC	technical change
TCU	Brazilian Federal Court of Audit
THIRDM	number os professors engaged in third mission activities
TSG	student degrees by registered students
VRS	variable returns to scale
YEAR	time variable

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1 INTRODUCTION

Efficiency is understood here as the capacity to produce the maximum results given the available resources. It is considered in relation to the maximum results empirically observed (and not a theoretical or hypothetical value). This way, the efficiency here considered is a relative efficiency in the sense that it compares each university with its efficient pairs in order to calculate/estimate its efficiency. This theme has been extensively studied in Economics and has become of an increasing importance to the public services provided by the government. It includes the study of the efficiency of higher education institutions (HEIs). Both education and efficiency in providing public services can be considered important factors to economic development. They present positive effects which are direct, indirect and inter-generational, as well as monetary and non-monetary effects to the entire society.

The approach of microeconomic theory allows researchers to model the university as a production unit that uses resources (inputs) to obtain results (outputs). In the models adopted throught this research, the inputs considered are only the financial ones and/or the human ones (professors and staff) and the outputs are those related to teaching, research, third mission and/or innovation. It may be considered a simplification of all direct and indirect overall results of a university (for example, the social and economic effects on the regions). Nevertheless, this is the same simplification generally considered by the university efficiency literature.

In the background of production frontiers, the efficiency of HEIs has been internationally studied considering two main methods: Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). This way, considering HEIs as a whole, the investigations of Brazilian HEIs have used only DEA, and it has followed basically two ‘schools’: one using the evaluation indexes from the TCU higher education institutions reports, the other using information from the Higher Education Census from the National Institute of Teaching and Educational Research (INEP). Taking these aspects into consideration, the present piece of research aims to fill this gap of investigation by applying both methods and data sources to federal universities (Appendix A), as well as by comparing the different results obtained. In Brazil, all federal universities are public, that is, students do not need to pay (a fee or tuition) in order to attend courses. In addition, federal universities should follow the same rules of governmental funding and are enforced by law to attend the three basic HE objectives (teaching, research and third mission). In addition, efficiency is a constitutional assumption of all public services provision, which includes higher education. Furthermore, in the context of almost constant stringency in the government budget, an investigation related to efficiency in the federal universities is of critical importance. In order to reach such goal, three independent essays with a similar line of investigation are presented here. This being said, an overview of what each article generally entails is given in the following paragraphs.

In the first essay, the literature about Brazilian HEIs efficiency is investigated in details and, after characterizing and categorizing the pieces of research encountered, some criticism about the investigations is presented. In addition, an exercise of comparing the most common method found with an alternative method (DEA with indices values versus DEA with raw values) is also presented, considering data from 2007, in order to allow a comparison with one of the most cited and followed Brazilian study.

The second essay continues with the DEA approach though now investigating the period of 2010 to 2016, comparing the efficiencies among Brazil´s five regions. This examination also presents an innovation - it considers information about registered patents and third mission activities from the universities, something not yet unveiled by other studies in Brazil. Efficiencies are thus calculated and compared considering models with and without financial inputs. Furthermore, the scale efficiency of the universities is also investigated, as well as the decomposition of the changes through time (technological, scale, and pure efficiency effects).

Finally, in an attempt to overcome a limitation of former Brazilian investigations, the third essay considers the possibility of existing noise in the data and, therefore, aims to discuss its influence on the efficiency measurement. This way, an econometric approach is presented by estimating a translog output distance function. Panel data from 2010 to 2016 to the Brazilian federal universities are used and the results are compared with parallel DEA models applied to the same data. This exercise, in addition to the models presented in the second essay, considers one more variable, CAPES index of postgraduate programs, in an attempt to capture some qualitative aspects regarding universities' teaching and research dimensions.

Taking into consideration what has been here proposed, the present study has made it possible to compare the results of different models, approaches and data sources. Aiming to contribute with the investigation, debate, design, selection and implementation of public policies in the context of the Brazilian higher education system, it is hoped that this piece of research may serve to move the area further.

2 SEARCHING FOR THE LOST EFFICIENCY: A REVIEW ABOUT BRAZILIAN UNIVERSITY PERFORMANCE EVALUATION[1]

ABSTRACT

The recent context of fiscal stringency and contingency in Brazilian economy has highlighted the theme of efficiency in public services, including those provided by the federal universities. Thus, the aim of this work was at first to analyze the literature about the application of Data Envelopment Analysis (DEA) to Brazilian universities. It also aimed to apply and compare the results among empirical models which consider diverse characteristics of the higher education production process. More specifically, the study compared the 2007 year results of Costa, Ramos and Souza considering 'raw values' instead of 'index values', BCC model instead of SBM-Min model, as well as different grouping criteria. The database came from the reports done by universities to the Brazilian Federal Court of Audit (TCU) in 2007. It is the first work that, following those guidances, empirically compared results between models using 'index values' versus 'raw values' from TCU reports. Overall, the results emphasized that the use of 'index values' resulted in multi criteria decision making (MCDM) performance measures, not in efficiency measures. Therefore, caution is required when using these results in any policy context.

Keywords: Higher Education. Efficiency. Performance. Data Envelopment Analysis. Brazil.

RESUMO

O atual contexto brasileiro de contingenciamento fiscal ressalta a importância da eficiência dos serviços públicos, incluindo os serviços educacionais prestados pelas universidades federais. Assim, o objetivo deste estudo foi inicialmente revisar a literatura sobre o uso de Análise Envoltória de Dados (DEA) para as universidades brasileiras. Além disso, resultados empíricos de diferentes modelos DEA foram comparados com base nos resultados de Costa, Ramos and Souza para dados do ano de 2007, considerando-se modelos que usam 'valores brutos' versus modelos que usam 'valores indices', modelos BCC versus SBM-Min, além de modelos com diferentes critérios de agrupamento. Para tanto, foram utilizados dados dos relatórios do ano de 2007 entregues ao Tribunal de Contas da União (TCU) pelas universidades. Este é o primeiro trabalho que, seguindo tais recomendações, empiricamente compara os resultados entre modelos que usam 'valores índices' e modelos que usam 'valores brutos' das prestações de contas ao TCU. De modo geral, tem-se que o uso de 'valores índices' resultam em uma análise multi-critério de decisão (MCDM) de performance e não necessariamente em medidas de eficiência. Desse modo, recomenda-se cautela quando do seu uso para políticas públicas.

Palavras-chave: Ensino Superior. Eficiência. Performance. DEA. Brasil.

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2.1 INTRODUCTION

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 course system in that year (SAMPAIO, 2017, p. 28). In addition, only recently a great part of the Brazilian young population has started a secondary course (IBGE, 2010) and will, potentially, be able to go to universities.

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). Considering the financial values, in the 21st century the Brazilian expenditures in public higher education has increased by a mean of 2.5% a year, which represents approximately 0.8% of the GDP in each year and an equivalent value of USD $ 14 billion in 2016 (INEP, 2017).

Inefficiency in higher education institutions raises a concern among policymakers and institutional administrators, as good performance in higher education is believed to produce growth effects (BLANCHARD, 2004). Also, its monetary and non-monetary benefits overall present strong external effects on the entire society (VILA, 2000; MORA; VILA, 2003). Since institutions may differ in their efficiency levels, “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).

Taking that into consideration, Aleskerov, Belousova and Petruschenko (2017) systematized the empirical results on efficiency studies applied to HEIs around the world and their findings suggested the use of Data Envelopment Analysis (DEA) for most studies. Some examples of the empirical application of DEA to HEIs around the world are Agasisti and Dal Bianco (2006) and Agasisti and Salermo (2007) to Italy, McMillan and Chan (2006) to Canada, Johnes (2006, 2008) and Thanassoulis et al. (2011) to England, Worthington and Lee (2008) to Australia, Pohl and Kempkes (2010) to Germany, Cinar (2013) to Turkey, Ruiz, Segura and Sirvent (2015) to Spain and Agasisti and Johnes (2018) comparing Spain and England.

No regarding the terms, efficiency and performance have been commonly used as synonymous; however, in some cases each one assumes particular meanings. This distinction is especially important in DEA, which can be used to study both efficiency and performance. This is because “while the DEA frontier can rightly be viewed as a production frontier”, being thus used to measure relative efficiency, “it must be remembered that ultimately DEA is a method for performance evaluation and benchmarking against best-practice”, being also used as a multi criteria decision making (MCDM) tool (COOK; TONE; ZHU, 2014, p. 1).

Therefore, the main objective of this work was to both present and criticize, following Cook, Tone and Zhu’s (2014) guidance, the Brazilian literature about HEIs efficiency which uses DEA. Furthermore, by using the same data source from Costa, Ramos and Souza (2010) - which is considered the most robust Brazilian work - this investigation aimed to carry out an empirical comparative exercise considering the results from different model specifications (type of DEA model, type of variables and type of HEIs grouping).

This being said, the study is here organized into five sections of which this introduction is the first. Subsequently, section 2 presents the fundamentals of the DEA framework, then section 3 is a critical analysis of the Brazilian literature, while section 4 presents the comparative exercise results. Final remarks are finally drawn in section 5.

2.2 THEORETICAL BACKGROUND: EFFICIENCY AND DEA

Efficiency – a key term in the present investigation - is defined, “from an output-oriented[2] 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, p. 274)[3]. Charnes, Cooper, and Rhodes (1978) (named CCR), following Dantzig (1951) and Farrell (1957), developed a strategy to measure the

2 The output-oriented model measures the efficiency keeping the inputs fixed and maximizing the outputs; differently, the input-oriented model measures the efficiency keeping the outputs fixed and minimizing the inputs.

3 According to Forsund (2018, p. 4), 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 a 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.”

efficiency of firms with DEA considering constant returns to scale (CRS)[4]. After them, Banker, Charnes and Cooper (1984) (named BCC) modified the DEA model to incorporate the variable returns to scale (VRS) keeping the model solvable by using linear programming (JOHNES, 2006).

Considering that, Forsund, Kittelsen and Krivonozhko (2009, p. 1540) affirmed that "the three postulates introduced by BCC, convexity, free disposability and tightness of envelopment [...] are the most reasonable assumptions for a production possibility set"; in addition, as they pointed out, "researchers in the field universally accept these conditions". Johnes (2006, p. 274) has also clarified that in a multi-output and multi-input production context, DEA provides estimates of the distance function (SHEPARD, 1970), which is a generalization of the single output production function.

On the other hand, considering practical implications, Johnes (2004, p. 663) presented DEA as a deterministic non-statistical non-parametric technique which "can provide information on realistic targets for an inefficient institution", in addition to "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." Therefore, as it may be noticed, different researchers have attempted to complement the interpretation of DEA in the literature. More information about DEA's background, foundations, advantages and drawbacks, with an emphasis to its empirical application in HEIs, can be found, for instance, in Johnes (2004, 2006) and Forsund (2018). The following paragraphs are then an attempt to explain the basics of DEA methodology, which served as the background for this study.

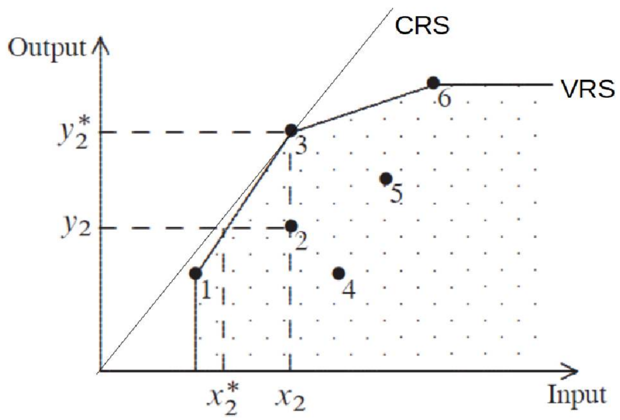
To begin with, a very general idea about the definition of a frontier can be found in Figure 1. It presents six decision making units (DMU) that use one input (x axis) to produce one output (y axis). The DMU 3 is the most productive (y produced by x used) and it is also the benchmark unit when considering CRS. Differently, the DMUs 1, 3 and 6 are the benchmarks when considering VRS. The VRS frontier is defined by the linear combination of the DMUs benchmark. The DMUs in the frontier were thus considered relatively efficient in relation to the other DMUs in the analysis.

4 CRS occurs when, considering a variation in the inputs, the outputs vary proportionally. VRS occurs 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) (BOGETOFT; OTTO, 2011).

Therefore, the efficiency measured is reference-set dependent, that is, “the measure is determined only by its reference set and not by statistics over the whole data set.” (TONE, 2001, p. 508). This way, the relative efficiency calculated here is in relation to the universities considered in the set specifically to the year analyzed, that is, federal universities for the year 2007.

Then, the relative efficiency of the DMUs 2, 4 and 5 can be estimated in comparison to the VRS frontier by calculating the efficiency with input orientation (how much the inputs should be reduced, maintaining the output constant, to reach the frontier) or with output orientation (how much the outputs should be improved, maintaining the input constant, to reach the frontier).

FIGURE 1 – EXAMPLES OF DEA FRONTIERS (CRS AND VRS)



SOURCE: adaptaded from Bogetoft and Otto (2011, pag. 12)

For example, the DMU 2 should reduce its inputs from x_2 to x_2^* (input orientation) or then improve its outputs from y_2 to y_2^* (output orientation) to reach the VRS frontier. In the first case, the ‘benchmarking production’ is defined by the combination of DMUs 1 and 3 and, in the second case, the ‘benchmarking production’ is exactly the same of DMU 3. Then, considering input orientation, the relative efficiency can be calculated as the proportion of x_2^* in relation to x_2 and interpreted as the proportional use of inputs to ‘transform’ the DMU in a relatively efficient one. On the other direction, considering output orientation, the relative efficiency can be calculated as the proportion of y_2 in relation to y_2^* and it can be interpreted as the produced proportion in relation to the potential production. This simplified example can be expanded to a multi-input and multi-output analysis defining n-dimensional frontiers and calculating the relative efficiency of the DMUs by comparing the distances of each DMU to that n-dimensional frontier.

Now, it seems important to highlight some assumptions about the production function considered not only in the example just presented, but also in this research and in the overall literature: (i) the DMUs follow the same technology; (ii) the DMUs are homogeneous in relation to the technology; and (iii) the production function presents monotonicity in relation to inputs. These assumptions are essential for validating the model used and making it possible for conclusion to be made.

In the context of production process and production functions, Tone (2001, p. 502) emphasizes that “the important characteristic of DEA is its dual side which links the efficiency evaluation with the economic interpretation”. 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)”.

Then, the standard primal problem in contemporary DEA literature using BCC model and output orientation is the one in Eq. 1 (FORSUND, 2018, p. 4). Furthermore, Thanassoulis et al. (2011, p. 1297) presented both output-oriented and input-oriented models (Eq. 1 and Eq. 2). According to them, in order to calculate the efficiency considering that DMUs[5] 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)	Input-oriented (VRS)
Maximize ϕ_k (Eq. 1) subject to $\phi_k y_{rk} - \sum_{j=1}^{n} \lambda_j y_{rj} \leq 0$ for $r=1,\dots,h$ $x_{ik} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0$ for $i=1,\dots,m$ $\sum_{j=1}^{n} \lambda_j = 1$, $\lambda_j \geq 0$ $\forall j=1,\dots,n$	Minimize θ_k (Eq. 2) subject to $y_{rk} - \sum_{j=1}^{n} \lambda_j y_{rj} \leq 0$ for $r=1,\dots,h$ $\theta_k x_{ik} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0$ for $i=1,\dots,m$ $\sum_{j=1}^{n} \lambda_j = 1$, $\lambda_j \geq 0$ $\forall j=1,\dots,n$

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

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. The vector λ represents 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.

It is important to highlight that the DEA models presented until this point considered radial (proportional) variation in inputs and/or outputs to reach the efficient production levels. In some cases, this may not be the most appropriate situation to the production function. In these cases, an alternative is to work with slacks and calculate the variation in each input and/or output independently in order to achieve the efficiency production level. Johnes and Tone (2017, p. 195) affirmed that non-radial measures are in many circumstances preferable to either an output or input-oriented approach. They stated that "in particular, where decision making units are free to vary some inputs and outputs, but face constraints in their ability to vary others, it is appropriate to focus on the input and output specific slacks.".

This way, Tone (2001, p. 508) proposed a scalar measure (Slack Based Measure – SBM) of efficiency in DEA. This measure "deals directly with input excess and output shortfall" and contrasts with "the CCR and BCC measures which are based on the proportional reduction (enlargement) of input (output) vectors and which do not take account of slacks.". In addition, the SBM measure also "satisfies such properties as unit invariance and monotone with respect to slacks, and it is reference-set dependent" (TONE, 2001, p. 508). Tone (2001, p. 500) presented the SBM model as the one following the fractional program (defined in λ , s+, s-) which permits to calculate the efficiency for each of the n DMUs (k = 1, …, n) as:

$$\text{Min} \quad \rho_k = \frac{1 - (\frac{1}{m}) \cdot \sum_{i=1}^{m} s_i^- / x_{ik}}{1 + (\frac{1}{h}) \cdot \sum_{r=1}^{h} s_r^+ / y_{rk}}$$

subject to (Eq. 3)

$$x_k = \lambda_j x_{ij} + s_{ij}^- \quad \text{for} \quad i = 1, \dots, m$$

$$y_k = \lambda_j y_{rj} + s_{rj}^+ \quad \text{for} \quad r = 1, \dots, h$$

$$\lambda_j \geq 0 \quad , \quad s_{ij}^- \geq 0 \quad s_{rj}^+ \geq 0$$

The vector ρ represents the relative efficiency of the DMUs and the vectors s^- and s^+ indicates the input excess and the output shortfall, respectively, and are called slacks. The value of the objective function will be $0 \leq \rho \leq 1$, and will decrease with increases in s_{ij}^- and in s_{rj}^+, ceteris paribus.

Similar to the CCR model, the presented SBM model can be transformed into a linear program using the Charnes-Cooper transformation (TONE, 2001, p. 500) and it can also be modified to cope with input or output-orientation as special cases (TONE, 2001, p. 508). It was used by Costa, Ramos and Souza (2010) which calculated the output-oriented efficiency of Brazilian public federal HEIs using the following equation:

$$\text{Min} \quad \rho_k = \frac{1}{1 + (\frac{1}{h}) \cdot \sum_{r=1}^{h} s_r^+ / y_{rk}}$$

subject to (Eq. 4)

$$x_k = \lambda_j x_{ij} \quad \text{for} \quad i = 1, \ldots, m$$

$$y_k = \lambda_j y_{rj} + s_{rj}^+ \quad \text{for} \quad r = 1, \ldots, h$$

$$\lambda_j \geq 0 \quad , \quad s_{rj}^+ \geq 0$$

Nevertheless, considering the empirical application of DEA and based on their experience as paper referees, Cook, Tone and Zhu (2014, p. 4) observed that “despite the many applications of DEA that have been advanced in the literature, it would appear that in many cases little attention is paid to a number of important modeling issues”. They also addressed important key issues and recommendations related to the use of DEA: model orientation (knowledge about the production process), inputs and outputs selection/definition, the use of mixed and raw data, and the number of inputs and outputs versus the number of DMUs. As an example, Johnes and Tone (2017) carried out a comparative exercise with three different DEA models using the same data from England HEIs. Their findings suggested that results are highly sensitive to the methodology chosen and that caution is required when applying the results in any policy context. Similarly, regarding homogeneity, Agasisti and Salermo (2007, p. 462) emphasized that the “high fixed costs associated with institutions having medical faculties do indeed bias efficiency scores if not properly accounted for.”. These key issues and recommendations were, thus, taken into consideration for the analysis of the Brazilian empirical uses of DEA to HEIs which are presented in the following section.

2.3 ANALYSING THE EMPIRICAL APPLICATION OF DEA TO BRAZILIAN HEIS

In this part of the work, a critical evaluation of some existent Brazilian studies is presented, considering their empirical uses of DEA to HEIs. As a preamble, it is briefly presented the evolution of earlier performance evaluations of Brazilian public HEIs and the availability of useful data.

Belloni (2000) presented a brief history of Brazilian HEIs evaluation and diagnosed that, even having started in the 1950s decade, it was only in 1990s that its principles and characteristics were established[6]. It is important to highlight that these principles are respected by DEA modeling and that is just one of its advantages in relation to other evaluation models. The indicators suggested by ANDIFES (1993) and MEC/PAIUB (1994), even trying to consider those principles, are partial efficiency ones, derived from a ratio between two diverse quantities (there are only two exceptions: the professor quality index and the courses quality index). Because of this, their methodologies do not handle so well the analysis of multiple inputs to produce multiple outputs such as the case of HEIs.

Since then, Brazilian researchers ahave beenre involved with measurement of HEIs efficiency using DEA. The first work known is Marinho, Resende and Façanha (1997), followed by some others such as Paredes (1999) and Belloni (2000), all of them studying the public federal HEIs to some year from the period 1993-1994. Façanha and Marinho (2001) used information from 1995-1998 and tried to analyze all Brazilian HEIs by grouping them according to types, regions and other characteristics. But, as they used separated models for undergraduate and

6 This is synthesized in two reports: the Proposta de Avaliação Institucional da Associação Nacional dos Dirigentes das Instituições de Ensino Superior – ANDIFES (ANDIFES, 1993); and the Documento Básico do PAIUB (MEC/PAIUB, 1994). Some common principles between both reports are: (i) globality, the HEIs should be evaluated in a global way, not only analyzing the characteristics individually, but considering simultaneously the dimensions – teaching, research, services and management; and (ii) respect of institutional identity, the particular characteristics of each institution should be respected, thus, two HEIs could give a different importance to the same dimension or academic activity. The current Brazilian higher education evaluation system (Sistema Nacional de Avaliação da Educação Superior - SINAES) follows similar principles.

postgraduate courses, the results are not comparable with other recent studies which considered jointly both courses.

After that, a new source of information, data from Federal Court of Audit (Tribunal de Contas da União – TCU), had inspired an increasing group of works[7]. The detailed criteria and methodology developed by TCU to orient the federal HEIs in the calculus of the values were presented in TCU (2010) and SESu/MEC (2018) and are synthesized in Appendices A1 and A2. Then, since 2010 it has become possible to use these raw values to calculate global efficiency. Despite that, until 2016 no studies had attempted to do it.

The following table, Table 1, presents a synthesis of the main works which focused on investigating Brazilian HEIs' performance. It shows the intended purpose of each work, the model specification and orientation, the number of DMUs, inputs and outputs, the type of HEIs analysed and the year considered. In general, all the studies presented explicitly intended to measure efficiency; however, a great part was actually about performance evaluation as a MCDM tool. These works are identified in Table 1 by the lines 4, 7, 8, 9, 10, 11, 12.

The first work identified as using TCU indicators was Oliveira and Turrioni (2006), with data from 2004. However, it considered only 19 out of a total of about 50 existing HEIs, according to the authors, because those were the only available data online in their sites. The study also used the TCU indicators in the same DEA model. It could be thus said that the work used partial performance indicators (including efficiency and productivity ones) with the intention of calculating a global indicator of efficiency. This strategy can hinder the analysis as well as the results' validity. According to Cook, Tone and Zhu's (2014, p. 2) guidance, this use of DEA could be considered as a MCDM tool, a situation in which "DEA can be viewed as a multi-criteria evaluation methodology where DMUs are alternatives, and DEA inputs and output are two sets of performance criteria.". Thus, the use of partial indicators in the DEA model resulted in a type of performance measure, and only in very specific circumstances it could be considered efficiency.

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7 The management reports are presented annually to the Federal Court of Audit (Tribunal de Contas da União – TCU) by federal HEIs. It resulted from the 408/2002 TCU decision. Since 2002 the TCU has started to demand specific information on performance indicators from Brazilian federal HEIs (TCU, 2002). In 2010 the TCU also started demanding the raw values used to calculate those indicators. Since then, the respective year values as well as the historic values to the four past years should be presented by the universities, considering both raw values and indices values (named indicators by TCU).

TABLE 1 – WORKS WHICH ANALYZE THE BRAZILIAN HEIS EFFICIENCY/PERFORMANCE

id	Author and year	Intended purpose	Model specification and orientation	DMUs		nr. of inputs				nr. of outputs				Type of institutions studied	Analised year
				Nr of DMUs	Characteristics of the sample of the subsets of DMUs group	all	raw	ratio	index	all	raw	ratio	index		
1	Marinho, Resende, and Façanha (1997)	efficiency	VRS input	38	38 of 52	3			3	3			3	Public federal	1994
2	Paredes (1999)	efficiency	VRS input	33	33 of 37	3	3			3	3			public federal	1993
						2	2			3	3				
3	Belloni (2000)	efficiency	VRS output	33	33 of 37	1	1			3	2		1	Public federal	1994
4	Corbucci (2000)	efficiency and productivity	ratio between indicators	35	35 of 37	7		7		7		7		Public federal	1995 to 1998
5	Façanha and Marinho (2001)	efficiency	VRS Input and output	894	210 public; 684 private	4	4			11	11			HEIs without postgraduate programs	1995-1998
				973	209 public; 764 private										
				349	grouped by postgraduate program areas and HEIs	2	2			6	6			postgraduate programs	1997
6	Alencastro and Fochezato (2006)	efficiency	CRS input	30	30	5	4	1		3	3			courses from a private HEI	2000
				34	34										2004
7	Oliveira and Turrioni (2006)	efficiency	CRS input and CRS output	19	19 of 55	7		5	2	2		1	1	Public federal	2004
8	Costa, Ramos and Souza (2010)	efficiency		49	49 of 55	4		3	1	2		1	1	public federal	2004-2008
			SBM output	28	with research (static)										
			DSBM output	28	with research (dynamic)										
			SBM output	21	low research (static)										
			DSBM output	21	low research (dynamic)										
9	Costa, Souza, Ramos and Silva (2012)	efficiency	SBM output	49	idem										
10	Costa, Ramos and Souza (2014)	efficiency	SBM output and DSBM output	49	idem										
11	Costa, Ramos, Souza and Sampaio (2015)	efficiency	DSBM output	49	idem										
12	Furtado and Campos (2015)	efficiency	VRS output	19	19 de 38	3		2	1	1		1		IFETS (federal public institutions of technlogy education – HE and tech high school)	2012-2013
13	Duenhas, França and Rolim (2013, 2015)	efficiency	SBM	75	75 of ??	2	2			4	3		1	federal public universities	2007-2008
				18	large										
				22	medium										
				35	small										
14	Bittencourt et al. (2016)	efficiency	VRS input	81	81 of 98	6	6			7	7			Selected public universities	2014
				45	large										
				30	medium										
				6	small										
15	Letti and Bittencourt (2017)	efficiency	VRS input	221	221 (total)	5	5			4	4			public HEIs	2012
				51	large										
				70	medium										
				103	small										
16	Letti, Vila and Bittencourt (2018)	efficiency	VRS input	97	97 of 97	1	1			7	7			public universities	2010
				97	97 of ??	3	3								2016

SOURCE: the author (2019)

In the same way, Costa, Ramos and Souza (2010) (prized by the National Treasury Department Award in 2010), Costa, Souza, Ramos and Silva (2012), Costa, Ramos and Souza (2014) and Costa, Ramos, Souza and Sampaio (2015) did similar works with the same data from TCU to the years of the period 2004-2008. The analysis followed the traditional DEA method using SBM and considering the evolution of efficiencies along the time (Malmquist (1953) index and Dynamic SBM – DSBM). All of them explicitly declared that the main purpose was to measure the relative efficiency of Brazilian federal HEIs. However, the DEA models used considered some of the 'TCU indexes' and not the 'TCU raw values'.[8] In that sense, these studies could also be considered MCDM. All four investigations used output-orientation, and, consequently, considered the inputs as nondiscretionary variables by the managers. Furthermore, to the case of variables that used financial values to perform an analysis through time, these values should have been deflated to a common reference year. That is because a simple variation of nominal values, but not necessarily a real variation, could be interpreted as a real increase in expenditures and, consequently, compromise or bias the frontier comparisons among the years. Other similar examples following the use of TCU indexes to 'measure efficiency' are Freire, Crisóstomo and Castro (2007), Barbosa, Freire and Crisóstomo (2011), Casado and Siluk (2011), Oliveira et al. (2014), Siqueira (2015), Furtado and Campos (2015), Cohen, Paixão and Oliveira (2018).

On the other hand, now using data from INEP (2018) and CAPES (2018), Duenhas, França and Rolim (2015) analyzed 62 Brazilian public HEIs by using SBM models and Malmquist index. The HEIs were first grouped by size into big (18), medium (22) and small (22) and then the efficiencies were calculated. The scholars concluded that the Brazilian public universities were inefficient, especially the small and medium ones. Also, they stated 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

8 More specifically, they used 2 indicators as outputs - (i) rate of undergraduate degrees by freshmen undergraduate students; (ii) quality index of postgraduate courses - and 4 indicators as inputs - (i) rate of current expenditures by equivalent student; (ii) rate of full time student by equivalent professor; (iii) rate of full time student by equivalent nonacademic staff; (iv) quality index of academic staff.

possible to increase the number of students in 2,8%, increasing the Brazilian public HE system in 36 thousand students without increasing the expenditures.

Moreover, Bittencourt, Gomes, Letti and Bragança (2016) and Letti and Bittencourt (2017) presented some contributions due to the use of information about registered patents and third mission as outputs. However, some limitations from these works were 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 these issues.

As a synthesis of the research review about Brazilian HEIs, they can be classified according to the data used in:

- before TCU indicators;
- after TCU indicators and using them;
- after TCU indicators but not using them.

The first ones had difficulties with useful and reliable data and with the challenge of this 'new type' of evaluation for Brazilian institutions, with multi-inputs, multi-products and heterogeneous contexts (size, age, regions, demographic variables, etc.).

In the case of those works which used TCU indicators, starting with Oliveira e Turrioni (2006), some made explicit the fact that the indicators were not the best, but they were the ones available. However, a lot of studies were carried out considering those indicators, including the ones evaluating some government programs[9] and aiming to orient the decisions of policymakers without emphasizing such a limitation and without suggesting more adequate indicators. Special attention should be given to the case of Costa, Ramos and Souza's (2010) work, which received a prize by the National Treasury Department Award, and other three sequential works from the same group of authors. In addition, still, to other subsequent investigations of different authors which were inspired by the work just mentioned. Just to cite an example, there was one from the UNB-UFPB-UFRN Accounting postgraduate program (SIQUEIRA, 2015), one from the UFPR Accounting postgraduate program (OLIVEIRA et al., 2014) and another from UFTO Regional Development master program (COHEN; PAIXÃO; OLIVEIRA, 2018). In general, the studies reviewed somewhat considered the importance of using adequate inputs and outputs variables, however a lot of them did not explicitly justify how/why the variables were

9 such as REUNI - a strong federal program for the restructuring and expansion of Brazilian HEIs.

chosen and, most importantly, what the relation of a given variable was in terms of the production process and, consequently, the DEA framework.

Now, taking into consideration the aspects just mentioned, the next section will present an exercise as a way to overcome some of the limitations identified in this review.

2.4 APPLYING AND COMPARING DEA MODELS TO BRAZILIAN HEIS

In this section, an exercise of comparison is carried out considering the differences in results of diverse DEA models. Here, the output-orientation was used to all the cases. The comparisons considered three levels, which were: (i) type of data - use of indexes versus use of raw values; (ii) type of DEA model - use of BCC (VRS) models versus use of SBM models; and, (iii) type of HEIs grouping - use of different subsets of HEIs to calculate the efficiency of each HEI (all in one group - all, or two groups by size – AB, or two groups with or without a university hospital - HU). This way, twelve models were defined by considering the combinations of these three levels (2 x 2 x 3). Each model specification is presented in Table 2. Model 5 is exactly the same one used by Costa, Ramos and Souza (2010).

TABLE 2 – DEFINITION OF THE MODELS USED FOR THE COMPARISON EXERCISE

	acronym	**type of variables**	**type of model**	**type of HEIs grouping**
Model 1	VRS_all_ind	indexes	VRS	all
Model 2	VRS_AB_ind	indexes	VRS	size (A and B)
Model 3	VRS_HU_ind	indexes	VRS	HU (with and without)
Model 4	SBM_all_ind	indexes	SBM	all
Model 5	SBM_AB_ind	indexes	SBM	size (A and B)
Model 6	SBM_HU_ind	indexes	SBM	HU (with and without)
Model 7	VRS_all_raw	raw and indexes	VRS	all
Model 8	VRS_AB_raw	raw and indexes	VRS	size (A and B)
Model 9	VRS_HU_raw	raw and indexes	VRS	HU (with and without)
Model 10	SBM_all_raw	raw and indexes	SBM	all
Model 11	SBM_AB_raw	raw and indexes	SBM	size (A and B)
Model 12	SBM_HU_raw	raw and indexes	SBM	HU (with and without)

SOURCE: the author (2019)

In addition, the inputs and outputs were selected considering the entire context of the HEI and the availability of information. The first six models used only indexes as variables (4 inputs and 2 outputs). These inputs and outputs are the same ones used by Costa, Ramos and Sousa (2010). This way, the 'TCU indicators' or '**TCU indexes**' used in the models were:

input 1 - current cost with HU by equivalent student - CCCHUAE;
input 2 - full time student by equivalent professor - ATIPE;
input 3 - full time student by equivalent employees with HU - ATIFECHU;
input 4 - qualification of teaching staff index - IQCD;
output 1 - student degrees by registered students - TSG;
output 2 - quality index of postgraduate courses - CCAPES.

Considering Cook, Tone and Zhu's (2014, p. 1) recommendations regarding the choices of inputs-outputs, in line with the purpose of measuring efficiency, and also considering the information available exclusively in the TCU reports, the other six models substituted three ratio variables by four raw values. Thus, the '**TCU raw values**' used in the models were:

input 1 - current cost with HU (university hospitals) - CCCHU;
input 2 - number of full time equivalent professors - PE;
input 3 - number of full time equivalent employees with HU - FECHU;
input 4 - qualification of teaching staff index - IQCD;
output 1- number of students equivalent (= AGE + APGTI + ARTI) – AE;
output 2 - student degrees by registered students - TSG;
output 3 - quality index of postgraduate courses - CCAPES.

In the same way, favoring the considerations of Cohn (1989) and Agasisti and Salermo (2007, p. 458) who stated "that scale effects are important to universities' cost efficiency", the present study also verified the differences by considering **BCC (VRS)** versus **SBM models**.

Observations about the efficiency measure by grouping the HEIs in more homogeneous peers are common in the literature. Some examples were Costa, Ramos and Souza (2010), Agasisti and Salermo (2007) and Johnes (2006). Cook, Tone and Zhu (2014) also emphasized the importance of the knowledge about the production process and their intern cost structure. Then, a diverse grouping criteria of HEIs was also considered: (i) all in the same group (as reference to comparison); (ii) by size (or research focus), as done by Costa, Ramos and Souza (2010); and, (iii) by

HEIs with or without a university hospital (HU), as suggested by Agasisti and Salermo (2007).

Data from the year 2007 was chosen because it was also used in Costa, Ramos and Souza (2010), and also because 2007 was the last year after a strong federal program for the restructuring and expansion of Brazilian HEIs (the REUNI program). It is important to mention that it was only the available part of the information from TCU reports which was used in the models. The variables from the TCU reports by HEI for 2007 are summarized in Table 3.

TABLE 3 – SUMMARY OF THE HEIS VARIABLES TO YEAR 2007

	n	CCCHU (R$)	PE	FECHU	IQCD	AE	TSG	CCAPES	CCCHUAE (R$)	ATIPE	ATIFECHU
max_all	49	761.063.804,40	3273	8306	4,81	54753,87	1,06	5,04	37.570,35	17,54	13,9
min_all	49	24.659.798,37	121	114,25	2,67	2470,57	0,22	0,88	5.243,63	6,33	1,08
means_all	49	222.687.050,61	996,86	2143,36	3,81	17927,91	0,66	3,75	11.856,90	12,24	6,65
sd_all	49	177.025.834,09	709,66	1720,46	0,51	13407,72	0,17	0,71	5.285,27	2,5	2,51
CV_all	49	0,79	0,71	0,8	0,13	0,75	0,25	0,19	0,45	0,2	0,38
max_A	28	761.063.804,40	3273	8306	4,81	54753,87	1,06	5,04	37.570,35	17,54	9,3
min_A	28	74.608.926,81	348	615	2,94	5320,66	0,22	3,25	8.045,38	8,47	2,26
means_A	28	324.858.035,17	1392,9	3106,27	3,92	25388,18	0,67	4,07	12.479,64	12,82	6,05
sd_A	28	167.695.779,56	661,48	1636,07	0,49	12809,44	0,17	0,55	5.414,80	2,14	1,61
CV_A	28	0,52	0,47	0,53	0,12	0,5	0,26	0,14	0,43	0,17	0,27
max_B	21	181.250.437,43	1137,65	2415	4,64	17798,98	0,97	4,67	28.931,90	16,63	13,9
min_B	21	24.659.798,37	121	114,25	2,67	2470,57	0,3	0,88	5.243,63	6,33	1,08
means_B	21	86.459.071,21	468,81	859,48	3,65	7980,89	0,65	3,34	11.026,58	11,45	7,44
sd_B	21	56.094.385,44	325	679,33	0,52	5303,02	0,17	0,71	5.117,89	2,78	3,24
CV_B	21	0,65	0,69	0,79	0,14	0,66	0,25	0,21	0,46	0,24	0,44
max_CHU	30	761.063.804,40	3273	8306	4,81	54753,87	1,06	4,99	37.570,35	17,54	9,45
min_CHU	30	115.955.125,84	164	1175,25	2,94	3646,63	0,22	3,25	8.045,38	8,07	1,08
means_CHU	30	306.537.769,99	1329,39	2986,83	3,76	23776,54	0,66	3,88	12.878,28	12,31	5,68
sd_CHU	30	165.576.246,31	641,81	1587,81	0,48	12186,99	0,17	0,5	6.060,10	2,37	1,75
CV_CHU	30	0,54	0,48	0,53	0,13	0,51	0,26	0,13	0,47	0,19	0,31
max_SHU	19	428.498.914,25	2102,5	3416,25	4,66	44561,35	0,97	5,04	17.323,26	16,02	13,9
min_SHU	19	24.659.798,37	121	114,25	2,67	2470,57	0,3	0,88	5.243,63	6,33	3,68
means_SHU	19	90.291.177,91	471,8	811,56	3,88	8693,22	0,67	3,55	10.244,20	12,12	8,18
sd_SHU	19	95.803.249,97	451,7	879,45	0,57	9646,97	0,16	0,94	3.292,26	2,76	2,8
CV_SHU	19	1,06	0,96	1,08	0,15	1,11	0,24	0,26	0,32	0,23	0,34

SOURCE: the author (2019)

In general, to the year 2007 on average, a common HEI expended R$ 222 million, had 996 equivalent professors (working 40h/week) with a quality index of 3.81 (it would be 5 if all professors had a doctorate degree) and 2143 equivalent employees (working 40h/week). The mean of equivalent students was almost 18 thousand and the degree rate indicated that 66% of the freshmen students actually concluded their studies in 2007 (considering the respective year of entrance of the cohort). The quality of the postgraduate courses was 3.75 (the maximum is 5.00).

Considering the relations (ratios) between some variables, it resulted in almost R$ 12 thousand by equivalent student per year, with one professor to 12.24 students and one employee to 6.65 students. Analyzing the values of standard deviation (SD) and the coefficient of variation (CV = SD / mean), it was possible to perceive the heterogeneity of the HEIs. This heterogeneity was most visible in the raw variables (CCCHU, PE, FECHU, AE). Besides, it decreased when considering the ratios (TSG, CCCHUAE, ATIPE and ATIFECHU) and decreased even more when considering the index values (IQCD, CCAPES[10]).

In relation to the HEIs' subsets, grouped by size (A and B) or grouped by with or without university hospital (CHU and SHU), it was also possible to perceive the heterogeneity, but with different patterns. By grouping them in big (A) and small (B), the heterogeneity within each group decreased in relation to almost all variables. On the other hand, by grouping them according to with or without a HU, the heterogeneity decreased within the HEIs with HU and increased within the HEIs without HU. It suggests that, in relation to the analyzed variables, the HEIs with HU were as homogeneous as the big ones, and that the HEIs without HU were more heterogeneous than the other groups, including the group of all HEIs. Therefore, the grouping effect probably diverges to each different grouping, which could be interesting when considering the variable returns to scale models, since it allows handling with the heterogeneity in the scale of production.

Table 4 then summarizes HEIs' efficiencies calculated to each model. First, it is important to remember that the concept of an efficient HEI and efficiency of the HEI here were always in relation to the other HEIs in the set or subset, according to the DEA framework. The efficient ones presented a value 1 of efficiency, while the inefficient ones presented values bigger than 0 and smaller than 1. Also, because of their construction characteristics, the models VRS and SBM always present the same number of efficient DMUs. In the case of the HEIs, it can be verified by comparing two and two (in pairs) the VRS model with its respective SBM model.

Then, in order to calculate the number of efficient HEIs, the useful comparisons were to the level of type of data and type of grouping. In this case, in general the 'raw values' models resulted in more efficient HEIs than the 'index values'

10 The minimum value observed of CCAPES was 0.88, to UNIFAP. It was the value informed by the university in its annual report, though it is quite probably incorrect. The value should be higher to 3 for each university. Even so, this specific value for this university did not influence the results because the university reached the efficient level.

models. The models which measured the efficiency of grouped HEIs also resulted in a higher number of efficient HEIs than 'all' their respective counterparts. In addition, between the two types of grouping, the AB presented more efficient HEIs than the HU models when using 'indexes', but less when using 'raw values'. The number of efficient HEIs to all models considering HU grouping was equal to 32.

In synthesis, the models considering all HEIs in a unique group resulted in less than 50% of efficient HEIs and the models which calculated the efficiency by grouped HEIs resulted in more than 50% of efficient HEIs. The mean of the efficiencies in each model varied from 0.89 (indexes_SBM_all) to 0.97 (raw_VRS_AB and raw_VRS_HU) and the standard deviations varied from 0.06 (raw_VRS_AB and raw_VRS_HU) to 0.13 (raw_SBM_all). The medians were 1 to all AB and HU models but they were near 0.90 to both SBM_all_ind and SBM_all_raw models. Considering only the efficiencies of the inefficient HEIs, the means varied from 0.80 (SBM_all_ind and SBM_all_raw) to 0.91 (raw_VRS_HU) and the medians varied from 0.82 (raw_SBM_all) to 0.93 (raw_VRS_AB). Considering their counterparts, these medians were lower to the models which used AB grouping.

TABLE 4 – STATISTICS OF THE EFFICIENCIES CALCULATED BY EACH MODEL

type of data	TCU indexes						TCU raw values					
type of model	VRS			SBM			VRS			SBM		
type of grouping	all	AB	HU	all	AB	HU	all	AB	HU	all	AB	HU
Model	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**	**M12**
number of efficient HEIs	22	28	32	22	28	32	24	34	32	24	34	32
mean of efficiency to all HEIs	0,93	0,96	0,95	0,89	0,93	0,93	0,94	0,97	0,97	0,90	0,95	0,95
standard deviation to all HEIs	0,09	0,07	0,08	0,12	0,10	0,11	0,08	0,06	0,06	0,13	0,09	0,08
mean to inefficient ones	0,87	0,90	0,87	0,80	0,84	0,80	0,89	0,90	0,91	0,80	0,84	0,85
median to all	0,97	1,00	1,00	0,87	1,00	1,00	1,00	1,00	1,00	0,93	1,00	1,00
median to inefficient ones	0,90	0,92	0,88	0,83	0,85	0,83	0,90	0,93	0,92	0,82	0,86	0,85

SOURCE: the author (2019)

Therefore, in general all the models showed higher values of mean efficiencies but with some particular patterns. The analysis of correlations presented in Table 5 was intended to facilitate its perception. In Table 5, the values on the left of the main diagonal refer to the Pearson correlation and the values to the right of the diagonal refer to the Spearman correlation. There is also information about the p-value and the significance of each estimation (* to <10% of significance, ** to <5% and *** to <1%).

The quadrants low-left and up-right in Table 5 represent the correlations between the ‘raw values models’ and the ‘indexes models’. All of these correlations can be considered weak (under 0.42 to Pearson values and under 0.46 to Spearman values). That is to say that there are differences in the results from models using raw values and models using indices values. These differences are both to the value of the efficiencies and to the rank of the efficiencies. It could result in different identification of efficient universities and efficiencies of the universities and could lead a policymaker to employ erroneous policies due to the consideration of an inadequate model to the situation in question. In the given case, the models using raw values are considered more adequate because they use unidimensional variables that are more easily interpreted and allow the definition of more objective goals.

TABLE 5 – PEARSON AND SPEARMAN CORRELATION MEASURES AMONG THE MODELS

		type of data	TCU indexes						TCU raw values					
		type of model	VRS			SBM			VRS			SBM		
		type of grouping	all	AB	HU	all	AB	HU	all	AB	HU	all	AB	HU
TCU indexes	VRS	all	1,00	0,82 ***	0,76 ***	0,93 ***	0,78 ***	0,72 ***	0,42 **	0,39 **	0,39 **	0,33 **	0,37 **	0,38 **
		p-value		0,000	0,000	0,000	0,000	0,000	0,003	0,006	0,005	0,021	0,010	0,007
		AB	0,84 ***	1,00	0,84 ***	0,79 ***	0,96 ***	0,82 ***	0,31 **	0,33 **	0,29 **	0,24 *	0,31 **	0,27 *
		p-value	0,000		0,000	0,000	0,000	0,000	0,028	0,020	0,041	0,098	0,030	0,063
		HU	0,85 ***	0,91 ***	1,00	0,79 ***	0,85 ***	0,98 ***	0,39 **	0,45 **	0,41 **	0,34 **	0,45 **	0,40 **
		p-value	0,000	0,000		0,000	0,000	0,000	0,006	0,001	0,004	0,016	0,001	0,005
	SBM	all	0,86 ***	0,73 ***	0,74 ***	1,00	0,83 ***	0,81 ***	0,41 **	0,35 **	0,40 **	0,36 **	0,37 **	0,41 **
		p-value	0,000	0,000	0,000		0,000	0,000	0,004	0,014	0,005	0,011	0,009	0,003
		AB	0,73 ***	0,87 ***	0,83 ***	0,86 ***	1,00	0,88 ***	0,30 **	0,32 **	0,25 *	0,26 *	0,34 **	0,26 *
		p-value	0,000	0,000	0,000	0,000		0,000	0,037	0,023	0,078	0,069	0,015	0,073
		HU	0,73 ***	0,81 ***	0,88 ***	0,84 ***	0,95 ***	1,00	0,34 **	0,4 **	0,34 **	0,32 **	0,43 **	0,35 **
		p-value	0,000	0,000	0,000	0,000	0,000		0,017	0,004	0,018	0,025	0,002	0,014
TCU raw values	VRS	all	0,37 **	0,28 *	0,35 **	0,38 **	0,25 *	0,29 **	1,00	0,75 ***	0,83 ***	0,94 ***	0,74 ***	0,83 ***
		p-value	0,010	0,051	0,015	0,006	0,080	0,044		0,000	0,000	0,000	0,000	0,000
		AB	0,4 **	0,3 **	0,37 **	0,29 **	0,2	0,25 *	0,85 ***	1,00	0,79 ***	0,68 ***	0,98 ***	0,77 ***
		p-value	0,005	0,034	0,008	0,047	0,177	0,081	0,000		0,000	0,000	0,000	0,000
		HU	0,4 **	0,32 **	0,38 **	0,31 **	0,2	0,24	0,85 ***	0,91 ***	1,00	0,72 ***	0,74 ***	0,99 ***
		p-value	0,004	0,025	0,007	0,029	0,167	0,103	0,000	0,000		0,000	0,000	0,000
	SBM	all	0,13	0,08	0,18	0,24 *	0,17	0,22	0,67 ***	0,49 ***	0,49 ***	1,00	0,70 ***	0,74 ***
		p-value	0,369	0,580	0,220	0,093	0,230	0,123	0,000	0,000	0,000		0,000	0,000
		AB	0,34 **	0,24 *	0,36 **	0,39 **	0,34 **	0,41 **	0,79 ***	0,85 ***	0,74 ***	0,61 ***	1,00	0,75 ***
		p-value	0,018	0,093	0,011	0,006	0,016	0,004	0,000	0,000	0,000	0,000		0,000
		HU	0,34 **	0,25 *	0,36 **	0,39 **	0,27 *	0,32 **	0,86 ***	0,81 ***	0,90 ***	0,61 ***	0,81 ***	1,00
		p-value	0,016	0,087	0,012	0,005	0,065	0,026	0,000	0,000	0,000	0,000	0,000	

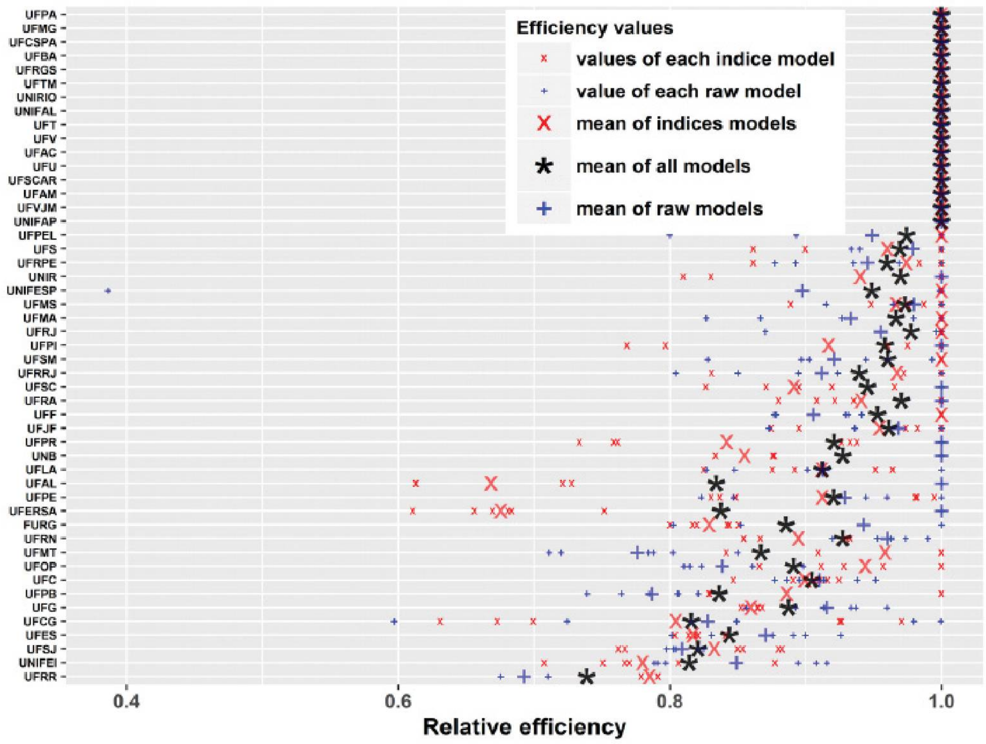
NOTE: * to <10% of significance, ** to <5% and *** to <1%

SOURCE: the author (2019)

On the other hand, the correlations within ‘indexes models’ and within ‘raw values models’ are in general strong (above 0.73 and 0.70, respectively). That is, the level ‘type of data’ (raw or index) matters more than the levels ‘type of DEA model’ (DEA or SBM) or ‘type of HEIs grouping’ (all, AB or HU). The exceptions were some Pearson correlation values beetwen raw_SBM_all and the other models, the values (under 0.68) highlighted in dark gray in Table 5. Nevertheles, the highlighted values in yellow are those with a strong Spearman but with a correspondent weak Pearson correlation. More specifically, the Pearson correlation of the raw_SBM_all efficiencies values is: (I) weak, in relation to the raw_VRS_AB and the raw_VRS_HU efficiencies (0.49 and 0.49); (ii) moderate, in relation to raw_SBM_AB and raw_SBM_HU efficiencies (0.61 and 0.61); and (iii) almost strong regarding the raw_VRS_all (0,67). However, in these cases the respective Spearman correlation (that considers the rank of the efficiency values) presented stronger values. Then, the only correlation considered not so strong by both measures was the one between raw_VRS_AB and the raw_SBM_all (0.49 to Pearson and 0.68 to Spearman correlation values).

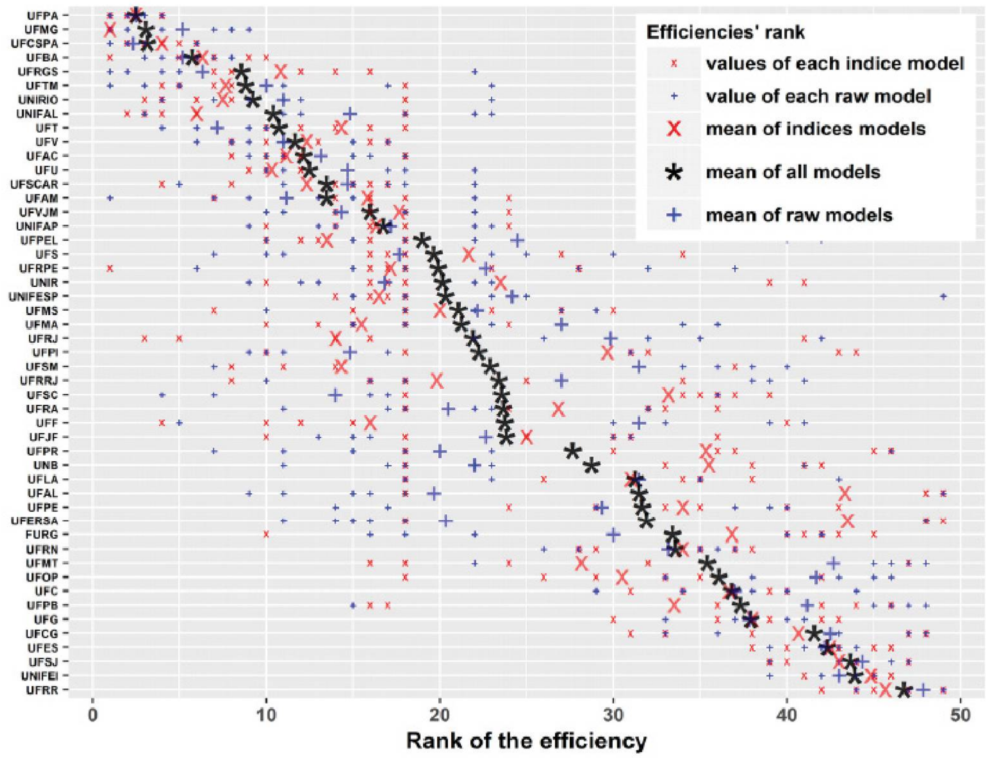
Figures 2 and 3 present another strategy in order to compare the results among the models. In Figure 2, it is possible to visualize efficiencies by HEI, by model; it also adds the information about the mean of the ‘indexes models’ efficiencies, the mean of the ‘raw models’ efficiencies and, finally, the general efficiency means. In Figure 3, the same information is presented, but now considering the rank of the HEIs efficiencies. In both figures the HEIs are ordered by their decreasing value of efficiency rank mean. As expected, according to the DEA framework, the efficient HEIs are the same to all comparisons between the correspondent VRS and SBM models. On the other hand, when comparing the correspondent indexes and raw models, it is possible to perceive that there are plenty of differences. it occurs both between and within indexes and raw models. Regarding the comparisons of the HEIs’ ranks, the results seem to show more divergences. They might have occurred due to the range of variation, which now will necessarily vary between 1 (the best place) and 49 (the worst place). It seems that in general the well-positioned HEIs present a lower variation of ranks among the models. It also seems to occur to the worst positioned HEIs. For the middle placed ones, it is only possible to affirm that the rank can vary a lot among the models.

FIGURE 2 – EFFICIENCY OF BRAZILIAN FEDERAL UNIVERSITIES IN 2007 BY MODEL



SOURCE: the author (2019)

FIGURE 3 – EFFICIENCY RANK OF BRAZILIAN FEDERAL UNIVERSITIES IN 2007 BY MODEL



SOURCE: the author (2019)

Finally, after all that has been taken into consideration, the following section concludes this essay by presenting the main findings and some implications.

2.5 FINAL REMARKS

Following the guidance of Cook, Tone and Zhu (2014) for doing DEA analysis, the findings of the present investigation showed that the empirical works regarding Brazilian public HEIs using DEA present differences in terms of: a) purposes; b) model orientation; c) selection and number of inputs and outputs variables; as well as regarding d) the use of mixed or raw data; and e) data sources.

Due to law enforcement, Brazilian federal HEIs should annually present a report describing some specific performance information to the Brazilian TCU. The report should contain 'performance indexes' as well as the 'raw values' used to calculate those indexes. The 'raw values' are very useful (though not sufficient) to the objectives of measuring efficiency. The 'indexes values' permit the realization of a MCDM analysis.

As the present investigation has pointed out, the majority of recent studies used DEA to measure the efficiency of HEIs; however, what they did, in fact, was to perform a MCDM analysis using just these 'performance indexes' from the TCU reports. Due to that observation, an empirical comparison was carried out considering different specifications of DEA models by using the information available in the TCU reports from the year 2007. This way, it was found that different DEA models present different results. Even though, in general, the mean of efficiencies was high in all of them. Besides, approximately 50% of the HEIs could be considered efficient.

In the particular case studied here, it is difficult to carry out this comparative exercise among results of models which used 'indexes values' and models which used 'raw values' due to the different focus of each of them. The former results in targets in relation to ratios of variables, and the latter results in targets about raw values; consequently, as suggested by Johnes and Tone (2017), caution is required when using these results in any policy context. Nevertheless, there were found differences in the results from models using raw values and models using indices values. These differences are both regarding the value and the rank of the efficiencies. It could result in different identification of efficient universities and efficiencies of the universities and could lead a policymaker to employ erroneous policies for considering a model which is not adequate to a given situation. In this case, as pointed out here, the models using raw values are thus considered more appropriate because they use unidimensional variables, being then more easily interpreted and allowing for more objective goals to be defined.

Regarding suggestions for future research, it would be important to use the results from this work to analyze the evolution of HEIs efficiency after 2007, as well as to consider information from sources other than the TCU reports to complement the DEA models. In that sense, specific information about postgraduate programs should be taken into consideration, as well as information about registered patents (as proxy to innovation) and third mission activities. A curious exercise could also be to compare the financial information from TCU reports (available only to federal universities) with the financial information from the Higher Education INEP Census and then, to validate or not the use of available INEP financial information to other HEIs (public state and municipal universities).

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3 THE EFFICIENCY OF BRAZILIAN FEDERAL UNIVERSITIES (2010-2016): A DATA ENVELOPMENT ANALYSIS THROUGH TIME AND SPACE

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. It became a critical topic when considering the importance of public institutions to the Brazilian Higher Education system, especially in the context of its current financial stringency, its recent restructuring program, and its regional idiosyncrasies. Taking these issues into consideration, the main goal of the present study was to apply Data Envelopment Analysis (DEA) in order to evaluate the relative efficiency of all 56 Brazilian federal universities for the period pertaining 2010 to 2016 considering some aspects of its regional distribution. The data used in the study came primarily from INEP Higher Education Census, CAPES and INPI. Regarding space, results have overall shown that 26 (47%) of the universities were efficient, with a general mean efficiency of 87%. Although the values by region have diverged, they ended up converging to efficiencies between 78.5% (North) and 91.6% (Center-West). Through time, the Malmquist index suggested improvements higher than 30% though with different characteristics regarding financial and human resources, as well as among regions. Results have also suggested that R$ 2.96 billion a year might have been wasted due to inefficiency, or that an additional 10% of outputs could have been obtained.

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

RESUMO

Eficiência pode ser entendida como a razão entre a produção atual e a máxima produção possível dados os recursos. Esse tema torna-se relevante no contexto das instituições públicas de ensino superior no Brasil, considerando o seu recente contingenciamento financeiro, seu programa de reestruturação e suas idiossincrasias regionais. Assim, este estudo teve como objetivo aplicar a metodologia de análise envoltória de dados (DEA) para mensurar a eficiência relativa das 56 universidades federais brasileiras para o período de 2010 a 2016, considerando alguns aspectos de sua distribuição regional. Os dados foram consultados nos sítios eletrônicos do INEP/MEC (Censo Superior), CAPES e INPI. Os resultados sugerem, considerando-se a questão espacial, que 26 (47%) das universidades foram eficientes, com uma média geral de eficiência igual 87%. Os valores por região variaram durante o período mas convergiram para eficiências entre 78,5% (Norte) e 91,6% (Centro-Oeste). Considerando-se a questão de tempo, o índice de Malmquist indicou que houve melhoria da eficiência ao longo do tempo mas com diferentes padrões entre recursos financeiros e humanos e entre regiões. Resultados sugerem também um desperdício de R$ 2,96 bilhões por ano e um potencial de incremento de 10% nos outputs em geral devido à ineficiência.

Palavras-chave: Eficiência. Universidade. DEA. Índice de Malmquist. Brasil.

3.1 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 has started a secondary course (IBGE, 2010) and potentially will be able to go to universities. In relation to the financial values, in the 21st 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).

Efficiency, the main construct of the present study, can be generalized as the use of the fewest resources to produce the most results. Thus, considering that the monetary and non-monetary benefits of education present strong external effects on the entire society overall (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) showed 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 may be also occurring in the supply of public higher education services and consequently to public HEIs’ efficiency.

Aleskerov, Belousova and Petruschenko’s (2017) findings suggested that most research on HEIs efficiency around the world used Data Envelopment Analysis

(DEA). Then, regarding the Brazilian case, the present study intended to be a contribution and a step forward to previous studies in HEIs efficiency using DEA.

The main objective of the study was, therefore, to evaluate the relative efficiency of all 56 Brazilian federal universities, for the period 2010 to 2016, considering its regional distribution. This was carried out by emphasizing the results of three empirical production models: (I) focusing on waste of financial resources (Model 1); (ii) focusing on potential outputs improvement by considering only financial resources (Model 2); and (iii) by considering only human resources (Model 3). For each model then the results from different returns to scale were considered; in addition, a regional approach was considered by comparing the values and their evolution through time (Malmquist index) among the five Brazilian Regions.

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, as well as a brief review of the most relevant international and Brazilian literature related to university efficiency using DEA. The third section presents the methodological procedures used, and the fourth section discusses the most relevant results. Finally, conclusions are drawn in the last section, section 5.

3.2 THE BACKGROUND OF EFFICIENCY AND ITS ASSESSMENT USING DEA

Efficiency is defined, “from an output-oriented[11] 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)[12]. Relative efficiency is here defined when that maximum is the observed value to the most productive(s) firm(s) in the group. Charnes, Cooper, and Rhodes (1978) (named CCR), following the work of Dantzig (1951) and Farrell (1957), developed a strategy to measure the efficiency of firms with DEA considering constant returns to scale (CRS)[13]. After them, Banker,

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

12 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 a 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.”

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

Charnes and Cooper (1984) (named BCC) modified the DEA model to incorporate variable returns to scale (VRS)[14] keeping the model solvable by using linear programming (JOHNES, 2006). Forsund, Kittelsen and Krivonozhko (2009, p. 1540) affirmed 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 conditions”. Johnes (2006, p. 274) clarified that in a multi-output, multi-input production context, DEA provides estimates of the distance function (SHEPARD, 1970), which is a generalization of the single output production function.

On the other hand, considering practical implications, Johnes (2004, p. 663) presented 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.”

Regarding the background, foundations, advantages and drawbacks of DEA with an emphasis on HEI’s empirical application, more information can be found in Johnes (2004, 2006) and Forsund (2018). The following paragraphs will now explain the basics of DEA methodology, which served as the background for the empirical work that follows. In that sense, Tone (2001, p. 502) emphasized 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[15] in contemporary DEA literature using BCC model and output orientation is the one in Eq. 1. (FORSUND, 2018, p. 4). In addition, Thanassoulis et al. (2011, p. 1297) presented both output-oriented and input-oriented models (Eq. 1 and Eq. 2). According to them, in order to calculate efficiency considering that DMUs[16] use m inputs to produce h outputs, under VRS,

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14 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).

15 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)”.

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

the following linear programming problem must be solved for each of the n DMUs (k =1,..., n):

Output-oriented (VRS)	Input-oriented (VRS)
Maximize ϕ_k (Eq. 1) subject to $\phi_k\, y_{rk} - \sum_{j=1}^{n} \lambda_j\, y_{rj} \leq 0$ for $r = 1, \ldots, h$ $x_{ik} - \sum_{j=1}^{n} \lambda_j\, x_{ij} \geq 0$ for $i = 1, \ldots, m$ $\sum_{j=1}^{n} \lambda_j = 1 \;,\; \lambda_j \geq 0 \quad \forall\; j = 1, \ldots, n$	Minimize θ_k (Eq. 2) subject to $y_{rk} - \sum_{j=1}^{n} \lambda_j\, y_{rj} \leq 0$ for $r = 1, \ldots, h$ $\theta_k\, x_{ik} - \sum_{j=1}^{n} \lambda_j\, x_{ij} \geq 0$ for $i = 1, \ldots, m$ $\sum_{j=1}^{n} \lambda_j = 1 \;,\; \lambda_j \geq 0 \quad \forall\; j = 1, \ldots, n$

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 ($0 < E_k \leq 1$)[17]. The vector λ represents 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 $E_{k,VRS}/E_{k,CRS}$ [18], 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).

In order to complement these analyses, it is also important to know how the efficiencies change through time. This can be done using the Malmquist index, which dates back to Malmquist (1953) and was made popular by Caves et al (1982)[19]. Let

17 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.

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

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

$E_k(s, t)$ be a measure of the performance of firm k in period s against the technology in period t [20]. To better understand the changes, Fare, Grosskopf, Lindgren and 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) [21]. Then:

Malmquist index

$$M_k(s, t) = TC_k(s, t) \,.\, PEC_k(s, t) \cdot SEC_k(s, t) \qquad \text{(Eq. 3)}$$

where

technical change index =

$$TC_k(s, t) = \left[\left(\frac{E_{k,CRS}(t, s)}{E_{k,CRS}(t, t)}\right) \cdot \left(\frac{E_{k,CRS}(s, s)}{E_{k,CRS}(s, t)}\right)\right]^{(1/2)} \qquad \text{(Eq. 4)}$$

pure efficiency change index =

$$PEC_k(s, t) = \frac{E_{k,VRS}(t, t)}{E_{k,VRS}(s, s)} \qquad \text{(Eq. 5)}$$

scale efficiency change index =

$$SEC_k(s, t) = \left(\frac{E_{k,CRS}(t, t)}{E_{k,VRS}(t, t)}\right) \,.\, \left(\frac{E_{k,CRS}(s, s)}{E_{k,VRS}(s, s)}\right)^{-1} \qquad \text{(Eq. 6)}$$

20 Note that now the technology and the production data are distinguished by period.

21 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 in the efficiency through time).

3.2.1 The assessment of university efficiency using DEA

In this part of the work, some of the existing studies about university efficiencies around the world are presented, with a special emphasis to the Brazilian case. Johnes and Tone (2017, p. 193) pointed out that the "workhorse analytical framework typically employed" to the studies reviewed by them "is a standard DEA model". Johnes (2004) presented 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 used DEA.

There are university efficiency studies using diverse models of DEA to several countries. The most relevant non-Brazilian works for the context of this study are Agasisti and Salermo (2007) and Agasisti and Dal Bianco (2006), to Italy, which compared the results of CCR and BCC models to analyze the scale efficiency; in addition, they also carried out comparisons among Italian regions. Besides these, and now comparing results between HEIs from England and Italy, Agasisti and Johnes (2009) measured the CCR and BCC efficiencies - they calculated the scale efficiencies considering both the data pooled and grouped by country and, then, compared the results. The scholars found that when comparing jointly England and Italy HEIs, the former presented a higher efficiency when compared to the latter. Also, the evolution of efficiencies presented different patterns for each country. Italian universities were found to be improving their technical efficiencies while English universities were found to be obtaining stable scores.

Regarding the Brazilian case, since the 1990's Brazilian researchers have involved with the measurement of HEIs efficiency using DEA. After some time, a new source of information - data from the Federal Court of Audit (Tribunal de Contas da União – TCU) - has inspired an increasing group of works. However, the DEA models used by former studies considered the 'TCU indexes', not the raw values of variables. Thus, they could be better considered as a type of multi criteria decision making (MCDM) analysis, which uses DEA as a tool than an efficiency analysis in fact. In that sense, the efficiencies found by the given pieces of research cannot be comparable with the results of the present work, considering the explanation just presented.

On the other hand, it is possible to compare this study with that of Duenhas, França and Rolim (2015), Bittencourt, Gomes, Letti and Bragança (2016), Letti and Bittencourt (2017), Villela (2017) and Letti, Vila and Bittencourt (2018). 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 terms of big (18), medium (22) and small (22) and then the efficiencies were calculated using data from INEP[22] and CAPES[23], and not data from TCU.[24] The scholars concluded that the Brazilian public universities are inefficient, especially the small and medium ones. Also, they stated that small and medium groups increased their productivity within the years 2012 and 2013. These results differed from other Brazilian studies both in terms of static and dynamic analyses. As a final 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%, elevating the Brazilian public HE system in 36 thousand 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, for instance)[25]. Furthermore, there are other outputs that could be considered, for example the innovation of HEIs due to their 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 when carrying out a dynamic analysis.

In a similar way, though using raw variables from the TCU reports and the Treasury Management System (SIAFI), Villela (2017) applied DEA and Malmquist index to analyze 55 Brazilian federal universities to the period 2012 - 2015. It considered three models named 'Resource allocation efficiency', 'Target/Quality efficiency' and 'Economic efficiency'. Each model used a different combination of

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

23 Coordination for the Enhancement of Higher Education Personnel – CAPES.

24 They used data from CAPES and considered four outputs (number of total students both in under and postgraduate courses, number of service 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).

25 For instance, the structure and process required to 'produce' a medical degree is very different from that required for a pedagogical degree or for an engineering degree. The TCU 'student equivalent' somehow tries to overcome this limitation.

inputs and outputs (financial resources, equivalent professor, equivalent faculty, equivalent student, number of undergraduate degrees, cost by professor and cost by faculty). Its results suggested that 45% of the universities were between 71% and 95% of efficiency level and that the variations were in average 1% through the period. The author thus explained that this variation occurred due to the scale change and not due to pure technical changes; it was also emphasized that the recent public policies should be reviewed in an attempt to focus more on social return.

Finally, Bittencourt, Gomes, Letti and Bragança (2016) and Letti and Bittencourt (2017) also presented some important contributions to the area when using information regarding registered patents as outputs, something not yet seen in the Brazilian literature up to that moment. Despite being a contribution, some limitations from these works have been perceived, such as the use of various inputs and outputs to a small number of HEIs (as a result from grouping by size) and the consideration of 'very young' HEIs (with 5 years of implementation or less). Keeping in mind such limitations, Letti, Vila and Bittencourt (2018) attempted to partially overcome some of them (e.g., using fewer variables and specific strategies to manage outlier observations). Nevertheless, considering the need for complementing and improving certain elements in such investigations, the present study was proposed in a way to fill this research gap by analyzing HEIs' efficiencies considering analyses by region and using Malmquist index.

3.3 METHODOLOGICAL PROCEDURES

In order to make it clearer, the focus of this essay was on HEIs classified as public, federal and as universities[26]. Regarding the specific case of DEA Model applications, it was considered only the 56[27] universities which had functioned from

26 The analyses did not consider other types of HEIs (such as state, municipal and private HEIs, nor faculties, federal institutes and HE centres). All the 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 activities. The 63 universities existent in 2016 represented only 2.62% of all Brazilian HEIs, but represented 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 federal universities considered in this study represented, in general, more than half of all public HEIs.

27 Until 2016 there were 7 other universities, 4 completely new ones, and 3 others created by disaggregation. The new ones were UFFS (2009), UNILA (2010), UNILAB (2010) and UFESBA (2013). The disaggregated ones were UFCA (2013, from UFC), UFOB (2013, from UFBA) and UNIFESSPA (2013, from UFPA).

2010 until 2016 and that had some student degree in 2010. The data used here came primarily from the Higher Education Census from INEP (2018), CAPES (2018), and the National Institute of Industrial Property (INPI, 2018). The inputs were selected considering the entire context of the HEI and the availability of the information, gathered online. The financial information about expenditures (EXPEND) from INEP HE Census was used as input. Alternatively, two non-financial variables were jointly considered as inputs - the number of equivalent full time professors weighted by academic formation level (PROFES) and the number of employees (EMPLOY); both did not consider the professionals working exclusively to university hospitals.

In the literature, there is still no consensus regarding the use of students as inputs or outputs, neither is there consensus regarding whether one should consider enrollments and/or degrees awarded. While the enrollment of students reflect expenditure to the HEI and represent some result in relation to human capital accumulation, the real objective of the dimension ‘teaching' is to form professionals. Therefore, the number of degrees awarded could better represent the output of this dimension. In the present investigation, I decided to consider the concluding students as an output and use two variables to represent it - the full time equivalent undergraduate degrees (DEGREU) and the number of postgraduate degrees (DEGREP). The last one considered the total number of the postgraduate degrees (master academic, master professional or doctorate course, not weighted); the former weighted the undergraduate students by type, field and duration of the course, following Sesu/MEC (2018) weights, which were directly related to the cost of each type of student (see Appendix A2).

Regarding innovation to the field, the two variables that added some innovative characteristic to this research were those related to third mission activities (THIRDM) and registered patents (PATENT). The former used the only piece of information available in the INEP HE Census about the professors engaged in third mission activities. For each professor, the available information was of whether the individual was or was not engaged in any third mission activity. Because of that, it provided quite limited information, especially when considering all the possibilities of a third mission activity[28] and its direct and indirect impact on the community. Despite

28 A third mission is usually an activity that involves the outside community.

not being the best option, it was the first attempt to consider something related to third mission.

The same could be said about the PATENT variable. Thursby and Kemp (2002) are cited by Siegel, Wright, Chapple and Locket (2008) to affirm that the use of patents as an indicator of technological variable is problematic because there is a substantial variation in quality and in patenting strategies across universities. Furthermore, the cost of enforcing patent is high and sometimes not worth the effort. Then, it does not represent all aspects about research and its results. In addition, not all research work results in a registered patent. It was considered here, though, that if some patent was registered, it is quite probably that it demanded some significant research effort (financial and non-financial).

Finally, after some data manipulation and considering the aspects just presented, the 9 variables presented in Table 1 were the ones used in this study.

The descriptive statistics regarding the 56 Brazilian federal HEIs are then presented in Table 2. When looking at the table, one can notice the large range in the size of the HEIs by considering both the standard deviation (SD) or max/min values of the variables EXPEND, PROFES, EMPLOY or ENROLU.

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 Center-West (CO) near 12% each one, respectively. In general, the proportion for 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 presented regional patterns which were different from Brazilian values, especially to the variables EXPEND, PATENT and THIRDM.

TABLE 1 – DEFINITION OF THE VARIABLES USED IN THE ANALYSIS

Variable	Description	Source
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.	INEP
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)	INEP
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	INEP
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)).	INEP
DEGREP	**Number of full time equivalent postgraduate degrees:** Total postgraduate degrees (master academic, master professional and doctorate courses)	CAPES
THIRDM	**Number of professors engaged 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'.	INEP
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'	INPI

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

A synthesis of the evolution of the values can be observed in the fourth column-block of Table 2. As it may be noticed, all variables presented some increase from 2010 to 2016, but in different magnitudes. PATENT presented the highest variation, 160%, while EXPEND and expenditure with people presented 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%.

TABLE 2 – DESCRIPTIVE STATISTICS OF THE 56 BRAZILIAN FEDERAL UNIVERSITIES – 2016

	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	427	171	178	223
THIRDM	30.290	541	603	3.153	1	39	19	23	6	13	52	97	64	32	6	15

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

Previous to the DEA efficiency calculus, robust techniques were used to identify and manage the potential outlier universities, following the recommendations and procedures of Wilson (1993, 2010), that extended Andrews and Pregibon's (1978) statistic to the case of multiple outputs and inputs[29]. The HEIs identified as potential outliers were different for each year and the most frequent were UFMG, UNB, UFRJ, UFPR, UFRGS and UFSC. The technological frontier defined by the efficiency units was constructed without the inclusion of these potential outlier universities; then, if some of these potential outlier universities presented an efficiency value higher than 1, this value was adjusted to 1 (full efficiency). This procedure allowed us to construct the frontier and calculate the efficiency values of all the other HEIs without the influence of these potential outlier universities. Therefore, as a result, the general efficiencies tended to be higher due to the exclusion of the potential outliers from the technological frontier determination.

29 These procedures were developed focusing on solving specifically DEA limitations regarding outlier DMU(s). Basically, the 'n-dimensional cloud of points' (where n is equal to the number of inputs plus the number of output) formed by all DMUs is compared with different subsets of DMUs that excluded some DMU or group of DMUs. Then, if the exclusion of some DMU (or group of DMUs) reduced significantly the volume of the cloud, then this DMU (or group of DMUs) would be considered a potentially outlier(s) DMU(s). Finally, even if this potentially outlier(s) DMU(s) presented an efficiency equal to 1, it would not be considered as a benchmark(s) and would not influence the efficiency of the other DMUs.

In order to reach the objectives of this research, three different DEA models were used, considering different characteristics of the production process of higher education services: **Model 1** allowed us to measure the potential waste of resources and used EXPEND as input and DEGREU, DEGREP[30], THIRDM and PATENT as output considering VRS and input-orientation; **Model 2**, as a complement, allowed us to measure the potential improvement in the outputs considering the same variables but with an output orientation; **Model 3** also allowed us to measure the outputs improvement but now by considering only human variables as inputs (PROFES and EMPLOY) and the same four outputs. Each model was applied to each year and also to the entire 7-year-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 university was working under, over or at the optimal scale. Also, the Malmquist index considered the annual values of the initial and the final years of the period (2010 and 2016). Therefore, the results of DEA application are presented in the following section.

3.4 RESULTS AND DISCUSSION

Regarding Model 1, results showed that, when including the 7-year-period as one production cycle, 26 (46.4%) of the universities were found to be efficient. The general mean efficiency was 87.0%, and among the inefficient ones, the efficiency was 75.8%. By region, the mean efficiencies were: Center-West (92.7%), Southeast (87.3%), Northeast (87.3%), South (85.9%) and North (84.1%)[31]. For the entire period (7-year-period), the general results did not differ significantly among the three models[32]. On the other hand, when considering the analysis year by year it was possible to identify some variation among the years in the same model[33], and among the models to the same year[34]. It occurred especially when comparing Models 2 and 3. The North region also presented peculiar visual differences among the results in

30 It presents very strong and statistically significant correlations with all the variables in relation to the research dimension.

31 Kruskal-Wallis test (chi-squared = 1.47, df = 4 , p-value = 0.83) suggests no differences among regions.

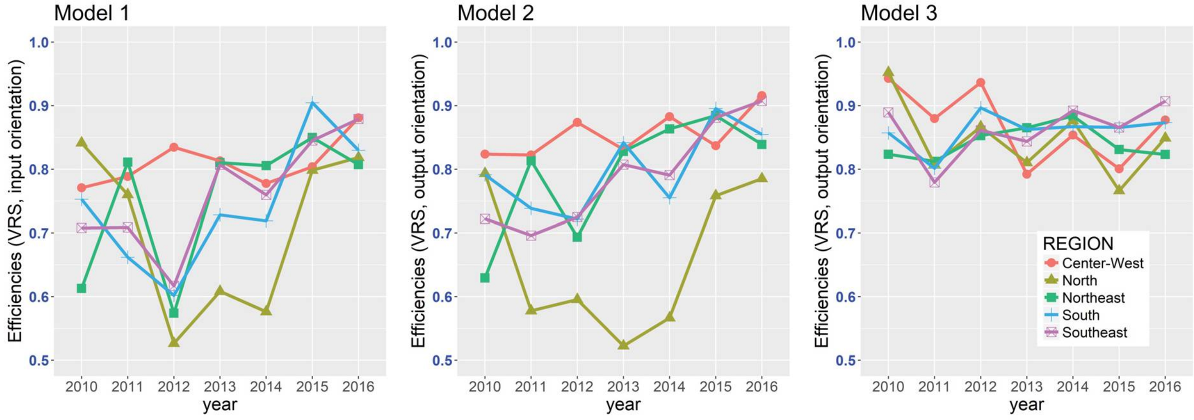
32 Friedman rank sum test (chi-squared = 1.39, df = 2, p-value = 0.50) suggests no statistically significant differences among models' results.

33 Friedman rank sum test results in p-values < 0.02 to each of the three models, suggesting differences in the efficiencies through time to each model.

34 Friedman rank sum test results in p-values <0.05 to each year with exception of 2015, suggesting differences among models to each year with the exception to 2015.

Models 1 and 2[35]. The variations through time and region can be visualized in Figure 1 which presents the mean values by region and year to each model.

FIGURE 1 – EFFICIENCY MEANS BY REGION, YEAR AND MODEL



SOURCE: the author (2019)

Regarding regions, different patterns were observed, with the minimum value to the North in 2013 in Model 2 (52.2%), and the maximum also to the North region, in 2010, in Model 3 (95.2%). Although the values by region diverged through time, they ended up converging to efficiencies between 78.5% (North, Model 2) and 91.6% (Center-West, Model 2). 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 occurred because some funds from one year are only 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 the consideration of a given university as efficient (or outlier) in one year and as extremely inefficient in the following year[36].

Table 3 now presents the results (VRS, scale value and type of returns to scale) for the Models 1, 2 and 3 to Brazil and to each region. The geometric means of the efficiency (effic.) among the three models were almost the same when

35 Nevertheless, the Kruskal-Wallis test comparing regions results in p-values > 0.10, suggesting no significant difference. The lowest value was found to Model 2 in the year 2013 (p-value = 0.1518).

36 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).

considering the entire set, but they varied 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 Center-West (0.94) also in Model 2. All models and regions presented geometric mean of returns to scale higher than 1, with higher values to Center-West to Model 2 (1.32 and 4 out of 5 universities presenting Decreasing Returns to Scale – DRS). The lowest value of returns to scale was presented by the South region to Model 3 (1.03 with 5 out of 9 universities presenting CRS). In general, Model 3 presented lower values of scale than models 1 and 2. That is to say that the human resources can take more advantage from scale returns than financial resources.

TABLE 3 – RESULTS TO BRAZIL AND REGIONS TO MODELS 1, 2, 3 (VALUES 2010 TO 2016 ADDED)

		Model 1 (VRS, input)					Model 2 (VRS, output)					Model 3 (VRS, output)				
		geometric means		number of HEIs presenting			geometric means		number of HEIs presenting			geometric means		number of HEIs presenting		
region	**N**	**effic.**	**scale**	**IRS**	**CRS**	**DRS**	**effic.**	**scale**	**IRS**	**CRS**	**DRS**	**effic.**	**scale**	**IRS**	**CRS**	**DRS**
Brazil	**56**	**0.851**	**1.16**	**13**	**15**	**28**	**0.855**	**1.16**	**7**	**14**	**35**	**0.87**	**1.06**	**9**	**25**	**22**
Center-West	**5**	**0.920**	**1.30**	**0**	**0**	**5**	**0.935**	**1.32**	**1**	**0**	**4**	**0.87**	**1.09**	**0**	**1**	**4**
Northeast	**14**	**0.854**	**1.10**	**3**	**3**	**8**	**0.863**	**1.11**	**0**	**5**	**9**	**0.86**	**1.06**	**3**	**7**	**4**
North	**9**	**0.823**	**1.24**	**5**	**1**	**3**	**0.743**	**1.12**	**3**	**2**	**4**	**0.87**	**1.12**	**2**	**3**	**4**
Southeast	**19**	**0.855**	**1.13**	**3**	**9**	**7**	**0.879**	**1.16**	**1**	**6**	**12**	**0.89**	**1.05**	**2**	**9**	**8**
South	**9**	**0.828**	**1.16**	**2**	**2**	**5**	**0.868**	**1.22**	**2**	**1**	**6**	**0.83**	**1.03**	**2**	**5**	**2**

SOURCE: the author (2019)

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 suggested a high improvement in 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 practically solely due to the technological increase (1.29), partially compensated by the pure efficiency decrease (0.98), and with a weak influence of scale increase (1.04). It may be suggested that even though the use of financial resources is becoming more efficient in general (even by changing the scale of values operation), the use of human resources is not increasing proportionally; and, more important, it is increasing due to the increase of the benchmarking's productivity (change of the technology/frontier) and not all HEIs are catching up to this change (pure efficiency decrease). Finally, for human resources the effect of scale change is lower than for financial resources.

TABLE 4 – MALMQUIST INDEX (2010 AND 2016) TO MODEL 2 AND MODEL 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: the author (2019)

This result indicates that despite the improvement in the efficiencies in both models (45% and 33%), the decomposition of this improvement is quite different[37]. 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 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 then, it could be said that the efficiency of both resources (financial and human) is improving, but due to 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 and the other universities are only accompanying this change.

Considering the Malmquist index results to each region, it is possible to perceive some particularities[38]. First, the means of the Southeast present a pattern and values which are similar to the means of Brazil. As this region represents almost

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

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

a third part of the nation, it could also be that it is actually influencing the general mean. Second, the Center-West region presents the lowest 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 highest values of scale efficiency occur to the North region in both models (42% and 35%, respectively), indicating that the universities of this region are developing to a size nearer the optimal and they are taking advantage of the scale economies. These values were small or negative to all other regions, which indicated that the universities, in general, were not taking advantages.

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 may also suggest that R$ 2.96 billion by year were wasted due to inefficiency, and if they had been used efficiently, it would have resulted 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 engaged 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 have been of 9.0%, 7.1%, 6.9%, and 5.1%, respectively.

Taking what has been presented into consideration, these results could be calculated and identified for each university under investigation; this way, such values could be used as a target by the policymaker or university managers to subsidize their activities. Since this objective is beyond the scope of the present work, it is suggested as an interesting focus of future investigations.

3.5 FINAL REMARKS

As previously presented, the main objective of this research was to study the relative efficiency of the Brazilian federal universities for the period of 2010 to 2016, as well as to analyze the regional patterns of their efficiency. This was carried out by using DEA models and the Malmquist index. Overall, the results have showed that, considering the entire period, 26 (46.4%) of the 56 universities were regarded as efficient presenting a high mean efficiency (87%) to Brazil and by region: Center-West (93%), Northeast (87%), Southeast (87%), South (86%) and North (84%). As already discussed, the general efficiencies tended to be higher due to the exclusion of the potential outlier universities from the technological frontier determination. On the other hand, the results presented should make evident a very realistic possibility regarding improvements to the universities identified as inefficient ones.

In the study, the values were also calculated by year. As noticed, 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 was improving through time and it seemed to occur due to different factors in relation to financial and human resources. Regarding the financial resources, the technological frontier was almost static, the universities were actually becoming more efficient, and only the North region was taking advantage of the scale change. On the other hand, regarding the human resources, it seemed that the frontier was changing (the benchmarks were improving) and the majority of the universities were not following such changes.

Finally, it is important to point out that some of the contributions of this study were mainly in terms of the variables used as inputs and outputs, such as holding simultaneously the three dimensions of university activities – teaching, research and third mission activities – as well as the aspect of innovation, when using registered patents as a proxy; in addition, another contribution regarded the period considered – each year from 2010 to 2016. Furthermore, the analysis included robust techniques to identify and manage potential outlier HEIs (Wilson, 1993, 2010), which is something not yet unveiled in previous investigations.

At last, as a follow-up stage in this research agenda, it would also be a great contribution to the area the consideration of quality and contextual variables, as well as the search for potential determinants which might better explain the performance of the institutions.

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4 THE EFFICIENCY OF BRAZILIAN FEDERAL UNIVERSITIES (2010-2016): COMPARING PARAMETRIC AND NON-PARAMETRIC METHODS

ABSTRACT

The theme of efficiency in public services, including those provided by federal universities, has recently increased its importance in the Brazilian economy. Frontier production methods such as Stochastic Frontier Analysis (SFA) and Data envelopment analysis (DEA) have often been used to evaluate efficiency in the context of higher education institutions (HEI). However, their results are not always uniform and there are no established methods/criteria for choosing one or the other approach. Taking that into consideration, this study aimed to compare efficiency scores obtained by SFA and DEA models for all the existing 56 Brazilian federal universities for the period of 2010 to 2016. An output distance function was used considering financial and human resources as inputs and the three pillars of higher education - teaching, research and third mission - as outputs. This investigation is, therefore, innovative considering: (i) the estimation of SFA to Brazilian HEIs, and (ii) its comparison with DEA; as well as (iii) the use of patents and third mission variables. The data came primarily from INEP/MEC ('Higher Education Census'), TCU, CAPES and INPI. The findings suggest inefficiency in HE production with no change through time and with some influence from environmental variables. The values and the rank of the efficiencies estimated/calculated are sensitive to the model/method employed, presenting highly significant but weak correlations. Hence, as advised in other international comparative analyses, caution is required when applying the results for management and policy purposes, being thus recommended the use and comparison of different methods to search for more trustworthy results.

Keywords: Higher Education. Efficiency. SFA. DEA. Brazil.

RESUMO

Eficiência na provisão de serviços públicos, inclusive ensino superior, tem sido cada vez mais discutida no contexto da economia brasileira. Internacionalmente este tema tem sido abordado usando tanto análises de fronteira estocástica (SFA) quanto análise envoltória de dados (DEA). Entretanto, esses métodos nem sempre apresentam resultados coincidentes e inexiste um critério único para seleção da abordagem mais adequada. Neste contexto, o objetivo do presente estudo foi mensurar e comparar a eficiência das 56 universidades federais brasileiras no período de 2010 a 2016. Usou-se o conceito de função distância com orientação para produto. Considerou-se que as universidades usam recursos financeiros e humanos para produzir ensino, pesquisa e extensão. Assim, este trabalho traz como inovações: (i) a estimação de uma fronteira estocástica para as universidades brasileiras, (ii) a comparação destes resultados com resultados DEA e (iii) o uso patentes e atividades de extensão como outputs. Os dados foram obtidos do Censo do Ensino Superior do INEP/MEC, do TCU, da CAPES e do INPI. Os resultados sugerem ineficiências das universidades, constantes ao longo do tempo e relacionadas com características das universidades e regiões onde se situam. O valor e o ranking das eficiências estimadas são sensíveis ao método empregado e apresentam correlação fraca e estatisticamente significativa. Como já observado em estudos para sistemas de ensino superior de outros países, é preciso muito cuidado quando do uso de um único método para analisar o setor e subsidiar ações de políticas públicas. Deste modo, recomenda-se o uso e comparação de diferentes métodos para obtenção de resultados mais confiáveis.

Palavras-chave: Ensino Superior. Eficiência. SFA. DEA. Brasil.

4.1 INTRODUCTION

In 2015 the Brazilian higher education (HE) sector overcame its record with 8 million students (6 in private and 2 in public system) and reached the same size of the secondary course system (SAMPAIO, 2017, p. 28). Considering that only recently a great part of the Brazilian young population has been taking a secondary course (IBGE, 2010), their potential might increase the demand for university courses (public and private). Regarding financial values, the Brazilian expenditure in public HE has increased by a mean of 2.5% per year in the 21st Century, representing approximately 0.8% of the GDP in each year and an equivalent value of USD $ 14 billion in 2016 (INEP, 2017). However, despite the high increase in the HE enrollments, not more than 15% of the Brazilians had an undergraduate degree, with no more than 17% for the younger population cohorts (OCDE, 2015) and presenting strong regional differences.

Because of the rising expectations for public sector performance, the publicly funded agencies, including public higher education institutions (HEI), are being exposed to a deeper scrutiny (McMILLAN; CHAN, 2006). As the monetary and non-monetary benefits from HE present strong external effects over the entire society (VILA, 2000) and as good performance in HE is believed to produce growth effects, inefficiency in HEI 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 HE system as a whole.” (JOHNES; JOHNES, 2013, p. 5).

The use of frontier production methods is common to investigate the relative efficiencies of HEIs. Earlier studies have relied on the non-stochastic data envelopment analysis (DEA) method and more recently on the stochastic frontier analysis (SFA) method. The studies of Lindsay (1982), Worthington (2001), Salerno (2003), Aleskerov, Belousouva and Petruschenko (2017) and Gralka (2018) are good reviews of both 'state of the art' methods applied specifically to HEIs' efficiency. The last one presents a systematic review specifically about SFA applied to HEIs. According to all of them, the efficiency values and rankings obtained by alternative methodologies are not always uniform and, there are no established methods or criteria for choosing one or the other approach. In addition, the reliability of the outcomes of an economic analysis' is very important because it allows those outcomes to be used for policy purposes. Consequently, if "policy implications from alternative methodologies are consistent, one can have greater confidence when making policy choices" (MCMILLAN; CHAN, 2006, p. 2). Hence, the present comparative analysis between parametric and non-parametric methods can be understood as valuable from a policy viewpoint as well.

Worthington (2001), examining both the measurement of inefficiency in education and the determinants of educational efficiency, affirmed that "educational institutions worldwide are increasingly the subject of analyses aimed at defining, measuring and improving efficiency." (p. 245). According to the scholar, "despite the importance of efficiency measurement in education, it is only relatively recently that the more advanced econometric and mathematical programming frontier techniques" (p. 245) have been applied to educational institutions (primary and secondary schools, university departments and degree programs, and universities as a whole). Also, according to Johnes (2013), "few studies have compared efficiency values of HEIs derived using both parametric and non-parametric output distance functions". In that sense, McMillan and Chan (2006) found significantly, though not particularly high, correlated efficiencies from DEA and SFA to Canadian universities to the year 1992/3, while Kempkes and Pohl (2010) found a higher correlation to German universities to the period 1998 to 2003, (but their use of DEA and SFA models are not entirely comparable). In their turn, studying Britain universities for the period from 1996/7 to 2008/9, Johnes (2013) found a significantly positive though low rank correlation between parametric and non-parametric efficiency estimates. A possible justification for the given results was highlighted by Gomez and Perez (2017, p. 5): “DEA cannot take into account statistical noise in the data, and efficiency estimates may be biased if the process is largely characterized by stochastic elements.”.

On the other hand, to the best of our knowledge, there are no studies in the literature regarding the efficiency of Brazilian public universities estimated by SFA, neither comparing results from DEA and SFA methods to HEIs. The two works found, which may be related somehow, were: (i) Zoghbi, Rocha and Matos (2013) which identified the variables associated with academic efficiency (improvement between freshmen students marks and concluding students marks in the Brazilian standardized higher education test), though they did not consider variables about postgraduate courses neither financial values; and (ii) Miranda, Gramani and Andrade (2009, 2012) that compared DEA and SFA methodogies, but applied it specifically to measure the efficiency of business administration courses offered by private for-profit institutions that focus only on education and that were located in the same geographical region. Therefore, taking such elements into consideration, the present investigation is considered new in relation to the existent literature.

Within this context, the main objective of this work was to compare efficiency scores obtained by DEA and SFA methods for all 56 Brazilian federal universities for the period 2010 to 2016. Different specifications of the models regarding different assumptions were considered for the analysis. The inputs used were current expenditures, professor equivalent and staff equivalent. Representing the three pillars of higher education - teaching, research and third mission -, the output measures used were: undergraduate degrees, postgraduate degrees, postgraduate national quality index, third mission activities and registered patents. In order to explain inefficiency, time trend and HEIs characteristics were used (such as region, being recently federalized, having a university hospital, the proportion of postgraduate in relation to undergraduate students, the proportion of full time students, and the proportion of success in undergraduate courses). To the best of our knowledge, the use of patents and third mission activities is unprecedented in the Brazilian literature on HEIs’ efficiency. The study of the period analyzed (2010 to 2016) and the use of data cloud strategy (WILSON, 1993, 2010) to identify and manage outlier universities are also research innovations to the Brazilian case.

This being said, and in order to reach the proposed objective, this study here presented is organized into five sections of which this introduction is the first. Section 2 then introduces the basic framework of both production frontier methods, DEA and SFA. Section 3 presents the methodological procedures to construct the database, to define the sample, and to calculate/estimate the relative efficiencies. Section 4 presents the results and discussion, while section 5 exposes the final remarks.

4.2 THEORETICAL BACKGROUND: EFFICIENCY, DEA AND SFA

Efficiency can be generally understood as the use of the fewest inputs (resources) to produce the most outputs (services). More formally, considering two firms (x_1, y_1) and (x_2, y_2) which use resource x to produce y, it can be said that firm 2 dominates or is more efficient than firm 1 if it uses no more inputs to produce no fewer outputs and is doing strictly better in at least one dimension. This way, “in economics, the efficient firms are those that cannot be dominated by other firms” (BOGETOFT; OTTO, 2011, p. 23-24). Furthermore, in order to determine which firms are efficient, it is necessary to have a description of all possible firms (e.g., a listing or a technology set). Then, for a given technology set T, efficiency can be defined as:

Efficiency: (x, y) is efficient in T if and only if it cannot be dominated by some (x’, y’) ϵ T

Johnes (2006, p. 274) defines efficiency, “from an output-oriented[39] perspective (FARREL, 1957), [...] as the ratio of a firm’s observed output to the maximum output which could be achieved given its input levels”. In a more didactical way, 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 a 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.”.

In that sense, Lindsay (1982) points out that efficiency is related to the input-output relationship and, differently, effectiveness is related to the output-goals relationship. To the case of educational production function, it could be understood

39 The output-oriented models measure the efficiency keeping fixed the inputs and maximizing the outputs while the input-oriented models measure the efficiency keeping fixed the outputs and minimizing the inputs.

under different perspectives (e.g., psychology, economics and business), each one with a particular comprehension about inputs and outputs and their relationships. For the second and third perspectives, the focus of this study, research could be grouped into three types: the output-input ratios, the regression analysis and the frontier/envelopment analysis (LINDSAY, 1982). The last two can be considered as studies about technological frontier and can also be classified according to the way the frontier is specified and estimated (parametric or not, statistical or not, deterministic or random/stochastic) (FORSUND; LOVELL; SCHMIDT, 1980; JOHNES, 2004). Nowadays, this grouping criterion maintains its coherence; this way, this study then focuses specifically on two approaches: DEA (non-parametric, non-statistical and deterministic) and SFA (parametric, statistic and stochastic). The following paragraphs are thus dedicated to briefly explain and compare their general background. But first, some aspects about distance functions which grounded both approaches should be made explicit.

4.2.1 Distance functions

As the assumption of separate production (an individual production function for each output) cannot obviously capture the jointness of production observed in HEIs, we therefore assume that HEIs use a vector of inputs $x \in \mathbb{R}_+^K$ to produce a vector of outputs $y \in \mathbb{R}_+^M$. In addition, as inputs to public higher education are often pre-determined by government policy, then an output-oriented perspective (inputs are fixed and outputs are expanded proportionally) is used here (JOHNES, 2013, p. 2).

Consider the production technology for the HEI defined by

$$P(x) = \{ y \in R_+^M | x \ \ can\,produce \ \ y \} \quad (1)$$

The output distance function (SHEPARD, 1970) is defined on the output set P(x) as:

$$D^o(x, y) = min_\theta \{ \theta > 0 | (y/\theta) \in P(x) \} \quad (2)$$

This distance function is non-decreasing, positively and linearly homogeneous of degree +1 in y, convex in y, and decreasing in x. It follows that

$$D^o(x, y) \leq 1 \Leftrightarrow y \in P(x) \quad (2a)$$

$$D^o(x, y) = 1 \Leftrightarrow y \in BoundP(x) \quad (2b)$$

where $BoundP(x)$ is the frontier of the output set (COELLI; RAO; O'DONNEL; BATTESE, 2005). Then, "if y is located on the boundary of the production possibility set, $D^o(x, y)=1$ and this represents technical efficiency; on the other hand, if $0 < D^o(x, y) < 1$, y lies inside the frontier and technical inefficiency exists" (JOHNES, 2013, p. 2)[40].

4.2.2 DEA approach

The pioneer work of Charnes, Cooper, and Rhodes (1978) (named CCR), following the works of Dantzig (1951) and Farrell (1957), developed a strategy to measure the efficiency of firms using DEA considering constant returns to scale (CRS)[41]. After them, Banker, Charnes and Cooper (1984) (named BCC) modified the DEA model to incorporate variable returns to scale (VRS), keeping the model solvable by using linear programming (JOHNES, 2006). On that aspect, Forsund, Kittelsen and Krivonozhko (2009, p. 1540) affirmed 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 conditions". Johnes (2006, p. 274) also clarified that in a multi-output, multi-input production context, DEA provides estimates of the distance function (SHEPARD, 1970), which is a generalization of the single output production function.

On the other hand, considering practical implications, Johnes (2004, p. 663) presented DEA as a non-parametric non-statistical deterministic 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 an emphasis to HEIs empirical application can be found in

40 Or equivalently, Henningsen (2018, p. 265) uses $D^o(x, y)=min_\lambda\{\lambda>0|(x, y/\lambda)\in T\}$ where T is the technology set; he points out that "it returns a value of one for fully efficient sets of inputs and outputs (x, y), whereas it returns a non-negative value smaller than one for inefficient sets of inputs and outputs (x, y)".

41 CRS occurs when, considering a variation in the inputs, the outputs vary proportionally. VRS occurs 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) (BOGETOFT; OTTO, 2011).

Johnes (2004, 2006) and Forsund (2018). Now, the following paragraphs explain the basics of the DEA methodology as a background for the present empirical work.

Tone (2001, p. 502) emphasized that "the important characteristic of DEA is its dual side which links efficiency evaluation with the economic interpretation" in the context of production process and production functions. In addition, Forsund (2018, p. 4) observed 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"; he also added that it 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)". Considering that, the standard primal problem in contemporary DEA literature using BCC model and output orientation is presented in Eq. 1 (FORSUND, 2018, p. 4; THANASSOULIS et al, 2011, p. 1297).

In order to calculate efficiency, considering that DMUs[42] produce outputs y_m (m = 1, ..., M) using inputs x_k (k = 1, ..., K), under VRS, the following linear programming problem must be solved for each *i* of the *N* DMUs (*i* = 1,..., N):

$$\begin{aligned}
&\textit{Maximize} \quad \phi_i \\
&\text{subject to} \\
&\phi_i y_{mi} - \sum_{j=1}^{N} \lambda_j y_{mj} \leq 0 \qquad \text{for} \qquad m=1,\dots,M; \\
&x_{ki} - \sum_{j=1}^{N} \lambda_j x_{kj} \geq 0 \qquad \text{for} \qquad k=1,\dots,K; \\
&\sum_{j=1}^{N} \lambda_j = 1 \ , \quad \lambda_j \geq 0 \ , \qquad \forall \ j=1,\dots,i,\dots,N
\end{aligned} \qquad (3)$$

The values of ϕ_i represent Farrel's output efficiency. The vector λ represents the *N* weights *j* 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. The overall Shepard output-oriented efficiency of DMU_i is measured by $E_i = 1/\phi_i$ and varies from 0 to 1. It can be interpreted as the level of efficiency of DMU_i relative to its efficient DMU (the benchmark) or its combination of efficient DMUs (benchmarks).

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

For example, if the value is E_i = 0.80, then the DMU_i is producing only 80% of its potential output (given the level of inputs).

Regarding empirical applications of DEA to HEIs, Aleskerova et al (2017) presented an extensive international literature review; in a complementary manner, Letti, Bittencourt and Vila (2018a, 2018b) presented extensive literature reviews regarding the use of DEA to measure efficiencies, or performances, particularly of Brazilian HEIs. In the literature, there have been some attempts of DEA in the stochastic direction – generally based on the bootstrapping strategy presented by Simar and Wilson's (1998) seminal work. However, Johnes (2013), based on Coelli et al (2005), pointed out that these methods address issues of sampling variability rather than stochastic error. Taking this into account, the DEA stochastic approach was not considered here, leaving it as a possibility for future studies. Instead then, efficiencies were calculated using four different specifications of DEA models, all of them considering the output approach:

a) dea1 (CRS pooled): considering the same technological frontier to the entire period (2010 to 2016) and measuring the efficiency of each HEI for each year in relation to this general CRS frontier;

b) dea2 (CRS within): considering one frontier for each year and measuring each annual efficiency of each HEI in relation to the respective annual CRS frontier;

c) dea3 (VRS pooled): similar to dea1 but considering VRS;

d) dea4 (VRS within): similar to dea2 but considering VRS.

One important characteristic of DEA is that it allows one to choose the weights of outputs and inputs that result in the best possible efficiency level for each DMU. This way, the weights are calculated within the model and can vary among DMUs, which can 'prefer' the specialization or not in some specific output to reach the highest efficiency level. This possibility does not occur in the SFA method, which defines by estimation the general weights of each input and output for all DMUs. Additional information about SFA approach is presented in the following paragraphs.

4.2.3 SFA approach

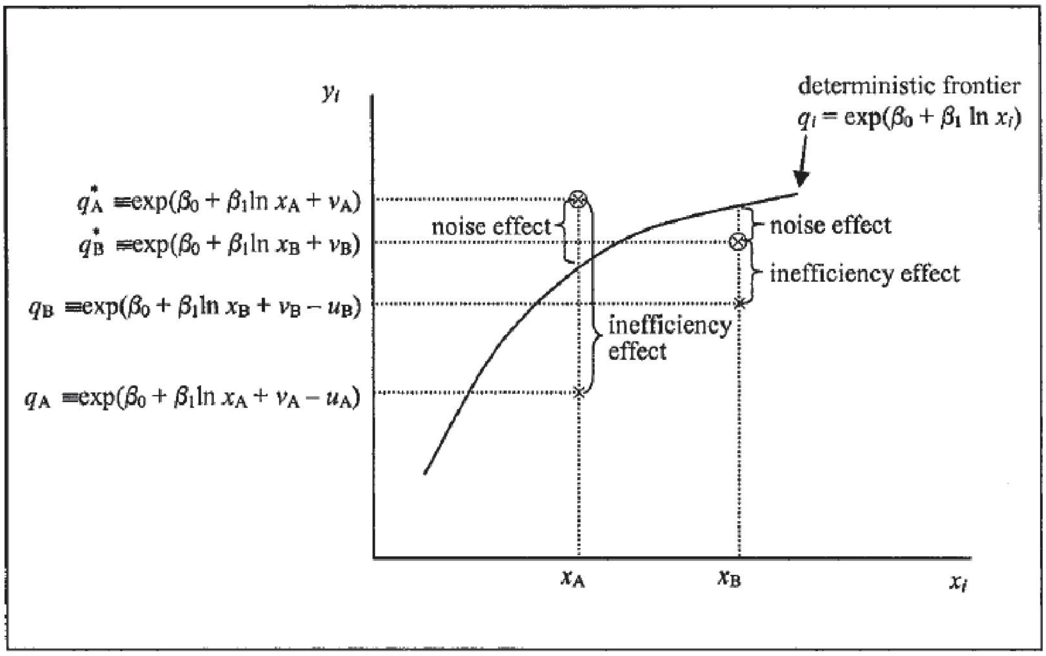
The SFA is a strategy also used to estimate de efficiency of firms. It is more directly linked to econometric theory (while DEA is based on mathematical programming). There are two main characteristics of SFA when compared to DEA. First, SFA is a parametric approach, and it makes additional assumptions about the structure of the possibilities set and the data generation process. Second, SFA assumes a stochastic relationship, so that deviations from the frontier may reflect not only inefficiencies but also noise in the data. These, and the following information in this item, are based mainly on Bogetoft and Otto (2011) and McMillan and Chan (2006), when not specifically identified in the text.

Consider a production function f that, based on the technology set T, is derived as: $f(x) = max\{\ y \mid (x,y) \in T\}$, where x and y are the input and output vectors, respectively. The SFA assumptions are that the production function has a specific functional form but that the details of this function, defined by parameters β, are unknown; and that $f(x) = f(x,\beta)$ for some unknown parameters β. Then, following the maximum likelihood principle, the values $\hat{\beta}$ which make the actual observations as likely as possible need to be 'chosen'. In order to do it, one more aspect needs to specified, the data generation process which can explain why the actual observations deviate from the production function (because of noise caused by luck/measurement error and/or by actual inefficiency). In this sense, three main processes have been suggested by researchers: (i) pure noise, which results in using ordinary last squares regression (OLS) models; (ii) pure inefficiency, which results in using deterministic frontier like DEA or corrected ordinary last squares (COLS) regression models; and (iii) both noise and inefficiency, which result in using SFA.

Then, as in the SFA seminal works of Aigner, Lovell and Schmidt (1977), as well as of Meeusen and Broeck (1977), the composed error term of the estimate will be $e_i = v_i - u_i$. Where v_i takes care of the possible measurement error and u_i takes care of the possible inefficiency of the firm i. Both v and u are assumed to be independent. "The interpretation of u in the multiplicative model is that it is the relative loss in output due to the inefficiency". Also, "if $u=0$ the firm is 100% efficient, and, if $u>0$, then there is some inefficiency" (BOGETOFT; OTTO, 2011, p.

199 and 204). As reminded by Kempkes and Pohl (2010, p. 2070), the term u_i displays total economic inefficiency, i.e. technical inefficiency plus allocative inefficiency. Figure 1 from Coelli et al (2005, p. 244) thus represents a deterministic frontier (OLS) and its comparison with the noise effect and the inefficiency effect of two DMUs, A and B. The horizontal axis represents the quantities of input x, and the vertical axis represents the quantities of output y. Both DMUs produce under the deterministic frontier, (x_A, q_A) and (x_B, q_B), respectively. But each DMU presents a different value of inefficiency effect, because the noise effect presents a positive effect to DMU A and a negative effect to DMU B.

FIGURE 1 - STOCHASTIC PRODUCTION FRONTIER (INEFFICIENCY AND NOISE EFFECTS)



SOURCE: Coelli et al (2005, p. 244)

Considering more than one time period, Battese and Coelli (1992), henceforth BC92, defined a stochastic frontier production function model for panel data in which technical efficiencies of firms may vary over time; also, Battese and Coelli (1993, 1995), henceforth BC95, improved this model to allow the inclusion of explanatory variables to the inefficiencies[43]. In BC92, the efficiencies are not

43 More recently, Coelli, Hajargasht and Lovel (2008) intended to identify the best way to estimate a system of equations involving an input distance function along with the first order equations that relate to shadow cost minimizing behavior. Their review led them to the conclusion that there is no model available that can capture both types of errors (management and non-management) in a reliable manner. They suggest as the least problematic model the one proposed by Karagiannis et al (2006) but only after an adjustment which involves re-expressing the first-order equations in

considered stochastic while in BC95 they are. Then, provided that the inefficiency effects are stochastic, the model permits the estimation of the technical change in the stochastic frontier and the time-varying technical inefficiencies[44].

Aiming to complement such issues, based on the seminal work of Lovell, Richardson, Travers and Wood (1994) about distance functions, Coelli and Perelman (2000) proposed a model which extends the technical efficiency effects model from BC95 to a general multi-input multi-output distance function to industries where behavioral assumptions such as cost minimization or profit maximization are unlikely to be applicable. Their results from distance functions were compared with those obtained from single-output production functions (aggregate output measures) and indicated “substantial differences in parameter estimates and technical efficiency rankings, casting significant doubt upon the reliability of these single-output models” (COELLI; PERELMAN, 2000, p. 1967). Coelli et al. (2005, p. 288) advised scholars to “see that distance functions can be used when no price information is available and/or it is inappropriate to assume that firms minimize costs”. Furthermore, “the decision to estimate a distance function, cost frontier, profit frontier or single-output production frontier is just one of the many decisions facing researchers who want to estimate efficiency using a parametric approach”. Other decisions were “concerning functional forms, error distributions, estimation methods and software.” Thus, “the need to make so many choices is often seen as a disadvantage of the parametric approach”.

For some of these decisions, this investigation followed Johnes (2013), whose study is the most recent one found using distance functions to compare DEA and SFA from HEIs. It is similar to the strategies adopted by Abbott and

ratio forms to avoid the invariance problem. Then they did an empirical application involving panel data on US electricity generation firms and found that technical inefficiency is the largest contributor to cost inefficiency, and that the majority of allocative mistakes involve under use of fuel relative to the other inputs. Despite the importance of this methodological development, the present research followed the Battese and Coelli (1992, 1995) tradition, as great part of the literature does. A future work could be done comparing the present results with those from Coelli et al (2008) model application.

44 Johnes and Johnes (2009) propose a random parameters model from which the random effects model (BC95) is a special case. The latter is the case of the former where only one parameter, namely the constant term, is allowed to vary across observations. This brings the analysis somewhat closer to the spirit of non-parametric techniques such as DEA and allows questions to be answered about the distinction between inefficiency and idiosyncratic cost technologies. On the other hand, these random parameters have some of DEA’s drawbacks, such as its sensitivity to the presence of outlier DMUs. Because of that, the BC95 model is used here and it could then be improved in a future study.

Doucouliagos (2009) and Agasisti, Barra and Zotti (2016)[45]. Furthermore, this research also followed the theoretical and operational recommendations of Henningsen (2018) in relation to SFA procedures.

Regarding the functional form, the desirable properties are that it should: (i) be flexible, (ii) be easy to estimate, and (iii) permit the imposition of homogeneity (COELLI; PERELMAN, 2000). The translog functional form presents all three characteristics and is commonly used to estimate distance functions. Then, it was used the translog distance function defined below for N HEIs using inputs x_k (k = 1, ..., K) to produce outputs y_m (m = 1, ..., M):

$$\begin{aligned} \ln D^o_{it}(x\,,\,y) = \alpha_0 + \sum_{m=1}^{M} \alpha_m \ln y_{mit} + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M} \alpha_{mn} \ln y_{mit} \ln y_{nit} \\ + \sum_{k=1}^{K} \beta_k \ln x_{kit} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \ln x_{kit} \ln x_{lit} \\ + \sum_{k=1}^{K}\sum_{m=1}^{M} \delta_{km} \ln x_{kit} \ln y_{mit} \end{aligned} \quad (4)$$

where subscript *it* refers to the *i*th HEI in the *t*th time period. Still following Johnes (2013, p. 3) and Henningsen (2018, p. 289), the distance function restrictions require the following conditions to hold:

a) homogeneity of degree +1 in outputs

$\sum_{m=1}^{M} \alpha_m = 1$ and (5a)

$\sum_{m=1}^{M} \alpha_{mn} = 0 \quad m=1,2,\ldots,M$ and (5b)

$\sum_{m=1}^{M} \delta_{km} = 0 \quad k=1,2,\ldots,K$ (5c)

b) symmetry

$\alpha_{mn} = \alpha_{nm} \quad m,n=1,2,\ldots,M$ and (6a)

$\beta_{kl} = \beta_{lk} \quad k,l=1,2,\ldots,K$ (6b)

45 It seems interesting to point out that Agasisti, Barra and Zotti (2016) implemented a procedure developed by Wang and Ho (2010) (WH10) to remove the fixed effects before the estimations (transforming the model by either first-difference or within-transformation). Indeed, their empirical evidence suggested the importance of removing time-invariant individual effects from the model. When they replicated the analysis without taking into account the unobserved heterogeneity, a bias was found in their estimations, meaning that the efficiency scores calculated might be over-estimated. On the other hand, considering the specifications of functional forms, the estimates were quite stable across all of them, suggesting that to the case of Italian universities it did not affect the quality of final judgments.

Due to the homogeneity in outputs restriction, the distance function D(x, *w*y) = *w*D(x, y) and so the *M*th output can be chosen arbitrarily such that $w = 1/y_M$ and, the equation (4) can be rewritten as:

$$\begin{aligned} -\ln y_{Mit} = {} & \alpha_0 + \sum_{m=1}^{M-1} \alpha_m \ln\left(\frac{y_{mit}}{y_{Mit}}\right) + \frac{1}{2}\sum_{m=1}^{M-1}\sum_{n=1}^{M-1} \alpha_{mn} \ln\left(\frac{y_{mit}}{y_{Mit}}\right) \ln\left(\frac{y_{nit}}{y_{Mit}}\right) \\ & + \sum_{k=1}^{K} \beta_k \ln x_{kit} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \ln x_{kit} \ln x_{lit} \\ & + \sum_{k=1}^{K}\sum_{m=1}^{M-1} \delta_{km} \ln x_{kit} \ln\left(\frac{y_{mit}}{y_{Mit}}\right) - \ln D_{it}^{o}(x, y) \end{aligned} \quad (7)$$

Then, “we can assume that $u = -\ln(D^o(x, y)) \geq 0$ follows a half-normal or truncated normal distribution (i.e. $u \sim N^{+}(\mu, \sigma_u^2)$)” and also we can “add a disturbance term *v* that accounts for statistical noise and follows a normal distribution (i.e. $v \sim N(0, \sigma_v^2)$)”[46] (HENNINGSEN, 2018, p. 291)[47], so that we get:

$$\begin{aligned} -\ln y_{Mit} = {} & \alpha_0 + \sum_{m=1}^{M-1} \alpha_m \ln\left(\frac{y_{mit}}{y_{Mit}}\right) + \frac{1}{2}\sum_{m=1}^{M-1}\sum_{n=1}^{M-1} \alpha_{mn} \ln\left(\frac{y_{mit}}{y_{Mit}}\right) \ln\left(\frac{y_{nit}}{y_{Mit}}\right) \\ & + \sum_{k=1}^{K} \beta_k \ln x_{kit} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \ln x_{kit} \ln x_{lit} \\ & + \sum_{k=1}^{K}\sum_{m=1}^{M-1} \delta_{km} \ln x_{kit} \ln\left(\frac{y_{mit}}{y_{Mit}}\right) + u_{it} + v_{it} \end{aligned} \quad (8)$$

Then, “this specification is equivalent to the specification of stochastic frontier models so that we can use stochastic frontier methods [...] to estimate this output distance function.” (HENNINGSEN, 2018, p. 291)[48]. Respecting the empirical aspects of SFA estimations, Coelli et al (2005, p. 288) “have two simple pieces of advice”:

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46 Both assumptions can be actually considered very strong assumptions and, maybe, not so realistic. However, both are usually considered by researchers of stochastic frontier in this context.

47 Thus, “if there were no inefficiencies, the output distance measure D° of all observations would be equal to 1 (which implies $u = -\ln D^o = -\ln 1 = 0$) and all observations would be on the frontier” (HENNINGSEN, 2018, p. 291).

48 According to Coelli et al. (2005) and O’Donnell (2014), cited in Johnes (2013), endogeneity could exist, caused by the relation of the explanatory variable and the error term (e_{it}). In order to avoid the simultaneous equation bias, some studies used instrumental variables (ATKINSON; CORNWELL; HONERKAMP, 2003) or bayesian methods (FERNÁNDEZ; KOOP; STEEL, 2000; O’DONNELL, 2014). However, Coelli and Perelman (2000, apud JOHNES, 2013, p. 5) argued that this “bias is not a problem in an output distance function which [as here] uses a translog functional form”.

(i) "always make decisions on a case-by-case basis" and (ii) "whenever possible, explore alternative models and estimation methods and (formally or informally) assess the adequacy and robustness of the results obtained". In that sense, a Cobb-Douglas functional form was also used. It is similar to the translog but without the interaction terms and, due to that, it can be considered as nested in the translog functional form. It was also done some experimentation with inclusion/exclusion of some inputs and/or outputs.

Regarding the error distribution, this choice directly influences the values of the distance ln D_{it} (x, y), and consequently, the individual inefficiency u values. Four alternative stochastic specifications were used, all of them assuming that the error term can be split into two components ($e_{it} = v_{it} - u_{it}$), where u_{it} is actually the inefficiency term[49]. As a reference to compare the estimated parameters, it is also presented an OLS specification that considers pure noise in error term and no inefficiency in the production ($u_{it} = 0$). Thus, the four alternative specifications are:

a) sfa1 (BC92pooled): as Aigner et al. (1977), without considering the panel structure, assuming v_i and u_i are independent and identically distributed (iid)[50] such that $v_i \sim N(0, \sigma_v^2)$ and $u_i \sim N^+(\mu, \sigma_u^2)$ where N^+ represented a truncated-normal distribution with mean = 0;[51]

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49 To estimate $\hat{u}_{it}$ of u_{it}, the largely used strategy is to look at the conditional distribution of u_{it} given e_{it} and use the conditional expectation EV($u_{it} \mid e_{it}$) as an estimator of u_{it}. The details of this procedure, following the seminal work of Jondrow et al (1982, p. 238) and Battese and Coelli (1988, p. 392), are described and commented with details in Bogetoft and Otto (2011, p. 217-219).

50 Battese and Coelli (1995, p. 327) argued that "the assumption that the u_{it} and the v_{it} are independently distributed for all t = 1, 2, ... , T and i = 1, 2, ... , N, is obviously a simplifying, but restrictive, condition". They also orient that alternative methods are "required to account for possible correlated structures of the technical inefficiency effects and the random errors in the frontier". Das (2016) presented a good review about this issue and its development. Smith (2008) and Wiboonponsgse, Sriboonchitta and Denoeux (2015) found differences when considering the error components independent or dependent. More recently, Gomez and Perez (2017) also did it considering a parametrization of bivariate distribution of the error components and found that the consideration of independent error terms results in overestimated cost efficiencies in a general magnitude lower than 5%. Because of this lower value and the novelty of this work to the Brazilian case, in the present research I chose to consider the 'classical' assumption of independent and identically distributed error terms to all models estimated.

51 Johnes and Schwarzenberger (2011, p. 498) pertinently observed that "a rarely noted conceptual issue arises" in relation to inefficiencies distribution. "Since the efficiency of an organization is, in some sense, made up of the sum of efficiencies of the individuals that make up that organization", considering the central limit theorem, "one might expect to find that the distribution of efficiencies across organizations is normal". This fact would violate a key assumption of the stochastic frontier approach. However, they affirmed to note that "evidence from numerous DEA studies – which impose no prior distribution on organization efficiency – does not suggest that inefficiency is normally distributed in practice". Then, they "regard this as sufficient evidence to support the use of the, now standard, statistical frontier methods". Moreover, in empirical applications, when sigma and gamma terms are statistically significant, different from zero, it suggests an appropriate

b) sfa2 (BC92ti): a time-invariant stochastic frontier model, as BC92, considering the panel structure and assuming v_{it} and u_{it} are *iid* such that $v_{it} \sim N(0, \sigma_v^2)$, $u_{it} \sim N^+(\mu, \sigma_u^2)$ where N^+ represented a truncated-normal distribution truncated at 0;[52]

c) sfa3 (BC92tv): a time-varying stochastic frontier model, as in BC92, it assumes that v_{it} and u_{it} are *iid* such that $v_{it} \sim N(0, \sigma_v^2)$, $u_{it} = \{ \exp[-\eta(t - T_i)] \} u_i$ where T_i is the last period in the *i*th panel, η is a decay parameter to be estimated, and u_i is the base level of inefficiency which in this case is the inefficiency for the last period observed for unit *i* ;

d) sfa4 (BC95tve): a time-varying stochastic frontier model with explanatory variables to the inefficiency term (following Battese and Coelli (1993, 1995)), where $u_{it} = \delta z_{it} + W_{it}$, with $W_{it} \geq -\delta z_{it}$, where z_{it} is a set of explanatory variables associated with technical inefficiency of production of firms over time; δ are the corresponding coefficients to be estimated; and the random variable W_{it} is defined by the truncation of the normal distribution with zero mean and variance σ_u^2 , such that the point of truncation is - δz_{it}).[53]

Finally, regarding the estimation method and the software used, all SFA estimations were done by maximum likelihood estimation using R (2017) and the package 'frontier' developed by Coelli and Henningsen (2017). It is an R version of the classical FRONTIER 4.1 software developed by Tim Coelli and presented in Coelli (1996). The DEA procedures were done using the package 'Benchmarking' developed by Bogetoft and Otto (2018).

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approach in relation to efficiency distribution.

52 Coelli (1996, p. 4) informed that BC92 utilized the same parameterization of Battese and Corra (1977) "who replace σ^2_v and σ^2_u with $\sigma^2 = \sigma^2_v + \sigma^2_u$ and $\gamma = \sigma^2_u / (\sigma^2_v + \sigma^2_u)$". It permits the calculation of the maximum likelihood using the log-likelihood function presented in the appendix in Battese and Coelli (1992). In addition to "the parameter γ must lie between 0 and 1 and thus this range can be searched to provide a good starting value for use in an iterative maximization process such as the Davidon-Fletcher-Powell (DFP) algorithm."

53 The log-likelihood function of this model is presented in the appendix of the working paper of Battese and Coelli (1993).

4.2.4 Comparing DEA and SFA approaches

Finally, summarizing the comparison between DEA and SFA methods, the major difference regarding the two approaches is the estimation principle. DEA follows the minimal extrapolation principle, which states that the technology set should be the smallest set containing all data and fulfilling certain technological assumptions, such as returns to scale. In its turn, SFA follows the maximum likelihood principle, which in this case refers to choosing as estimate parameters the values that maximize the likelihood function (the values that make our observation set the most likely observation set). Daghbashyan (2009) argued that the clearest advantage of DEA is that it does not need assumptions about the functional form of the production function and, on the other hand, the clearest advantage of SFA is that, given the specifications of functional form and the error term, it allows one to test the significance of the model's components (which is not directly possible in DEA).

In a complementary manner, Johnes and Schwarzenberger (2011) emphasized that "while stochastic frontier analysis has the appealing characteristic that the well-understood statistical tools become available", less attractively, "it requires one to assume that the parameters of the cost (or production) function are identical across units of assessment". Pozo (2002, p. 14) presented the advantages and drawbacks between DEA and SFA with a focus on the public sector efficiencies measurement. He groups them in two classes,as presented in the sequence:

Advantages of DEA and the SFA drawbacks:	**Advantages of SFA and DEA drawbacks:**
- it is not necessary to specify the functional form while in SFA it is necessary to define a priori a form to the production function and also the distribution of the noise and efficiency; - results in information directly useful to management (comparison groups, definition of objectives and knowledge about benchmark units to each unit not efficient); - it is not necessary to weight, a priori, the variables of a multi-input and multi-output model, perhaps it would be possible; while in SFA the production frontier necessarily weighs the products considering a 'mean standard HEI'.	- the error term is composed between noise and inefficiency, while DEA is deterministic; - it allows the possibility to test the model adjustment and parameters significance while DEA demands other strategies to perform the sensitivity analysis (i.e., bootstrapping); - it permits causality analysis, while DEA is more similar to an improvement in multi indicators analysis; - its results are less sensitive to extreme values (outliers) while DEA results are more influenced by outliers and demand a special care when considering it.

Thus, as it could be noticed, the two approaches have different assumptions to measure the same phenomenon, technical efficiency. In that sense, some earlier studies comparing the results of both approaches were Lovell and Schmidt (1987), Thanasoulis (1993) and Coelli y Perelman (1999), among others.

Specifically investigating higher education, there are various international studies using SFA. Some examples of more recent studies are, for instance: Izadi, Johnes, Oskrochi and Crouchley (2002) and Johnes and Johnes (2009, 2013) to UK; Stevens (2004, 2005) to England and Wales; Siegel, Waldmand and Link (2003) and Agasisti and Belfield (2016) to the USA; Johnes and Schwarzenberger (2013) to Germany; Agasisti and Johnes (2010) to Italy; Worthington and Higgs (2011) to Australia. There are also cases of comparisons between HEIs of different countries such as Agasisti and Haelermans (2016) comparing Netherlands and Italy.

In addition, some studies similar to the present one were also found in relation to two main aspects (almost all using panel data): to compare DEA and SFA efficiencies and to consider distance functions to do it. Examples of the first case were: Chapple, Locket, Siegel and Wright (2005) to the UK using cross-section data in a production function, McMillan and Chan (2006) to Canada using cross-section data in a cost function, Castano and Cabanda (2007) to the Philipines using revenue function, Kempkes and Pohl (2010) to Germany using cost function. Examples of the second case were: Siegel, Wright, Chapple and Locket (2008) to the USA and the UK using cross-country data in the BC95 model; Abbott and Doucouliagos (2009) to Australia and New Zealand using BC95 model; and, Agasisti, Barra and Zotti (2016) to Italy using WH10 model. Finally, the work of Johnes (2013) was the only one which used panel data in a distance function to compare DEA and SFA efficiencies of HEIs. He analyzed Britain HEIs during the period 1996/97 to 2008/09 using BC92 model and considering a translog functional form with five inputs, three outputs and the time trend as explanatory/control variable of efficiency. Additional information about some of these studies can be found in Appendix B.

Now, for the specific case of Brazilian higher education, only two studies were found using SFA (as already cited in the introduction): Miranda, Gramani and Andrade (2012), that compared DEA and SFA efficiencies to private management courses in HEIs (non-universities) from the state of São Paulo; and Zohgbi, Rocha and Matos (2013), which used SFA to measure only a qualitative aspect that can be called ‘academic efficiency’ of the Brazilian HEIs. In addition, both studies have quite specific objects if compared with the present study of federal universities considering under- and postgraduate courses on the three dimensions - teaching, research and third mission.

Despite the different goals, much information from the given studies was quite useful here. For example, Zoghbi et al (2013, p. 98) showed that there was a higher percentage of non-white students in private institutions than in public ones. This fact reflects a strong characteristic of the Brazilian higher education system, in which students of a more vulnerable socioeconomic background who wish to pursue higher education generally need to pay for it. Taking this and other students' characteristics into account when estimating efficiency, the estimate efficiencies suggested that "there seems to be an enormous amount of waste of resources (more in public than private universities) what brings concern especially because public universities in Brazil are completely financed by the government". Finally, in terms of policy, they suggested that "the distribution of resources to public universities should be related to their performance". Moreover, another suggestion was "to link additional resources to good performance in order to reduce the tremendous amount of waste that apparently involves the provision of tertiary public education". As the authors considered only a partial dimension of HEIs to make such affirmations, the importance of the present research can be also highlighted considering it attempted to analyze the HEI entirely, considering all of its three dimensions.

After having presented the theoretical background, the following chapter explains the procedures used to construct the data base and to apply the empirical data to the models investigated.

4.3 METHODOLOGICAL PROCEDURES: DATA AND MODELS SPECIFICATIONS

In this section, the dataset is first described, together with the specifications of the variables used as inputs and outputs. As a second step, the descriptive statistics of the universities studied is provided. As it might have already been made clear, the focus of this work was on Brazilian HEIs which were classified as public, Federal and as university[54]. The study thus considered only the 56 universities that

54 The analyses did not consider other types of HEIs (State, Municipal and Private, nor Faculties, Federal Institutes and HE centers). All the 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 63 federal universities existents 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

have been in activity since 2010, and until 2016, and that had presented some concluding student in 2010[55].

The data used in the study came primarily from the given sources:

i) the Higher Education Census from the National Institute of Teaching and Educational Research (INEP, 2018);

ii) the Coordination for the Enhancement of Higher Education Personnel (CAPES, 2018), in order to obtain information about postgraduate degrees;

iii) the National Institute of Industrial Property (INPI, 2018), to obtain information about registered patents; and,

iv) the annual reports delivered from HEIs to the Brazilian Federal Court of Audit (Tribunal de Contas da União – TCU (2018)[56]).

The inputs were selected considering the entire context of the HEI and the availability of the information, which was gathered online. An initial attempt was to use financial information from INEP HE Census, but after the analysis of the data, it was decided to use the information about current expenditures from TCU reports (CCCHU). This is because information from the TCU reports excludes some expenditures (such as pensions, judicial sentences, not active workers) and includes others (35% from university hospital expenditures, for instance) and, this way, it seems to better represent the real expenditure of the HEI[57]. On the other hand, two non-financial variables were also considered as inputs: the number of equivalent full time professors (PROFEQ)[58] and the number of full time equivalent employees (FUNCEQSHU); neither variable considered the professionals working exclusively to university hospitals.

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engaged in third mission activities. Furthermore, the federal universities considered in this study represent, in general, more than half of all public HEIs.

55 Until 2016 there were 7 other universities, 4 completely new ones, and 3 others created by disaggregation. The new ones were: UFFS (2009), UNILA (2010), UNILAB (2010) and UFESBA (2013). The disaggregated ones were UFCA (2013, from UFC), UFOB (2013, from UFBA) and UNIFESSPA (2013, from UFPA).

56 Appendixes A1 and A2 present the variables and the calculus procedures (raw values and indexes) demanded by TCU in the annual reports.

57 Appendix C presents the comparison among some variables from INEP (2018) and (TCU, 2018) by HEI through time. It is noticeable the higher disturbance (by HEI along time) of the variable EXPEND from INEP when comparing it with the variable CCCHU from TCU. The other variables in Appendixes D, E, F and G (professors, employees, under- and postgraduate enrollments, respectively) also present some divergence among the data source and time, but none of them equal to EXPEND.

58 It was also tested the use of full time equivalent professor weighted by academic formation level (PROFES) but the estimations presented do not fit as good as when using PROFEQ.

There is no consensus in the literature regarding the use of students as inputs or outputs, neither of whether it should be considered enrollments and/or degrees awarded. While the enrollment of students reflects expenditure to the HEI and represents some results in relation to human capital accumulation, the real objective of the dimension ‘teaching’ is to form professionals; then, the number of degrees awarded could better represent the output of this dimension. I chose to consider the concluding students as an output and use two variables to represent it: the full time equivalent undergraduate degrees (DEGREU) and the number of postgraduate degrees (DEGREP). The latter considered the total number of the postgraduate degrees (such as master academic, master professional or doctorate course, not weighted). The former weighted the undergraduate students by type, field and duration of the course, following Sesu/MEC (2018) weights, which are directly related to the cost of each type of student (see Appendix A2). There was also an inclusion of one variable that represented the quality of the postgraduate courses (CCAPES), in an attempt to represent not necessarily (but also) the quality of the courses but also a proxy to research. This variable presented a direct relation with the quantity and the quality of the research developed by the postgraduate programs.

The two variables that added some innovative characteristic to this research were those related to third mission activities (THIRDM) and registered patents (PATENT). The former used the only information available in the INEP HE Census about the professors engaged in third mission activities. To each professor, the only piece of information was of whether the individual was or was not engaged in any third mission activity. Because of that, it provides limited information, especially when considering all the possibilities of a third mission activity and its direct and indirect impact on the community. Despite not being the best option, it was the first attempt to consider something related to third mission.

The same could be said about the PATENT variable. Thursby and Kemp (2002) are cited by Siegel et al (2008) to affirm that the use of patents as an indicator of technological variable is problematic because there is a substantial variation in quality and in patenting strategies across universities. Furthermore, the cost of enforcing patent is high and sometimes not worth the effort. Then, it does not represent all aspects about research and its results.

TABLE 1 – VARIABLE DEFINITIONS AND SOURCES

Variable	Description	Source
Inputs		
CCCHU	**Current cost with UH (university hospitals) (R$ million, constant prices of 2010):** current expenditures of HEI (excluding expenditures with pensions, judicial sentences, not active staff) and including 35% of the university hospital expenditures.	**TCU**
PROFEQ	**Number of full time equivalent professors:** Permanent professors, substitute professor, visiting professors (consider only active ones) – weighted by time of work proportionally to one professional who works 40h/week (full time = 1, partial time = 0.5)	**TCU**
PROFES	**Number of full time equivalent professors with doctorate degree:** Equal PROFEQ but also weighted by academic degree (doctor = 1, master = 0.6, specialist = 0.4, undergraduate level = 0.2, without undergraduate level = 0.1)	**INEP**
FUNCEQSHU	**Number total of employees:** permanent employees (only active ones) not professors, temporary contract employees not professors (exclude all employees from UH) - calculated by time of work, proportionally 40h/week	**TCU**
ENROLU	**Number of full time equivalent undergraduate enrollments:** Sum of all courses value to each HEI according to the equation { (NDI * DPC) * (1 + [retention factor]) + (((NI – NDI) / 4) * DPC) } * [course group weight]; In which: NDI = number of undergraduate degrees in the year; DPC = standard course duration (in years); (see SESu/MEC (2018)); NI = number of fresh undergraduate students in the years; Retention factor = factor calculated by HE governmental office (see SESu/MEC (2018)); Course group weight = calculated by HE governmental office considering the peculiarities of internal cost structure of each type of course (see Sesu/Mec (2018)).	**INEP**
ENROLP	**Number of postgraduate enrollments:** Total of enrolled postgraduate students (master academic, master professional and doctorate courses)	**CAPES**
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 governmental office considering the peculiarities of internal cost structure of each type of course (see SESu/MEC (2018)).	**INEP**
DEGREP	**Number of full time equivalent postgraduate degrees:** Total postgraduate degrees (master academic, master professional and doctorate courses)	**CAPES**
CCAPES	**Quality index of postgraduate programs** (concept attributed by CAPES) = [sum of the CAPES quality index of each postgraduate program from the HEI] / [number of postgraduate programs from the HEI]	**CAPES**
THIRDM	**Number of professors engaged in third mission activities:** Number of professors with register of being engaged in third mission activities according to the INEP HE Census, data base named DM_DOCENTE_[ANO], variable 'IN_ATU_EXTENSAO'.	**INEP**
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'	**INPI**

SOURCE: elaborated from TCU (2018), INEP (2018), CAPES (2018) and INPI (2018)

In addition, not all research work results in a registered patent. It was considered here, though, that if some patent was registered, it is quite probable that it demanded some significant research effort (financial and non-financial). Finally, after a lot of data manipulation, these procedures resulted in 10 variables which are then described in Table 1. The information about the definition of the variables is based on TCU (2002, 2010) and on SESu/MEC (2018). Both definitions are better presented in Appendixes A1 and A2.

The descriptive statistics of the variables, here presented in Table 2, allows one to notice the large variability/range of almost all variables, when considering both the standard deviation (SD) and the max/min values. Nevertheless, a federal university with mean values annually spends R$ 378 million[59] to employ 1,453 equivalent full-time professors and 2,150 employees, 'producing' 4,257 equivalent undergraduate degrees, 750 postgraduate degrees, 13 registered patents and 541 third mission activities by year.

A synthesis of the evolution of the values can be observed in the third column block of Table 2[60]. All variables presented some increase from 2010 to 2016, but in different magnitudes. PATENT presented the highest variation, 160%, while CCAPES and CCCHU presented the lowest, 1.6% and 21%, respectively. The variables related to undergraduate courses increased 24% to enrollments and 35% to degrees, while to postgraduate courses the variations were 63% and 66%, respectively. When comparing these values, some issues emerged. First, both values increased but the postgraduate values increased more than the undergraduate values, suggesting a general increase in the level of qualification. Second, the undergraduate degrees increased more than their respective enrollments. Thus, it represented a higher proportion of concluding students (and more efficiency); perhaps it could also implicate in some facilitation to conclude the course and consequently lower quality.

In addition, the total number of professors and employees (not shown in Table 2) increased similarly in 25%, but PROFEQ (professors weighted by hour/week) increased 28%, PROFES (professors weighted by level and hour/week) increased 37% and FUNCEQSHU (employees weighted by hour/week) increased

59 Measured in R$ of year 2000, deflated by the GDP implicit index.

60 The Appendixes H and I1 present the boxplots of the TCU indexes by year and of the inputs and outputs used in the estimation analysis. In both Appendixes it is also possible to identify the general evolution of the variables through time. Also, Appendix I2 presents the matrix of correlations among the variables used in the estimations.

34%. That is to say that the PROFES increased in equivalent work hours (PROFEQ) and in their level of qualification. Employees also increased in equivalent work hours (FUNCEQSHU) and in qualification (the proportion of staff with undergraduate degree, not in Table 2 either, increased from 50.5% to 59.5%). It thus suggests an increase in the number and in the qualification of the professors and employees.

Furthermore, Table 2 also shows the representativeness by region[61]. In general, though the variations by regions were diverse, the variables followed the same proportions in each year. The Southeast (SE) region represented a third of the national figures, the Northeast (NE) and South (S) regions 25% and 20%, and the North (N) and Center-West (CO) regions near 10% each one, respectively. In general, the proportion to each variable by region was similar to the proportion of number of HEIs, with the exception of the North region which presented less than proportional values, and the South region that presented more than proportional values. It is suggesting that, compared to other regions, the general size of the HEIs was thus lower in the North and higher in the South region.

TABLE 2 – DESCRIPTIVES STATISTICS OF THE 56 BRAZILIAN FEDERAL UNIVERSITIES – 2016 TO 2010

	Values in 2016						Representativeness by region in 2016 (% of Brazil)					variation from 2010 to 2016 (Δ%)					
	total	mean	SD	min	median	max	SE	NE	S	CO	N	BR	SE	NE	S	CO	N
N	56						34	25	16	9	16						
CCCHU	21,145	378	267	23	344	1,501	36	27	19	10	8	21	22	27	19	0.1	32
PROFEQ	81,381	1,453	885	322	1,333	4,517	33	27	19	11	10	28	25	25	39	25	33
PROFES	73,444	1,311	823	278	1,192	3,703	34	27	19	11	9	37	33	40	39	36	45
FUNCEQSHU	120,401	2,150	1,644	348	1,769	9,819	37	27	17	10	9	34	41	29	35	16	39
ENROLU	1,289,356	23,024	12,513	4,882	22,489	54,975	33	28	17	10	11	24	28	22	20	24	27
ENROLP	146,363	2,614	2,484	236	1,749	10,829	36	26	21	10	7	63	57	68	54	66	103
DEGREU	238,407	4,257	2,447	861	4,008	10,087	33	28	17	10	12	35	34	50	21	32	33
DEGREP	41,980	750	674	44	509	2,754	37	25	21	11	6	66	63	62	57	88	96
CCAPES	3.85	3.85	0.54	3.00	3.72	5.23	106	96	107	97	88	1.6	0.8	0.1	1.7	0.1	6.3
PATENT	747	13	15	0	9	70	32	36	21	6	3	160	59	427	171	223	178
THIRDM	30,290	541	603	1	333	3,153	39	19	23	13	6	52	98	64	32	15	6

SOURCE: INEP (2018), TCU (2018), CAPES (2018), INPI (2018) and Sesu/MEC (2018)

The variation from 2010 to 2016 presented regional patterns which were different from national values, especially to CCCHU, PATENT and THIRDM. The first increased 21% to Brazil but nothing in the Center-West region, and 32% in the North region. The second increased 16% to Brazil, but 427% in the Northeast region, 223%

61 It is important to clarify (or remember) that the Brazilian regions are very heterogeneous regarding their natural, social and economic characteristics.

in the Center-West and only 59% to the Southeast. Also, THIRDM increased 52% to Brazil, but 98% to the Northeast and only 15% and 6% to the Center-West and North regions. In general, it seems that the North region increased more than the national means in all variables except for DEGREU and THIRDM; also, the South region increased less than the national means to enrollments and degrees but not in terms of professors and employees.

Regarding financial and non-financial inputs, all regions presented a lower increase in CCCHU than in PROFEQ, PROFES and FUNCEQSHU (especially the Center-West region). It suggests that they had increased the number of professionals with a less than proportional increase in the expenditures, which could indicate some increase in cost efficiency or simply a reduction of investments in capital and a consequent increase in the relation between human/physical resources. If we look at the output increases, they were generally higher than the increase in inputs (exception to CCAPES); this fact could also suggest an increase in general efficiency.

Besides being interesting, this table analysis presented clear limitations for handling simultaneously multi input and multi output in a set considering various years and HEIs. As a way to overcome such issue, and in order to reach the objectives of this research, frontier analysis was used to overcome those limitations. Two different approaches were thus used, parallel to DEA and SFA, and four different specifications for each approach (not exactly comparable) which considered different characteristics of the production process of higher education services, as follows:

- **DEA models** – output approach considering both CRS and VRS in a pooled set and in a within year set, providing four sets of non-parametric results named CRS pooled, CRS within, VRS pooled and VRS within. All of them considered three inputs (CCCHU, PROFEQ and FUNCEQSHU) and five outputs (DEGREU, DEGREP, THIRDM, PATENT and CCAPES).

Previous to the DEA efficiency calculus, robust techniques were used to identify and manage the potential outlier universities, 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[62]. The HEIs identified as

62 These procedures were developed focusing on solving specifically DEA limitations regarding outlier DMU(s). Basicaly, the 'n-dimensional cloud of points' (where n is equal the number of inputs plus de number of output) formed by all DMUs is compared with different subsets of DMUs that exclude some DMU or group of DMUs. Then, if the exclusion of some DMU (or group of DMUs) reduce significantly the volume of the cloud, then this DMU (or group of DMUs) will be considered, potentially, an outlier(s) DMU(s). Finally, even though this potentially outlier(s) DMU(s) presents an

potential outliers were the following: UFMG, UFRJ, UNB, UTFPR, UFRGS, UNIFESP, UFPR, UFV. The technological frontier defined by the efficiency units was constructed without the inclusion of these potential outlier universities; then, if some of these potential outlier universities presented an efficiency value higher than 1, this value was adjusted to 1 (full efficiency). This procedure allowed us to construct the frontier and calculate the efficiency values of all the other HEIs without the influence of this potential outlier university. Therefore, as a result, the general efficiencies tended to be higher when excluding potential outliers from the technological frontier determination.

- **SFA models** – output distance function considering translog[63] functional form and four different error terms specifications named BC92 pooled, BC92ti, BC92tv and BC95tve. The inputs and outputs were the most similar possible to those used in DEA. The last specification included some explanatory variables to inefficiency. In the same way that Stevens (2004, 2005) and McMillan and Chan (2006), it was done some experimentation to include the variables directly in the distance function or in the inefficiency equation[64]. Thus, similar to Johnes (2013, p. 8) and Henningsen (2018, p. 291), the precise specification of the parametric distance function to be estimated is:

efficiency equal 1, it will not be considered as a benchmark(s) and will not influence the efficiency of other DMUs.

63 The Cobb-Douglas functional form was tested versus the complete Translog functional form (the former is nested in the latter). The LR test suggested best fit to Translog.

64 In a more operational sense, Battese and Coelli (1992, 1995) suggested and used the likelihood-ratio test statistic, LR = -2 { loglikelihood (H_0) – loglikelihood (H_1) } to do tests of hypotheses about parameters of inefficiency between nested models. The statistic test LR "has approximately chi-square distribution with parameter equal to the number of parameters assumed to be zero in the null hypothesis, H_0, provided H_0 is true" (BATTESE; COELLI, 1995, p. 330). Also, Chapple et al (2005) used the akaike information criterion (AIC) to choose inputs and outputs in the model selection phase when the models compared were not nested: "The AIC can be estimated by AIC = -2 * loglikelihood + 2 * p, where p is the number of parameters estimated in the models". This way the AIC scores were adjusted for the number of parameters involved in each model, allowing the comparison between models with different variables and functional forms. Chapple et al (2005) chose the models with the lowest AIC score as the best fitting models. I also computed the BIC values (-2 * loglikelihood + log(n) * p) as complementary information with a higher penalized likelihood criterion, because BIC penalizes more heavily the model complexity.

$$
\begin{aligned}
-\ln y_{DEGREU\,it} = {} & \alpha_0 + \sum_{m=1}^{4} \alpha_m \ln\left(\frac{y_{mit}}{y_{DEGREU\,it}}\right) \\
& + \frac{1}{2}\sum_{m=1}^{4}\sum_{n=1}^{4} \alpha_{mn} \ln\left(\frac{y_{mit}}{y_{DEGREU\,it}}\right) \ln\left(\frac{y_{nit}}{y_{DEGREU\,it}}\right) \\
& + \sum_{k=1}^{3} \beta_k \ln x_{kit} + \frac{1}{2}\sum_{k=1}^{3}\sum_{l=1}^{3} \beta_{kl} \ln x_{kit} \ln x_{lit} \\
& + \sum_{k=1}^{3}\sum_{m=1}^{4} \delta_{km} \ln x_{kit} \ln\left(\frac{y_{mit}}{y_{DEGREU\,it}}\right) \\
& + \omega_1\, HU_i + \sum_{r=2}^{5} \omega_r\, REGION_{ri} + \omega_6\, YEAR_{it} + \omega_7\, NEWSF_i \\
& + u_{it} + v_{it}
\end{aligned}
\qquad (9)
$$

where the y_m variables represent the outputs (DEGREP, CCAPES, THIRDM and PATENT); the x_k variables represent the inputs (CCCHU, PROFEQ and FUNCEQSHU); HU_i is a fixed-HEI dummy to capture changes in the frontier due to university hospitals[65]; and $YEAR_{it}$ is the time variable included to try to capture changes in the technological frontier over time; $NEWSF_i$ is a fixed-HEI dummy variable relative to year of federalization of the HEI ('1' if it occurred after 2001, and '0' if did occurred before)[66]. In addition, as an attempt to capture some regional idiosyncrasies, $REGION_{ri}$ are dummies to the Brazilian regions (where Center-West is the reference region). The numeraire is y_{DEGREU} = DEGREU[67]. All values of inputs and outputs were mean-scaled previous to the estimations (then the coefficients of each variable can be interpreted as elasticities at the average point). The error term u_{it} is estimated using, respectively: a) BC92pooled, b) BC92ti, c) BC92tv, and d) BC95tve - providing four sets of parametric efficiency estimates. Also, the last model has the inefficiency term u_{it} specified as follows:

65 Kempkes and Pohl (2010) used dummy variables and interaction between dummies and other variables. They found significance in several interaction terms and explicitly concluded "that universities with medical and/or engineering faculties not only have a different cost level but also different marginal cost structures" (p. 2070).

66 Some of the recent federal universities present different years of creation and federalization, that is, they were created originally as another type of institution and worked for a certain time until the federal government 'federalized' them. Then, both 'year of creation' and 'year of federalization' were tested in the models and only the last presented statistical significance in the models.

67 The sensibility of the results was checked by using the other outputs as numeraire; results then showed the insensibility of the change, as expected, according to Coelli and Perelman (2000) and Johnes (2013).

$$
\begin{aligned}
u_{it} = {} & \delta_0 + \delta_1 \, HU_i + \sum_{r=2}^{5} \delta_r \, REGION_{ri} + \delta_6 \, NEWSF_i + \omega_7 \, YEAR_{it} \\
& + \delta_8 \, TSG_{it} + \delta_9 \, GPE_{it} \\
& + \delta_{10} \, ATIPE_{it} + \delta_{11} \, ATIFESHU_{it} \\
& + \delta_{12} \, IQCD_{it} + \delta_{13} \, FESHUPE_{it} + w_{it}
\end{aligned} \qquad (10)
$$

where HU, REGION, YEAR and NEWSF are the same presented above and the other variables are from TCU reports: TSG is the proportion of student's degrees by enrolled students, GPE is the index of students participation, ATIPE is the rate of full time students by equivalent professors, ATIFESHU is the rate of full time students by equivalent employees, IQCD is an index related to professor qualifications and FESHUPE is the rate of equivalent employees by equivalent professors. They are from TCU (2018) and are described in details in Appendixes A1 and A2. The boxplots of these TCU's indexes by year are also presented in Appendix H.

Now, in an attempt to help with the interpretation of the results, Table 3 presents a comparison among the parametric and non-parametric specifications in relation to some characteristics.

TABLE 3 – COMPARISON OF PARAMETRIC AND NON-PARAMETRIC MODELS

Model	Allows for efficiency change over time	Allows for technology change over time	Imposes CRS	Allows for stochastic error	Applies the same parameters to all observations	Includes explanatory variables to inefficiency term
Non-parametric						
CRS pooled	Yes	No	Yes	No	No	No
CRS within year	Yes	Yes	Yes	No	No	No
VRS pooled	Yes	No	No	No	No	No
VRS within year	Yes	Yes	No	No	No	No
Parametric						
BC92 pooled	No	Yes	No	Yes	Yes	No
BC92ti	No	Yes	No	Yes	Yes	No
BC92tv	Yes	Yes	No	Yes	Yes	No
BC95tve	Yes	Yes	No	Yes	Yes	Yes

SOURCE: the author (2019)

The model BC95tve permitted the inclusion of explanatory variables to the error term equation. In a similar situation, Stevens (2004) estimated 32 different specifications with variables distributed in different subsets (some in the estimated function and some in the error term); and by using the LR test, the scholar chose the specifications which best fit. In the present study, some experimentation with environmental variables were also carried out (related to time, dummy to university hospital, dummy to registered patent in the period, dummies to region, dummies to new universities or recently federalized institutions, and inclusion of index variables from the TCU reports) in the output distance function and/or in the error term equation. Therefore, here, only the considered best fit BC95tve specification is presented and compared with the other models.

It is important to emphasize that 24 HEIs presented zero value to some outputs in some year, in special to PATENT, which presented 98 zero values. Some HEIs presented no patents in the entire period investigated (UFAC, UFRR, UNIR, UNIRIO); others presented no patents in six years (UFCSPA, UFERSA, UFRA, UNIFAP, UNIPAMPA) or in five years (UFOPA, UFTM) or in three (UFCG, UFMT, UFRRJ, UFT, UFVJM, UNIFAL-MG, UNIVASF). Finally, UFABC, UFRB and UNIFESP presented no patent in two years and UFGD, UFPEL and UFSJ presented no patent in one year. The other 32 HEIs presented registered patents in every year of the period. Other HEIs, even presenting registered patents, presented zero value to THIRDM in the respective year. It occurred four times (to UFV and UNIFAL-MG in 2010 and to UFPEL and UFV in 2011), quite probably due to the inexistence of information provided by the HEI and not because of the inexistence of these activities in the given years. In these cases of obviously no available information, a value was inputted based on the informed values from other years to the same HEI. This procedure, however, did not influence the results. UFPEL, for instance, informed only one third mission activity in each year and these values were maintained. Regarding DEGREP, there were only three zero values, to UFOPA in 2010 and to UNIPAMPA in 2010 and 2011. To all of these zero values it was attributed an infinitesimal value only to permit the calculus of the estimations using logarithms. This procedure presented no problems except to the value of UFABC in 2010 with zero to DEGREU. Then, UFABC was dropped from the analysis only to year 2010.

Taking these aspects into consideration, at first, a model of ‘Error Components Frontier’ (BC92) was selected by comparing different combinations of inputs, outputs and environmental variables to the translog output distance function (Appendix J)[68]. After selecting the two BC92 models with the best fit by LR tests

68 In an attempt to choose the final specification of the BC92 models, first I estimated eight models considering different inputs and only CCCHU as output. Then, the same eight models were estimated but considering only PROFEQ and FUNCEQSHU as inputs and, after, the same eight

(Appendix K), the same inputs, outputs and environmental variables were used in an 'Efficiency Effects Frontier' (BC95) with gradual inclusion of explanatory variables to the inefficiency equation (Appendixes L1 and L2). These models were also compared using LR tests (see Appendix M). These procedures thus resulted: a) first, in two selected BC92 base models (named fip7 and fip8 in Appendix J); b) then, in one selected BC95 base model (named fip7tve8 in Appendix L) and c) consequently, in choosing the BC92 named fip7 as the BC92 base model. Finally, using these selected base models, the four stochastic translog output distance functions were estimated. The next section thus presents and discusses the results of efficiency considering the findings from DEA and SFA.

4.4 RESULTS AND DISCUSSION

The results to the four estimated stochastic translog output functions are presented in Table 4: BC92pooled, BC92ti, BC92tv (from fip7) and BC95tve (from fi7tve8). Table 4 also presents the OLS estimation of the panel (that considered pure noise and full efficiency) as a base to the comparison between the models and their respective OLS estimation. The OLS presented the same results that the pooled model. The pooled model emphasized that the results change when considering the panel structure used in the other models. The BC92ti and BC92tv presented a simple difference regarding the inefficiency: in the first, it was considered constant to each HEI through time, while in the second, the inefficiency followed a linear trend (estimated by the coefficient *time*). The specification BC95tve is different from the BC92s because it includes an equation to inefficiency and uses simultaneous equations to estimate the coefficients (and it consequently has a completely different likelihood function). Thus, the results from the models can be compared by LR test and also by the AIC and BIC values presented in the last two rows of Table 4. All of them suggest that the BC92ti model seems to better represent the university production system. Then, the other models can be used as a comparison and as a way to check the consistency of the results in relation to efficiencies both between SFA models themselves and between SFA and DEA models.

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models were estimated considering the three outputs (Appendix J). The results were compared by using the LR test and all models with the three inputs presenting best fit. Then, I compared these eight models with three inputs within themselves, and selected the model with the best fit (see Appendix K).

TABLE 4 – ESTIMATIONS OF THE STOCHASTIC TRANSLOG OUTPUT DISTANCE FUNCTION

Variable	OLS or BC92pooled	BC92ti	BC92tv	BC95tve
(Intercept)	-0,015	-0,129 ***	-0,126 ***	-0,195 ***
DEGREP	-0,094 ***	0,032 **	0,036 **	-0,072 ***
THIRDM	0,001	0,001	0,001	0,006 **
PATENT	-0,006	-0,002	-0,002	-0,006
CCAPES	0,988 ***	0,932 ***	0,926 ***	0,967 ***
DEGREP^2	-0,010 ***	0,002	0,002	-0,006 ***
THIRDM^2	0,001	0,001	0,001	0,001
PATENT^2	-0,001	0,000	0,000	-0,001 *
CCAPES^2	0,135 ***	0,067 **	0,067 **	0,178 ***
DEGREP * THIRDM	-0,012 ***	-0,006 ***	-0,006 ***	-0,012 ***
DEGREP * PATENT	0,000	-0,001	-0,001	0,000
DEGREP * CCAPES	-0,054 **	-0,034 **	-0,035 **	-0,065 ***
THIRDM * PATENT	0,000	0,000	0,000	0,001
THIRDM * CCAPES	0,005	0,005 **	0,005 **	0,006 *
PATENT * CCAPES	0,002	0,003 *	0,003	0,002
CCCHU	-0,161 ***	-0,073 ***	-0,072 ***	-0,078 ***
PROFEQ	0,140 ***	-0,096 ***	-0,096 ***	-0,231 ***
FUNCEQSHU	-0,074 ***	-0,037 **	-0,038 **	0,184 ***
CCCHU^2	-0,133	-0,082	-0,082	-0,133 *
PROFEQ^2	-0,113	-0,201 *	-0,194 *	-0,216
FUNCEQSHU^2	0,081	-0,010	-0,011	-0,071
CCCHU * PROFEQ	0,103	0,014	0,011	0,170
CCCHU * FUNCEQSHU	-0,001	0,053	0,056	-0,039
PROFEQ * FUNCEQSHU	0,012	0,046	0,044	0,182 *
DEGREP * CCCHU	0,042 *	0,043 ***	0,044 ***	0,034
DEGREP * PROFEQ	-0,086 *	-0,032	-0,030	-0,136 ***
DEGREP * FUNCEQSHU	-0,031	-0,038	-0,041	0,010
THIRDM * CCCHU	-0,028 **	0,002	0,002	-0,006
THIRDM * PROFEQ	0,069 ***	0,018 *	0,018 *	0,040 ***
THIRDM * FUNCEQSHU	-0,027 ***	-0,015 ***	-0,015 ***	-0,023 ***
PATENT * CCCHU	-0,005	0,000	0,000	0,000
PATENT * PROFEQ	0,008 *	0,004	0,004	0,004
PATENT * FUNCEQSHU	0,000	0,000	0,000	0,000
CCAPES * CCCHU	0,030	0,004	0,004	0,022
CCAPES * PROFEQ	0,000	-0,025	-0,026	0,046
CCAPES * FUNCEQSHU	0,096 *	0,048	0,048	0,133 **
HU	0,034 **	0,057 ***	0,050 **	0,108 ***
regionNorth	0,028	0,120 ***	0,115 ***	0,149 ***
regionNortheast	-0,022	-0,008	-0,010	0,070 ***
regionSouth	-0,072 ***	-0,065 **	-0,071 *	-0,023
regionSoutheast	-0,057 ***	-0,101 ***	-0,105 ***	-0,146 ***
NEWSF	0,006	-0,004	0,002	-0,139 ***
sigmaSq	0,004	0,024 ***	0,025 ***	0,004 ***
gamma		0,954 ***	0,955 ***	0,879 ***
time			0,005	
Z_(Intercept)				0,870 ***
Z_HU				-0,094 ***
Z_regionNorth				-0,193 ***
Z_regionNortheast				-0,133 ***
Z_regionSouth				-0,064 *
Z_regionSoutheast				0,114 ***
Z_NEWSF				0,127 ***
Z_YEAR				0,007 **
Z_TSG				-0,001 ***
Z_GPE				0,003
Z_ATIPE				-0,024 ***
Z_ATIFESHU				0,018 ***
Z_IQCD				-0,068 ***
Z_FESHUPE				-0,131 ***
n.obs.	391	391	391	391
logLikelihood	531,00	667,66	667,76	600,88
df	43	44	45	58
LRtest (in relation to OLS)		273,31 ***	273,51 ***	139,75 ***
AIC	-976,00	-1247,31	-1245,52	-1085,76
BIC	-805,35	-1072,69	-1066,93	-855,57

*** coefficient significantly different from zero at 1% significance level.
** coefficient significantly different from zero at 5% significance level.
* coefficient significantly different from zero at 10% significance level.

SOURCE: the author (2019)

The results of estimations considering both the ‘Error Components Frontier’ (BC92) and the ‘Efficiency Effects Frontier’ (BC95) using translog functional forms strongly suggest that there is some inefficiency in the federal universities when considering the panel data to the five outputs and three inputs used here. The LR tests (in relation to OLS) presented in the last third row of Table 4 are just about the comparison between the models that considered efficiency and the OLS model (which did not consider efficiency). Thus, it is possible to perceive that all the results of the LR tests were statistically significant (with the exception of the pooled model, which suggested no inefficiency in the production system).

The values of the coefficients of gamma also allowed us to analyze the presence (influence) of inefficiency in each model. Values near zero from BC92pooled and OLS models suggest no inefficiency and only noise, while values near 1 from BC92ti and BC92tv suggest more inefficiency effects on the production system. The gamma value to BC95tve also presents a high value (0.879). The gamma values to these final three models can be considered statistically significant from zero at a 1% significance level.

After confirming that some inefficiency exists, it is now possible to identify what functional form better represents the university activities and inefficiency. As the Cobb-Douglas form is nested in the translog form, the comparison can be made by using a LR test. It can also be used to compare the BC92 models among themselves, as well as to compare the BC95tve models among themselves. Then, comparing the functional forms first, all tests rejected the null hypothesis of Cobb-Douglas functional form (Appendix K)[69] when compared with the translog functional form. Second, when investigating the time trend, the comparison between translog BC92ti and BC92tv (LR = 0.8, $\chi^2_{0.95}$ = 3.84) did not allow us to reject the null hypothesis of BC92ti (with time unvarying efficiency). Also, when comparing the models translog BC95tve (with and without time as an inefficiency explanatory variable), the variable time presented no statistical significance at a 10% confidence level. This way, as a result, it could be considered that the general efficiency level did not change significantly through time.

69 Appendix K also presents the LR test of models with different combinations of input and output variables. All of them suggest the use of the initial five outputs and three inputs. The AIC and BIC decisions vary among the models considered and, sometimes, suggest different decisions.

Regarding the dummy variables in the output distance function, it coud be understood that the subset of universities with HU follow a different technological frontier, higher than the frontier of the other subset of universities (the coefficients of HU are positive and statistically significant to all models). Regarding regional patterns, the coefficients for each region dummy (with the Center-West as reference) were not the same. The Southeast presented the most consistent result among models, suggesting that the universities in this region follow a lower technological frontier (statistically significant negative coefficients). The South region also presented a different though not quite lower technological frontier, and it presented no statistical significance in this difference to Model BC95tve. On the other hand, the North region presented a statistically significant higher technological frontier when considering the SFA models, while the Northeast region presented a statistically significant higher technological frontier only to Model BC95tve. Finally, the variable NEWSF, presented values which were statistically different from zero only to BC95tve model; in other words, only in this case the results suggested that the subset of universities which were federalized after 2012 presented a lower technological frontier.

The distance elasticities of the translog output distance with respect to input and with respect to output quantities could be calculate following the guidance of Henningsen (2008, p. 293). It resulted, to model BC92ti, in an elasticity (median) of -0.0855 to CCCHU; in other words, it indicates that a 1% increase in this input results in, ceteris paribus, a 0.0855% decrease of the distance measure (i.e. efficiency decreases and inefficiency increases). The elasticity to PROFEQ is -0.096 and to FUNCEQ is -0.025. Regarding inputs, the elasticities are: 0.032 to DEGREU, 0.0337 to DEGREP, 0.002 to THIRDM, -0.0016 to PATENT and 0.930 to CCAPES. These values indicate that a 1% increase in the output results in, ceteris paribus, a respective increase of the distance measure (i.e. efficiency increases and inefficiency decreases). Finally, the estimated elasticity of scale (0.20) indicates decreasing returns to scale. To model BC95tve the median distance elasticities are: -0.082, -0.249 and +0.196 to CCCHU, PROFEQ and FUNCEQ, respectively; and 0.094, -0.066, 0.008, -0.005 and 0.966 to DEGREU, DEGREP, THIRDM, PATENT and CCAPES, respectively. The estimated elasticity of scale (0.13) also indicates decreasing returns to scale. To both cases, the highest elasticity is to CCAPES.

Other explanatory variables of inefficiency were analyzed in the BC95 models. The BC95tve model with all explanatory variables was suggested as the most explicative of the other BC95tve specifications. In this specification, the coefficients of the inefficiency explanatory variables present different signals. Z_TSG, Z_ATIPE, Z_IQCD and Z_FESHUPE present statistically significant negative coefficients. They are negatively related to inefficiency and, consequently, positively related to efficiency. We can thus affirm that they present a positive correlation with efficiency but, according to Henningsen (2018, p. 257), the "size of the coefficients of the inefficiency model cannot be reasonably interpreted". Then, as expected, more conclusions by enrollments, more students by professor, more qualification to professors and more staff by professor seem to be related to more efficiency.

On the other hand, Z_YEAR, Z_ATIFESHU, Z_GPE (not significant) and the Southeast region present a positive relation to inefficiency. That is, when using these explanatory variables as controls, it seems inefficiency is increasing through time. More students by staff also present a positive relation to inefficiency. The dummy variables also present statistically significant coefficients. The university dummies from the Southeast region suggest this condition is related to inefficiency, while the North, Northeast and South[70] regions seem to be related to the efficiency of the universities (in relation to the reference region, the Center-West). It therefore suggests that, controlling all explanatory variables, environmental characteristics present in these three regions may influence positively the efficiency levels of their universities. Finally, the dummies to Z_HU and to Z_NEWSF present a negative and positive relation to inefficiency, respectively. It suggests that universities with hospitals, ceteris paribus, tend to present a higher efficiency, while young universities, ceteris paribus, tend to present a lower efficiency.

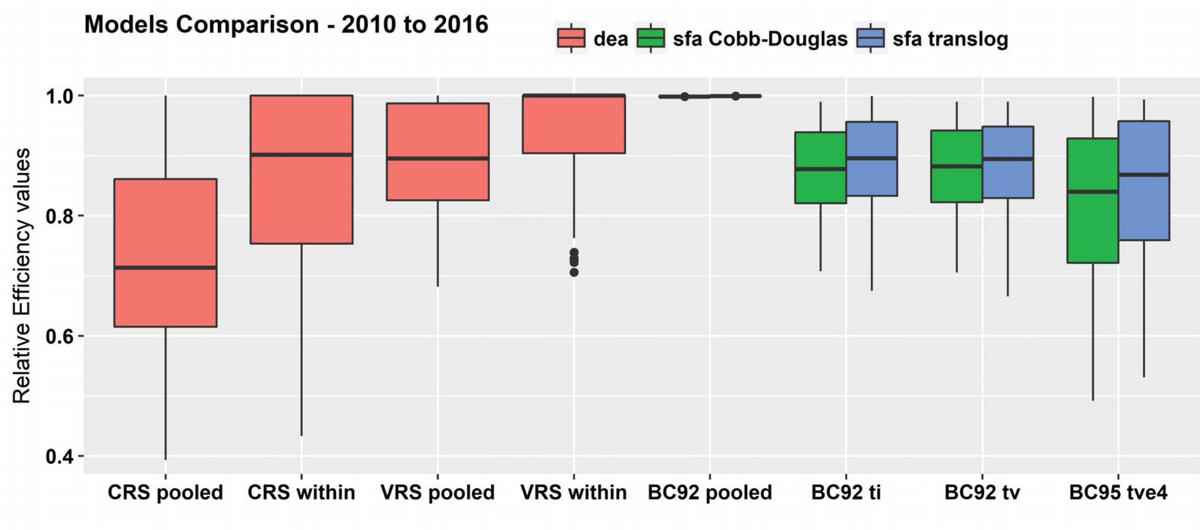
4.4.1 Comparing DEA and SFA results

Now, comparing the results from DEA and SFA approaches, regarding the values and distributions of the estimated efficiencies, Figure 2 presents some boxplots by model and approach and permits the visual comparison of the ranges and distributions of the efficiency values. In general, the universities presented values higher than 0.8, except to the CRS pooled model. It presented the lowest values of

70 Only if considering a 10% significance level.

efficiencies while the BC92 pooled presented the highest values. This last model, in fact, resulted in practically no inefficiencies when considering the pooled data (as presented in the analysis of SFA results).

FIGURE 2 – BOXPLOTS OF THE EFFICIENCIES OF BRAZILIAN FEDERAL UNIVERSITIES (2010 TO 2016) ESTIMATED FROM DIFFERENT SPECIFICATIONS OF DEA AND SFA MODELS



SOURCE: the author (2019)

The other three SFA models presented themselves as very similar in means and medians, only with the range increasing from BC92ti to BC95tve (this with a little lower averages). On the other hand, the range of DEA models decreased while the medians and means seemed to increase from the models CRS to VRS and from pooled to within models. The VRS within specification presented the lowest efficiencies, with almost 50% of the observations being considered efficient. This information is presented in a more precise manner in the descriptive statistics in Table 5.

The results shown in Table 5 bring more details to the information of Figure 2, also presenting the values of standard deviations and coefficient of variation (mean/sd). It can be observed the higher range and variability of CRS models and BC95tve models (and the lowest minimum values observed). The CRS within presented similar means to VRS pooled but with a higher range. All BC92 models presented a very similar pattern among themselves with mean and medians near 0.90 and ranging from 0.67 to 1.00.

TABLE 5 - DESCRIPTIVE STATISTICS OF EFFICIENCIES FROM BRAZILIAN FEDERAL UNIVERSITIES (2010 TO 2016) CONSIDERING DIFFERENT SPECIFICATIONS FROM DEA AND SFA MODELS

	DEA CRS		DEA VRS		SFA Translog				SFA Cobb-Douglas			
Model	pooled	within	pooled	within	BC92 pooled	BC92ti	BC92tv	BC95 tve	BC92 pooled	BC92ti	BC92tv	BC95 tve
Measure	dea1	dea2	dea3	dea4	sfa1	sfa2	sfa3	sfa4	sfa1c	sfa2c	sfa3c	sfa4c
mean	0.73	0.87	0.89	0.95	1.00	0.89	0.88	0.85	1.00	0.88	0.88	0.81
sd	0.17	0.14	0.09	0.07	0.00	0.08	0.08	0.12	0.00	0.08	0.08	0.13
CV	0.23	0.16	0.10	0.08	0.00	0.09	0.09	0.15	0.00	0.09	0.09	0.16
max	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	1.00	0.99	0.99	1.00
median	0.71	0.90	0.90	1.00	1.00	0.90	0.89	0.87	1.00	0.88	0.88	0.84
min	0.39	0.43	0.68	0.71	1.00	0.67	0.67	0.53	1.00	0.71	0.71	0.49

SOURCE: the author (2019)

The results presented in Table 5 can be directly compared with the values obtained by Johnes (2013), which studied the Britain universities to the period from 1996/7 to 2008/9: he found efficiency means (and standard deviations) of 0.75 (0.09), 0.87 (0.08), 0.83 (0.09) and 0.93 (0.07) to the DEA models. The values and pattern were very similar to those found here, except the standard deviations of DEA CRS models which were higher in our case. To SFA models, both BC92ti and BC92tv were estimated by him, resulting in mean efficiencies and standard deviations of 0.803 (0.097), 0.801 (0.097). Our results here suggest a higher value of mean efficiencies with a lower variance to Brazilian universities.

Beyond the means/medians and variations, it is also important to analyze the HEIs' rank of efficiencies among the models. More importantly yet, for considering public policies, it is to analyze the correlations among the ranks. This is done to verify whether both approaches are able to identify similar HEIs as the best ones, and similar HEIs as the lowest efficient ones. If both approaches present similar results, a policymaker can make decisions with more confidence, for instance. In this sense, Table 6 presents the correlations estimated by Pearson's values, Spearman's rho values and Kendall's tau values. The three values can vary from -1 to 1 with 0 indicating no association/correlation. The last two correlation values are rank-based measures of association (keeping in mind that these correlations were calculated considering the annual rank of each HEI that varies from 1, the best position, to 56, the worst position).

TABLE 6 – PEARSON, SPEARMAN'S RHO AND KENDALL'S TAU VALUES OF ASSOCIATION

MODEL		DEA				SFA translog				SFA Cobb-Douglas			
Pearson correlation		dea1	dea2	dea3	dea4	sfa1	sfa2	sfa3	sfa4	sfa1c	sfa2c	sfa3c	sfa4c
DEA	dea1	1											
	dea2	0.79	1										
	dea3	0.85	0.63	1									
	dea4	0.72	0.79	0.81	1								
SFA translog	sfa1	0.23	0.22	0.39	0.31	1							
	sfa2	0.34	0.27	0.35	0.31	0.48	1						
	sfa3	0.36	0.30	0.36	0.32	0.51	0.98	1					
	sfa4	0.13	**0.06**	0.29	0.19	0.36	0.60	0.6	1				
SFA Cobb-Douglas	sfa1c	0.43	0.33	0.52	0.42	0.81	0.66	0.69	0.34	1			
	sfa2c	0.37	0.29	0.4	0.36	0.51	0.94	0.97	0.63	0.7	1		
	sfa3c	0.36	0.29	0.39	0.35	0.51	0.95	0.97	0.63	0.69	1	1	
	sfa4c	0.19	0.12	0.31	0.22	0.37	0.67	0.69	0.97	0.46	0.70	0.71	1

Note: all values are statistically significant at 5% significance level (except the value in bold)

MODEL		DEA				SFA translog				SFA Cobb-Douglas			
Spearman's *rho*		dea1	dea2	dea3	dea4	sfa1	sfa2	sfa3	sfa4	sfa1c	sfa2c	sfa3c	sfa4c
DEA	dea1	1											
	dea2	0.8	1										
	dea3	0.85	0.64	1									
	dea4	0.72	0.73	0.76	1								
SFA translog	sfa1	0.25	0.28	0.38	0.3	1							
	sfa2	0.36	0.29	0.35	0.29	0.54	1						
	sfa3	0.37	0.3	0.36	0.30	0.54	1	1					
	sfa4	0.18	**0.07**	0.34	0.22	0.35	0.54	0.55	1				
SFA Cobb-Douglas	sfa1c	0.25	0.28	0.38	0.3	1	0.54	0.54	0.35	1			
	sfa2c	0.36	0.29	0.35	0.29	0.54	1	1	0.54	0.54	1		
	sfa3c	0.37	0.3	0.36	0.3	0.54	1	1	0.55	0.54	1	1	
	sfa4c	0.18	**0.07**	0.34	0.22	0.35	0.54	0.55	1	0.35	0.54	0.55	1

Note: all values are statistically significant at 5% significance level (except the value in bold)

MODEL		DEA				SFA translog				SFA Cobb-Douglas			
Kendall's tau		dea1	dea2	dea3	dea4	sfa1	sfa2	sfa3	sfa4	sfa1c	sfa2c	sfa3c	sfa4c
DEA	dea1	1											
	dea2	0.62	1										
	dea3	0.68	0.47	1									
	dea4	0.55	0.56	0.63	1								
SFA translog	sfa1	0.17	0.19	0.27	0.21	1							
	sfa2	0.26	0.2	0.24	0.2	0.39	1						
	sfa3	0.27	0.21	0.25	0.21	0.39	0.97	1					
	sfa4	0.12	**0.05**	0.23	0.15	0.24	0.39	0.39	1				
SFA Cobb-Douglas	sfa1c	0.17	0.19	0.27	0.21	1	0.39	0.39	0.24	1			
	sfa2c	0.26	0.20	0.24	0.2	0.39	1	0.97	0.39	0.39	1		
	sfa3c	0.27	0.21	0.25	0.21	0.39	0.97	1	0.39	0.39	0.97	1	
	sfa4c	0.12	**0.05**	0.23	0.15	0.24	0.39	0.39	1	0.24	0.39	0.39	1

Note: all values are statistically significant at 5% significance level (except the two values in bold)

SOURCE: the author (2019)

The results presented by the three association measures were quite similar in magnitude and significance, and allowed the same findings. The Pearson's values were in general a bit higher than the rank-based measures, while the Spearman's rho values seemed to be higher than the Kendall's tau values.

Comparing the models, the values of association are higher to DEA among themselves and SFA among themselves. When comparing DEA and SFA models, the correlations were lower (the maximum is 0.52, 0.38 and 0.27, to Pearson's, Spearman's and Kendall's values, respectively). Also, the five lowest values of correlations (in bold in Table 6) cannot be considered statistically different from zero, and they occurred just when comparing DEA vs SFA (the translog and the Cobb-Douglas BC95tve models versus the CRSwithin model). To these cases, the rho and tau values suggest no association.

Differently from the findings of McMillan and Chan (2006) - that studied Canadian universities in a cross-section analysis, comparing DEA and SFA values of efficiencies - the rho and tau values in general suggested a statistically significant though not so strong association. The highest association was 0.52 to Pearson correlation between translog BC92tv (sfa3) and VRS_pooled (dea3) models. Actually, the values of association among SFA models themselves were not so strong either, with the exception of the association between BC92ti and BC92tv to each pair of translog and Cobb-Douglas (rho and tau values near or equal 1). These results highlight, for instance, the importance to consider more than one model or specification in order to evaluate efficiencies.

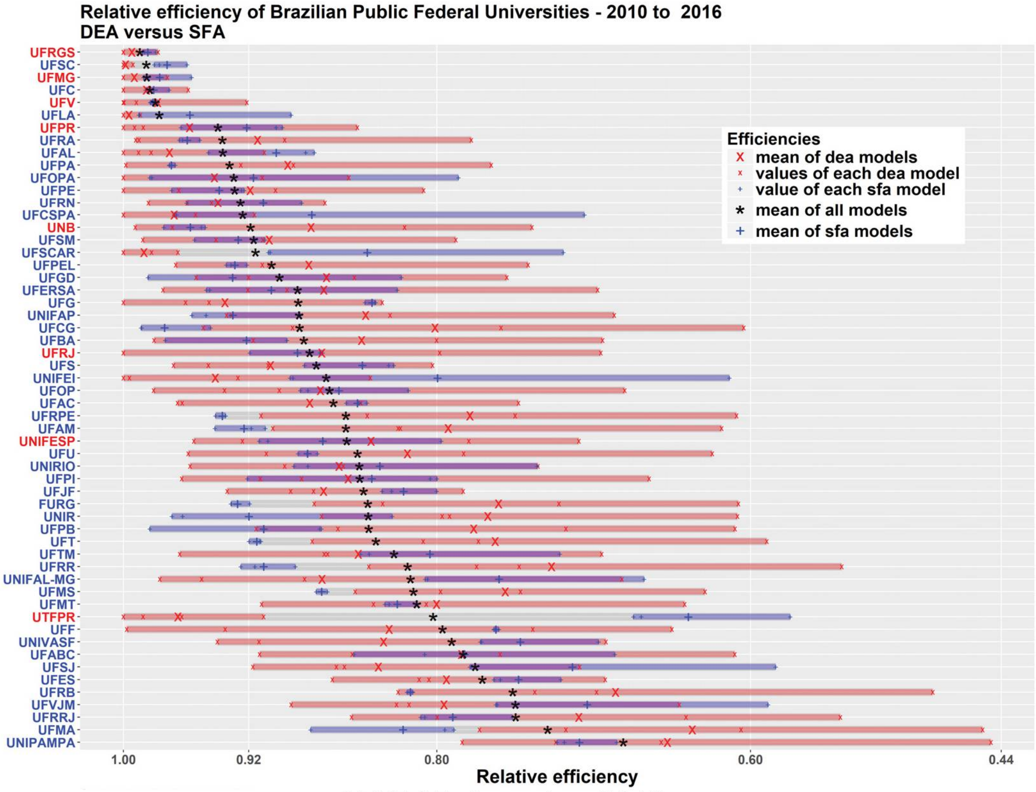
The same pattern presented by numbers in Table 6 can be visualized in the images of Appendix N1 - which are relative to the scatter plots among each DEA versus each translog SFA efficiency values - and in Appendix N2, relative to the efficiency ranks. The comparison to each of the 56 HEIs through time among VRS pooled, VRS within, translog BC92ti, and translog BC92tv can also be visualized in Appendix O1 to efficiency values, as well as in Appendix O2 to the rank of efficiencies; it thus allows the identification of each university and the differences among the efficiencies and ranks by model through time. In addition, Appendix P presents the correlations among the variables used in the estimations and the efficiencies' estimates. At this point, our findings corroborate the results of the comparison between DEA and SFA done by Tabak, Cajueiro and Dias (2014a, 2014b) to Chinese and Indian banks, respectively. They found that these models steadily inform the efficiency of the sector system as a whole, but they become inconsistent at an individual level, presenting low rank correlations.

In the review of comparisons between DEA and SFA to the healthcare system, Katharakisa and Katosteras (2013) found divergent efficiency estimates and they attribute it to factors such as statistical noise, the way inputs and outputs were defined, as well as data availability. Considering our results, these divergent efficiency estimates might be due: i) to statistical noise, and/or; ii) to the different assumptions of the models (regarding efficiency distribution), and/or; iii) to the different estimation principles (minimal extrapolation to DEA and the maximum likelihood to SFA), and/or; iv) to the great heterogeneity of the studied HEIs, some of them in regions quite different from others, some specialized in specific courses, others very young.

It is known that one assumption regarding DEA is the relative homogeneity of the DMUs assessed. Katharakisa and Katosteras (2013) emphasized that there is a need for careful attention by stakeholders since the nature of the data and its availability can influence the measurement of efficiency. This could be the case here in relation to the variable THIRDM and PATENT that quite probably failed in capturing some information about third mission and applied research. This is also suggested by the low impact of the inclusion of these variables in the model (in Appendix J, this could be noticed by comparing models fip7 and fip8).

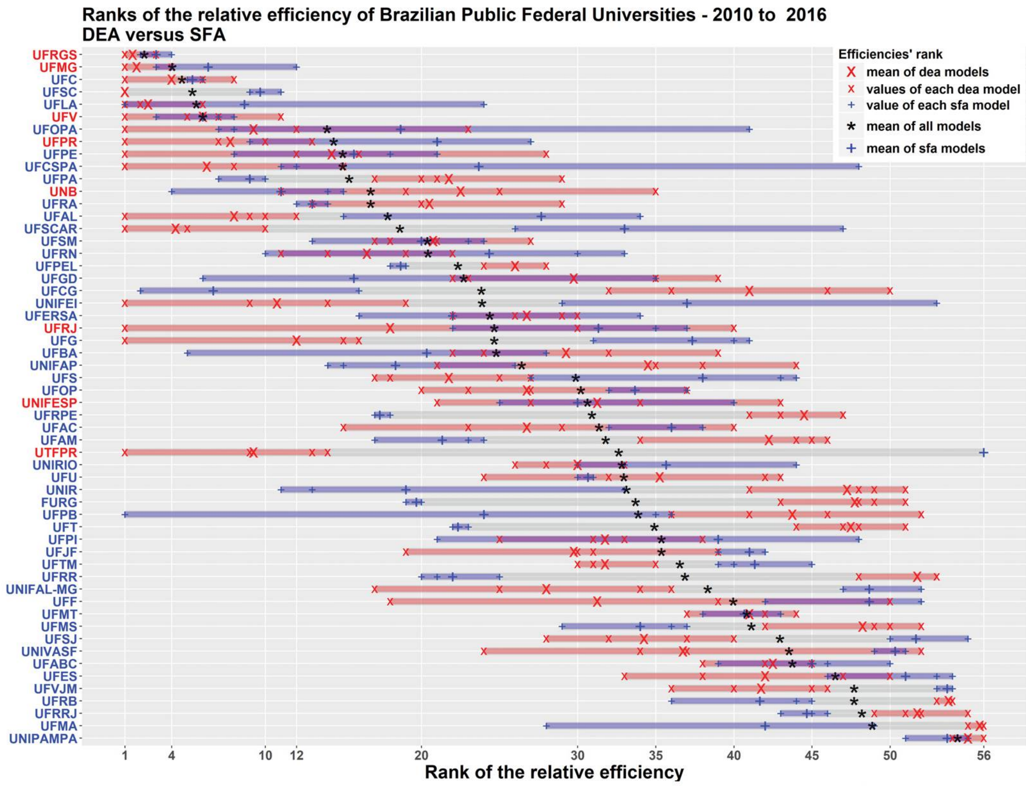
Finally, in an attempt to synthesize results regarding the efficiencies and the ranks of the HEIs through models, the results presented in Figures 3 and 4 suggest that they do not present so much similarity. It is clearly possible to discriminate only the best positioned university - UFRGS, with a mean-annual rank which is not worse than the 4^{th} to every model; and the worst positioned university - UNIPAMPA, with mean-annual rank which is not better than the 54^{th} position to every model.

FIGURE 3 – DISCRIMINATION OF MEAN-ANNUAL EFFICIENCIES BY MODEL



SOURCE: the author (2019)

FIGURE 4 – DISCRIMINATION OF MEAN-ANNUAL RANK OF EFFICIENCIES BY MODEL



SOURCE: the author (2019)

With a little lower precision, it is also possible to discriminate the five best positioned HEIs - UFRGS, UFMG, UFC, UFSC and UFV, ranked between the 1st and the 12th mean-annual rank in every model (and with more than 92% of an annual-mean efficiency value in every model), and the 5 worst HEIs – UNIPAMPA, UFRRJ, UFRB, UFVJM and UFABC, positioned between the 36st and the 56st mean-annual rank to every model (and with efficiencies between 44% and 92%). In fact, these ranks are defined excluding the BC92pooled model because it suggests no inefficiency.

In the intermediate positions, some HEIs present a better position to DEA models in general and a very bad position to SFA models. But caution is demanded at this point. It is extremely important to emphasize that these affirmations about rank are conditioned to all assumptions and limitations of the models and variables used. It is possible to affirm that parametric and non-parametric models considering the three inputs and five outputs used here, despite their theoretical and methodological differences, permit the investigation of some characteristics of the federal HEI regarding efficiency in the 'production process'. The results suggest that some institutions present higher or lower relative efficiencies and these results could subside information to policymakers or managers regarding the factors that better explain these inefficiencies. Furthermore, it permits a better understanding of the relations among the variables considered in the production process and their impact on efficiency.

4.5 FINAL REMARKS

The present piece of research used both parametric and non-parametric methods in order to estimate and analyze the efficiency of the Brazilian federal universities in the period of 2010 to 2016, which was the main goal of the study. Non parametric models were employed considering both constant and variable returns to scale, and also considering seven (annual) or one (entire period) technological frontier(s). The parametric models used made it possible to split the efficiencies between noise and 'real' inefficiency by assuming an 'a priori' production functional form (translog and Cobb-Douglas were applied here) and a half-normal non negative distribution of the inefficiency. Additionally, this parametric procedure presented the advantage of making it possible to have statistical tests about the estimates. Both approaches have been largely used in research for decades, because they can handle the particular multi-input and multi-output characteristics of the provision of higher educational services. Event though, DEA seems to be largely used to the case of HEIs, especially considering the Brazilian case. To the best of our knowledge, this study was the first one to use SFA to estimate the efficiency of Brazilian universities considering the institutions as a whole. Other innovative aspects were the consideration of the information about registered patent and third mission activities, even though their use might not have influenced results so much.

Discussions here just presented have been able to show that both approaches, DEA and SFA, can be considered fruitful to investigate the efficiency of the Brazilian federal higher education institutions for the period 2010 to 2016. As explored in the literature review, each approach presents its idiosyncrasies, with advantages and disadvantages in relation to each other. The methodological approaches also present differences in their assumptions and they are reflected in the values of the efficiency measurement. The rank-based correlations between the efficiencies by approach are lower than 0.4. This result is persistent in relation to the translog and Cobb-Douglas functional forms. Then, despite the fact that the set of efficiencies by model presents some similarities, the individual values present a statistically significant though weak rank-based correlation. The general pattern, both regarding values and rankings, is that all models are able to identify the overall five best-performing and five worst-performing universities.

Another innovative characteristic of this investigation is the comparison of some values from different parallel sources of information about Brazilian HEIS, such as INEP and TCU. In general, the information regarding professors, students and employees is consistent between the sources, but the financial information through time presents some inconsistency. The values from INEP suffer a lot of disturbance regarding some HEIs from one year to the other. This could be occurring due to accounting characteristics. On the other hand, the TCU explicitly advises HEIs to calculate the current expenditure costs without considering values of retirement, pensions, judicial sentences, staff/teachers assigned and staff/teacher studying abroad, and considering only 35% of the expenditures of the university hospital. This value seemed to better reflect the reality of universities' efficiency and was thus used in the estimations. Consequently, the critical thinking about the actual utility of the financial information from INEP HE Census (in the form that its data were available and can be collected nowadays) is also a result of this investigation.

Due to the innovative aspects of the study, the most common stochastic frontier strategies in the literature were chosen to be applied, that is, the Battese and Coeli (1992) model and the Batesse and Coeli (1995) model. Since new developments exist (as random parameters, unobserved heterogeneity control, transient vs. persistent efficiency), they should now, after this first approach, be considered for application in order to compare the present results, in a way to enrich the analysis and move the investigation further. Finally, with a focus on policy implications, the measurement of institutional efficiency can be recognized as a first step for the implementation, monitoring and/or evaluation of public-sector reforms, as well as other strategies regarding the Brazilian educational system. It is also in this sense – raising discussion on relevant issues such as those presented – that the given study has attempted to be a contribution to the area.

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5 FINAL REMARKS

This investigation focused on the efficiency measurement of Brazilian federal HEIs. After the presentation of the three essays, each one with its own focus, findings and final remarks, now a more general consideration about this doctoral dissertation as a whole is then presented.

An overall finding suggested by the literature review and by the results of the three essays is that there is inefficiency in the Brazilian federal higher education institutions. Another finding is that there were gaps of investigation in the area, regarding mainly: (i) the difficulty to find and use information about third mission activities; (ii) the identification and management of outlier observations in DEA; (iii) the use of raw values instead of index values from TCU; (iv) finally, and more important, making the estimates using stochastic parametric methods. This research fulfilled these research gaps and found that the results from different approaches can present important differences. Despite of this, it was possible to identify the general system efficiencies with some similarities but, regarding individual efficiencies, the approaches presented weak correlations/consistencies. Using the results from both approaches it was only possible to identify, with some confidence, the five best and the five worst institutions in terms of inefficiency.

Regarding regional aspects, the non-parametric approach did not allow us to bring claims about statistical differences, while the parametric approach suggested different technological frontiers by region and, considering that, a lower efficiency to the Southeast and a higher efficiency to North region in general. The heterogeneity of the institutions could strongly influence the non-parametric approach in relation to the parametric one. The parametric approach could identify different frontiers to different conditions, such as the existence of a university hospital or the recent federalization/implantation of the university. Both of these factors seemed to change the technological frontier and the efficiency measurement, but with opposite signals. The universities with a university hospital tended to present a higher technological frontier and a higher efficiency level. Due to these divergences, it is understood that both approaches complement each other and that attention is needed towards the assumptions of each model in relation to the real situation of the HEIs production processes.

In order to summarize the findings, some features emerging from the systemic analysis which are relevant to be highlighted at this point are the following:

- it is important to consider characteristics such as region, university hospital and the 'youth' of the university;
- it is important to consider variable returns to scale due to the heterogeneity of the universities;
- the financial information from INEP Higher Education Census is not so consistent when compared with the financial information from the TCU reports, but the last exists only to federal institutions;
- there is no systematized information about third mission, neither of registered patents (or technology transfer), so the INEP HE Census could attempt to do it.

Finally, it is important to recognize that despite the fact that this dissertation is a complete piece of research, the investigation is actually only beginning. It should be thus emphasized the importance to improve the analysis presented here by using new methods and/or new data and expand the analysis to estate and/or to other types of institutions, other than universities. It could be also fruitful, for instance, for further studies to investigate the 'multi-campi' characteristic of some IES, and its relation to efficiency. This way, it is hoped that the results from this piece of research can contribute to the improvement of the Brazilian higher education system.

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APPENDIX A - BRAZILIAN FEDERAL UNIVERSITIES

	Acronym	COD	Name	Region	State	City	Include hospital university?	year of foundation	year of federaliz.
1	FURG	12	UNIVERSIDADE FEDERAL DO RIO GRANDE	South	RS	Rio Grande	1	1964	1964
2	UFABC	4925	FUNDAÇÃO UNIVERSIDADE FEDERAL DO ABC	Southeast	SP	Santo André	0	2005	2005
3	UFAC	549	UNIVERSIDADE FEDERAL DO ACRE	North	AC	Rio Branco	0	1974	1974
4	UFAL	577	UNIVERSIDADE FEDERAL DE ALAGOAS	Northeast	AL	Maceió	1	1961	1961
5	UFAM	4	UNIVERSIDADE FEDERAL DO AMAZONAS	North	AM	Manaus	1	1962	1962
6	UFBA	578	UNIVERSIDADE FEDERAL DA BAHIA	Northeast	BA	Salvador	1	1946	1946
7	UFC	583	UNIVERSIDADE FEDERAL DO CEARÁ	Northeast	CE	Fortaleza	1	1954	1954
8	UFCG	2564	UNIVERSIDADE FEDERAL DE CAMPINA GRANDE	Northeast	PB	Campina Grande	1	1963	2002
9	UFCSPA	717	FUND. UNIV. FED. DE CIÊNC. DA SAÚDE DE PORTO ALEGRE	South	RS	Porto Alegre	0	1987	2008
10	UFERSA	589	UNIVERSIDADE FEDERAL RURAL DO SEMI-ÁRIDO	Northeast	RN	Mossoró	0	2005	2005
11	UFES	573	UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO	Southeast	ES	Vitória	1	1961	1961
12	UFF	572	UNIVERSIDADE FEDERAL FLUMINENSE	Southeast	RJ	Niterói	1	1960	1960
13	UFG	584	UNIVERSIDADE FEDERAL DE GOIÁS	Center-West	GO	Goiânia	1	1960	1960
14	UFGD	4504	FUND. UNIV. FEDERAL DA GRANDE DOURADOS	Center-West	MS	Dourados	1	2005	2005
15	UFJF	576	UNIVERSIDADE FEDERAL DE JUIZ DE FORA	Southeast	MG	Juiz de Fora	1	1960	1960
16	UFLA	592	UNIVERSIDADE FEDERAL DE LAVRAS	Southeast	MG	Lavras	0	1994	1994
17	UFMA	548	UNIVERSIDADE FEDERAL DO MARANHÃO	Northeast	MA	São Luís	1	1966	1966
18	UFMG	575	UNIVERSIDADE FEDERAL DE MINAS GERAIS	Southeast	MG	Belo Horizonte	1	1927	1927
19	UFMS	694	UNIVERSIDADE FEDERAL DE MATO GROSSO DO SUL	Center-West	MS	Campo Grande	1	1979	1979
20	UFMT	1	UNIVERSIDADE FEDERAL DE MATO GROSSO	Center-West	MT	Cuiabá	1	1970	1970
21	UFOP	6	UNIVERSIDADE FEDERAL DE OURO PRETO	Southeast	MG	Ouro Preto	0	1969	1969
22	UFOPA	15059	UNIVERSIDADE FEDERAL DO OESTE DO PARÁ	North	PA	Santarém	0	2009	2009
23	UFPA	569	UNIVERSIDADE FEDERAL DO PARÁ	North	PA	Belém	1	1957	1957
24	UFPB	579	UNIVERSIDADE FEDERAL DA PARAÍBA	Northeast	PB	João Pessoa	1	1960	1960
25	UFPE	580	UNIVERSIDADE FEDERAL DE PERNAMBUCO	Northeast	PE	Recife	1	1946	1946
26	UFPEL	634	UNIVERSIDADE FEDERAL DE PELOTAS	South	RS	Pelotas	1	1969	1969
27	UFPI	5	UNIVERSIDADE FEDERAL DO PIAUÍ	Northeast	PI	Teresina	1	1968	1968
28	UFPR	571	UNIVERSIDADE FEDERAL DO PARANÁ	South	PR	Curitiba	1	1950	1950
29	UFRA	590	UNIVERSIDADE FEDERAL RURAL DA AMAZÔNIA	North	PA	Belém	0	1998	2002
30	UFRB	4503	UNIVERSIDADE FEDERAL DO RECÔNCAVO DA BAHIA	Northeast	BA	Cruz das Almas	0	2005	2005
31	UFRGS	581	UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL	South	RS	Porto Alegre	0	1950	1950
32	UFRJ	586	UNIVERSIDADE FEDERAL DO RIO DE JANEIRO	Southeast	RJ	Rio de Janeiro	1	1920	1920
33	UFRN	570	UNIVERSIDADE FEDERAL DO RIO GRANDE DO NORTE	Northeast	RN	Natal	1	1960	1960
34	UFRPE	587	UNIVERSIDADE FEDERAL RURAL DE PERNAMBUCO	Northeast	PE	Recife	0	1967	1967
35	UFRR	789	UNIVERSIDADE FEDERAL DE RORAIMA	North	RR	Boa Vista	0	1985	1985
36	UFRRJ	574	UNIVERSIDADE FEDERAL RURAL DO RIO DE JANEIRO	Southeast	RJ	Seropédica	0	1963	1963
37	UFS	3	UNIVERSIDADE FEDERAL DE SERGIPE	Northeast	SE	São Cristóvão	1	1967	1967
38	UFSC	585	UNIVERSIDADE FEDERAL DE SANTA CATARINA	South	SC	Florianópolis	1	1960	1960
39	UFSCAR	7	UNIVERSIDADE FEDERAL DE SÃO CARLOS	Southeast	SP	São Carlos	0	1960	1960
40	UFSJ	107	UNIVERSIDADE FEDERAL DE SÃO JOÃO DEL REI	Southeast	MG	São João del Rei	0	2002	2002
41	UFSM	582	UNIVERSIDADE FEDERAL DE SANTA MARIA	South	RS	Santa Maria	1	1960	1960
42	UFT	3849	FUNDAÇÃO UNIVERSIDADE FEDERAL DO TOCANTINS	North	TO	Palmas	0	1990	2000
43	UFTM	597	UNIVERSIDADE FEDERAL DO TRIÂNGULO MINEIRO	Southeast	MG	Uberaba	1	2005	2005
44	UFU	17	UNIVERSIDADE FEDERAL DE UBERLÂNDIA	Southeast	MG	Uberlândia	1	1969	1969
45	UFV	8	UNIVERSIDADE FEDERAL DE VIÇOSA	Southeast	MG	Viçosa	0	1969	1969
46	UFVJM	596	UNIV. FED. DOS VALES DO JEQUITINHONHA E MUCURI	Southeast	MG	Diamantina	0	2002	2005
47	UNB	2	UNIVERSIDADE DE BRASÍLIA	Center-West	DF	Brasília	1	1961	1961
48	UNIFAL-MG	595	UNIVERSIDADE FEDERAL DE ALFENAS	Southeast	MG	Alfenas	0	2005	2005
49	UNIFAP	830	UNIVERSIDADE FEDERAL DO AMAPÁ	North	AP	Macapá	0	1986	1986
50	UNIFEI	598	UNIVERSIDADE FEDERAL DE ITAJUBÁ - UNIFEI	Southeast	MG	Itajubá	0	1998	2002
51	UNIFESP	591	UNIVERSIDADE FEDERAL DE SÃO PAULO	Southeast	SP	São Paulo	1	1994	1994
52	UNIPAMPA	5322	FUND. UNIV. FEDERAL DO PAMPA - UNIPAMPA	South	RS	Bagé	0	1998	2008
53	UNIR	699	FUNDAÇÃO UNIVERSIDADE FEDERAL DE RONDÔNIA	North	RO	Porto Velho	0	1982	1982
54	UNIRIO	693	UNIV. FEDERAL DO ESTADO DO RIO DE JANEIRO	Southeast	RJ	Rio de Janeiro	1	1979	1979
55	UNIVASF	3984	FUND. UNIV. FEDERAL DO VALE DO SÃO FRANCISCO	Northeast	PE	Petrolina	0	2002	2002
56	UTFPR	588	UNIVERSIDADE TECNOLÓGICA FEDERAL DO PARANÁ	South	PR	Curitiba	0	1978	1978

Universities not included in the analyses

	Acronym	COD	Name	Region	State	City	Include hospital university?	year of foundation	year of federaliz.
57	UFFS	15121	UNIVERSIDADE FEDERAL DA FRONTEIRA SUL	South	SC	Chapecó		2009	2009
58	UNILA	15001	UNIV. FEDERAL DA INTEGRAÇÃO LATINO-AMERICANA	South	PR	Foz do Iguaçu		2010	2010
59	UNILAB	15497	UNIV. INTEG. INTERN. DA LUSOFONIA AFRO-BRASILEIRA	Northeast	CE	Redenção		2010	2010
60	UFESBA	18812	UNIVERSIDADE FEDERAL DO SUL DA BAHIA	Northeast	BA	Itabuna		2013	2013
61	UFCA	18759	UNIVERSIDADE FEDERAL DO CARIRI	Northeast	CE	Juazeiro do Norte		2013	2013
62	UFOB	18506	UNIVERSIDADE FEDERAL DO OESTE DA BAHIA	Northeast	BA	Barreiras		2013	2013
63	UNIFESSPA	18440	UNIV. FEDERAL DO SUL E SUDESTE DO PARÁ	North	PA	Marabá		2013	2013

APPENDIX A1 - TCU RAW AND INDICES VALUES: DEFINITIONS/CALCULUS ORIENTATION

Synthesis of TCU (2010) orientations about the definitions and calculus of the indexes and raw values

	Acronym	Raw values	Definition
1	CCCHU	current cost with HU (university hospitals);	current expenditures of HEI with additional 35% of the university hospital expenditures (not considering pensions, judicial sentences and not active staff)
2	CCSHU	current cost without HU;	similar but no additional 35% of HU
3	PE	number of full time equivalent professors;	permanent professors, substitute professors, visiting professors (considering only active ones) – calculated by time of work proportionally to one professional working 40h/week
4	FECHU	number of full time equivalent employees with HU;	permanent employees not professors, temporary contract employees not professors, including all employees from HU (considering only active ones) - calculated by time of work proportionally to one professional working 40h/week
5	FESHU	number of full time equivalent employees without HU;	similar but excluding that ones working exclusively for HU
6	AG	Number of enrolled students in undergraduate courses	total of enrolled undergraduate students – not considering participants of third mission activities, not considering students in non-presencial courses
7	APG	number of enrolled students in postgraduate courses (master and doctorate)	total of enrolled postgraduate students (only master and doctorate courses)
8	AR	number of intern students (medical residence);	total of undergraduate students enrolled as interns
9	AGTI	number or full time undergraduate students;	sum of all courses value according to the equation: { (NDI*DPC) * (1 + [retention factor]) + (((NI – NDI)/4)*DPC)} In which: NDI = number of undergraduate degrees in that year; DPC = standard course duration (in years); (see Appendix B2); NI = number of fresh undergraduate students in the years; Retention factor = factor calculated by HE governmental office (see Appendix B2)
10	AGE	number of undergraduate students equivalent	= AGTI * [course group weight]; (see Appendix B2)
11	APGTI	number of full time equivalent postgraduate students;	= APG * 2
12	ARTI	number of full time equivalent interns (medical residence).	= AR *2

	acronym	Indicators	definition
1	CCCHUAE	current cost with HU by equivalent student;	= CCCHU / (AGE + APGTI + ARTI)
2	CCSHUAE	current cost without HU by equivalent student	= CCSHU / (AGE + APGTI + ARTI)
3	ATIPE	full time student by equivalent professor;	= (AGTI + APGTI + ARTI) / PE
4	ATIFECHU	full time student by equivalent employees with HU;	= (AGTI + APGTI + ARTI) / FECHU
5	ATIFESHU	full time student by equivalent employees without HU;	= (AGTI + APGTI + ARTI) / FESHU
6	FECHUPE	equivalent employees with HU by equivalent professors;	= FECHU / PE
7	FESHUPE	equivalent employees without HU by equivalent professors	= FESHU / PE
8	GPE	index of students participation;	= AGTI / AG
9	GEPG	ratio of postgraduate students;	= APG / (AG + APG)
10	TSG	student degrees by registered students;	= [nr. of undergraduate degrees in the year] / [nr. of fresh undergraduate students in the respective cohort considering the standard duration of the course]
11	IQCD	qualification of teaching staff index	= (5*D + 3*M + 2*E + 1*G) / (D + M + E + G), In which: D is the number of professors with doctorate degree; M is the number of professors with master degree; E is the number of professors with specialization degree; G is the number of professors with undergraduate degree.
12	CCAPES	quality index of postgraduate programs (concept of Coordination for Enhancement of Higher Education Personnel for Post-Graduate Progams)	= [sum of the CAPES quality index of each postgraduate program from the HEI] / [number of postgraduate programs from the HEI]

SOURCE: adapted from TCU (2010) and SESu/MEC (2018)

APPENDIX A2 - WEIGHTS FOR STUDENT VARIABLE

Information used to calculate the number of full time equivalent students and undergraduate students equivalent from Appendix B1.

EDUCATION MINISTRY
HIGHER EDUCATION SECRETARY

Table to calculate the performance indices from federal higher education institutions - following TCU demands.
(retention factor and standard average duration of knowledge areas)

Area	Area description	Retention factor	Standard average duration	Group	Group weight
A	ARTS	0,1150	4	A3	1,5
CA	AGRICULTURAL SCIENCES	0,0500	5	A2	2,0
CB	BIOLOGICAL SCIENCES	0,1250	4	A2	2,0
CET	EARTH AND EXACT SCIENCES	0,1325	4	A2	2,0
CH	HUMAN SCIENCES	0,1000	4	A4	1,0
CH1	PSYCHOLOGY	0,1000	5	A4	1,0
CS1	MEDICINE	0,0650	6	A1	4,5
CS2	VETERINARY MEDICINE, ODONTOLOGY, ZOOTECHNICS	0,0650	5	A1	4,5
CS3	NUTRITION, PHARMACY	0,0660	5	A2	2,0
CS4	NURSING, PHYSIOTHERAPY, SPEECH THERAPY, PHYSICAL EDUCATION	0,0660	5	A3	1,5
CSA	APPLIED SOCIAL SCIENCES	0,1200	4	A4	1,0
CSB	LAW	0,1200	5	A4	1,0
ENG	ENGINEERING	0,0820	5	A2	2,0
LL	LINGUISTICS AND LANGUAGES	0,1150	4	A4	1,0
M	MUSIC	0,1150	4	A3	1,5
TEC	TECHNOLOGIST	0,0820	3	A2	2,0
CET	EXACT SCIENCES - MATHEMATICS, COMPUTER SCIENCE, STATISTICS	0,1325	4	A3	1,5
CSC	ARCHITECTURE / URBANISM	0,1200	4	A3	1,5
CH2	TEACHER TRAINING DEGREE	0,1000	4	A4	1,0

SOURCE: adapted from ANDIFES (2017)

APPENDIX B - LITERATURE REVIEW

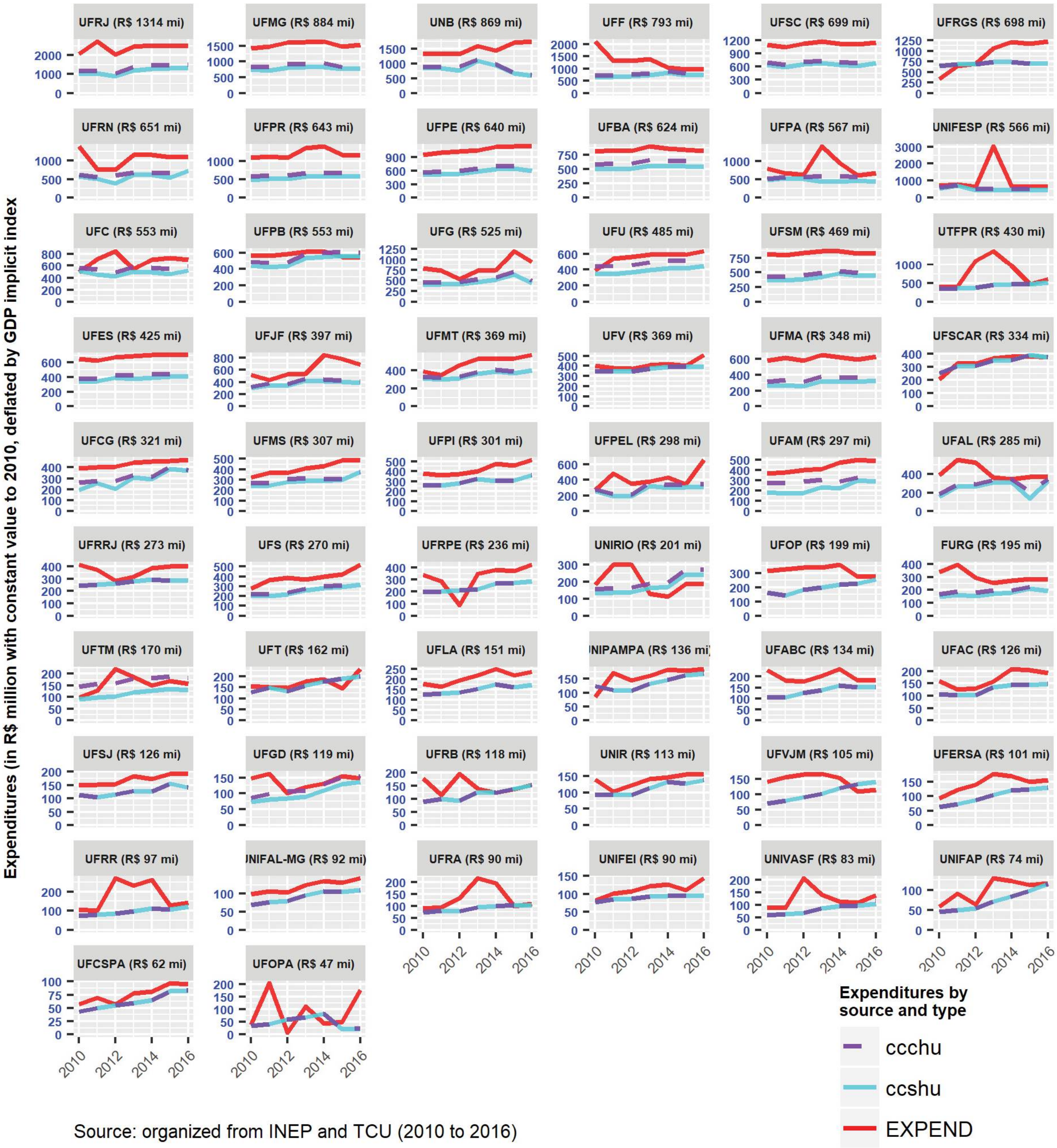
	Author	object	country	period	method	seminal	software
1	Izadi, Johnes, Oskrochi and Crouchley (2002),	HEIs	Britain	1994/95	sfa	J	Limdep
2	Siegel, Waldman and Link (2003),	TTOs from 113 universities	US	1991/1996	sfa	BC95	frontier
3	Stevens (2004, 2005),	80 HEIs	English and Welsh	95/96 to 98/99	sfa	BC95	---
4	Chapple, Lockett, Siegel and Wright et al (2005),	TTOs from 50 univ.	UK	2001	DEA x sfa	BC95	frontier
5	McMillan and Chan (2006), and	45 universities	Canada	1992-93	DEA x sfa	BC95 (KGM)	frontier
6	Castano and Cabanda (2007),	30 private HEIs	Philipines	1999 to 2003	Malm and sfa	BC95	frontier
7	Siegel, Wright, Chapple and Lockett (2008),	TTOs (83 + 37)	USA and UK	2001	sfa	BC(95) KGM	
8	Abbott and Doucouliagos (2009)		Australia and New Zeland		sfa	BC(95)	frontier
9	Johnes and Johnes (2009),	121 HEIs	England	2000/01 to 2002/03	random parameters model	Tsionas (2002) and Greene (2005)	Limdep
10	Kempkes and Pohl (2010),	72 public universities	German	1998 to 2003	DEA x sfa	BC(95)	
11	Agasisti and Johnes (2010),	57 public universities	Italy	2001/02 to 2003/04	random param.	Tsionas (2002) and Greene (2005)	Limdep
12	Worthington and Higgs (2011)	36 universities	Australia	1998 to 2006	OLS ???		
13	Johnes and Schwarzenberger (2013)	?#? public universities	German	2002/03 to 2004/05	random parameter sf model	Greene (2005)	Limdep
14	Johnes (2013)	113 public funded HEIs (unbalanced panel)	Britain	1996/97 to 2008/09	DEA x sfa	BC(92)	
15	Johnes and Johnes (2013) (BIS report)		England		sfa		
16	Agasisti and Belfield (2014)	950 community colleges	US	2003 to 2010	sfa	BC(92) and BC(95)	
17	Agasisti, Barra and Zotti (2015)	212 public universities	Italia	2008 to 2011	sfa	Wang and Ho (2010)	Stata
18	Agasisti and Haelermans (2016)	13+58 public universities	Dutch and Italian	2005/06 to 2008/09	sfa		

		type analysis	type of function	orientation	functional form	nr. inputs	use prices	nr. outputs	explain inefficiencies
1	Izadi, Johnes, Oskrochi and Crouchley (2002),	Cros-section	cost	input	CES	1	y	4	no
2	Siegel, Waldman and Link (2003),	Cros-section	production	output	production	3		1	yes
3	Stevens (2004, 2005),	panel	cost	output	translog	1		5	yes
4	Chapple, Lockett, Siegel and Wright et al (2005),	Cros-section	production	output	Cobb x translog	3		1	yes
5	McMillan and Chan (2006), and	Cros-section	cost	input	partial translog	14	1	14	yes
6	Castano and Cabanda (2007),	panel	revenue	output	cobb x translog	3	0	1	yes
7	Siegel, Wright, Chapple and Lockett (2008),	Cros-country	distance		Cobb with interactions	5 with interactions		3	yes
8	Abbott and Doucouliagos (2009)	panel	distance	output	translog				no
9	Johnes and Johnes (2009),	panel	cost	input	quadratic cost	1	0	4	no
10	Kempkes and Pohl (2010),	panel	cost	output	translog	4	0	2	yes
11	Agasisti and Johnes (2010),	panel	cost	input	quadratic cost	1	0	4	yes
12	Worthington and Higgs (2011)	panel	cost	input	quadratic cost	4	3	5	no
13	Johnes and Schwarzenberger (2013)	panel	cost	input	quadratic cost	1	0	4	no
14	Johnes (2013)	panel	distance	output	translog	5	0	3	no
15	Johnes and Johnes (2013) (BIS report)	cross and panel 3year	cost		linear vs quad. Lin lat vs quad lat.				no
16	Agasisti and Belfield (2014)	panel	cost	output	1x1 x cobb	1	0	1 (weighted degrees)	yes
17	Agasisti, Barra and Zotti (2015)	panel	distance	output	cobb x translog	3	0	3	yes
18	Agasisti and Haelermans (2016)	panel	cost	input	translog	expenditures	0	4	

APPENDIX C - CCCHU AND EXPEND

Brazilian Federal Universities (2010 - 2016)

Financial information from:
INEP (EXPEND = total expenditures), and
TCU (ccchu = net expenditures* including 35% of university hospital expenditures and
ccshu = net expenditures* excluding all expenditures from university hospital)



Source: organized from INEP and TCU (2010 to 2016)

Notes: universities ordered by annual mean expenditures (ccchu mean by HEI in the parenthesis, in R$ million with constant values to 2010, deflated by GDP implicit index)
* the net expenditures consider the current expenditures minus expenditures with retirement, pensions, judicial sentences, staff/professors assigned and staff/professors abroad.

APPENDIX D - PROFES INEP VS TCU

Brazilian Federal Universities (2010 - 2016)

Professor information from:
INEP (tot_prof = number of professors in undergraduate courses,
PROF_INEP = number of equivalent professors*), and
TCU (PROFES_TCU = number of equivalent professors**)

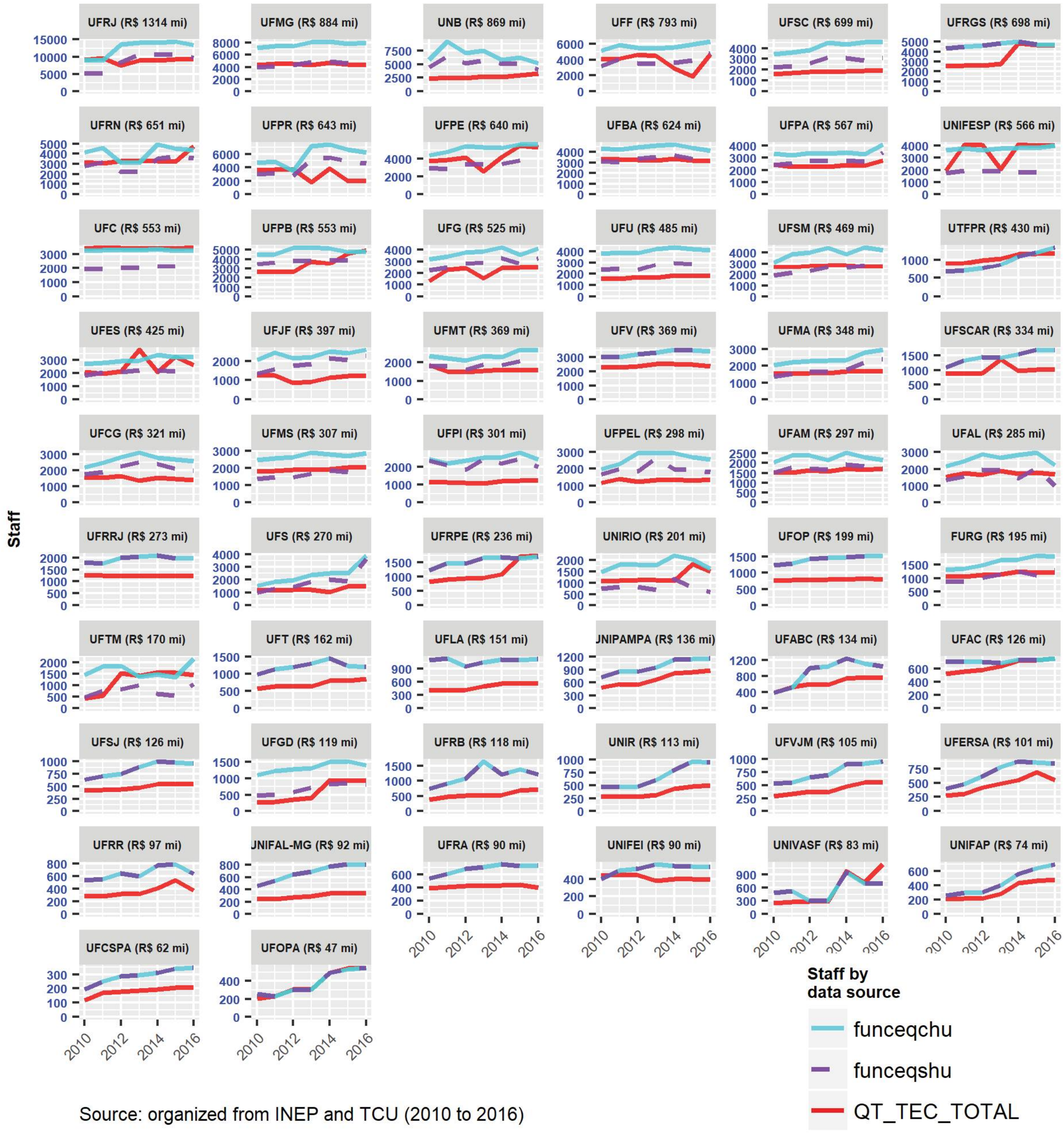
Source: organized from INEP and TCU (2010 to 2016)

Notes: universities ordered by annual mean expenditures (ccchu mean by HEI in the parenthesis, in R$ million with constant values to 2010, deflated by GDP implicit index)
* calculated considering permanent professors, substitute professors, visiting professors (considering only active ones) – weighted by time of work proportionaly to one professional working 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)
** calculated considering permanent professors, substitute professors, visiting professors (considering only active ones) – weighted by time of work proportionaly to a one professional which work 40h/week

APPENDIX E - EMPLOY VS FUNCEQSHU

Brazilian Federal Universities (2010 - 2016)

Staff information from:
INEP (QT_TEC_TOTAL = number of of staff non professors), and
TCU (funceqchu = # of equiv. staff* non professors including those working in univ. hospital,
funceqshu = # of equiv. staff* non professors excluding those working in univ. hospital)



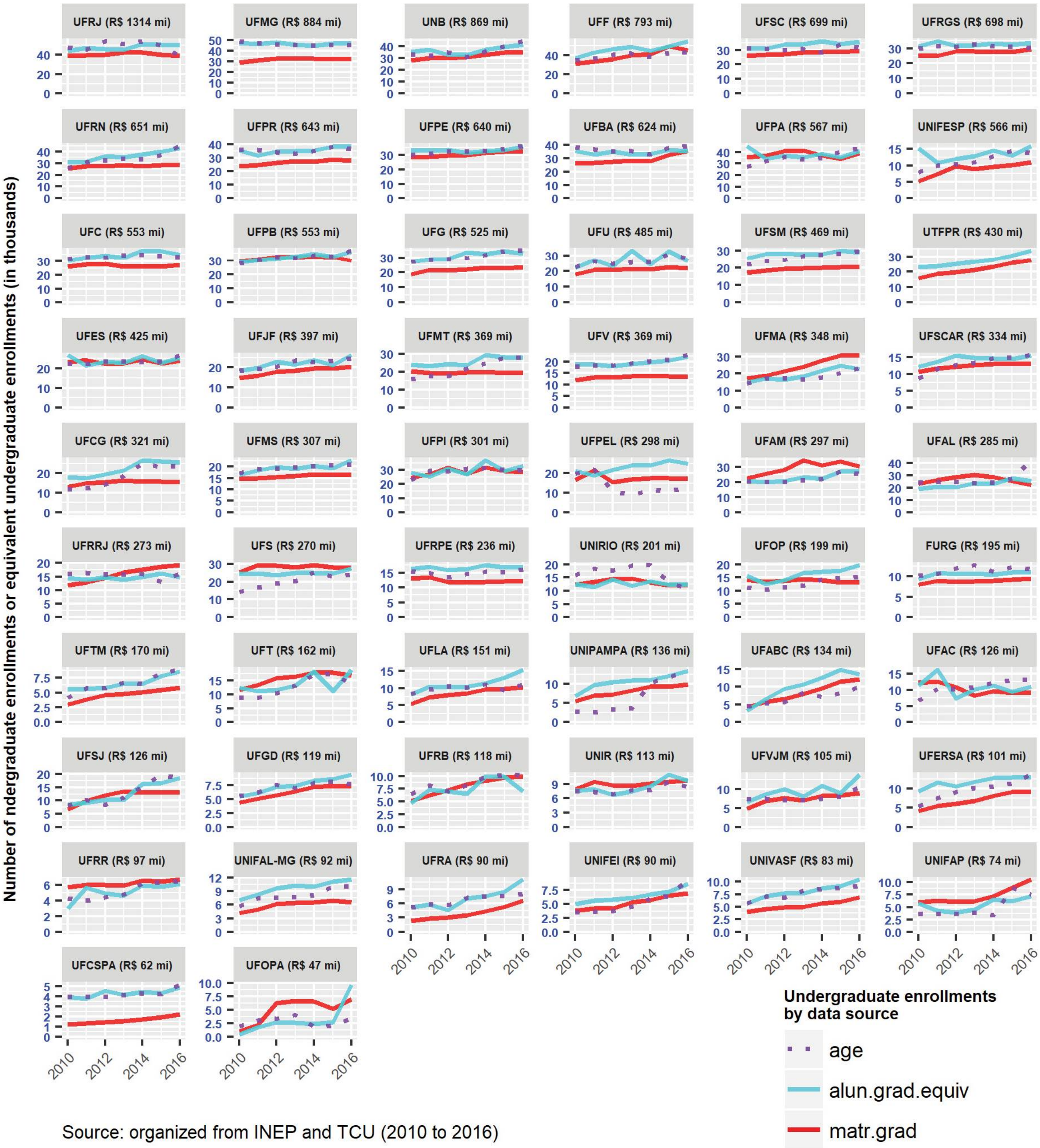
Source: organized from INEP and TCU (2010 to 2016)

Notes: universities ordered by annual mean expenditures (ccchu), maximum value of year expenditure to each HEI is in the parenthesis (in R$ million with constant values to 2010, deflated by GDP implicit index)
* Number of permanent employees not professors, temporary contract employees not professors (consider only active ones) - it was not possible to weigh by time of work due to inexistent information in INEP HE Census
** Number of permanent employees not professors, temporary contract employees not professors (consider only active ones) - calculated by time of work proportionaly to a one professional which work 40h/week

APPENDIX F - ENROLU FROM INEP VS TCU

Brazilian Federal Universities (2010 - 2016)

Undergraduate enrollments information from:
INEP (matr.grad = number of of undergraduate enrollments and
alun.grad.equiv = equivalent undergraduate enrollments*)
TCU (age = equivalent undergraduate enrollments*)



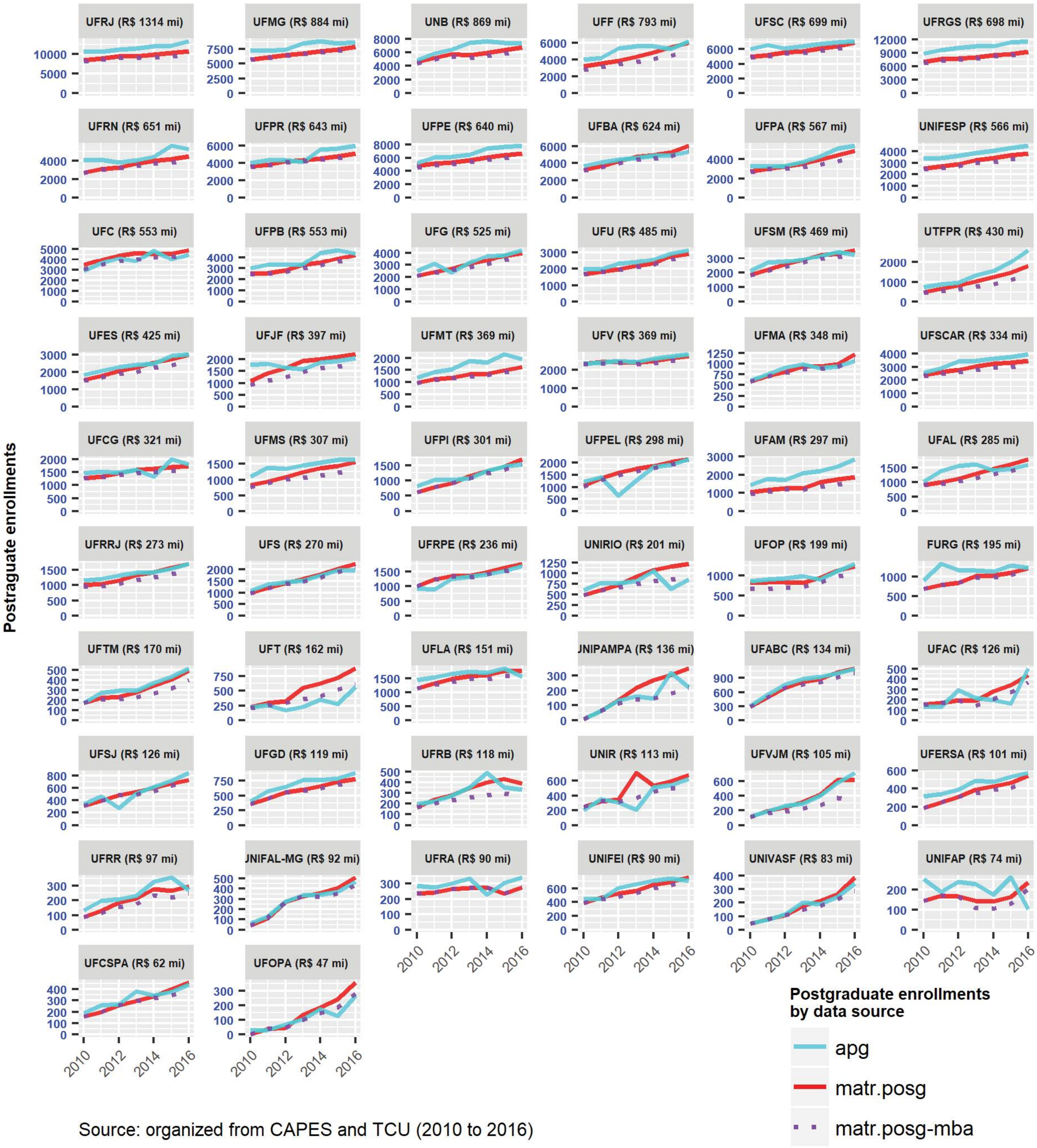
Source: organized from INEP and TCU (2010 to 2016)

Notes: universities ordered by annual mean expenditures (ccchu), maximum value of year expenditure to each HEI is in the parenthesis (in R$ million with constant values to 2010, deflated by GDP implicit index)
* Weighted by type and duration of the course according to TCU(2018) and Sesu/MEC(2018)

APPENDIX G - ENROLP INEP VS TCU

Brazilian Federal Universities (2010 - 2016)

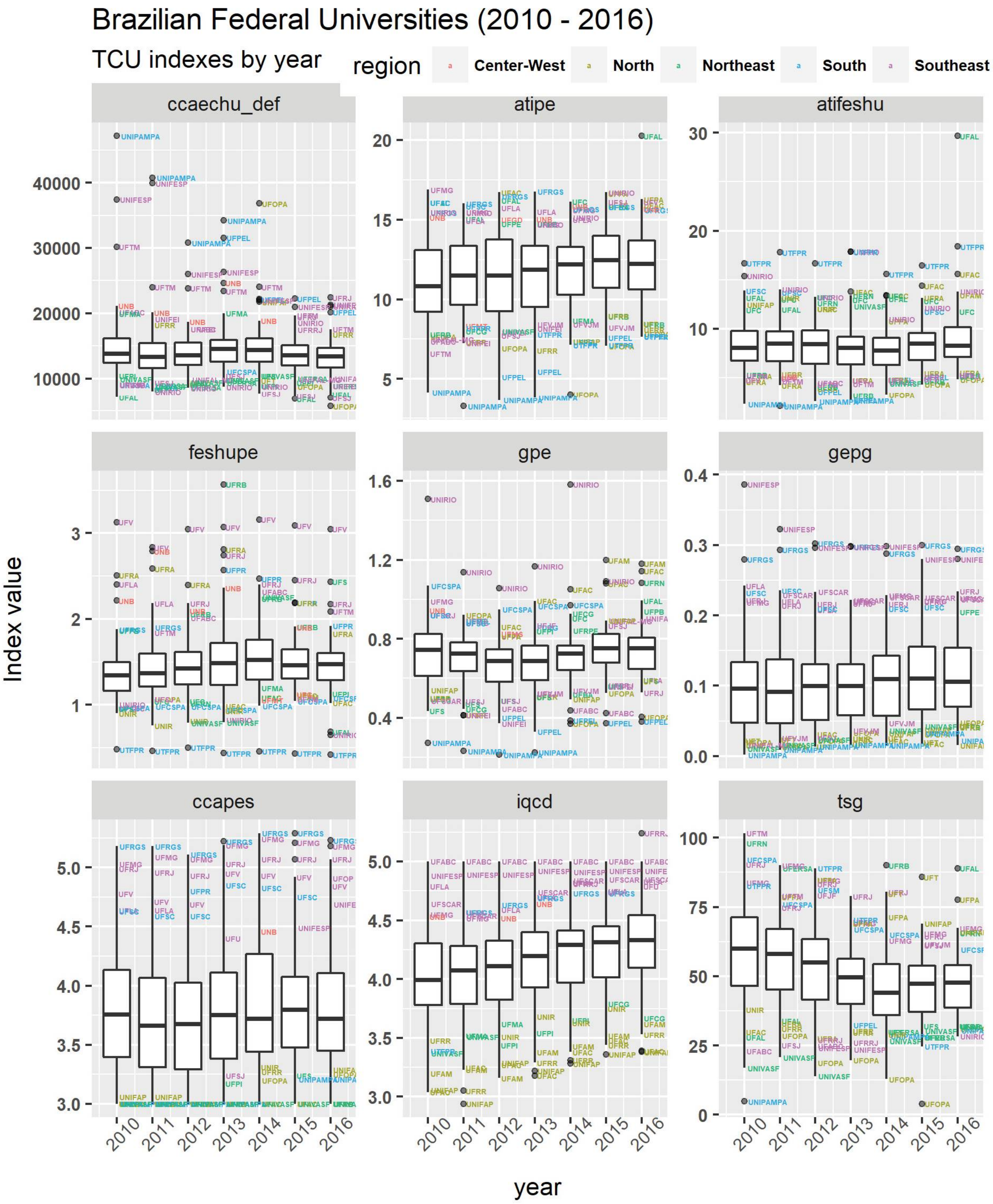
Postgraduate enrollments information from:
INEP (matr.posg = number of of postgraduate enrollments including mba courses and
matr.posg-mba = postgraduate enrollments excluding mba courses)
TCU (apg = number of of postgraduate enrollments)



Source: organized from CAPES and TCU (2010 to 2016)

Notes: universities ordered by annual mean expenditures (ccchu), maximum value of year expenditure to each HEI is in the parenthesis (in R$ million with constant values to 2010, deflated by GDP implicit index)

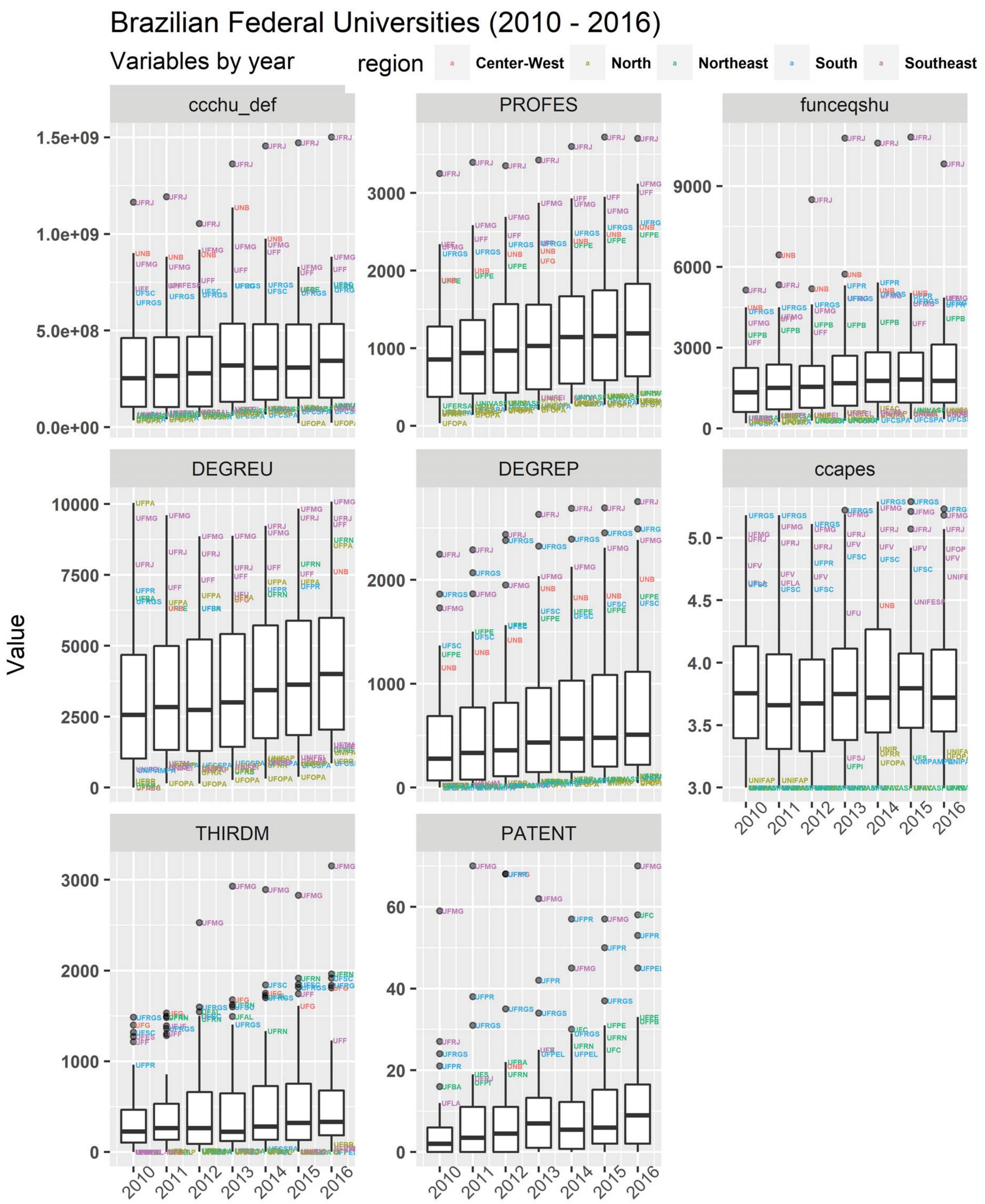
APPENDIX H - BOX PLOT OF TCU INDEXES BY YEAR



Source: organized from TCU (2010 to 2016)

Notes: The central line corresponds to the median. The lower and upper hinges correspond to the first and third quartiles (the 25th and 75th percentiles).
The upper whisker extends from the hinge to the largest value no further than 1.5 * IQR from the hinge (where IQR is the inter-quartile range, or distance between the first and third quartiles).
The lower whisker extends from the hinge to the smallest value at most 1.5 * IQR of the hinge.
Data beyond the end of the whiskers are called 'outlying' points and are plotted individually.

APPENDIX I1 - INPUTS AND OUTPUTS USED IN DEA AND SFA MODELS



Source: organized from TCU and INEP (2010 to 2016)

Notes: The central line corresponds to the median. The lower and upper hinges correspond to the first and third quartiles (the 25th and 75th percentiles).
The upper whisker extends from the hinge to the largest value no further than 1.5 * IQR from the hinge (where IQR is the inter-quartile range, or distance between the first and third quartiles).
The lower whisker extends from the hinge to the smallest value at most 1.5 * IQR of the hinge.
Data beyond the end of the whiskers are called 'outlying' points and are plotted individually.

APPENDIX I2 - CORRELATION MATRIX

Inputs, outputs and environmental variables

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Pearson correlations matrix	**ccchu_def**	**profeq**	**PROFES**	**funceqshu**	**DEGREU**	**DEGREP**	**THIRDM**	**PATENT**	**ccapes**	**hu**	**newsf**	**ano**	**tsg**	**gpe**	**atipe**	**atifeshu**	**iqcd**	**feshupe**
1	ccchu_def	1	0.95	0.96	0.92	0.89	0.92	0.59	0.6	0.7	0.58	-0.53	0.09	0.33	0.11	0.47	0.14	0.33	0.2
2	profeq	0.95	1	0.99	0.89	0.92	0.89	0.59	0.6	0.62	0.59	-0.56	0.13	0.31	0.09	0.42	0.21	0.22	0.08
3	PROFES	0.96	0.99	1	0.89	0.92	0.92	0.65	0.64	0.66	0.57	-0.55	0.16	0.3	0.09	0.45	0.19	0.31	0.12
4	funceqshu	0.92	0.89	0.89	1	0.82	0.89	0.52	0.57	0.68	0.47	-0.45	0.12	0.27	0.07	0.45	-0.09	0.29	0.44
5	DEGREU	0.89	0.92	0.92	0.82	1	0.85	0.61	0.67	0.61	0.63	-0.55	0.16	0.37	0.18	0.53	0.22	0.22	0.11
6	DEGREP	0.92	0.89	0.92	0.89	0.85	1	0.64	0.69	0.8	0.46	-0.48	0.16	0.31	0.11	0.56	0.11	0.42	0.26
7	THIRDM	0.59	0.59	0.65	0.52	0.61	0.64	1	0.5	0.49	0.34	-0.34	0.1	0.23	0.08	0.4	0.14	0.23	0.09
8	PATENT	0.6	0.6	0.64	0.57	0.67	0.69	0.5	1	0.59	0.33	-0.35	0.18	0.25	0.04	0.38	0.09	0.29	0.18
9	ccapes	0.7	0.62	0.66	0.68	0.61	0.8	0.49	0.59	1	0.28	-0.37	0.07	0.32	0.15	0.5	0.01	0.6	0.36
10	hu	0.58	0.59	0.57	0.47	0.63	0.46	0.34	0.33	0.28	1	-0.43	0	0.19	0.17	0.37	0.21	0.05	-0.05
11	newsf	-0.53	-0.56	-0.55	-0.45	-0.55	-0.48	-0.34	-0.35	-0.37	-0.43	1	0	-0.2	-0.19	-0.44	-0.33	0.05	0.04
12	ano	0.09	0.13	0.16	0.12	0.16	0.16	0.1	0.18	0.07	0	0	1	-0.29	0.07	0.14	0.04	0.25	0.06
13	tsg	0.33	0.31	0.3	0.27	0.37	0.31	0.23	0.25	0.32	0.19	-0.2	-0.29	1	0.25	0.31	0.23	0.09	-0.03
14	gpe	0.11	0.09	0.09	0.07	0.18	0.11	0.08	0.04	0.15	0.17	-0.19	0.07	0.25	1	0.58	0.42	0.03	-0.01
15	atipe	0.47	0.42	0.45	0.45	0.53	0.56	0.4	0.38	0.5	0.37	-0.44	0.14	0.31	0.58	1	0.44	0.22	0.25
16	atifeshu	0.14	0.21	0.19	-0.09	0.22	0.11	0.14	0.09	0.01	0.21	-0.33	0.04	0.23	0.42	0.44	1	-0.14	-0.65
17	iqcd	0.33	0.22	0.31	0.29	0.22	0.42	0.23	0.29	0.6	0.05	0.05	0.25	0.09	0.03	0.22	-0.14	1	0.29
18	feshupe	0.2	0.08	0.12	0.44	0.11	0.26	0.09	0.18	0.36	-0.05	0.04	0.06	-0.03	-0.01	0.25	-0.65	0.29	1

APPENDIX J - ESTIMATIONS OF STOCHASTIC TRANSLOG OUTPUT DISTANCE FUNCTION

BC92ti

Variable	fip1	fip2	fip3	fip4	fip5	fip6	fip7	fip8
(Intercept)	-0.496 ***	-0.331 **	-0.486 ***	-0.419 ***	-0.400 ***	-0.148 ***	-0.129 ***	-0.144 ***
logmDEGREP	0.616 ***	0.382 ***	0.574 ***	0.461 ***	0.564 ***	0.029 *	0.032 **	0.031 **
logmTHIRDM		0.042 **	0.030 **	0.020	0.027 **	0.001	0.001	
logmPATENT				-0.021	-0.088 ***	-0.001	-0.002	
logmCCAPES						0.950 ***	0.932 ***	0.937 ***
I(0.5 * logmDEGREP^2)	0.047 ***	0.034 ***	0.047 ***	0.240 ***	0.057 ***	-0.102 **	0.002	0.002 *
I(0.5 * logmTHIRDM^2)		0.024 ***	0.009 ***	0.013 **	0.010 ***	0.002	0.001	
I(0.5 * logmPATENT^2)				-0.026	-0.009 ***	-0.018 ***	0.000	
I(0.5 * logmCCAPES^2)						-0.225 **	0.067 **	0.005
I(logmDEGREP * logmTHIRDM)		-0.055 ***	0.004	-0.080 ***	0.002	-0.017 *	-0.006 ***	
I(logmDEGREP * logmPATENT)				0.001	-0.008 **	0.020	-0.001	
I(logmDEGREP * logmCCAPES)						0.144 ***	-0.034 **	0.002
I(logmTHIRDM * logmPATENT)				0.014 *	-0.002	0.005 *	0.000	
I(logmTHIRDM * logmCCAPES)						0.002	0.005 **	
I(logmPATENT * logmCCAPES)						0.000	0.003 *	
logmccchu_def	-0.441 ***	-0.455 ***	-0.475 ***	-0.420 ***	-0.444 ***	-0.080 ***	-0.073 ***	-0.053 ***
logmprofeq	-0.756 ***	-0.526 ***	-0.616 ***	-0.589 ***	-0.603 ***	-0.047	-0.096 ***	-0.123 ***
logmfunceqshu	-0.172 ***	-0.210 ***	-0.220 ***	-0.224 ***	-0.185 ***	-0.054 ***	-0.037 **	-0.032 **
I(0.5 * logmccchu_def^2)	-1.259 ***	-1.022 ***	-1.086 ***	-0.003	-0.692 ***	-0.148	-0.082	-0.048
I(0.5 * logmprofeq^2)	-0.255	0.257	0.160	1.942 ***	0.529	-0.328 *	-0.201 *	-0.212 **
I(0.5 * logmfunceqshu^2)	-0.386	-0.038	-0.305	0.638 ***	-0.175	0.060	-0.010	-0.015
I(logmprofeq * logmccchu_def)	0.466	0.364	0.271	-0.694 **	0.043	-0.063	0.014	-0.038
I(logmfunceqshu * logmccchu_def)	0.952 ***	0.867 ***	0.981 ***	0.872 ***	0.688 ***	0.023	0.053	0.056
I(logmprofeq * logmfunceqshu)	-0.627 **	-0.838 ***	-0.737 ***	-1.452 ***	-0.605 ***	0.022	0.046	0.056
I(logmDEGREP * logmccchu_def)	-0.067	-0.101 **	-0.099 **	-0.411 ***	-0.116 ***	0.181 ***	0.043 ***	0.027 **
I(logmDEGREP * logmprofeq)	0.011	-0.050	-0.036	0.561 ***	-0.091	0.016	-0.032	0.046 **
I(logmDEGREP * logmfunceqshu)	0.242 ***	0.185 **	0.287 ***	-0.045	0.378 ***	-0.033	-0.038	-0.065 **
I(logmTHIRDM * logmccchu_def)		-0.027	-0.023	0.017	-0.049	0.006	0.002	
I(logmTHIRDM * logmprofeq)		0.157 ***	0.131 ***	0.092 *	0.130 ***	0.020	0.018 *	
I(logmTHIRDM * logmfunceqshu)		-0.136 ***	-0.132 ***	-0.133 ***	-0.102 ***	-0.026 **	-0.015 ***	
I(logmPATENT * logmccchu_def)				0.046	0.027 **	-0.046 *	0.000	
I(logmPATENT * logmprofeq)				-0.090	-0.021	0.030	0.004	
I(logmPATENT * logmfunceqshu)				0.038	-0.012	0.014	0.000	
I(logmCCAPES * logmccchu_def)						-0.143 *	0.004	-0.003
I(logmCCAPES * logmprofeq)						-0.182	-0.025	-0.077 *
I(logmCCAPES * logmfunceqshu)						0.026	0.048	0.039
hu	0.263 ***	0.130 *	0.234 ***	0.206 **	0.183 **	0.059 **	0.057 ***	0.062 ***
regionNorth	0.341 ***	0.193 *	0.346 ***	0.120	0.186 *	0.116 *	0.120 ***	0.132 ***
regionNortheast	0.154	0.092	0.185 *	0.071	0.101	0.017	-0.008	0.002
regionSouth	0.092	-0.013	0.116	0.057	0.039	-0.051	-0.065 **	-0.058 *
regionSoutheast	0.099	0.044	0.117	0.020	0.074	-0.067 **	-0.101 ***	-0.097 ***
newsf	0.075	0.026	0.072	-0.024	0.025	0.023	-0.004	-0.006
sigmaSq	0.206 ***	0.127 ***	0.163 ***	0.095 ***	0.131 ***	0.025 ***	0.024 ***	0.027 ***
gamma	0.838 ***	0.799 ***	0.816 ***	0.868 ***	0.793 ***	0.962 ***	0.954 ***	0.956 ***
n.obs	391	386	391	294	391	294	391	391
logLikelihood	40.66	97.45	66.17	164.43	88.08	510.34	667.66	657.83
df	23	29	29	36	36	44	44	29
LRtest_chisq	188.13 ***	169.55 ***	160.60 ***	105.94 ***	135.10 ***	194.20 ***	273.31 ***	296.68 ***
AIC	-35.31	-136.91	-74.33	-256.86	-104.17	-932.68	-1247.31	-1257.66
BIC	55.97	-22.19	40.76	-124.25	38.70	-770.60	-1072.69	-1142.57

*** coefficient significantly different from zero at 1% significance level.

** coefficient significantly different from zero at 5% significance level.

* coefficient significantly different from zero at 10% significance level.

APPENDIX K - TESTS OF MODELS BC92

Table K1 - LR test with Cobb-Douglas as null hypothesis versus translog as alternative hypothesis

Model H0	h0df	h0log	h1df	h1log	LR	chisq	df	LRdecision	h0AIC	h1AIC	AICdecision	h0BIC	h1BIC	BICdecision
BC92ti Cobb	13	-76.6	23	40.7	234.5	18.3	10	reject H0	179.2	-35.3	not reject H0	230.8	56.0	not reject H0
BC92ti Cobb	14	-9.6	29	97.5	214.2	25.0	15	reject H0	47.3	-136.9	reject H0	102.6	-22.2	not reject H0
BC92ti Cobb	14	-74.3	29	66.2	280.9	25.0	15	reject H0	176.5	-74.3	not reject H0	232.1	40.8	not reject H0
BC92ti Cobb	15	105.8	36	164.4	117.2	32.7	21	reject H0	-181.7	-256.9	reject H0	-126.4	-124.3	not reject H0
BC92ti Cobb	15	-73.1	36	88.1	322.3	32.7	21	reject H0	176.2	-104.2	not reject H0	235.7	38.7	not reject H0
BC92ti Cobb	16	476.0	44	510.3	68.8	41.3	28	reject H0	-919.9	-932.7	reject H0	-861.0	-770.6	not reject H0
BC92ti Cobb	16	637.4	44	667.7	60.5	41.3	28	reject H0	-1242.8	-1247.3	reject H0	-1179.3	-1072.7	not reject H0
BC92ti Cobb	14	615.2	29	657.8	85.3	25.0	15	reject H0	-1202.4	-1257.7	reject H0	-1146.8	-1142.6	not reject H0

SOURCE: the author (2019)

Table K2 – LR test H0: CCCHU as input; H1: three inputs (CCCHU, PROFEQ and FUNCEQSHU)

Model	h0df	h0log	h1df	h1log	LR	chisq	df	LRdecision	h0AIC	h1AIC	AICdecision	h0BIC	h1BIC	BICdecision
fipcchu1	14	-52.11	23	40.66	185.54	16.92	9	reject H0	132.23	-35.31	not reject H0	187.79	55.97	not reject H0
fipcchu2	18	2.21	29	97.45	190.48	19.68	11	reject H0	31.58	-136.91	reject H0	102.78	-22.19	not reject H0
fipcchu3	18	-38.26	29	66.17	208.86	19.68	11	reject H0	112.53	-74.33	not reject H0	183.97	40.76	not reject H0
fipcchu4	23	95.51	36	164.43	137.84	22.36	13	reject H0	-145.02	-256.86	reject H0	-60.30	-124.25	reject H0
fipcchu5	23	7.62	36	88.08	160.93	22.36	13	reject H0	30.76	-104.17	reject H0	122.04	38.70	not reject H0
fipcchu6	29	482.25	44	510.34	56.17	25.00	15	reject H0	-906.51	-932.68	reject H0	-799.68	-770.60	not reject H0
fipcchu7	29	637.24	44	667.66	60.84	25.00	15	reject H0	-1216.47	-1247.31	reject H0	-1101.38	-1072.69	not reject H0
fipcchu8	18	630.87	29	657.83	53.92	19.68	11	reject H0	-1225.74	-1257.66	reject H0	-1154.30	-1142.57	not reject H0

Table K3 – LR test H0: PROFEQ and FUNCEQSHU as inputs; H1: three inputs

Model	h0df	h0log	h1df	h1log	LR	chisq	df	LRdecision	h0AIC	h1AIC	AICdecision	h0BIC	h1BIC	BICdecision
fipprofeqfunceqshu1	18	11.21	23	40.66	58.89	11.07	5	reject H0	13.58	-35.31	reject H0	85.01	55.97	not reject H0
fipprofeqfunceqshu2	23	67.04	29	97.45	60.83	12.59	6	reject H0	-88.07	-136.91	reject H0	2.91	-22.19	reject H0
fipprofeqfunceqshu3	23	35.29	29	66.17	61.75	12.59	6	reject H0	-24.58	-74.33	reject H0	66.70	40.76	not reject H0
fipprofeqfunceqshu4	29	128.84	36	164.43	71.19	14.07	7	reject H0	-199.67	-256.86	reject H0	-92.85	-124.25	reject H0
fipprofeqfunceqshu5	29	57.44	36	88.08	61.28	14.07	7	reject H0	-56.89	-104.17	reject H0	58.20	38.70	not reject H0
fipprofeqfunceqshu6	36	495.26	44	510.34	30.16	15.51	8	reject H0	-918.52	-932.68	reject H0	-785.91	-770.60	not reject H0
fipprofeqfunceqshu7	36	654.82	44	667.66	25.68	15.51	8	reject H0	-1237.64	-1247.31	reject H0	-1094.76	-1072.69	not reject H0
fipprofeqfunceqshu8	23	650.21	29	657.83	15.25	12.59	6	reject H0	-1254.41	-1257.66	reject H0	-1163.13	-1142.57	not reject H0

Table K4 – LR test H0: each specification of fip ; H1: specification fip7

Model	h0df	h0log	h1df	h1log	LR	chisq	df	LRdecision	h1AIC	h0AIC	AICdecision	h1BIC	h0BIC	BICdecision
fip1	23	40.66	44	667.66	1254.00	32.67	21	reject H0	-1247.31	-35.31	reject H0	-1072.69	55.97	reject H0
fip2	29	97.45	44	667.66	1140.41	25.00	15	reject H0	-1247.31	-136.91	reject H0	-1072.69	-22.19	reject H0
fip3	29	66.17	44	667.66	1202.98	25.00	15	reject H0	-1247.31	-74.33	reject H0	-1072.69	40.76	reject H0
fip4	36	164.43	44	667.66	1006.45	15.51	8	reject H0	-1247.31	-256.86	reject H0	-1072.69	-124.25	reject H0
fip5	36	88.08	44	667.66	1159.14	15.51	8	reject H0	-1247.31	-104.17	reject H0	-1072.69	38.70	reject H0
fip6	44	510.34	44	667.66	314.63	0.00	0	reject H0	-1247.31	-932.68	reject H0	-1072.69	-770.60	reject H0
fip7	44	667.66	44	667.66	0.00	0.00	0	not reject H0	-1247.31	-1247.31	not reject H0	-1072.69	-1072.69	not reject H0
fip8	29	657.83	44	667.66	19.66	25.00	15	not reject H0	-1247.31	-1257.66	not reject H0	-1072.69	-1142.57	not reject H0

APPENDIX L1 - ESTIMATIONS OF TRANSLOG OUTPUT DISTANCE FUNCTION

BC95TVE

Variable	fip7tve1	fip7tve2	fip7tve3	fip7tve4	fip7tve5	fip7tve6	fip7tve7	fip7tve8
(Intercept)	-0.015	-0.038 *	-0.047 **	-0.033	-0.031	-0.155 ***	-0.153 ***	-0.195 ***
logmDEGREP	-0.094 ***	-0.09 ***	-0.096 ***	-0.098 ***	-0.099 ***	-0.079 ***	-0.066 ***	-0.072 ***
logmTHIRDMadj	0.001	0.002	0.002	0.004	0.004	0.005 **	0.006 **	0.006 **
logmPATENTadj	-0.006	0	-0.001	0.001	0	-0.003	-0.005	-0.006
logmCCAPES	0.988 ***	0.988 ***	1.006 ***	0.99 ***	0.984 ***	0.968 ***	0.957 ***	0.967 ***
I(0.5 * logmDEGREP^2)	-0.01 ***	-0.004 *	-0.004 *	-0.004 *	-0.004 *	-0.006 ***	-0.005 **	-0.006 ***
I(0.5 * logmTHIRDMadj^2)	0.001	0.001 **	0.001 **	0.001 **	0.002 ***	0	0.001	0.001
I(0.5 * logmPATENTadj^2)	-0.001	0	0	0	0	-0.001	-0.001	-0.001 *
I(0.5 * logmCCAPES^2)	0.135 ***	0.127 ***	0.107 **	0.108 **	0.111 **	0.189 ***	0.166 ***	0.178 ***
I(logmDEGREP * logmTHIRDMadj)	-0.012 ***	-0.01 ***	-0.009 ***	-0.009 ***	-0.01 ***	-0.012 ***	-0.011 ***	-0.012 ***
I(logmDEGREP * logmPATENTadj)	0	-0.001	-0.002	-0.001	-0.002	0	0	0
I(logmDEGREP * logmCCAPES)	-0.054 **	-0.053 ***	-0.044 **	-0.053 **	-0.057 ***	-0.063 ***	-0.059 ***	-0.065 ***
I(logmTHIRDMadj * logmPATENTadj)	0	0	0	0	0	0.001 *	0	0.001
I(logmTHIRDMadj * logmCCAPES)	0.005	0.005	0.003	0.003	0.003	0.008 **	0.006	0.006 *
I(logmPATENTadj * logmCCAPES)	0.002	0.005 **	0.006 **	0.005 *	0.005 **	0.003	0.003	0.002
logmccchu_def	-0.161 ***	-0.122 ***	-0.122 ***	-0.118 ***	-0.113 ***	-0.104 ***	-0.082 ***	-0.078 ***
logmprofeq	0.14 ***	0.059 *	0.069 **	0.066 *	0.053	-0.16 ***	-0.206 ***	-0.231 ***
logmfunceqshu	-0.074 ***	-0.04	-0.035	-0.042 *	-0.041 *	0.136 ***	0.149 ***	0.184 ***
I(0.5 * logmccchu_def^2)	-0.133 *	-0.169 **	-0.149 *	-0.165 **	-0.155 *	-0.187 **	-0.14 *	-0.133 *
I(0.5 * logmprofeq^2)	-0.113	-0.255 *	-0.244	-0.32 **	-0.3 *	-0.261	-0.244	-0.216
I(0.5 * logmfunceqshu^2)	0.081	0.02	0.007	0.044	0.046	-0.13 *	-0.185 **	-0.071
I(logmprofeq * logmccchu_def)	0.103	0.258 **	0.241 **	0.289 **	0.271 **	0.162	0.148	0.17
I(logmfunceqshu * logmccchu_def)	-0.001	-0.003	-0.007	-0.05	-0.051	-0.008	0	-0.039
I(logmprofeq * logmfunceqshu)	0.012	-0.034	-0.035	0.012	0.013	0.226 ***	0.213 **	0.182 *
I(logmDEGREP * logmccchu_def)	0.042 *	0.008	0.002	0.01	0.015	0.032	0.03	0.034
I(logmDEGREP * logmprofeq)	-0.086 *	-0.146 ***	-0.136 ***	-0.154 ***	-0.157 ***	-0.148 ***	-0.131 ***	-0.136 ***
I(logmDEGREP * logmfunceqshu)	-0.031	0.052	0.062	0.052	0.046	0.031	0.019	0.01
I(logmTHIRDMadj * logmccchu_def)	-0.028 **	0	-0.002	0.005	0.004	-0.004	-0.008	-0.006
I(logmTHIRDMadj * logmprofeq)	0.069 ***	0.032 **	0.031 **	0.026 *	0.023	0.042 ***	0.044 ***	0.04 ***
I(logmTHIRDMadj * logmfunceqshu)	-0.027 ***	-0.021 ***	-0.021 ***	-0.024 ***	-0.022 ***	-0.024 ***	-0.024 ***	-0.023 ***
I(logmPATENTadj * logmccchu_def)	-0.005	-0.007 *	-0.005	-0.004	-0.004	0	0.001	0
I(logmPATENTadj * logmprofeq)	0.008 *	0.014 ***	0.014 ***	0.013 ***	0.013 ***	0.006	0.004	0.004
I(logmPATENTadj * logmfunceqshu)	0	0	-0.001	-0.002	-0.001	-0.002	0.001	0
I(logmCCAPES * logmccchu_def)	0.03	0.046	0.054	0.049	0.049	-0.003	0.028	0.022
I(logmCCAPES * logmprofeq)	0	0.04	0.016	0.019	0.015	0.086	0.072	0.046
I(logmCCAPES * logmfunceqshu)	0.096 *	0.018	0.008	0.025	0.029	0.127 **	0.074	0.133 **
hu	0.034 ***	0.038 **	0.048 ***	0.038 **	0.036 **	0.11 ***	0.09 ***	0.108 ***
regionNorth	0.028 *	0.009	0.01	0.01	0.007	0.098 ***	0.125 ***	0.149 ***
regionNortheast	-0.022	-0.066 ***	-0.06 ***	-0.063 ***	-0.066 ***	0.042 *	0.05 **	0.07 ***
regionSouth	-0.072 ***	-0.128 ***	-0.126 ***	-0.13 ***	-0.127 ***	-0.047 ***	-0.047 **	-0.023
regionSoutheast	-0.057 ***	-0.679 ***	-0.316 ***	-0.326 **	-0.329 **	-0.152 ***	-0.158 ***	-0.146 ***
newsf	0.006	-0.079 ***	-0.089 ***	-0.09 ***	-0.089 ***	-0.213 ***	-0.126 ***	-0.139 ***
Z_(Intercept)	-0.016	-0.137 *	-0.13 *	-0.062	-0.003	0.353 ***	0.664 ***	0.87 ***
Z_hu		0.011	0.003	0.019	0.021	-0.076 ***	-0.062 ***	-0.094 ***
Z_regionNorth		0.058	0.043	0.051	0.053	-0.092 **	-0.176 ***	-0.193 ***
Z_regionNortheast		0.154 **	0.144 **	0.148 **	0.15 **	-0.102 ***	-0.115 ***	-0.133 ***
Z_regionSouth		0.155 **	0.15 **	0.173 **	0.16 **	-0.06	-0.041	-0.064 *
Z_regionSoutheast		0.759 ***	0.396 ***	0.429 ***	0.424 **	0.111 ***	0.13 ***	0.114 ***
Z_newsf		0.11 ***	0.114 ***	0.118 ***	0.109 ***	0.212 **	0.113 ***	0.127 ***
Z_mYear			0.009 **	0.002	0.003	0.004	0.007 **	0.007 **
Z_tsg				-0.002 ***	-0.002 ***	-0.001 **	-0.001 **	-0.001 ***
Z_gpe					-0.09 **	0.026	0.002	0.003
Z_atipe						-0.036 ***	-0.036 ***	-0.024 ***
Z_atifeshu						0.031 ***	0.032 ***	0.018 ***
Z_iqcd							-0.071 ***	-0.068 ***
Z_feshupe								-0.131 ***
sigmaSq	0.004 ***	0.006 ***	0.006 ***	0.006 ***	0.006 ***	0.004 ***	0.004 ***	0.004 ***
gamma	0	0.932 ***	0.915 ***	0.877 ***	0.878 ***	0.864 ***	0.899 ***	0.879 ***
n.obs	391	391	391	391	391	391	391	391
logLikelihood	531.00	557.07	561.23	570.95	573.83	590.79	595.28	600.88
df	45	51	52	53	54	56	57	58
LRtest (in relation to OLS)	0.00	52.13 ***	60.46 ***	79.89 ***	85.65 ***	119.58 ***	128.55 ***	139.75 ***
AIC	-972.00	-1012.13	-1018.46	-1035.89	-1039.66	-1069.59	-1076.55	-1085.76
BIC	-793.41	-809.73	-812.09	-825.55	-825.35	-847.34	-850.34	-855.57

*** coefficient significantly different from zero at 1% significance level.
** coefficient significantly different from zero at 5% significance level.
* coefficient significantly different from zero at 10% significance level.

APPENDIX L2 - ESTIMATIONS OF TRANSLOG OUTPUT DISTANCE FUNCTION

BC95TVE ALTERNATIVE (EXCLUDING THIRDM AND PATENT VARIABLES)

Variable	fip8tve1	fip8tve2	fip8tve3	fip8tve4	fip8tve5	fip8tve6	fip8tve7	fip8tve8
(Intercept)	-0.006	-0.016	-0.085 ***	-0.074 ***	-0.044 *	-0.162 ***	-0.182 ***	-0.252 ***
logmDEGREP	-0.113 ***	-0.098 ***	-0.109 ***	-0.112 ***	-0.108 ***	-0.095 ***	-0.068 ***	-0.052 ***
logmCCAPES	1.009 ***	1.004 ***	1.039 ***	1.027 ***	1.003 ***	1.013 ***	1.01 ***	0.972 ***
I(0.5 * logmDEGREP^2)	-0.008 ***	-0.005 ***	-0.006 ***	-0.006 ***	-0.006 ***	-0.006 ***	-0.005 ***	-0.003 **
I(0.5 * logmCCAPES^2)	0.071 ***	0.076 ***	0.08 ***	0.084 ***	0.08 ***	0.09 ***	0.093 ***	0.085 ***
I(logmDEGREP * logmCCAPES)	0.003	0.001	0.003	-0.004	-0.005	0	0.003	0.004
logmccchu_def	-0.109 ***	-0.105 ***	-0.119 ***	-0.116 ***	-0.102 ***	-0.095 ***	-0.054 ***	-0.057 **
logmprofeq	0.112 ***	0.027	0.062 **	0.061 **	0.034	-0.12 ***	-0.196 ***	-0.266 ***
logmfunceqshu	-0.071 ***	-0.017	-0.005	-0.011	-0.022	0.128 ***	0.168 ***	0.224 ***
I(0.5 * logmccchu_def^2)	-0.035	-0.053	-0.102	-0.125 *	-0.102	-0.142 **	-0.126 ***	-0.065
I(0.5 * logmprofeq^2)	-0.02	-0.012	-0.06	-0.15	-0.121	-0.169	-0.129	-0.206
I(0.5 * logmfunceqshu^2)	0.1	0.095	0.076	0.1	0.097	-0.089	-0.235 ***	-0.129
I(logmprofeq * logmccchu_def)	-0.004	0.151	0.192 *	0.247 **	0.212 *	0.118	0.057	0.119
I(logmfunceqshu * logmccchu_def)	-0.04	-0.102	-0.084	-0.11 *	-0.101	-0.014	0.084	-0.072
I(logmprofeq * logmfunceqshu)	0.019	-0.045	-0.036	-0.003	-0.011	0.141 *	0.14 **	0.179 **
I(logmDEGREP * logmccchu_def)	0.007	-0.019	-0.027	-0.023	-0.019	-0.011	-0.008	-0.014
I(logmDEGREP * logmprofeq)	0.03	-0.029	-0.032	-0.044	-0.045	-0.028	-0.009	-0.025
I(logmDEGREP * logmfunceqshu)	-0.062 *	0.015	0.032	0.023	0.016	0.012	0.003	0.028
I(logmCCAPES * logmccchu_def)	-0.012	0.022	0.016	0.018	0.021	-0.016	0.014	0.015
I(logmCCAPES * logmprofeq)	-0.014	0.083	0.117 *	0.108	0.078	0.063	0.063	0.026
I(logmCCAPES * logmfunceqshu)	0.076	-0.044	-0.044	-0.026	-0.021	0.064	0.029	0.035
hu	0.025 *	0.054 ***	0.084 ***	0.07 ***	0.052 ***	0.117 ***	0.083 ***	0.119 ***
regionNorth	0.009	-0.013	0.018	0.016	-0.001	0.081 ***	0.14 ***	0.143 ***
regionNortheast	-0.032 **	-0.075 ***	-0.026 *	-0.03 **	-0.053 ***	0.039 *	0.074 *	0.093 ***
regionSouth	-0.082 ***	-0.154 ***	-0.112 ***	-0.11 ***	-0.124 ***	-0.055 ***	-0.064 ***	-0.024
regionSoutheast	-0.07 ***	-1.184 **	-0.26 **	-0.279 **	-0.318 *	-0.157 ***	-0.142 ***	-0.119 ***
newsf	0.008	-0.096 ***	-0.254	-0.233 *	-0.116 ***	-0.275 **	-0.28 ***	-0.209 ***
Z_(Intercept)	-0.016	-7.186 **	-0.026	0.03	0.004	0.329 ***	0.702 ***	0.989 ***
Z_hu		-0.01	-0.04 *	-0.025	-0.001	-0.092 ***	-0.059 ***	-0.126 ***
Z_regionNorth		7.044 **	0.014	0.012	0.06	-0.093 **	-0.184 ***	-0.188 ***
Z_regionNortheast		7.159 **	0.019	0.022	0.112	-0.115 ***	-0.158 ***	-0.171 ***
Z_regionSouth		7.199 **	0.07	0.074	0.144	-0.064 *	-0.021	-0.062 **
Z_regionSoutheast		8.279 **	0.266 **	0.294 **	0.392 **	0.102 ***	0.092	0.064 **
Z_newsf		0.137 ***	0.292 *	0.27 **	0.142 ***	0.281 **	0.297 ***	0.226 ***
Z_mYear			0.008 ***	0.003	0.003	0.005	0.005 *	0.004
Z_tsg				-0.001 ***	-0.001 ***	-0.001 **	-0.001 ***	-0.001 **
Z_gpe					-0.082 **	-0.002	-0.009	-0.003
Z_atipe						-0.03 ***	-0.033 ***	-0.026 ***
Z_atifeshu						0.027 ***	0.032 ***	0.024 ***
Z_iqcd							-0.082 ***	-0.091 ***
Z_feshupe								-0.102 **
sigmaSq	0.004 **	0.006 ***	0.006 ***	0.006 ***	0.006 ***	0.005 ***	0.005 ***	0.004 ***
gamma	0	0.762 ***	0.865 ***	0.851 ***	0.815 ***	0.884 ***	1 ***	0.997 ***
n.obs	391	391	391	391	391	391	391	391
logLikelihood	509.49	536.52	544.48	550.81	552.81	570.06	581.58	582.09
df	30	36	37	38	39	41	42	43
LRtest (in relation to OLS)	0.00	54.05 ***	69.97 ***	82.64 ***	86.65 ***	121.13 ***	144.17 ***	145.19 ***
AIC	-958.98	-1001.03	-1014.96	-1025.63	-1027.63	-1058.11	-1079.15	-1078.17
BIC	-839.92	-858.16	-868.11	-874.81	-872.85	-895.40	-912.47	-907.52

*** coefficient significantly different from zero at 1% significance level.

** coefficient significantly different from zero at 5% significance level.

* coefficient significantly different from zero at 10% significance level.

APPENDIX M - TESTS OF MODEL BC95TVE

Table M1 - LR test with H0: each fip8tve specification; H1: each fip7tve specification, respectively

Model H0	h0df	h0log	h1df	h1log	LR	chisq	df	LRdecision	h0AIC	h1AIC	AICdecision	h0BIC	h1BIC	BICdecision
fip8tve1	30	509.5	45	531.0	43.0	25.0	15	reject H0	-959.0	-972.0	reject H0	-839.9	-793.4	not reject H0
fip8tve2	36	536.5	51	557.1	41.1	25.0	15	reject H0	-1001.0	-1012.1	reject H0	-858.2	-809.7	not reject H0
fip8tve3	37	544.5	52	561.2	33.5	25.0	15	reject H0	-1015.0	-1018.5	reject H0	-868.1	-812.1	not reject H0
fip8tve4	38	550.8	53	570.9	40.3	25.0	15	reject H0	-1025.6	-1035.9	reject H0	-874.8	-825.5	not reject H0
fip8tve5	39	552.8	54	573.8	42.0	25.0	15	reject H0	-1027.6	-1039.7	reject H0	-872.8	-825.3	not reject H0
fip8tve6	41	570.1	56	590.8	41.5	25.0	15	reject H0	-1058.1	-1069.6	reject H0	-895.4	-847.3	not reject H0
fip8tve7	42	581.6	57	595.3	27.4	25.0	15	reject H0	-1079.2	-1076.6	not reject H0	-912.5	-850.3	not reject H0
fip8tve8	43	582.1	58	600.9	37.6	25.0	15	reject H0	-1078.2	-1085.8	reject H0	-907.5	-855.6	not reject H0

SOURCE: the author (2019)

Table M2 - LR test H0: each specification fip7tve; H1: specification fip7tve8

Model	h0df	h0log	h1df	h1log	LR	chisq	df	LRdecision	h0AIC	h1AIC	AICdecision	h0BIC	h1BIC	BICdecision
fip7tve1	45	531.00	58	600.88	139.75	22.36	13	**reject H0**	-972.00	-1085.76	**reject H0**	-793.41	-855.57	**reject H0**
fip7tve2	51	557.07	58	600.88	87.62	14.07	7	**reject H0**	-1012.13	-1085.76	**reject H0**	-809.73	-855.57	**reject H0**
fip7tve3	52	561.23	58	600.88	79.29	12.59	6	**reject H0**	-1018.46	-1085.76	**reject H0**	-812.09	-855.57	**reject H0**
fip7tve4	53	570.95	58	600.88	59.87	11.07	5	**reject H0**	-1035.89	-1085.76	**reject H0**	-825.55	-855.57	**reject H0**
fip7tve5	54	573.83	58	600.88	54.10	9.49	4	**reject H0**	-1039.66	-1085.76	**reject H0**	-825.35	-855.57	**reject H0**
fip7tve6	56	590.79	58	600.88	20.17	5.99	2	**reject H0**	-1069.59	-1085.76	**reject H0**	-847.34	-855.57	**reject H0**
fip7tve7	57	595.28	58	600.88	11.20	3.84	1	**reject H0**	-1076.55	-1085.76	**reject H0**	-850.34	-855.57	**reject H0**
fip7tve8	58	600.88	58	600.88	0.00	0.00	0	**not reject H0**	-1085.76	-1085.76	**not reject H0**	-855.57	-855.57	**not reject H0**

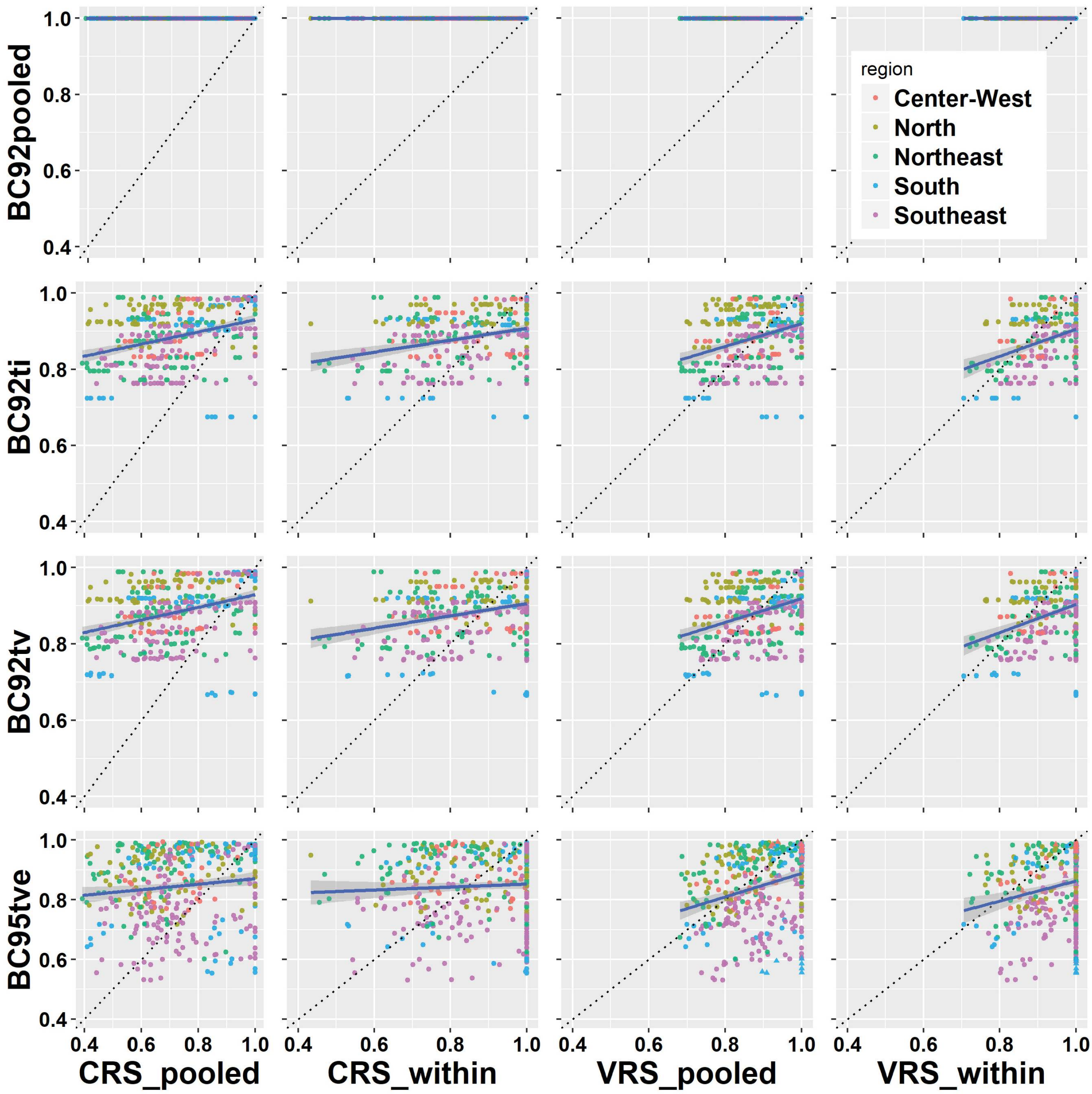
SOURCE: the author (2019)

Table M3 – LR test H0: each specification fip8tve; H1: specification fip8tve8

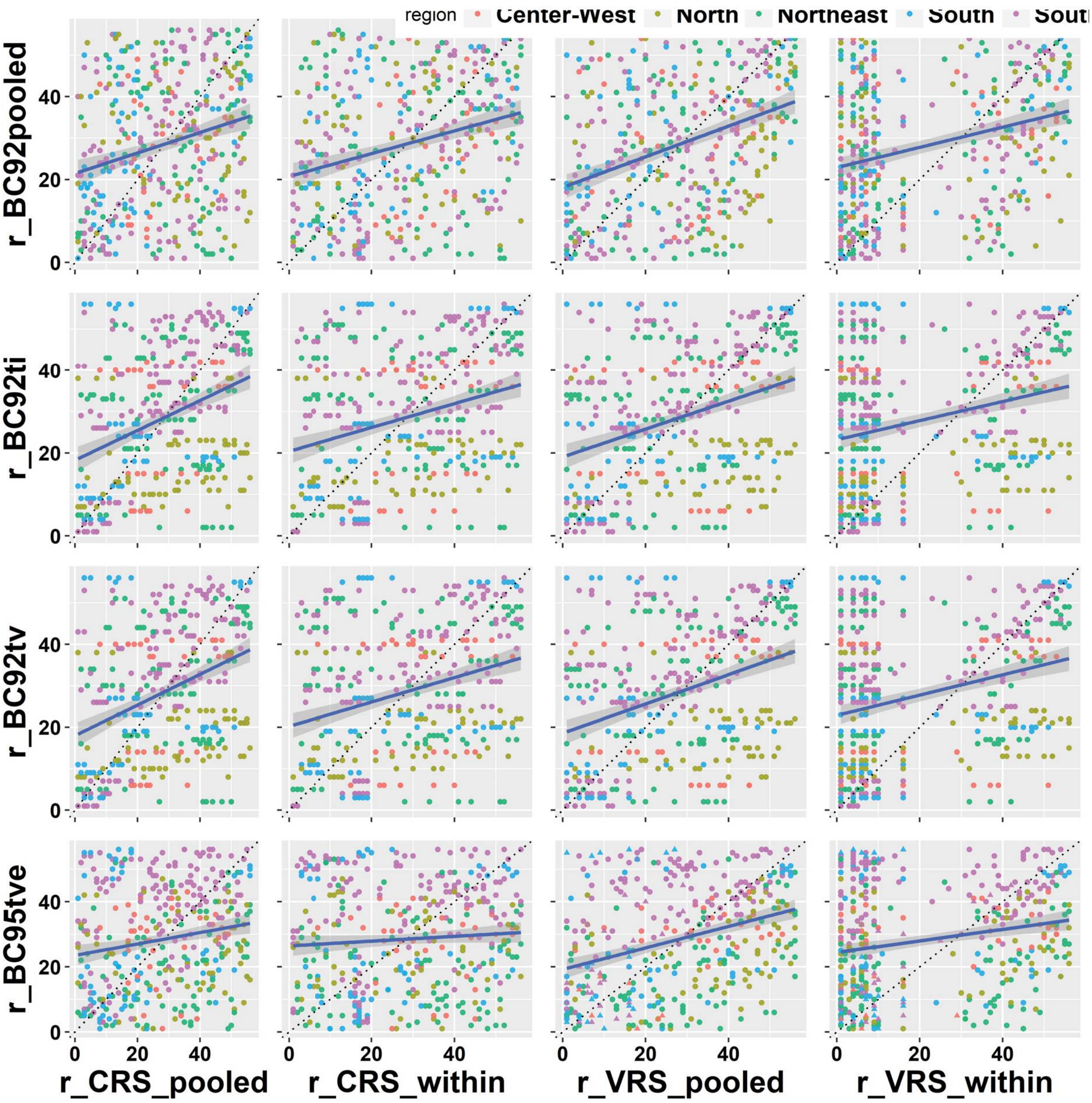
Model H0	h0df	h0log	h1df	h1log	LR	chisq	df	LRdecision	h0AIC	h1AIC	AICdecision	h0BIC	h1BIC	BICdecision
fip8tve1	30	509.49	43	582.09	145.19	22.36	13	**reject H0**	-958.98	-1078.17	**reject H0**	-839.92	-907.52	**reject H0**
fip8tve2	36	536.52	43	582.09	91.14	14.07	7	**reject H0**	-1001.03	-1078.17	**reject H0**	-858.16	-907.52	**reject H0**
fip8tve3	37	544.48	43	582.09	75.22	12.59	6	**reject H0**	-1014.96	-1078.17	**reject H0**	-868.11	-907.52	**reject H0**
fip8tve4	38	550.81	43	582.09	62.55	11.07	5	**reject H0**	-1025.63	-1078.17	**reject H0**	-874.81	-907.52	**reject H0**
fip8tve5	39	552.81	43	582.09	58.54	9.49	4	**reject H0**	-1027.63	-1078.17	**reject H0**	-872.85	-907.52	**reject H0**
fip8tve6	41	570.06	43	582.09	24.06	5.99	2	**reject H0**	-1058.11	-1078.17	**reject H0**	-895.40	-907.52	**reject H0**
fip8tve7	42	581.58	43	582.09	1.02	3.84	1	**not reject H0**	-1079.15	-1078.17	**no reject H0**	-912.47	-907.52	**not reject H0**
fip8tve8	43	582.09	43	582.09	0.00	0.00	0	**not reject H0**	-1078.17	-1078.17	**no reject H0**	-907.52	-907.52	**not reject H0**

SOURCE: the author (2019)

APPENDIX N1 - DEA VS SFA EFFICIENCY SCATTERPLOTS



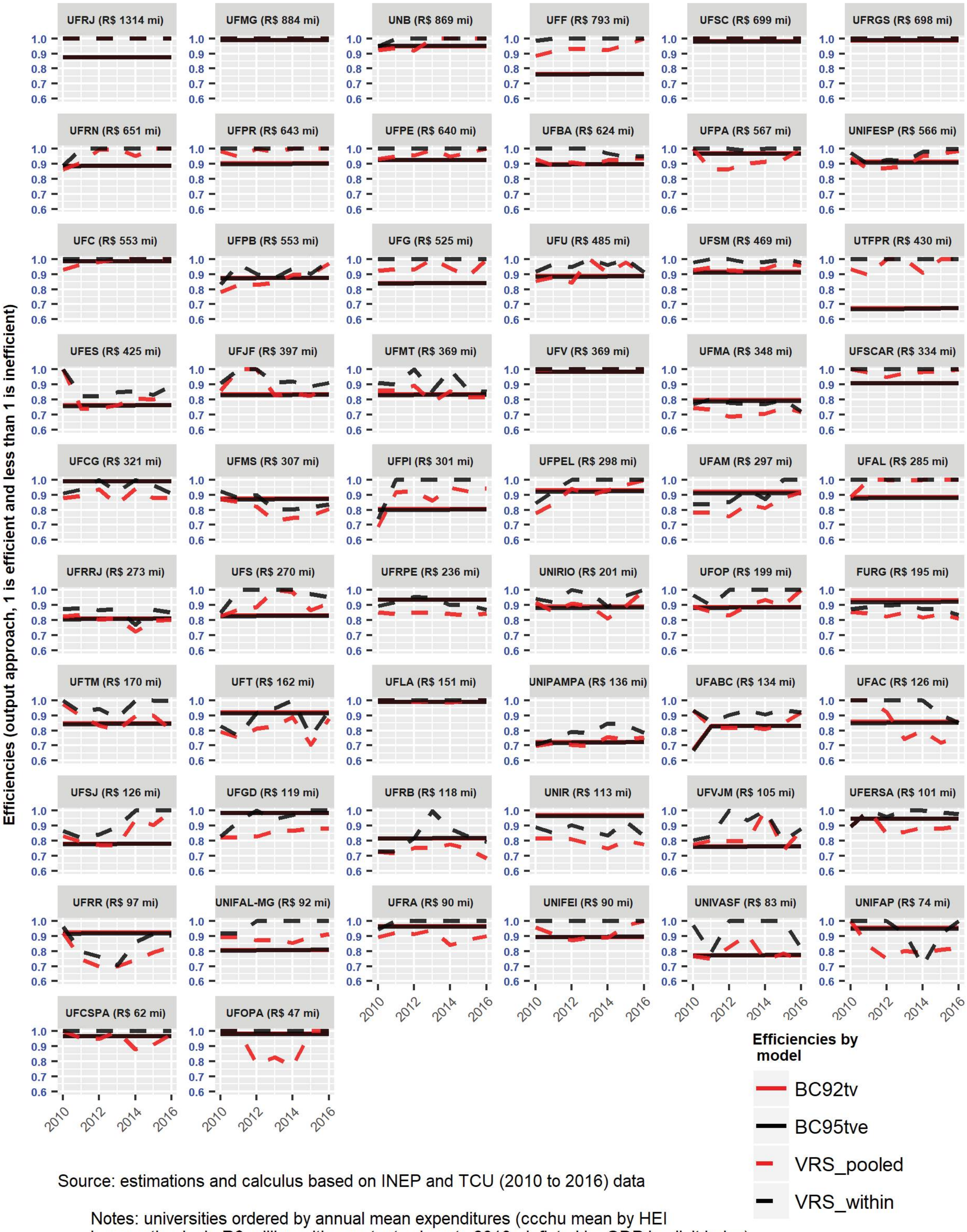
APPENDIX N2 - DEA VS SFA RANK SCATTERPLOTS



APPENDIX O1 - DEA VS SFA EFFICIENCIES BY HEI BY YEAR IN SELECTED MODELS

Brazilian Federal Public Universities (2010 - 2016)

Efficiencies by model



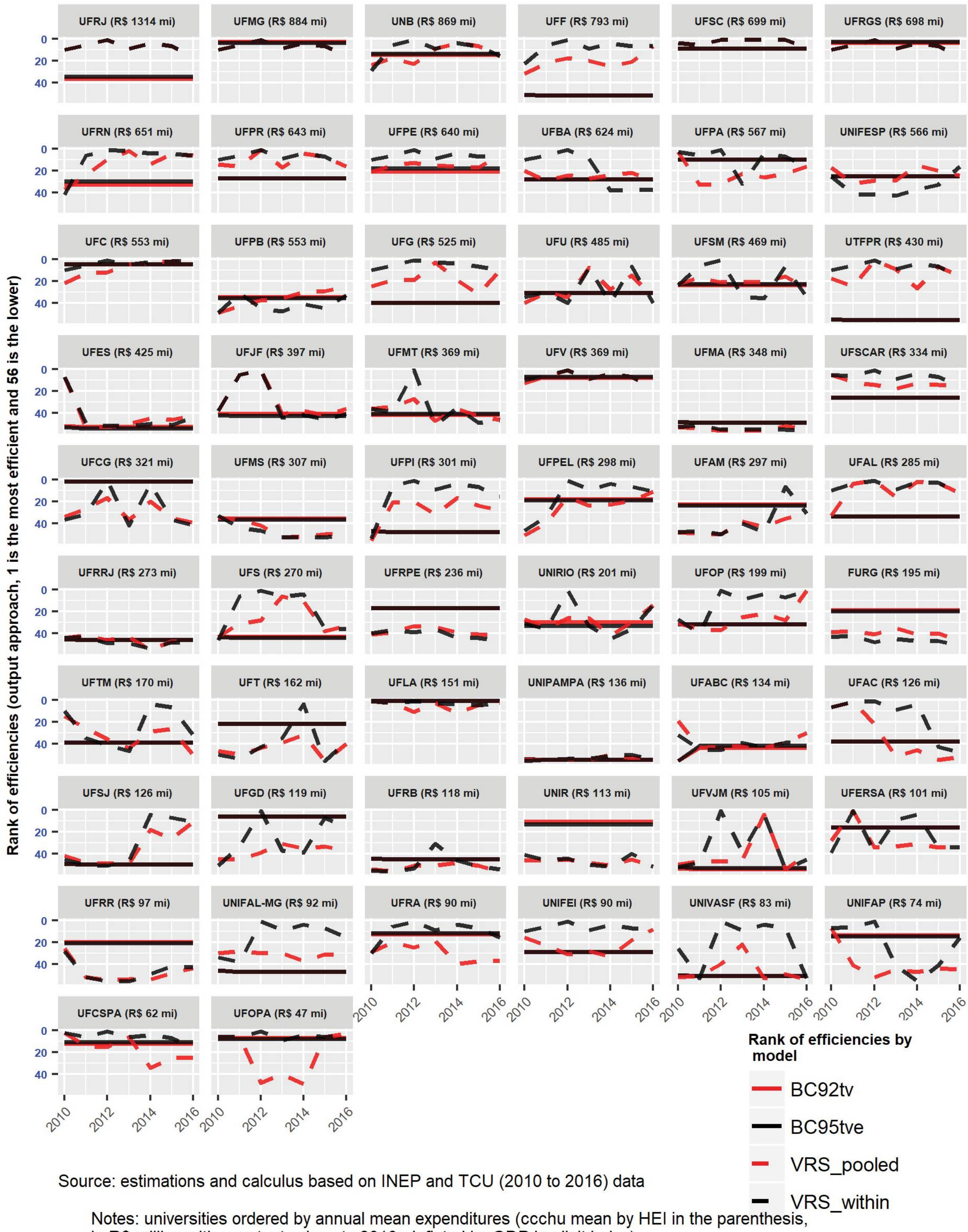
Source: estimations and calculus based on INEP and TCU (2010 to 2016) data

Notes: universities ordered by annual mean expenditures (ccchu mean by HEI in parenthesis, in R$ million with constant values to 2010, deflated by GDP implicit index)

APPENDIX O2 - DEA VS SFA RANK OF EFFICIENCIES BY HEI BY YEAR IN SELECTED MODELS

Brazilian Federal Public Universities (2010 - 2016)

Rank of efficiencies by model



Source: estimations and calculus based on INEP and TCU (2010 to 2016) data

Notes: universities ordered by annual mean expenditures (ccchu mean by HEI in the parenthesis, in R$ million with constant values to 2010, deflated by GDP implicit index)

APPENDIX P – PEARSON CORRELATIONS MATRIX

INPUTS, OUTPUTS, ENVIRONMENTAL VARIABLES AND EFFICIENCY ESTIMATES

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	Pearson correlations matrix	ccchu_def	profeq	PROFES	funceqshu	DEGREU	DEGREP	THIRDM	PATENT	ccapes	hu	newsf	ano	tsg	gpe	atipe	atifeshu	iqcd	feshupe	dea1	dea2	dea3	dea4	sfa1	sfa2	sfa3	sfa4
1	ccchu_def	1	0.95	0.96	0.92	0.89	0.92	0.59	0.6	0.7	0.58	-0.53	0.09	0.33	0.11	0.47	0.14	0.33	0.2	0.24	0.02	0.47	0.29	0	0.09	0.1	0.43
2	profeq	0.95	1	0.99	0.89	0.92	0.89	0.59	0.6	0.62	0.59	-0.56	0.13	0.31	0.09	0.42	0.21	0.22	0.08	0.21	0.01	0.44	0.27	0.01	0	0.01	0.41
3	PROFES	0.96	0.99	1	0.89	0.92	0.92	0.65	0.64	0.66	0.57	-0.55	0.16	0.3	0.09	0.45	0.19	0.31	0.12	0.25	0.03	0.48	0.29	0	0.01	0.03	0.4
4	funceqshu	0.92	0.89	0.89	1	0.82	0.89	0.52	0.57	0.68	0.47	-0.45	0.12	0.27	0.07	0.45	-0.09	0.29	0.44	0.15	-0.03	0.41	0.24	0	0.12	0.14	0.5
5	DEGREU	0.89	0.92	0.92	0.82	1	0.85	0.61	0.67	0.61	0.63	-0.55	0.16	0.37	0.18	0.53	0.22	0.22	0.11	0.31	0.15	0.52	0.36	0.1	0.09	0.1	0.51
6	DEGREP	0.92	0.89	0.92	0.89	0.85	1	0.64	0.69	0.8	0.46	-0.48	0.16	0.31	0.11	0.56	0.11	0.42	0.26	0.39	0.15	0.56	0.36	0.07	0.26	0.28	0.48
7	THIRDM	0.59	0.59	0.65	0.52	0.61	0.64	1	0.5	0.49	0.34	-0.34	0.1	0.23	0.08	0.4	0.14	0.23	0.09	0.46	0.27	0.48	0.32	0.09	0.08	0.09	0.29
8	PATENT	0.6	0.6	0.64	0.57	0.67	0.69	0.5	1	0.59	0.33	-0.35	0.18	0.25	0.04	0.38	0.09	0.29	0.18	0.42	0.27	0.47	0.32	0.11	0.19	0.2	0.38
9	ccapes	0.7	0.62	0.66	0.68	0.61	0.8	0.49	0.59	1	0.28	-0.37	0.07	0.32	0.15	0.5	0.01	0.6	0.36	0.42	0.19	0.64	0.42	0.44	0.45	0.47	0.45
10	hu	0.58	0.59	0.57	0.47	0.63	0.46	0.34	0.33	0.28	1	-0.43	0	0.19	0.17	0.37	0.21	0.05	-0.05	0.04	-0.09	0.2	0.1	0.01	0.07	0.06	0.44
11	newsf	-0.53	-0.56	-0.55	-0.45	-0.55	-0.48	-0.34	-0.35	-0.37	-0.43	1	0	-0.2	-0.19	-0.44	-0.33	0.05	0.04	-0.14	0.02	-0.22	-0.08	-0.01	-0.13	-0.11	-0.52
12	ano	0.09	0.13	0.16	0.12	0.16	0.16	0.1	0.18	0.07	0	0	1	-0.29	0.07	0.14	0.04	0.25	0.06	0.1	0.14	0.08	0.09	-0.11	0	0.01	0
13	tsg	0.33	0.31	0.3	0.27	0.37	0.31	0.23	0.25	0.32	0.19	-0.2	-0.29	1	0.25	0.31	0.23	0.09	-0.03	0.26	0.19	0.33	0.25	0.2	0.11	0.11	0.15
14	gpe	0.11	0.09	0.09	0.07	0.18	0.11	0.08	0.04	0.15	0.17	-0.19	0.07	0.25	1	0.58	0.42	0.03	-0.01	0.13	0.12	0.16	0.16	0.13	0.19	0.18	0.15
15	atipe	0.47	0.42	0.45	0.45	0.53	0.56	0.4	0.38	0.5	0.37	-0.44	0.14	0.31	0.58	1	0.44	0.22	0.25	0.41	0.28	0.46	0.37	0.14	0.37	0.37	0.51
16	atifeshu	0.14	0.21	0.19	-0.09	0.22	0.11	0.14	0.09	0.01	0.21	-0.33	0.04	0.23	0.42	0.44	1	-0.14	-0.65	0.37	0.27	0.27	0.25	0.09	-0.04	-0.05	-0.1
17	iqcd	0.33	0.22	0.31	0.29	0.22	0.42	0.23	0.29	0.6	0.05	0.05	0.25	0.09	0.03	0.22	-0.14	1	0.29	0.3	0.09	0.39	0.21	0.03	0.12	0.14	-0.09
18	feshupe	0.2	0.08	0.12	0.44	0.11	0.26	0.09	0.18	0.36	-0.05	0.04	0.06	-0.03	-0.01	0.25	-0.65	0.29	1	-0.03	-0.02	0.1	0.06	0.01	0.24	0.25	0.44
19	dea1	0.24	0.21	0.25	0.15	0.31	0.39	0.46	0.42	0.42	0.04	-0.14	0.1	0.26	0.13	0.41	0.37	0.3	-0.03	1	0.79	0.85	0.72	0.23	0.34	0.36	0.13
20	dea2	0.02	0.01	0.03	-0.03	0.15	0.15	0.27	0.27	0.19	-0.09	0.02	0.14	0.19	0.12	0.28	0.27	0.09	-0.02	0.79	1	0.63	0.81	0.22	0.28	0.29	0.07
21	dea3	0.47	0.44	0.48	0.41	0.52	0.56	0.48	0.47	0.64	0.2	-0.22	0.08	0.33	0.16	0.46	0.27	0.39	0.1	0.85	0.63	1	0.81	0.39	0.35	0.36	0.28
22	dea4	0.29	0.27	0.29	0.24	0.36	0.36	0.32	0.32	0.42	0.1	-0.08	0.09	0.25	0.16	0.37	0.25	0.21	0.06	0.72	0.81	0.81	1	0.31	0.33	0.34	0.2
23	sfa1	0	0.01	0	0	0.1	0.07	0.09	0.11	0.44	0.01	-0.01	-0.11	0.2	0.13	0.14	0.09	0.03	0.01	0.23	0.22	0.39	0.31	1	0.5	0.5	0.37
24	sfa2	0.09	0	0.01	0.12	0.09	0.26	0.08	0.19	0.45	0.07	-0.13	0	0.11	0.19	0.37	-0.04	0.12	0.24	0.34	0.28	0.35	0.33	0.5	1	1	0.61
25	sfa3	0.1	0.01	0.03	0.14	0.1	0.28	0.09	0.2	0.47	0.06	-0.11	0.01	0.11	0.18	0.37	-0.05	0.14	0.25	0.36	0.29	0.36	0.34	0.5	1	1	0.6
26	sfa4	0.43	0.41	0.4	0.5	0.51	0.48	0.29	0.38	0.45	0.44	-0.52	0	0.15	0.15	0.51	-0.1	-0.09	0.44	0.13	0.07	0.28	0.2	0.37	0.61	0.6	1