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Efficiency of Engineering Graduate Programs in Brazil

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Abstract

The efficiency of graduate programs is directly linked to a country's capacity for innovation, which entails the need to diagnose the causes of low academic performance, as well as the development of techniques and methods to evaluate and measure the performance of educational units. Thus, the aim of this research is to analyze the efficiency of Brazilian graduate programs using Multiple Regression and Data Envelopment Analysis tools from 2014. In order to do this, a specific area was selected, called Engineering III, which includes production, mechanical, industrial and aerospace engineering programs. The results of this research can contribute to a better understanding of the dynamics and determining factors of the national academic production in order to generate knowledge concerning graduate programs, especially courses that did not meet the technical production efficiency standards required by the Coordination for the Improvement of Higher Education Personnel (CAPES), an organ responsible for graduate studies in Brazil. By analysis, there is a need to reposition the CAPES evaluation process in terms of the variables to be considered, as well as the criteria applied for this.

Keywords: Data Envelopment Analysis, Regression Analysis, Efficiency, Higher Education.

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Introduction

According to Faria et al. [1], the need to obtain greater efficiency in public spending has made it possible to improve decision-making tools and techniques to evaluate public policies in the country. The Federal Government is responsible for providing technical and financial assistance to the states and municipalities, as well as organizing the Higher Education system [2].

According to Ruggiero [3], an important political implication is that school districts need to use their budget more wisely, as well as improve their results to acceptable levels. Authors such as Kashim et al [4] and Johnes and Yu [5] emphasize that university research is important because it has effects on local companies, thus it is a fundamental tools for regional economic development.

According to Goksen et al [6], interest in performance measures at Higher Education institutions has increased on a daily basis. In addition, according to Johnes [7] and Abbott and Doucouliagos [8], Higher Education institutions are important components of human capital formation and knowledge, however, according to Gomes et al [9], productivity assessments in education are usually subjective due to the large number of variables to be considered. Another aspect to be taken into account, according to Meza et al [10], is that educational evaluation should be preferentially quantitative and comparative.

According to Kuah and Wong [11], the number of student enrollments in public universities is increasing, therefore it can be considered that these institutions function more efficiently because of their scarce resources. Universities, in turn, have some difficulty in measuring their efficiency due to two factors: first, as in any other non-profit organization, it is, of course, difficult to allocate monetary values for inputs and outputs; also, a university produces multiple outputs such as graduates and publications, using multiple inputs (teachers, financial resources and facilities).

Thus, it can be affirmed that seeking efficiency is the object of concern of institutions that produce science and technology, such as universities where graduate courses are run. Pereira [12] points out that efficient technical production is an important tool to support decision-making as it offers instruments for implementing actions that ensure graduate courses have a better quality of teaching.

Considering the reality of graduate programs in Brazil, the main aim of the Coordination for the Improvement of Higher Education Personnel (CAPES) is to help the Ministry of Education (MEC) shape graduate policies, coordinating and motivating by awarding scholarships, funding and other mechanisms, the training of qualified human resources for Higher Education, research and fulfilling the professional demand of the public and private sectors. CAPES is the only graduate development agency in Brazil to maintain a course evaluation system, recognized and used by other national institutions.

It should be mentioned that CAPES was created in 1951 by Decree No. 29,741 aiming to ensure qualified personnel at a higher level to meet the demands of education and scientific development in Brazil. It is the main agent for regulating and fostering development of national graduate programs [13].

Currently, there are 48 evaluation areas of CAPES, including a wide range of knowledge areas. Among them, the area of Engineering III was selected for analysis, which includes the Master´s courses (academic and professional) and the Doctoral program in the following knowledge areas: Mechanical Engineering; Aeronautical Engineering; Production Engineering; Space Engineering and Technologies; Petroleum

Engineering; Ocean Engineering; Mechatronics Engineering; Natural Resources Engineering of the Amazon; Automotive Engineering; Naval Engineering; Energy Engineering; Metrology and Logistics; and Operational Research. It is noteworthy that this area has 93 graduate programs in Master's and Doctoral degrees and has doubled the number of programs in almost 10 years. Another important point is that this area was consolidated internationally in 2003, reaching the level of international excellence in the last evaluation.

CAPES establishes criteria based on the bibliographic production score and the concepts of distribution and production to measure the quality of the Master's and Doctoral courses [12]. It should be emphasized that the logic considered by CAPES for this evaluation is efficiency, and therefore all the outputs taken into account in the evaluation are relativized by the number of teachers, which makes the most efficient programs the ones that also have the highest grades.

According to Barbosa and Wilhelm [14], the need to diagnose the causes of low educational performance leads researchers to develop techniques to evaluate and measure the performance of educational units. Therefore, analytical tools should be used to evaluate the performance, as well as the variables that influence the educational dynamics.

Given this context, the Data Envelopment Analysis (DEA) technique stands out as it offers the main advantage of the ability to handle multiple inputs and outputs, making it an attractive technique to measure the efficiency of Higher Education institutions.

In addition, this technique is able to generate a ranking that identifies units with greater relative efficiency, and helps inefficient units to improve their performance. Thus, according to Meza et al [10], the DEA technique is an interesting tool to evaluate graduate programs as it considers multiple variables without needing to introduce arbitrary weights in the Evaluation as the technique itself determines these weights.

In this context, this work leads to the following research question: Are the programs considered efficient by the DEA tool those that have the highest CAPES scores?

The main objective of this study is to analyze the relative efficiency of graduate programs in Engineering III at Brazilian universities using data that are used to evaluate these programs by CAPES adopting the DEA tool.

Thus, the results of this work can contribute to a better understanding of the dynamics and determining factors of the national academic production in order to generate knowledge about graduate programs, especially courses that do not meet the required technical production efficiency standards by CAPES.

The present work is organized into four sections besides this introduction. The second section presents a literature review regarding the evaluation of higher education efficiency through Data Envelopment Analysis, as well as the CAPES evaluation process. The third section describes the research method and the fourth section presents the results and discussions. Finally, the main considerations are found in the fifth section of this paper.

Theoretical reference

The Web of Science and Scopus platforms were used in the process to search for and analyze the articles. In the Scopus database, 19 papers were found using the Data Envelopment Analysis (article title) AND Higher Education (article title) parameters, and in the Web of Science platform, 12 papers with the same parameters were found.

In Scopus, 35 studies were found using the Data Envelopment Analysis (article title) AND university (article title) parameters,

and no results were found using the Data Envelopment Analysis (article title) AND graduate (article title) parameters. In the Web of Science, 24 papers were found using the Data Envelopment Analysis (article title) AND university (article title) parameters, and no results were obtained using the Data Envelopment Analysis (article title) AND graduate (article title) parameters.
Figures 1 and 2 show the number of jobs

per study area for the parameters used. As shown in Figure 1, the Engineering area has the largest number of published studies on the topic in question. Furthermore, Figure 2 was highlighted in the area of Management, Business and Accounting.
In Tables 1 and 2, we present the works, author(s), year of publication and the main contributions/ focus of analysis for the parameters used in the Web of Science and Scopus search platforms.

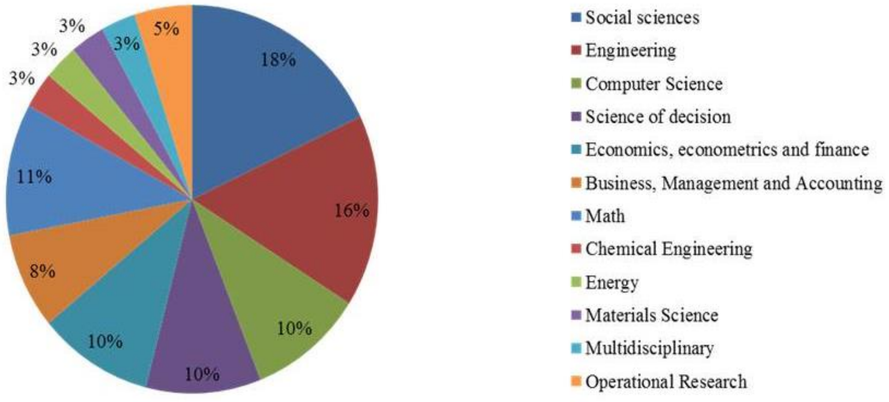

Fig 1. Number of papers by study area (Web of Science and Scopus) - Data Envelopment Analysis AND higher education parameters.

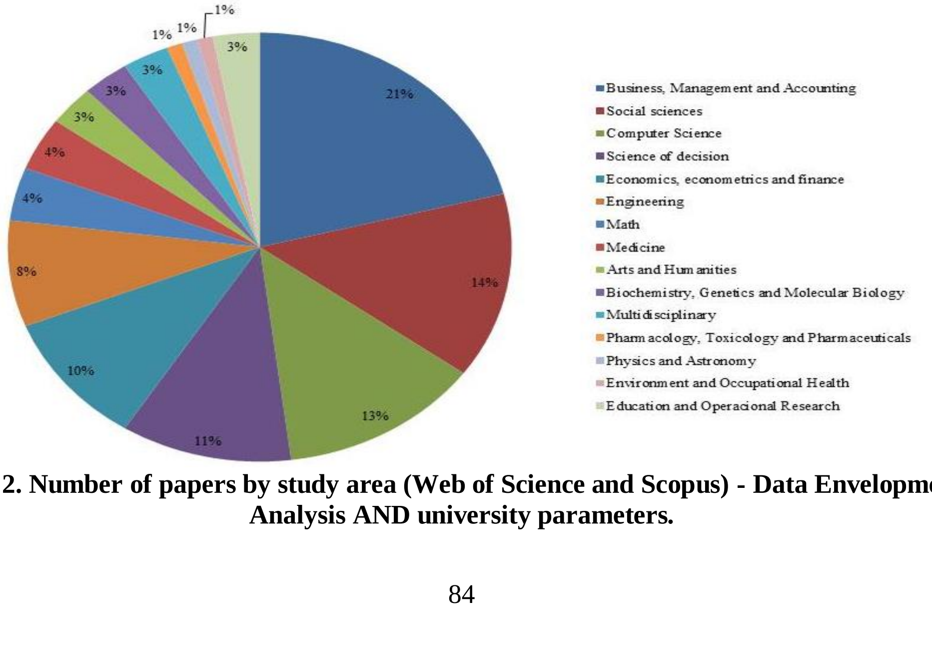

Fig 2. Number of papers by study area (Web of Science and Scopus) - Data Envelopment Analysis AND university parameters.

Table 1. Author (s), year and main contributions/analysis focus using Data Envelopment Analysis AND higher education parameters (Web of Science and Scopus)

Author (s)/Year	Database	Focus of Analysis/Contributions
Munoz [15]	Scopus/Web of Science	The objective of this study was to evaluate the efficiency of Higher Education institutions in Chilean universities. Universities with a mixed (traditional private) financing structure are more efficient than both public and purely private universities.
Barra and Zotti [16]	Scopus	This paper used Data Envelopment Analysis (DEA) to evaluate the technical efficiency in a large public university. Particular attention was paid to the two main activities, teaching and research, and in two large TSgroups, the Social Sciences (SSC) and Technology sectors (ST). The results, based on data from 2005 to 2009, suggest that the TS sector is more efficient in terms of the quality of the survey than the SSC sector.
Torre et al. [17]	Scopus	In this chapter, Data Envelopment Analysis (DEA) and Multidimensional Scheduling (MDS) were integrated with the objective of discussing the potential complementarities and advantages of combining both methodologies in order to reveal the efficiency framework and strategies of the organizations.
Ramírez and Martínez [18]	Scopus	This paper describes and discusses the application of the DEA technique to establish a relative measurement model to determine efficiency in academic organizations. The case study had a data sample from 321 Higher Education institutions in Colombia.
Blidisel [19]	Scopus/Web of Science	The author of the article examines the possibility of measuring efficiency in the context of Romanian Higher Education. Data Envelopment Analysis was used to evaluate the efficiency of 40 universities, revealing a satisfactory performance in all efficiency tests.
Kabók et al. [20]	Scopus/Web of Science	The aim of the research was to determine the level of competitiveness of Higher Education in the Republic of Serbia and its autonomous province in a European region compared to selected European countries. The results of the research indicate that adopting the new investment model would improve the unsatisfactory competitiveness of higher education in the Republic of Serbia.
Maleki et al. [21]	Scopus/Web of Science	This research contribution describes possible solutions based on DEA models and includes the additional problem of quality measurement and quality control in productivity analysis for the example of university service production.
Chen and Chen [22]	Scopus/Web of Science	By using the Data Envelopment Analysis (DEA), the Inno-Qual efficiency of 99 Taiwan universities was divided into five types (intensive research, intensive learning, intensive profession, research & teaching-intensive and education, intensive practice). Based on empirical results, it was found that more than half (73%) of the universities are highly inefficient.
Liu and Liu [23]	Scopus	The Data Envelopment Analysis model determines the performance of higher education and identifies the best institution among 76 private universities in the south of the United States. The objective is to demonstrate the benchmarking process and determine the overall benchmark for inefficient institutions, as well as general guidance for other private universities.
Bacs et al. [24]	Web of Science	The objective of this study was to compare the efficiency of higher education systems and to analyze the influence of socioeconomic aspects on educational performance.
Comes et al. [25]	Web of Science	The purpose of this study was to analyze the research efficiency of 29 European states through the DEA. Bulgaria was considered with the highest efficiency in the ranking.
Zhou and Wang [26]	Scopus	Efficient assessment methods and mechanisms are important approaches to ensure and improve the level of higher education, cultivating innovative people of a much higher level. This article systematically analyzed the research content and characteristics of the input and output evaluation process.
Johnes and Yu [5]	Scopus/Web of Science	This study used Data Envelopment Analysis (DEA) to examine the relative efficiency in research output of 109 Chinese regular universities in 2003 and 2004. The rankings of universities across models and time periods are significantly highly correlated. Further research suggests that average efficiency is higher in comprehensive universities compared to specialized universities, and in universities located in the coastal region compared to those in western China.

Xu and Li [27]	Scopus	This article addresses the index system of greater integration of educational resources. It also assesses greater integration of teaching resources in Heilongjiang (China) with DEA based on higher education research in the province. It then suggests ways to implement integration of teaching resources in Heilongjiang using these data.
Johnes [28]	Scopus/Web of Science	Data Envelopment Analysis (DEA) was conducted with 2.547 graduates in Economics from UK universities in 1993 in order to assess teaching efficiency. The results suggest that efficiency derived from the DEA performed at an aggregate level include both institutional and individual components, and are therefore misleading. Thus, the unit of analysis in the DEA is highly important.
Salerno [29]	Scopus	This paper uses the Data Envelopment Analysis (DEA) approach to estimate Higher Education institutions' costs per student of education in an effort to correct a number of methodological problems endemic to such calculations, particularly the allocation of shared expenditures between education and other institutional activities. Although there are several methodological concerns, the use of DEA is argued to increase the likelihood of producing more realistic cost estimates for each institution.
Johnes [30]	Scopus/Web of Science	The purpose of this article is to examine the possibility of measuring efficiency in the context of higher education. Thus, the quantity and quality of graduate students, the number of graduate students, administration expenses and the value of interest payments and amortizations are significant inputs, and the quantity and quality of undergraduate courses, and the quality of research are significant outputs in the education process.
Martín [31]	Scopus	This paper adopted the Data Envelopment Analysis (DEA) methodology to evaluate the performance of the departments from the University of Zaragoza (Spain). The results show that departments perform activities more efficiently according to the variables included in each analysis. It was highlighted that there are differences in strengths and weaknesses between departments covering different areas, suggesting several initiatives aimed at improving their performance, in light of the current reform of Spanish higher education.
Ng and Li [32]	Scopus	Using data from 84 key Chinese Higher Education institutions, the present study seeks to analyze the effectiveness of the Education Reform implemented in the mid-1980s in China. The decomposition of the group's efficiency measure indicates that, for the 3 years under study, the 84 key institutions suffered from technical, allocative and reallocation inefficiency.
Breu and Raab [33]	Scopus/Web of Science	Data Envelopment Analysis (DEA) was used to measure the relative efficiency of the "top 25" US and World Report-ranked universities. Improvements in technical efficiency are proposed using input readjustments.

Source: Prepared by the authors (2017)

Table 2. Author (s), year and main contributions / analysis focus using Data Envelopment Analysis AND university (Web of Science and Scopus) parameters

Author (s)/Year	Database	Focus of Analysis/Contributions
Esmaeili and Rezaeian [34]	Scopus	This study was conducted to evaluate the performance of educational groups from Farhangian University, Guilan Province. Data collection was performed using real information from the University's research center. The results of the research showed that the educational physics group had higher performance and efficiency.
Castro Lobo and Gazzola [35]	Web of Science	The objective of this study was to develop a tool to evaluate the efficiency of federal general university hospitals using the DEA. The mean scores for health care, teaching and research over the period were 58.0%, 86.0%, and 61.0%, respectively.
Kashim et al. [4]	Scopus/Web of Science	Three conceptual models are proposed to evaluate the performance of a university. An efficiency model is developed in the first phase using a hierarchical network model. The following is an efficacy model, which uses the output from the hierarchical structure in the first step as an input for the second step. As a result, a new overall performance model is proposed by combining both models for effectiveness and efficiency.

Amariles and Soto-Mejia [36]	Web of Science	A research group from the Technological University of Pereira proposed an alternative model to calculate the efficiency of public universities.
Sagarra et al. [37]	Scopus	A combined approach was used, which includes traditional relationships, as well as a Data Envelopment Analysis model. This combination made it possible to evaluate the changes in efficiency at each university individually and analyzed these changes, whether they are related to teaching, research, or both. Statistics from 55 universities were used over a period of six years (2007-2012).
Esfandnia et al. [38]	Scopus	The aim of this study was to analyze the technical efficiency of Gorgan University Hospitals of Medical Sciences using the Data Envelopment Analysis in 2013. The results showed that the hospitals in the province did not use their resources efficiently.
Goksen et al. [6]	Web of Science	The objective of this work was to analyze the efficiency of departments at the University of Dokus Eylul (Turkey).
Shetabi et al. [39]	Scopus	The research was descriptive-analytical and cross-sectional research was conducted among 7 Kermanshah educational universities during 2013, and data were collected using the Data Envelopment Analysis (DEA). Among all the hospitals studied, 1 hospital had an increase in its efficiency, 2 hospitals had a decrease in its efficiency, and 4 hospitals had a constant efficiency equal to one.
Anindita and Hilmiana [40]	Scopus	The objective of the research was to measure the role of higher education as a learning organization to improve the performance of lecturers. The survey was conducted by sending out questionnaires to 187 lecturers from 13 universities in and around Jakarta. Results showed that Trisakti University is more efficient as a learning organization, both in terms of management and in improving the performance of lecturers.
Askari et al. [41]	Scopus	This study aims to evaluate the efficiency of affiliated hospitals with Yazd University of Medical Sciences using the Data Envelopment Analysis (DEA) method. Although the efficiency of the hospitals studied showed a favorable level and there was a slight improvement in required efficiency, managers still expect to provide the necessary planning to increase efficiency.
Rosenmayer [42]	Scopus	The purpose of this article is to analyze the adequacy of using Data Envelopment Analysis (DEA) in various studies that deal with the effectiveness of the university economy.
Nasiripour et al. [43]	Scopus/Web of Science	In this work, the DEA was used to model and evaluate financial performance including 4 inputs and 3 outputs. In addition, linear regression is applied to determine the effectiveness of the indices, as well as the level of financial performance of universities.
Kubák et al. [44]	Scopus	Data Envelopment Analysis was used to study the technical efficiency of colleges in the Slovak Republic. Our finding shows that there are serious differences in the effectiveness of colleges. The most serious imbalances are within the Economic Sciences, Technical Sciences, Theological Sciences and Arts groups.
Pranesh et al. [45]	Scopus/Web of Science	This paper proposes and demonstrates the application of Data Envelopment Analysis (DEA) to evaluate the measures of the Indian Institute of Technology, Chennai and Anna University. The results of the research can be used to identify a better educational establishment in order to maximize the contribution to society.
Jiang and Wu [46]	Web of Science	A two-stage efficiency evaluation model was proposed by means of factor analysis and DEA to analyze the efficiency of technological and scientific innovation.
Selim and Bursalioglu [47]	Web of Science	The objective of the work was to develop two stages of DEA to determine the efficiency of universities in Turkey from 2006-2010. The results showed that the project allocation effect found was insignificant.
Ramírez and Alfaro [48]	Scopus	The paper used Data Envelopment Analysis (DEA) to evaluate the reality of the Chilean university system. A DEA model with an input variable (operating expenses) and two output variables (publications and the number of students enrolled) was developed to evaluate the

		performance of the universities. The empirical results indicate that 3 out of the 25 institutions are efficient in terms of research and teaching.
Ardakani and Delavar Khalafi [49]	Scopus	The objective of this paper was to evaluate the performance of the Elmi-Karbordi universities through Data Envelopment Analysis. Data were calculated based on the output-oriented VRS DEA method.
Kiakojoori et al. [50]	Scopus	The objective of the research is to evaluate the performance of each branch of the Azad Islamic University (IAU) in the province of Mazandaran. Thus, the performance of the 12 branches of the university each with two input variables (education and services) and two output variables (Educational and research productivity) were studied. Research results show that Behshahr, Savadkouh, Mahmoud-Abad, Nour, Chalous and Tonekabon are efficient branches and Ghaemshahr, Neka, Amol, Babol, Noshahr and Ramsar are inefficient.
Kuah and Wong [11]	Scopus	The study presented a Data Envelopment Analysis model to jointly evaluate the relative efficiency of universities in terms of teaching and research. The application of the DEA allowed academics to identify deficient activities in their universities.
Andres Lopes et al. [51]	Web of Science	The article presents a generic model of efficiency and productivity measurement of public institutions in Mexico using the DEA.
Inoue et al. [52]	Scopus	In order to evaluate universities in various aspects, this study used the DEA. Managing universities is complex and their strengths and weaknesses need to be understood.
Din and Cretan [53]	Scopus	The input-oriented BCC model was used for university analysis. In an environment with limited resources, measuring the relative efficiency of each university would define an ideal budget for each state university.
Liu et al. [54]	Web of Science	The objective of this work was to apply the DE to analyze the competitiveness of nine universities, due to the allocation of resources.
Rayeni and Saljooghi [55]	Scopus	The objective of this study was to calculate disaggregated performance measures of universities. The Malmquist index has shown that universities have, on average, 1.1% productivity gains. The main factor in increasing productivity is progress in technical change.
Ramon et al. [56]	Scopus	The Miguel Hernandez University evaluates its processes through a complete system of quality. Departments, research institutes, courses and units of administration and service are evaluated in terms of a set of quality indicators that are aggregated using a common set of weights previously set. To address this assessment, the DEA was used because of its flexibility in the choice of weights.
Li [57]	Web of Science	The purpose of this study was to evaluate the scientific and technological innovation capacity of Chinese universities.
Saber-Mahani et al [58]	Scopus	The objective of this study was to determine the technical efficiency of 13 hospitals at Kerman University of Medical Sciences using DEA.
Wang and Chong [59]	Scopus/Web of Science	The DEA was used to analyze the efficiency of 11 faculties, in which the results helped to strengthen internal management and decision making.
Wu and Zhang [60]	Web of Science	The study applied the DEA to analyze the effectiveness of 12 Physical Education faculties in Beijing (China).
Chen and Li Chen [61]	Web of Science	The DEA was used to evaluate the efficiency of scientific research activities in 31 Chinese colleges.
Duan et al. [62]	Scopus	This paper presents research on the impact of government policies on the efficiency of Australian universities in 2000-2005 using the DEA. The results have shown that the overall efficiency of Australian universities remains at a high level.
Duan et al. [63]	Scopus	Understanding how teaching and research contribute to the overall efficiency of university operations is of great importance for universities to improve their performance. This article evaluated the efficiency of Australian universities from three perspectives: global efficiency

		of university operations; Educational efficiency of universities; and, efficiency of university research.
Duan and Huo [64]	Scopus	The DEA was used to evaluate the performance of scientific research in 50 universities. The results indicate that, in more than 70% of these universities, efficiency is higher than 0.8.
Agasisti and Dal Bianco [65]	Scopus	In this study, the problem of determining the technical efficiency of 58 Italian universities through the DEA was considered.
Chuang [66]	Scopus	In this work, two CCR and BCC models are used to analyze the efficiency of 14 private technical universities in Taiwan during the school year in 2003. Three inputs and two outputs are used to calculate relative efficiency, scale efficiencies, technical efficiency and overall efficiency. The study proposes some guidelines to improve school management inefficiencies.
Reichmann [66]	Scopus	This article examined the technical efficiency of 118 university libraries randomly selected from German-speaking countries (Germany, Austria, Switzerland) and English-speaking countries (USA, Australia and Canada) using the DEA. Among the 118 libraries analyzed, 10 are classified as efficient.
Flegg et al. [68]	Scopus	This paper used the DEA to examine the technical efficiency of 45 British universities in the 1980-1993 period.
Taylor and Harris [69]	Scopus	Based on a sample of 10 out of 21 public universities in the country, this article analyzes the relative efficiency of South African universities between 1994 and 1997 through the DEA.
Ferrari and Laureti [70]	Web of Science	The objective of this study was to analyze the technical efficiency of an Italian university in two stages through the DEA. Variables related to the characteristics of graduate students were used.
Abbott and Doucoliagos [8]	Scopus/ Web of Science	In this study, the DEA was used to evaluate the technical and scale efficiencies of individual Australian universities. The results showed that Australian universities have very different levels of efficiency.
Dyson et al. [71]	Scopus	The sixteenth European Summer Institute was held during the summer of 1998 by the University of Warwick. It was organized by the Warwick Business School, under the auspices of the European Operational Research Association.
Avkiran [72]	Scopus	The main objective of this study is using DEA to examine the relative efficiency of Australian universities in 1995.
Kao and Liu [73]	Scopus	A fuzzy DEA model was used to calculate the efficiency scores of 24 Taiwan university libraries.
Hanke and Leopoldseder [74]	Scopus	This paper aimed to apply the DEA to compare the efficiency of Austrian universities. The results showed that the universities accused of being publicly inefficient were actually considered efficient.
Sarrico et al. [75]	Scopus	This article is related to the efficiency analysis of UK universities, using the DEA, focusing on the student body.

Source: Prepared by the authors (2017)

Table 3. Evaluation of efficiency in educational institutions at several different levels

Author (s)/ Year	Efficiency of university departments	Efficiency between universities in the same region	Efficiency between higher education courses at a university	Efficiency of higher education between regions	Academic research efficiency	Evaluation of the impact of educational and political programs on the efficiency of the country
Munoz [15]		x				

Barra and Zotti [16]			X			
Torre et al. [17]		x				
Ramírez e Martínez [18]		x				
Blidisel [19]		x				
Kabók et al [20]				X		
Maleki et al [21]		x				
Chen and Chen [22]		x				
Liu and Liu [23]		x				
Bacs et al [24]						X
Comes et al. [25]					X	
Zhou and Wang [26]					X	
Johnes and Yu [5]		x				
Xu and Li [27]						X
Johnes [28]		x				
Salerno [29]		x				
Johnes [30]		x				
Martín [31]	X					
Ng and Li [32]						X
Breu and Raab [33]		x				

Source: Prepared by the authors (2017)

Table 4. Assessment of efficiency in educational institutions at several different levelsAuthor (s)/Year

	Efficiency of university departments	Efficiency between universities in the same region	Efficiency between higher education courses at a university	Efficiency of higher education between regions	Academic research efficiency	Evaluation of the impact of educational and political programs on the efficiency of the country
Esmaeili and Rezaeian [34]		x				
Castro Lobo and Gazzola [35]		X				
Kashim et al. [4]						x
Amariles and Soto-Mejia [36]		X				
Sagarra et al. [37]		X				
Esfandnia et al. [38]			X			
Goksen et al. [6]	X					
Shetabi et al. [39]		X				
Anindita and Hilmiana [40]					X	
Rosenmayer [42]					X	
Nasiripour et al. [43]		X				
Kubák et al. [44]		X				
Pranesh et al. [45]		X				
Jiang and Wu [46]					X	
Selim and Bursalioglu [47]		X				
Ramírez and Alfaro [48]				x		

Ardakani and Delavar Khalafi [49]		X				
Kiakojoori et al. [50]			X			
Kuah and Wong [11]					X	
Andres Lopes et al. [51]				x		
Inoue et al. [52]				x		
Liu et al. (2010)		X				
Rayeni and Saljooghi [55]				x		
Li [57]				x		
Wang and Chong [59]	X					
Chen and Li Chen [61]		X				
Duan et al. [62]		X				
Duan et al. [63]						x
Duan e Huo [64]					X	
Agasisti and Dal Bianco [65]		X				
Chuang [66]		X				
Flegg et al. [68]		X				
Taylor and Harris [69]		X				
Abbott and Doucoliagos [8]		X				
Dyson et al. [71]			X			
Avkiran [72]		X				
Hanke e Leopoldseder [73]		X				
Sarrico et al. [74]				x		

Source: Prepared by the authors (2017)

According to the review, the DEA was successfully used to assess the efficiency in educational institutions at several different levels. It was used to evaluate efficiency at the departmental level of universities [31; [6] comparing efficiencies between universities [34]; [37], evaluating efficiency among higher education courses [20]; [48] and evaluating the impact of educational programs and policies on the efficiency of the country [32], [4].

Figure 3 shows the percentage of studies that evaluated the efficiency of educational institutions at different levels.

According to Figure 3, it can be observed that the majority of the studies analyzed the efficiency between universities of the same region, but no studies were found that dealt with the efficiency of graduate programs in these two databases. Thus, this study is relevant to the literature to highlight DEA application work in Master's and Doctoral programs.

Evaluating Graduate Programs

University management is a complex process according to Aoki et al. [76], and their strengths and weaknesses need to be discovered so that they can become better institutions.

The product of education, according to Hwarng and Cynthia [77] is generally intangible and difficult to measure, as it is reflected in the transformation of individuals, their knowledge, their characteristics and behavior. Even with difficulties, there are some universities concerned with improving the quality of their teaching.

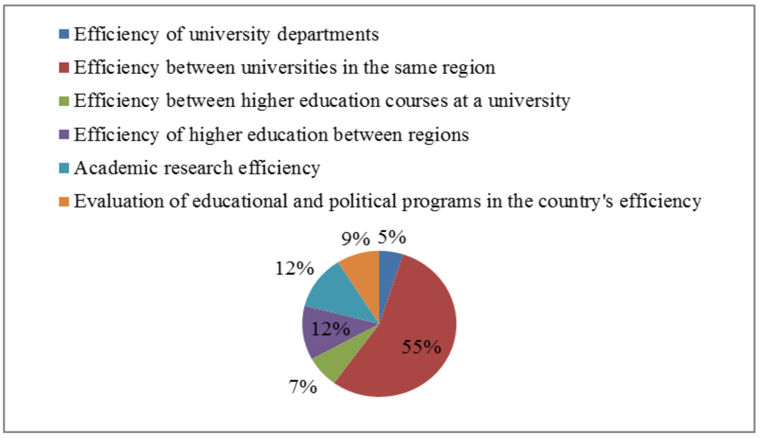

Fig 3. Percentage of work-evaluation of educational institutions at different levels

Due to its accumulated experience and an indisputably pioneering evaluation program, Brazil contributed most to the development of the organized history of institutional evaluation in Latin America [78]. This evaluation experience has consolidated over the years, and is considered a great advance in educational evaluation systems.

The objectives initially stated to justify designing and adopting the graduate course evaluation system were: (a) to facilitate the distribution of scholarships for Master's and Doctoral students and to guide investment from federal agencies in training high level human resources; (B) to subsidize educational policy regarding graduate and university education; and (C) creating a permanent system of information on Brazilian graduate studies [13].

However, according to Córdoba [79], at least two other objectives must be added to those officially declared: (a) to regulate graduate expansion, recommending support for new courses and progressively incorporating them into the evaluation system; and (b) to accredit these courses, making the certificates issued by them valid at the national level. Initially, when the graduate evaluation system was implemented, it was decided that its systematics would be guided by the results achieved, which would enable the data collected to be processed.

Nowadays, the idea of improving education is disseminated, aiming at a new structure of Higher Education institutions to train professionals required by the market, as according to Belhot [77], in an era of social change technology plays a major role in teaching.

Thus, there is a need to diagnose the causes of low educational performance so that researchers can develop techniques and methods for the purpose of evaluating and measuring the performance of educational units, as Barbosa and Wilhelm [14] affirm.

These techniques support decision making in the pedagogical sphere, seeking alternatives to improve teaching quality and in administration, allocating resources to improve the efficiency of institutions, taking into account that universities train professionals to deal with problems that have not yet occurred, thus raising concern about the quality of higher education, as well as graduate programs.

In the case of graduate programs, the Coordination of Improvement of Higher Education Personnel (CAPES) is responsible for evaluating their performance.

General considerations about CAPES

The Coordination for the Improvement of Higher Education Personnel (CAPES), created in 1951 by decree no. 29, 741, aiming to ensure qualified personnel at a higher level to meet the demands of education and scientific development in Brazil, has been the main agent for regulating and fostering development of national graduate programs [13].

Since 1976, when it implemented the National System of Evaluation of graduate courses, it has been considered the main reference for developing strategies to develop these programs. Since then, the Stricto Sensu graduate programs in Brazil have shaped their improvement policies based on what the quality criteria defined by the system proposed [13].

Detailed reports on the programs and courses evaluated are prepared on an annual basis, and the data collected are processed by CAPES and analyzed by expert committee members trained for this purpose. However, in order to analyze the data in more depth made available annually by the evaluated programs in 1980, the system was improved by including on-site visits, carried out every two years by ad hoc consultants designated by CAPES [80].

Classifying the knowledge areas of CAPES has a practical purpose, aiming to provide teaching, research and innovation institutions an agile and functional way to systematize and provide information concerning research projects and human resources to management bodies in the area of science and technology (Capes, 2014).

The organization of the knowledge areas has a hierarchy from the most general to the most specific, comprising nine main areas in which the 48 evaluation areas of CAPES are distributed (Capes, 2014).

In order to facilitate the development of evaluation activities, the 48 evaluation areas are aggregated using affinity criterion in two levels: the first level consists of colleges; the second level comprises large areas. According to Table 9, the areas are distributed into 3 Colleges and 9 Major Areas.

For this study, the knowledge area to be analyzed is Engineering III, which was consolidated internationally in 2003, reaching the level of international excellence in the last evaluation.

Fig 4. CAPES knowledge areas

COLLEGES OF LIFE SCIENCES		
AGRICULTURAL SCIENCES	**BIOLOGICAL SCIENCES**	**HEALTH SCIENCES**
Food Science Agricultural Sciences I Veterinary Medicine Animal Husbandry Fishing Resources	Biodiversity Biological Sciences I Biological Sciences II Biological Sciences III	Physical Education Nursery Pharmacy Medicine I Medicine II Medicine III Nutrition Odontology Collective Health
COLLEGES OF EXACT, TECHNOLOGICAL AND MULTIDISCIPLINARY SCIENCES		
EXACT AND EARTH SCIENCES	**ENGINEERS**	**MULTIDISCIPLINARY**
Astronomy / Physics Computer Science Geosciences Mathematics/Probability and Statistics Chemistry	Engineering I Engineering II Engineering III Engineering IV	Biotechnology Environmental Science Teaching Interdisciplinary Materials
COLLEGE OF HUMANITIES		
HUMAN SCIENCES	**APPLIED SOCIAL SCIENCES**	**LINGUISTICS, LANGUAGE AND LITERATURE, AND ARTS**
Anthropology/Archeology Political Science and International Relations Education Philosophy/Theology Geography History Psychology Sociology	Administration, Accounting and Tourism Architecture and Urbanism Applied Social Sciences Business Economy Urban and Regional Planning/Demography Social Work	Arts / Music Language and Literature / Linguistics

Evaluation System of Engineering III

In the evaluation procedure of Engineering III, concepts are initially assigned for all subitems, items and requirements of the evaluated programs, according to the evaluation rules of Engineering III.

Basically, CAPES adopts five evaluation criteria and each one has a different weight in the composition of the final grade:

a. Program proposal: This criterion is qualitative and has no weight in the evaluation. It is interpreted as adequate or inadequate. In this criterion, the areas of concentration, lines of research and projects that are in progress are described in the programs. Moreover, the consistency and comprehensiveness of the curriculum framework, the infrastructure for teaching, research and extension and teacher training activities can be observed in this item;

Teaching staff: this has a weight of 20%. It consists of the following items: training permanent teachers; dimension adequacy; composition and dedication of permanent teachers; permanent body profile in relation to the program proposal; permanent teaching activities in graduate studies; permanent teaching activity at undergraduate level; participation of teachers in research and development of projects;

b. Student body: this has a weight of 35%. The following items are included: percentage of Master´s/ Doctorate defenses in relation to the permanent teaching staff; adequacy and compatibility of the counselor/ student relationship; participation of graduate students; dissertations/theses linked to publications; quality of theses and dissertations; average time of Master´s and Doctoral degrees;

c. Intellectual production: this has a weight of 35%. This criterion consists of the following items: qualified publications of the program by permanent teacher; distribution of qualified publications in relation to the permanent teaching staff; technical or technological production; high impact production; and,

d. Social insertion: this has a weight of 10%. It consists of the following items: insertion and regional and/ or national impact of the program; integration and cooperation with other programs; and visibility and transparency of the program (CAPES, 2013).

These concepts, therefore, are transformed into scores. After calculating the total number of points for each program, taking into account the weights of items and sub-items, the weighted value in the quadrennium is called the "Program Score" (CAPES, 2013).

The programs are therefore classified, in descending order, by the Program Score. Groups of programs are defined that tend to receive scores 3, 4 and 5 as well as programs that tend to be awarded scores 6 and 7 (CAPES, 2013).

After the programs have been classified, for each program the following alternative is proposed: the program has the same grade as the previous quadrennium; the program has a lower score compared to the previous quadrennium; or the program has a higher score compared to the previous quadrennium. Thus, groups of programs with scores 3, 4 and 5 (or higher) (CAPES, 2013) are fixed.

From the programs that are awarded scores 6 and 7, extensive data analysis is carried out to classify them according to scores 5, 6 or 7. The observed data are as follows:

- Average in the four years of publications in journals A and B, as well as in conferences by permanent members of faculty;
- Average in the four years of publications in journals A and B published only by permanent members of faculty;
- Average in the quadrennium of Doctoral and Master´s students supervised by permanent members of faculty;
- Absolute number of Master´s and Doctoral students graduated in the quadrennium;

- Percentage of permanent teachers who participated in at least 1 article in A or B1 journals per year;
- Official international cooperation, funded by development agents, that the program has participated in the quadrennium;
- Medium and large research projects received by researchers in the quadrennium;
- Participation of researchers in important international events (chairperson, organizer, member of scientific committee, guest speaker, among others);
- Relevant participation (mamagement, commissions, councils) in national and international professional and technical-scientific bodies;
- National and international awards and distinctions;
- Members of editorial staff in national and international journals;
- Fundraising with international support;
- Exceed levels of production (intellectual and doctoral theses) that demonstrate exceptional performance in each of the areas of engineering); and,
- Present consolidation and national leadership of the program as trainer of human resources for research and graduate studies (CAPES, 2013).

Scores 6 and 7 will be awarded if this data evaluation is fulfilled.

This methodology has been widely discussed with graduate program coordinators both at annual meetings and at national/international scientific events organized by societies and associations in the area (CAPES, 2013).

According to the Quadrennial Evaluation Regulations, the following recommendations for grading are followed.

Score 3: Score 3 corresponds to the minimum quality standard for the recommendation of the program and consequent permanence in the National graduate System (SNPG in Portuguese).

Score 4: Score 4 is awarded for courses that have achieved at least a "Good" concept in at least three requirements, including (compulsory) the Student Body and End of Course Projects, as well as Intellectual Production (Questions 3 and 4).

Score 5: In order to obtain a final score of 5, the program must obtain "Very Good" in at least four out of the five existing items, among which items 3 and 4 must appear. Score 5 is the maximum grade allowed for programs offering only the Master´s degree.

Scores 6 and 7: Scores 6 and 7 are reserved exclusively for the doctoral programs that obtained a score of 5 and a "Very Good" concept in all subjects (Program Proposal, Faculty, Thesis and Dissertation, Intellectual Production and Social Insertion) of the assessment which must fulfill three conditions:

Score 6: Predominance of the concept "Very Good" in the items of all the items of the assessment, even with the concept of "Good" in some items; level of performance (doctorate and intellectual production) differentiated compared to the other programs in the area; and, equivalent to that of international centers of excellence in the area (internationalization and leadership).

Score 7: "Very Good" concept in all items of all items in the assessment; level of performance (doctorate and intellectual production) highly differentiated compared to the other programs in the area; and performance equivalent to that of the international centers of excellence in the area (internationalization and leadership) (CAPES, 2013).

DEA and Capes Methods - Graduate Programs

Based on the literature, the characteristics of the CAPES and DEA evaluation process can be described and compared, according to Table 5.

It can be seen from Table 5 that both evaluation processes have advantages and disadvantages and, therefore, are complementary. The findings suggest that further research should be carried out to develop more effective instruments to evaluate the performance of the programs in order to help plan strategically, as well as to advise funding agencies to appropriately distribute resources required by the institutions.

The evaluation method of the programs is based on pre-determined assessments by the institutions, which may affect the real knowledge of the efficiency of these programs and their characteristics. Due to this, an impatient search for the achievement of concepts rather than qualitative results is provoked. As program productivity becomes quantitative production, efficiency becomes synonymous of reaching standards rather than wisely using resources.

Table 5. Characteristics of the CAPES and DEA evaluation processes

CAPES	DEA
Qualitative and Quantitative Analysis: The CAPES evaluation system of graduate programs includes qualitative and quantitative criteria, but both are converted into qualitative considerations and, at the end of the evaluation, based on the assessments made, a numerical concept is established, scaling the quality of the programs evaluated.	**Quantitative Analysis:** There is an inability of differentiating the effects of change in the composition of the inputs and in the pedagogical projects of the graduate programs, which requires using a relative analysis technique of efficiency that considers the specificities of Higher Education institutions.
Assignment of arbitrary weights: Graduate courses at the national level are periodically evaluated by different entities according to criteria that are not always clear. The quantification of academic excellence is not usually performed as it is done in a qualitative way. Thus, productivity assessments in education are usually subjective, especially due to the large number of variables to be considered. To quantify and aggregate these variables into a single index, there is a need to impose weights, whose subjectivity may cause discomfort and non-acceptance of results.	**Attribution of benevolent weights for each unit:** The DEA is an important tool to evaluate graduate programs, considering multiple variables that present a causal relationship, without introducing arbitrary weights. Thus, the results obtained are regardless of subjective opinions, and almost always controversial (from the assessors), whether internal or external. The DEA method enables flexibility when allocating weights, avoiding excessive arbitrariness and allowing for a better representation of the uncertainties involved in the decision process.
Quality versus efficiency: Even if it is presented as the only evaluation framework available in the country to regulate the quality of the offer at graduate level, its actions do not have proper instruments available that can evaluate the productivity and efficiency of these programs, nor does it help in terms of quickly developing consistent promotion strategies. Program infrastructure indicators, such as quantity and level of teacher training, pedagogical projects and program proposals, facilities, range of research lines and projects, as well as other elements to promote research and training activities at graduate level, have been used to assess the quality of the programs but have also been mistakenly associated with performance indicators and used to differentiate programs from efficiency, even though efficiency is in fact not being measured [13]	**Quality versus efficiency:** For a more accurate analysis of the performance of the programs, qualitative analyses should be carried out in order to complement the presented results as the DEA measures the efficiency of the programs, i.e., the maximum production with the minimum resources possible, and not the way they are "producing" these resources.

Efficiency analysis: Analyzing the efficiency of graduate programs through the DEA shows the possibility of corroborating the hypothesis that CAPES evaluated programs considering the same concepts or scores can present differentiated levels of efficiency. Moreover, the evaluation carried out under such parameters can jeopardize programs in terms of obtaining resources and favoring inefficient ones.	**Efficiency analysis:** Analyzing the efficiency of educational organizations should be done in relative terms, taking as a reference one or some institutions that, in a given similar or equivalent context, can be considered more efficient, as the DEA technique offers[81].

Source: Prepared by the authors (2017)

Method

Data Envelopment Analysis

The Data Envelopment Analysis (DEA), according to Barra and Zotti [16] is a non-parametric approach with a mathematical programming model, which is often used to evaluate the relative efficiency of units with multiple inputs and outputs.

Ferreira and Gomes [82] point out that the DEA evaluates the performance of organizations and activities, mainly through technical efficiency measures. The technical efficiency is a relative concept that compares what was produced per unit of input used with what could be produced, as follows: the production/input ratio performed compared to the adequate or desired production/input ratio.

Kuah and Wong [11] point out that the DEA is a simple but powerful methodology used to measure the relative efficiency of a group of companies or homogeneous Decision-making Units (DMUs). According to Pereira [83], DMU is defined as a firm, department, division, administrative or operational units whose efficiency is evaluated. Each DMU is represented by inputs (input variables) and products (output variables), and the main aim is to compare products and inputs.

Adopting the DEA methodology to any problem comprises three main steps, according to Lins and Meza [84]: defining and selecting the DMUs (Decision Making Units) for analysis; selecting variables (inputs and outputs) that are relevant and appropriate to establish the relative efficiency of the selected DMUs; and, the using the DEA models.

According to the authors Vasconcelos et al. [85], the DEA models are classified according to the type of envelope surface, the orientation (inputs or outputs) and the efficiency measure, which are classified as: Constant Returns to Scale (CRS) and the Variable Returns to Scale (VRS) models.

The CRS model, according to Kanesiro [86], was developed by Charnes, Cooper and Rhodes in 1978 and allows for an objective assessment of the overall efficiency. It also identifies the sources and estimates of the inefficiencies identified. The VRS model generalizes the CRS model, considering technologies with constant, increasing and decreasing returns to scale, i.e., variable returns to scale [87].

Study population and variables

In this study, the study population (DMUs) are graduate programs classified by CAPES in the area of Engineering III at the national level, totaling 93 DMUs. According to Nakano [88], the method of research used in this work is "the use of mathematical techniques to describe the functioning of a system or part of a production system".

To use the DEA methodology, the second step is to select the variables, so that the technical production efficiency of the graduate courses will be analyzed based on 2014 as a reference. Therefore, the inputs and outputs will be analyzed, as presented in Table 6.

Table 6. Variables (inputs and outputs) to be evaluated in the DMUs

Selected Variables for the DEA – 2014	
Inputs	***Outputs***
X1 = Total number of faculty members (includes permanent faculty members, visitors and collaborators) X2 = Students enrolled in Master´s and Doctoral programs	Y1 = Number of funded projects Y2 = Number of publications in A1 journals Y3 = Number of publications in A2 journals Y4 = Number of publications in B1 journals Y5 = Number of publications in B! journals Y6 = Number of theses defended Y7 = Number of dissertations defended Y8 = Number of patents (deposited, granted, licensed, national or international) Y9 = Other technical productions (includes everything that is not an article in a journal, or a patent); Y10 = Student bibliographic production (includes journals and congresses)

Source: Prepared by the authors (2017)

As observed in the inputs and outputs, the CAPES assessment takes place in the financial sphere and in human resources.
The data on inputs and outputs are secondary data that were extracted from the Sucupira Platform, the graduate program websites from selected universities and the CAPES website.

Econometric analysis
The Multiple Regression helps to analyze data establishing a functional relationship between the independent variables that can influence a dependent variable.
Thus, an equation is made which relates each output to the established inputs. It can be observed that each output is a dependent variable (Y) and the inputs are independent variables (Xn). By analysis, the influence that one of the inputs has on a given output can also be observed. Therefore, this study carries out a multiple regression analysis for each output.
However, for the econometric analysis that preceded the Data Envelopment Analysis, a macro factor view was considered, i.e. some variables were coupled for econometric analysis and later dismembered again for the efficiency analysis. Thus, for the econometric analysis, consider Y2 as the sum of publications A1, A2, B1 and B2, and the sum of the theses and dissertations as Y3. The Y1 variable remains as the number of funded projects, and the Y4 variables becomes the number of patents. Y5 corresponds to other technical productions and Y6 is student production.
Multiple regression analysis was performed using Excel at a 95% confidence level model to establish the individual significance test of the estimated parameters.
The variables used in each analysis were selected according to the statistical relevance of the inputs. The outputs that did not present statistical significance with the inputs were not used in the Data Envelopment Analysis.

DEA Model
As mentioned, the third step of the DEA is to apply the model. The DEA technique was followed according to the VRS model, with output orientation, as proportionality between inputs and outputs cannot be established, i.e., it is not expected to double the number of articles published with the duplication of the number of National Council for Scientific and Technological Development (CNPq in Portuguese) scholarship holders, using Equations 1 and 2.

$$\text{Min Eff0} = \sum_{i=1}^{r} v_i y x_{i0} + uo$$

Subject to

$$\sum_{j=1}^{s} u_j y_{j0} = 1$$

$$- \sum_{i=1}^{r} v_i x_{ik} + \sum_{j=1}^{s} u_j y_{jk} + v0 \leq 0$$

$$k = 1,...,s$$

$$v_i, u_j \geq \varepsilon \qquad \text{For all x, y v0} \in R$$

Output-oriented VRS multiplier model (1)

Where v_0 = dual variable (scale factor).
Max h_0
Subject to
$\mathbf{x_{io}} - \sum_{\mathbf{k=1}}^{\mathbf{n}} \mathbf{x_{ik}} \lambda_{\mathbf{k}} \geq 0$, for all i
$-\mathbf{h_0 y_{jo}} + \sum_{\mathbf{k=1}}^{\mathbf{n}} \mathbf{y_{jk}} \lambda_{\mathbf{k}} \geq 0$, for all j
$\sum_{\mathbf{k=1}}^{\mathbf{n}} \lambda_{\mathbf{k}} = 1$
$\lambda_{\mathbf{k}} \geq 0$, for all K
Output-oriented VRS Envelope Model (2)

The efficiency calculation was performed using the SIAD 3.0 software, showing a ranking of the programs with greater relative efficiency, as well as identifying benchmark institutions.
The virtual input and output restriction method was used, which prevents them from being null when lower limits are applied to the data, and the lower and upper limits of the weights were applied according to the importance level of the variables. Thus, no variable can be disregarded in the evaluation. Different weight restrictions were considered for some variables because they presented higher or lower levels of importance in the evaluation of the program, according to the data in Table 7.

Results and discussions

Validation of variables

The econometric model can validate and quantify the contribution of each input to each of the outputs in question. The validation results are shown in Table 8.
Based on the analysis in Table 8, it can be seen that the variables Y4 and Y5 did not present statistical significance with the two inputs, and therefore they were discarded from the efficiency analysis step.

Table 7. Restrictions on virtual weights

Lower Limit		Variable		Higher Limit
5%	<=	*Input_1*	<=	
5%	<=	*Input_2*	<=	
5%	<=	*Output_1*	<=	
25%	<=	*Output_2*	<=	35%
20%	<=	*Output_3*	<=	25%
10%	<=	*Output_4*	<=	15%
5%	<=	*Output_5*	<=	10%
10%	<=	*Output_6*	<=	15%
5%	<=	*Output_7*	<=	
5%	<=	*Output_8*	<=	

Source: Prepared by the authors (2017)

Table 8. Coefficients β - Engineering III. Y1 = Number of funded projects; Y2 = Number of publications A1, A2, B1 and B2; Y3 = Theses and dissertations; Y4 = Patents; Y5 = Other technical productions; and, Y6 = Student bibliographic production. Consider: * p <0.1; ** p <0.05; *** p <0.01.

Variable	Y1	Y2	Y3	Y4	Y5	Y6
X1	0.6596**	0.8302***	0.4638***	0.0622	3.0749***	1.7670***
X2	0.1622***	0.0584**	0.1333***	-0.0255	0.0769	0.4217***
Intersection	1.2522	-2.0276	0.3086	2.8432	40.425	0.2540

Source: Prepared by the authors (2017)

It is also worth noting the absence of statistical significance with the variable Y4 (patents), which shows that the variable is not relevant to the area and is possibly misunderstood in the CAPES evaluation as few programs have patents. The Mechanical Engineering programs are more likely to develop patents than Production Engineering programs. This difference in only one variable can be biased towards the results between the groups.

Therefore, for the Data Envelopment Analysis step, the variables in Table 9 were selected, considering that variables Y2 and Y3 were dismembered again.

The results of the efficiency ranking generated by the DEA are shown in Table 10.

Table 9. Variables selected for the DEA stage

Variables selected for the DEA	
Inputs	***Outputs***
X1 = Number of total teachers (includes permanent teachers, visitors and collaborators); X2 = Students enrolled in masters and doctorates.	Y1 = Number of funded projects Y2 = Number of publications in A1 journals Y3 = Number of publications in A2 journals Y4 = Number of publications in B1 journals Y5 = Number of publications in B2 journals; Y6 = Number of theses defended; Y7 = Number of dissertations defended; Y8 = Student bibliographic production (includes journals and congresses).

Source: Prepared by the authors (2017)

Table 10. Efficiency ranking (Engineering III - 2014)

DMUs		Efficiency
DMU_1	UFPA - Mechanical Engineering	0.000003
DMU_2	UFC - Mechanical Engineering	0.000006
DMU_3	UFRN - Production Engineering	0.000001
DMU_4	UFRN - Mechatronics Engineering	1
DMU_5	UFPB / J.P - Production Engineering	0.000003
DMU_6	UFPB / J.P - Renewable Engineering	0.000003
DMU_7	UFCG - Mechanical Engineering	0.000002
DMU_8	UFPE- Production Engineering (Agreste)	0.000003
DMU_9	UFF - Mechanical Engineering	0.000002
DMU_10	IME - Mechanical Engineering	0.000008
DMU_11	CEFET / RJ - Mechanical Engineering	0.000002
DMU_12	UCAM- Production Engineering	0.000002
DMU_13	UENF - Production Engineering	0.000002
DMU_14	UENF - Reservoir Engineering	0.000003
DMU_15	UNIFEI - Energy Engineering	0.000003
DMU_16	UFSJ - Mechanical Engineering	0.000002
DMU_17	CEFET / MG - Energy Engineering	0.000002
DMU_18	UFSCAR - Production Engineering	0.000004
DMU_19	UNICAMP / Li - Operational Research	0.000003
DMU_20	UNIMEP - Production Engineering	0.000009
DMU_21	FEI - Mechanical Engineering	0.000002
DMU_22	IFSP - Mechanical Engineering	0.000001
DMU_23	UFABC - Mechanical Engineering	0.000003

DMU_24	UFPR - Production Engineering	0.000002
DMU_25	EMU - Mechanical Engineering	0.000005
DMU_26	UTFPR - Mechanical Engineering - CP	0.000001
DMU_27	UTFPR - Mechanical Engineering - PG	0.000003
DMU_28	UTFPR - Production Engineering	0.00001
DMU_29	UDESC - Mechanical Engineering	0.000006
DMU_30	UFSM - Production Engineering	0.000003
DMU_31	FURG - Ocean Engineering	0,.000002
DMU_32	FURG - Mechanical Engineering	1
DMU_33	UNISINOS - Mechanical Engineering	0.000003
DMU_34	UNISC - Systems and Processes	0.000002
DMU_35	UNIPAMPA - Mechanical Engineering	0.000002
DMU_36	PUC - Goiás - Production Engineering	0.000003
DMU_37	UNB - Integrity of Materials	0.000003
DMU_38	UFPA - Resource Engineering	0.000007
DMU_39	UFRN - Mechanical Engineering	0.000003
DMU_40	UFRN - Science and Engineering	0.833384
DMU_41	JFPB / J.P - Mechanical Engineering	0.000003
DMU_42	UFPE - Mechanical Engineering	0.232531
DMU_43	UFBA – Mechatronics	0.000003
DMU_44	UFES - Mechanical Engineering	0.000003
DMU_45	UFF - Production Engineering	0.265641
DMU_46	UERJ - Mechanical Engineering	0.16114
DMU_47	PUC - RIO – Metrology	1
DMU_48	CEFET / RJ - Production Engineering	0.000027
DMU_49	UFMG - Production Engineering	0.00001
DMU_50	PUC / MG - Mechanical Engineering	0.208601
DMU_51	UFSCAR - Production Engineering	0.675415
DMU_52	USP - Naval and Ocean Engineering	0.489862
DMU_53	USP - Production Engineering	0.170707
DMU_54	UNICAMP - Sciences and Engineering	0.000003
DMU_55	UNESP / BAU - Mechanical Engineering	0.000003
DMU_56	UNESP / BAU- Production Engineering	0.000003
DMU_57	INPE - Engineering and Technology	0.000001
DMU_58	ITA - Space Sciences and Technologies	0.000003
DMU_59	UNINOVE - Production Engineering	0.000002
DMU_60	UFPR - Numerical Methods	0.287314
DMU_61	PUC / PR - Production Engineering	0.388702
DMU_62	UTFPR - Mechanical Engineering	0.000003
DMU_63	UTFPR - Production Engineering	0.000003
DMU_64	UNB - Mechatronics Systems	0.000002
DMU_65	UNB - Mechanical Engineering	0.308766
DMU_66	UFPE - Production Engineering	0.671829
DMU_67	UFBA - Industrial Engineering	0.61562
DMU_68	UFRJ - Mechanical Engineering	0.561104
DMU_69	UFRJ - Ocean Engineering	0.000003
DMU_70	UFRJ - Production Engineering	0.000001
DMU_71	UFRJ - Energy Planning	0.222284
DMU_72	UFF - Mechanical Engineering	0.736258

DMU_73	PUC-RIO - Mechanical Engineering	0.652504
DMU_74	PUC-RIO - Production Engineering	0.000004
DMU_75	UFMG - Mechanical Engineering	0.591496
DMU_76	UNIFEI - Mechanical Engineering	0.197071
DMU_77	UNIFEI - Production Engineering	0.144363
DMU_78	UFU - Mechanical Engineering	0.989884
DMU_79	USP - Mechanical Engineering	0.62758
DMU_80	USP / SC - Mechanical Engineering	0.532034
DMU_81	USP / SC - Production Engineering	0.448553
DMU_82	UNICAMP - Mechanical Engineering	0.591384
DMU_83	UNESP / GUAR - Mechanical Engineering	0.634252
DMU_84	UNESP / IS - Mechanical Engineering	0.358775
DMU_85	ITA - Aeronautical Engineering	1
DMU_86	UNIP - Production Engineering	0262691
DMU_87	UFPR - Mechanical Engineering	0.403852
DMU_88	PUC / PR - Mechanical Engineering	0.498257
DMU_89	UFSC - Mechanical Engineering	0.734427
DMU_90	UFSC - Production Engineering	0.305355
DMU_91	UFRGS - Mechanical Engineering	1
DMU_92	UFRGS - Production Engineering	0.719237
DMU_93	UNISINOS - Production Engineering	0.000006

Source: Prepared by the authors (2017)

According to Table 10, only five DMUs were efficient according to the DEA: DMU_4 (UFRN- Mechatronics Engineering); DMU_32 (FURG- Mechanical Engineering); DMU_47 (PUC- RIO - Metrology); DMU_85 (ITA- Aeronautical Engineering); And, DMU_91 (UFRGS- Mechanical Engineering). Thus, 5.4% of the sample was efficient.

For the tie-breaking criterion considering the qualitatively efficient DMUs, the number of units that each DMU has a reference was analyzed. The most efficient benchmarks were considered those which have a greater number of references (inefficient units). The number of DMUs is considered as a reference for each benchmark according to Table 11, and the efficiency ranking.

According to Table 11, the most efficient program according to the DEA is Mechanical Engineering at UFRGS, and in second place Aeronautical Engineering at ITA. These programs have CAPES scores of 5, 6 or 7. The PUC/RIO-Metrology program (3rd place) has a CAPES score of 4, the Mechanical Engineering program at FURG (4th place) has a score of 3, and the Mechatronics Engineering program at UFRN (5th place) also has a CAPES score of 3.

Table 11. Benchmarkings and rankings of efficiency

Benchmarkings	**Number of mirroring DMUs**	**Efficiency rating**
DMU_4 (UFRN - Mechatronics Engineering)	1	5°
DMU_32 (FURG - Mechanical Engineering)	6	4°
DMU_47 (PUC - RIO - Metrology)	15	3°
DMU_85 (ITA - Aeronautical Engineering)	24	2°
DMU_91 (UFRGS - Mechanical Engineering)	80	1°

Source: Prepared by the authors (2017)

It can be said that the evaluation method of the programs is based on pre-determined assessments by the institutions, which may affect the real knowledge of the efficiency of these programs and their characteristics. Due to this, an impatient search for the achievement of concepts rather than qualitative results is provoked. As program productivity becomes quantitative production, efficiency becomes synonymous of reaching standards rather than wisely using resources.

More efficient programs were expected as the CAPES evaluation data were used for the DEA and these efficient programs had, in fact, the highest CAPES scores.

Thus, there is a need to reposition the CAPES evaluation process in terms of the variables to be considered, as well as the criteria that are used for this as only 5.4 % of the sample was efficient according to the DEA.

Final considerations

Due to the need of diagnosing the causes of low educational performance, researchers attempt to develop techniques and methods to evaluate and measure the performance of educational units, and as can be observed, the Data Envelopment Analysis (DEA) tool is as an interesting tool to evaluate graduate programs, considering multiple variables that present a causal relationship.

The evaluation method of the programs is based on pre-determined assessments by the institutions, which may affect the real knowledge of the efficiency of these programs and their characteristics. Due to this, an impatient search for the achievement of concepts rather than qualitative results is provoked. As program productivity becomes quantitative production, efficiency becomes synonymous of reaching standards rather than wisely using resources.

By analysis, there is a need for repositioning the Capes evaluation process in terms of the variables to be considered, as well as the criteria used for this.

It can be observed that both evaluation processes (DEA and CAPES) have advantages and disadvantages, and therefore are complementary. The findings suggest that further research should be carried out to develop more effective instruments to evaluate the performance of the programs in order to help plan strategically, as well as to advise funding agencies to appropriately distribute resources required by the institutions.

For a more accurate analysis of the performance of these programs, qualitative analyses should be carried out in order to complement the results found.

The variables were limited to 2 inputs and 10 outputs due to the availability of data in the Sucupira Platform and the CAPES website. The time period (2014) was also selected due to the availability of data.

For future work, other DEA models for tie-breaking among efficient DMUs are proposed. It is also recommended to add more years to calculate the efficiency to analyze its evolution. To do this, i the Window Analysis tool is suggested in which multiple DMUs and multiple years can be used.

The aim of this study is to offer guidance to the CAPES evaluation process in order to contribute to the selection of factors/requirements in the assessment of Engineering III as quality and efficiency are expected to be simultaneous.

It is also worth noting that studies of performance improvements in graduate programs are important factors in technological progress, helping the country to lose the immature consensus in the national innovation system.

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