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Ph.D. Thesis:

Institutional Missions, Performance, and External Factors. The Case of High-quality Colombian Universities

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The term "quality" has ambiguous and subjective connotations in an organizational context. However, quality in this context is related to meeting the expectations of either a good or service (Cano, 1998). In other words, it can be defined as the "ability of a set of inherent characteristics of a product, system or process to meet the requirements of customers and stakeholders" (AENOR, n.d.).

In this way, quality control has emerged from the business sector to expand to social services such as education. This expansion has occurred in developed countries after achieving quantitative targets in their school systems of which the entire population has access (Gálvez, 2005). Thus, to speak of quality in the educational context implicitly implies talking about evaluation processes. To evaluate, an educational system must measure, analyze, compare, and judge the established criteria to determine whether it can certify the object of the study as being of quality or not.

Currently, certification and evaluation processes are some of the most potent institutional forces in education (Bowman and Bastedo, 2011). For higher education, classifications and certifications are factors that represent the performance of these institutions as organizations and are the primary mechanisms for establishing an image of prestige (Perrow, 1961).

Although the government cannot measure educational institutions exclusively by their profitability, it can measure their efficiency (Pérez, 1990) in optimizing means and resources. The discourses and reflections that the economy can make about education can be from multiple perspectives, one of these is the rationalization of educational resources and their results. “Educational institutions are social resources, and these resources need to be distributed appropriately” (Gálvez, 2005).

The Higher Education Institutions (HEI) in Colombia are regulated by Law No. 30 (1992), where three types of HEI have been defined: the technical professional institutions, the university institutions or technological schools, and the universities. The first and second types of institutions focus on developing training programs in the operative and instrumental occupations and professions or disciplines and specialization programs. By its side, the universities are the institutions that, in addition to the training processes, develop the functions related to scientific or technological research and the transmission of knowledge and universal and national culture. Thus, in Colombia, the universities are the unique HEI that develop the three functions of the knowledge triangle.

The National Accreditation Council (CNA, by its Spanish acronym) carries out the quality assurance process through high-quality accreditations for Colombian universities (National Accreditation Council, 2013). The universities can decide voluntarily to apply to institutional accreditation, which represents the adoption of continuous improvement in their organizational culture and the interest of considering information that allows them to be more competitive and efficient in their processes.

The CNA is part of the National Council for Higher Education (CESU) which states in Agreement No. 02 of 2017 that "the decision-making based on evidence" and the "efficient and effective management of resources" are relevant principles for the improvement of government in the higher education institutions. Consequently, this study provides information to support governmental actions that allow universities to make better investments of their resources and improve their processes.

Similarly, our study intends to provide information for the renewal processes of the current accreditation and other certifications that can give them competitive advantages (e.g., international accreditations). We refer to more remarkable competitive advantages, considering that the high-quality accreditation by CNA represents differentiation only concerning the 29.89% of the university population in Colombia; therefore, some of these universities are looking to accredit their academic offer internationally (Technological University of Pereira, 2019).

Thus, we identify the variables that represent crucial inputs to develop the universities' objectives (i.e., teaching, research, and knowledge transference) and those that represent the main outputs of each of these functions. In the second chapter, we implement data envelopment analysis (DEA) models with a variable returns scale (VRS), considering the significant difference in the variable's levels of the universities under study. The DEA approach was selected because it does not impose a functional relationship, considering multi-input and multi-output. Thus, the DEA's results can offer greater clarity for an efficiency analysis in cases when it is difficult formally to explain the relationship between numerous resources and outputs of a system (Timovski and Atanasova-Pacemska, 2021).

Aiming to give more insights into the universities' performance given by the DEA analysis, we apply a Malmquist productivity index (MPI) to understand the positive or negative changes in the efficiency of the universities and to analyze what type of factors (e.g., policies and investments) are conducive to such changes.

Accordingly, the empirical evidence of the second chapter and previous studies (OECD, 2016; Fried et al., 2002) show that exogenous variables can influence the universities' performance. Thus, in the third chapter, we have implemented a separability test (Daraio et al., 2018) considering as independent variables representative indicators of social and economic conditions of the environment where the universities develop their functions, and as dependent variables, we set the universities' efficiencies. In that sense, to quantify the influence of external variables over the universities' performance, we employed a double-bootstrapped data envelopment from the non-parametric perspective and a stochastic frontier approach (SFA) following a Cobb-Douglas (CD) function to perform a parametric analysis.

In this order, the SFA implementation is proposed as a supplement to broaden understanding of the external factors that influence the inefficiency of universities. In addition, the SFA considers in its base significance tests: sensitivity, resampling, bootstrapping, and asymptotic theory (Timovski and Atanasova-Pacemska, 2021). Thus, the proposed methodology allows us to compare the differences between the parametric and non-parametric approaches in the performance analysis of Colombian universities.

Related work

In the literature review, we identified studies that refer to the quality control and necessity of good management of resources in social services organizations. Gálvez (2005) asserts that the quality control on social services as education has increased in recent decades. In addition, society demands transparency and accountability from social services and public organizations, which means improving quality and efficiency in using public resources (Ramirez-Gutierrez et al., 2020). Thus, we recognize several approaches to measure the HEI's performance.

In this order, mathematical models such as the Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) are probably the most widespread methods to evaluate the performance of the HEI from a perspective of efficiency analysis in both developed and developing countries (Timovski and Atanasova-Pacemska, 2021). These efficiencies analysis applied to the universities have been implemented from diverse analysis amplitudes comparing the universities' performance among continents, countries, or universities from the same country.

Concerning the comparison of universities' performance from diverse continents, we found the work developed by Wolszczak-Derlacz (2017) that evaluated the technical efficiency of public European and American HEIs using a DEA method with global, regional, country-specific frontiers. Likewise, Ramirez-Gutierrez et al. (2020) analyzed the efficiency in public higher education to compare countries from different continents (i.e., Colombia and Spain).

By contrast, some studies have analyzed the university's performance in a more homogenous global environment, specifically, in European countries. For example, Agasisti and Bertoletti (2019) employed data relating to twenty-nine European countries tested through Structural Equation Modelling. Similarly, Bruni et al., (2020) combined national (macro) and institution (micro) data from the European Tertiary Education Register to measure research and teaching activities, identifying significant differences between the European countries. Finally, in this line of work, Pastor and Serrano (2016) took the European universities identifying primary sources of heterogeneity in scientific outputs are related to the resources allocated per researcher and, to a lesser extent, the differences in efficiency within each knowledge field.

Finally, we found the analysis perspective at the institutional level where the authors compare the efficiency level of the universities to their peers or internally to benchmark their departments. For example, the study developed by Barra and Zotti (2016a) evaluates departments and faculties of a specific university applying DEA models for teaching and research activities. On its side, other authors limited the benchmarking in their studies from a criterion of a particular field of knowledge (González-Garay et al., 2019), private or public universities (De La Torre et al., 2017), or comparison among the universities in a specific country as the related in Table P.1.

Thus, Table P.1. shows relevant state-of-the-art works that analyzed the universities' performance in different countries, including Colombia. Therefore, we expose the used methods by the authors, remarking on the high presence of the SFA and DEA methods. However, the System Generalized Method Moment (sys-GMM) estimator, the Multiple Factorial Analysis (MFA) and cluster analysis techniques also have been implemented to study the university's performance. In our analysis, we proposed using DEA, SFA, and Malmquist Productivity Index (MPI) to analyze the Colombian universities.

Also, we identified that the university functions (i.e., teaching, research and knowledge transference - KT) have been partially considered in a significant part of the studies and analyzing their representative variables from a join (J) way and not separate (S) by function. In our proposal, the three missional objectives are considered jointly and separately and take into consideration the influence of external factors.

Source	Method	University functions					External factors	University sector		Country
		Teaching	Research	KT	J	S		Private	Public	
Agasisti et al., (2019b)	SFA GMM	✓	✓	✓	✓	✗	✓	✗	✓	Italy
Barra et al., (2018)	Double-bootstrap DEA SFA	✓	✓	✗	✓	✗	✓	✗	✓	Italy
Barra and Zotti (2016b)	SFA GMM	✓	✗	✗	✓	✗	✓	✓	✓	Italy
Barra and Zotti, (2016c)	DEA	✓	✗	✗	✓	✗	✗	✓	✓	Italy
De La Torre et al. (2017)	DEA	✓	✓	✓	✓	✓	✗	✗	✓	Spain
Moreno-Gómez et al. (2019)	Two-stage DEA	✓	✓	✗	✓	✓	✗	✓	✓	Colombia
Navas et al., (2020)	Cluster Analysis (K-means) DEA	✓	✓	✗	✓	✓	✗	✓	✓	Colombia
Papadimitriou and Johnes (2019)	DEA	✓	✓	✗	✓	✗	✗	✓	✓	England
Visbal-Cadavid et al. (2020)	MFA	✓	✓	✗	✓	✗	✗	✗	✓	Colombia
Visbal-Cadavid et al. (2017)	DEA	✓	✓	✗	✓	✗	✗	✗	✓	Colombia
Proposal	DEA MPI SFA	✓	✓	✓	✓	✓	✓	✓	✓	Colombia

Table P.1. Survey of relevant related studies

ABSTRACT

The National Accreditation Council certify universities with high institutional quality developed through their internal improvement processes, determined in a competitive context of decreasing demand. In this regard, it is useful to provide these universities with information about: their performance and their changes over time, reference groups, mechanisms able to achieving better performance, and analysis about possible external factors which could affect the results. This information can represent a basis for sound decision-making about resource management and policy creation that helps the regulators and policy-makers to make appropriate decisions in order to provide high quality education.

Thus, we propose a non-parametric approach, based on Data Envelopment Analysis (DEA) method, assuming variable return scale, in order to calculate the universities' performance. Moreover, a productivity index suggested by Malmquist has also been implemented to measure the changes over time of the universities' performance. We implement different combinations and variables that describe the three key missions of universities and evaluate them from a separate and a global perspective.

Finally, in order to check how external factors could affect the universities' performance, our analysis concludes implementing both non-parametric approach (double-bootstrap-DEA) and parametric approach (Stochastic Frontier Analysis-SFA) that follows a production function specification Cobb-Douglas (CD). In both approaches, we follow a truncated regression. The analysis is performed on a sample of Colombian universities, both public and private.

The analysis shows significant improvements, in terms of performance, needed to achieve university missions, in particular for research and knowledge transfer. Furthermore, the analysis shows that the Gini indicator (proxy of the poverty) influences in particular the teaching activities, while the gross domestic product (proxy of the economic development of the territory) and the age of the university (proxy of the reputational status of universities) have a strong impact on research and knowledge transfer activities. These results highlight not only interesting policy implications policy, but also the need for further research in this area.

JEL codes: C14 (Semiparametric and nonparametric methods), C44 (Operations research – Statistical decision theory), I21 (Analysis of education), I23 (Higher education – research institutions), O54 (Latin America - Caribbean)

Keywords

Higher education institutions, Data Envelopment Analysis, Malmquist Index, Truncated regression, Research, Knowledge Transfer, Teaching, Performance.

SOMMARIO

Il Consiglio Nazionale di Accreditamento certifica le università con un'elevata qualità istituzionale sviluppata attraverso i loro processi di miglioramento interno, determinato in un contesto competitivo di riduzione della domanda. A tal riguardo, è utile quindi fornire a queste università informazioni utili su: loro performance e come esse cambiano nel tempo, gruppi di riferimento, meccanismi in grado di raggiungere performance migliori, obiettivi e analisi su possibili fattori esterni che potrebbero influenzare i risultati. Queste informazioni possono rappresentare una base per un solido processo decisionale sulla gestione delle risorse e la creazione di politiche che aiutino regolatori e policy makers a prendere decisioni adeguate allo scopo di fornire un'istruzione di elevata qualità.

Pertanto, in questa tesi di ricerca, proponiamo un modello non parametrico, basato sul concetto di Data Envelopment Analysis (DEA), assumendo rendimenti di scala variabile, per calcolare le performance delle università. Inoltre, implementiamo l'indicatore di produttività, suggerito da Malmquist, per misurare cambiamenti nel tempo delle performance universitarie. Per il modello DEA, implementiamo diverse combinazioni e variabili che descrivono le tre funzioni cardine delle università, analizzandole sia isolatamente che globalmente. Infine, allo scopo di verificare come fattori esterni possano influenzare le performance delle università, l'analisi si conclude implemendando sia un approccio non-parametrico (double-bootstrap-DEA), sia un approccio parametrico (Stochastic Frontier Analysis-SFA) che segue una specificazione della funzione di produzione a' la Cobb-Douglas (CD). In entrambi gli approcci, seguiamo una regressione troncata. L'analisi è eseguita su un campione di università Colombiane, sia pubbliche che private

L'analisi mostra significativi miglioramenti, in termini di performance, necessari per raggiungere gli obiettivi delle università, in particolare per la ricerca e il trasferimento di conoscenze. Inoltre, l'analisi mostra che l'indicatore di Gini (indicatori di povertà) influenza particolarmente le attività della didattica, mentre il prodotto interno lordo (proxy dello sviluppo economico del territorio) e l'età dell'università (proxy dello stato reputazionale delle università) hanno un forte impatto sulle attività di ricerca e trasferimento di conoscenze. Questi risultati sottolineano non solo interessanti implicazioni di politica economica, ma anche la necessità di ulteriori ricerche in quest'ambito.

Codici JEL: C14 (Metodi semi-parametrici e non parametrici), C44 (Ricerca operativa - Teoria delle decisioni statistiche), I21 (Analisi dell'educazione), I23 (Educazione superiore - istituti di ricerca), O54 (America Latina - Caraibi)

Parole chiave

Istruzione Universitaria; Data Envelopment Analysis; indice di Malmquist; Stochastic Frontier Analysis; Regressione Troncata; Ricerca; Trasferimento di Conoscenze, Didattica, Performance.

1 CHAPTER

Main Institutional Variables Related to the Developing Missional Objectives of Universities

1.1. Contextualization of Higher Education and Accreditation Process in Colombia

The Ministry of National Education in Colombia is responsible for formulating policies to strengthen and promote a competitive, pertinent, and quality education system that contribute to creating opportunities that reduce inequity gaps (Ministry of National Education, 2020). The Ministry has two vice-ministries: one focuses on pre-school, primary, and secondary education; the other devoted exclusively to higher education.

Higher education in Colombia is regulated under Law 30 of 1992. This law defines higher education as a permanent process that comprehensively develops human potential. It is carried out after secondary education and aims to fully develop students and their academic or vocational training that in turn is divided into two levels: undergraduate and postgraduate. The undergraduate level prepares students for the performance of occupations such as the exercising of a particular profession or discipline like technical-professional programs, technology, or professional programs. The postgraduate level has specialized programs, master's, and doctorate degrees.

There are three different types of higher education institutions (HEI): the first is technical institutions that offer training programs in operational and instrumental occupations and specialization in their respective fields of action. The second type is university institutions and technological schools that provide academic training programs in professions and disciplines and technological schools that provide training programs in the trades and specialization programs. The third type is universities that develop scientific or technological research; academic training in occupations or fields; and the production, development, and transmission of knowledge and universal and national culture. The third type are the institutions empowered to offer master's degrees and doctorates.

According to data from the National System of Information of Higher Education (SNIES, by its Spanish acronym), there are 319 HEI in Colombia (27.27% of the public sector) of which 29 correspond to technical institutions, 48 technological schools, 138 are university institutions, and 87 are universities of which 37.93% are public and the rest are private institutions (SNIES, 2019). Currently, the picture for public and private universities is unfavorable due to the reduced the number of enrollments. In the first semester of 2016, the country counted 952.988 new students; for the same period in 2017, it had 912.468 or a decrease of 4.25%; in 2018, the decrease was 1.5% in contrast to the previous year (SNIES, 2019).

The data on the decrease in demand has generated a need for the differentiation and development of competitive advantages by HEIs (Rosario University, 2019). This is especially true for the private universities that make up 73% of the HEIs in the country and that have an income model that is 85% more dependent on tuition fees.

The Ministry of National Education must ensure quality processes in these heterogeneous universities. Therefore, it has established monitoring strategies based on the universities' self-assessments that provide evaluations of the quality of their conditions that leads to a qualified registration that allows universities to operate their programs. Following this quality assessment process, the universities can voluntarily accept a program accreditation or institutional accreditation process.

For this accreditation, the Ministry has established the National Accreditation System (SNA, by its Spanish acronym) as a set of policies, strategies, procedures as well as bodies that socially guarantee that the HEIs which voluntarily participate in this process have a high level of compliance and meet the quality requirements. The CNA emerged from Law 30 of December 28 of 1992 to lead the development and conceptual enrichment of the SNA in close collaboration with the academic and scientific communities of the country. Thus, the CNA is responsible for carrying out the analysis process that defines whether a university is granted top-quality accreditation according to established guidelines.

In this study, our focus is on the universities which have applied to the CNA and it has granted institutional accreditation. This focus reflects that the CNA has evaluated the quality conditions of these universities according to elements related to their mission and purpose for students, teachers, social relevance and impact, self-assessment processes, management, physical plant, and resources of educational support, among others.

1.2. Analysis Units

The universities for this study are Colombian HEIs, both public and private, which have obtained high-quality accreditation by the CNA. The conjunction of public and private universities is because the efficiency of process development and adequate resource management is necessary for both types of institutions working in a context where the resources are limited (Anzola Montero, 2017; Visbal-Cadavid et al., 2020). The limitation in recourses can compromise the continuity of quality in university processes. In this case, the public and private universities face the same risk for what has been considered in the same analysis group.

Thus, Colombia in October 2019 had 61 universities accredited as high quality. However, before this first data collection step, we discarded 10 based on the following considerations: First, nine of these universities were "technical institutions" or "university institutions". Second, the institution "Admiral Padilla Naval Cadets College" represents the alma mater of a Colombian naval officer that presents an entirely different dynamic in the variables than the rest of the universities considered in this work.

Among the universities that meet the selection criteria, some have two types of institutional accreditations. The first type of accreditation is granted only to the main headquarters; these universities are named in Table 1.1. The second is the multi-campus institutional accreditation in which the university's main campus and its headquarters are in different geographical locations in the country.

	University	Sector HEI	City	Region
1	EAFIT University	Private	Medellín	Western
2	University of La Sabana	Private	Chía	Central
3	University of North	Private	Barranquilla	Northern
4	Colegio Mayor de Nuestra Señora del Rosario University	Private	Bogotá	Central
5	Externado University of Colombia	Private	Bogotá	Central
6	Autonomous University de Bucaramanga - UNAB	Private	Bucaramanga	Eastern

Main institutional variables related to the developing missional objectives of universities

	University	Sector HEI	City	Region
7	De la Salle University	Private	Bogotá	Central
8	University of Caldas	Public	Manizales	West-central
9	University of Antioquia	Public	Medellín	Western
10	University of Cauca	Public	Popayán	Southern
11	Technological University of Pereira	Public	Pereira	West-central
12	University of Medellín	Private	Medellín	Western
13	University of Valle	Public	Cali	Southern
14	University of Cartagena	Public	Cartagena	Northern
15	CES University	Private	Medellín	Western
16	Industrial University of Santander UIS	Public	Bucaramanga	Eastern
17	ICESI University	Private	Cali	Southern
18	EIA University	Private	Medellín	Western
19	University of the Andes	Private	Bogotá	Central
20	University of Manizales	Private	Manizales	West-central
21	Autonomous University of Manizales	Private	Manizales	West-central
22	Technological University of Bolivar	Private	Cartagena	Northern
23	Nueva Granada Military University	Public	Bogotá	Central
24	El Bosque University	Private	Bogotá	Central
25	National Pedagogical University UPN	Public	Bogotá	Central
26	University of Magdalena	Public	Santa Marta	Northern
27	Simón Bolívar University	Private	Barranquilla	Northern
28	Francisco José de Caldas District University	Public	Bogotá	Central
29	Pontifical Bolivarian University	Private	Medellín	Western
30	University of Nariño	Public	Pasto	Southern
31	Autonomous University of West - UAO	Private	Cali	Southern
32	EAN University	Private	Bogotá	Central
33	Surcolombiana University	Public	Neiva	West-central
34	University of Quindio	Public	Armenia	West-central
35	Central University	Private	Bogotá	Central
36	University of Cordoba	Public	Montería	Northern
37	University of the Atlantic	Public	Barranquilla	Northern
38	Antonio Nariño University	Private	Bogotá	Central
39	University of Sinú - Elias Bechara Zainun - UNISINU	Private	Montería	Northern
40	Catholic University of the East (UCO)	Private	Rionegro	Western
41	University of the Coast (CUC)	Private	Barranquilla	Northern

	University	Sector HEI	City	Region
42	Catholic University of Colombia	Private	Bogotá	Central
43	University of Ibagué	Private	Ibagué	West-central

Table 1.1. Universities with institutional accreditation for single headquarters.

In Table 1.2, we list the universities with multi-campus accreditation. In this case, the main headquarter location is also called "the father location" and is highlighted in bold.

	University	Sector HEI	City	Region
1	National University of Colombia	Public	**Bogotá**	**Central**
			Medellín	Western
			Manizales	West-central
			Palmira	Southern
2	Pontifical Javeriana University	Private	**Bogotá**	**Central**
			Cali	Southern
3	Sergio Arboleda University	Private	**Bogotá**	**Central**
			Santa Marta	Northern
4	Pedagogical and Technological University of Colombia	Public	**Tunja**	**Eastern**
			Duitama	Eastern
			Sogamoso	Eastern
			Chiquinquirá	Eastern
5	Santo Tomás University	Private	**Bogotá**	**Central**
			Bucaramanga	Eastern
			Tunja	Eastern
6	Libre University	Private	**Bogotá**	**Central**
			Cali	Southern
			Barranquilla	Northern
			Pereira	West-central
			Cúcuta	Eastern
			Socorro	Eastern
7	San Buenaventura University	Private	**Cali**	**Southern**
			Medellín	Western
			Bogotá	Central
			Cartagena	Northern
8	Jorge Tadeo Lozano University	Private	**Bogotá**	**Central**
			Cartagena	Northern

Table 1.2. Universities with multi-campus institutional accreditation. *Source: The authors based in CNA information*

Thus, we have a population of 51 universities that are accredited as having high institutional quality (Table 1.1 and Table 1.2). Figure 1.1 shows the geographic locations of these universities; for the multi-campus universities, we indicate only the location of its main campus.

Figure 1.1. Geographical location of universities under study. *Source: The authors - Google maps.*

Therefore, we can identify a high density of universities accredited as high quality in the Center zone of Colombia (37.3%) that when added to the region center-west, reach 51% of the total of these universities. Similarly, the North zone has a significant accumulation of 17,6%; meanwhile, the West Zone and the South zone reach 13.7% and 11.8%, respectively; finally, the East region gets the lowest percentage with only 5.9% of the considered universities.

1.3. Data and Variables

In this subsection, we describe the main variables that can represent the universities' operations in their missional teaching, research, and knowledge transfer objectives. These variables are classified into inputs and outputs of the processes; each is defined and explained through their main descriptive statistics that represent their levels in the universities under analysis.

1.3.1. Input variables

Input variables represent the resources for developing universities' substantives objectives. Other studies have mainly used two inputs to analyze the efficiency of universities. The first input is the "students". They are measured by the numbers enrolled and their quality in terms of entry scores (González-Garay et al., 2019) or by the numbers who attended a lyceum in the Italian context (Barra and Zotti, 2016a). The second is the availability of resources to develop the missions, that is, financial (Mikušová, 2017), physical (Visbal-Cadavid et al., 2017), human, and learning resources such as the library, computing facilities, laboratories, among others (González-Garay et al., 2019; Papadimitriou and Johnes, 2019).

Of these resources, human factors are divided into two main components: academic and non-academic staff. They are defined in terms of amounts, expenditures (Visbal-Cadavid et al., 2017), and ratio. The ratio shows the staff members who spend a significant portion of their time in a specific mission (teaching and research activities) or the form of a staff-to-student balance (González-Garay et al., 2019). For the academic staff, different studies use the education level (Papadimitriou and Johnes, 2019) or the position in the universities as an essential determinant (Barra and Zotti, 2016b). Or they use the dedication time by considering only full-time staff (Wolszczak-Derlacz, 2017).

Variable	Available data	Period	Source	Data Collection	CD
Academic Staff	2013-2018	Six months	SNIES (2019)	January 2020	51
Number of enrrolled students.	2013-2018	Six months	SNIES (2019)	December 2019	51
The ratio between enrolled students and teachers	2013-2018	Six months	Calculated based in SNIES information	January 2020	51
Non-academic Staff	2013-2018	Six months	SNIES (2019)	January 2020	39

Table 1.3. Information on input variables

Considering these variables, we establish those in Table 1.3 in the analysis proposed in this thesis. For these variables, Table 1.3 shows the years in which the data are available, the period, the source of the information, the date the data were collected, and the number of universities with complete data (CD). As is possible to see, all the variables are available in six months periods. In the following analysis, these periods will be represented by “year-1” for the first semester of the respective year and “year-2” for the second one.

Academic Staff

The SNIES generates the statistics about the academic staff in Colombia. We have identified that this information is available up to 2018 and define "academic staff" as people who guide the training, teaching, and learning of university students. Therefore, the available data are:

- The number of teachers in each institution per academic semester.
- Their highest level of training.
- The time that the teacher spends on their activities.

Hence, to build the variable, we consider four education levels: doctorate, master’s, specialization, and undergraduate (Figure 1.2.). Furthermore, we specify the time spent on their teaching duties by using three types: “full-professor”, “associate”, and “lecturer”. Thus, this information is available for the period from 2013 to 2018 for their respective semesters.

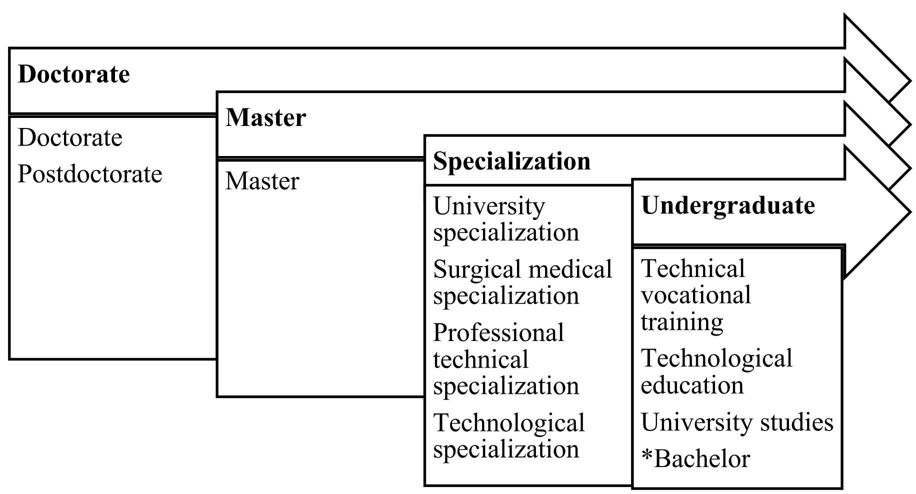

Figure 1.2. Subcategories considered by each education level

Note: Education level “Bachelor” appears in the dataset belonging to the years 2013, 2014, and 2015. We consider that such education level belongs to the category “Undergraduate” for subsequent years.

Thus, the academic staff is composed of sub-variables according to training levels and positions. We assigned a weight based on a hierarchical differentiation between the levels of the sub-variables (Table 1.4) because the level of academic and research output must be proportional.

Highest level of education		Position	
☐ Doctorate	1	☐ Full-Professor	1
☐ Master	0.8	☐ Associate	0.8
☐ Especialization	0.6	☐ Lecturer	0.6
☐ Undergraduate	0.4		

Table 1.4. Weights assigned to professors

In the dataset, we have identified some missing values. Thus, we assume these missing values as the average computed over the last two data points registered for the observed unit to have data completeness for the 51 universities that make up the database. We obtain the representative values for the academic staff of the universities with the respective weights of the data. Table 1.5 presents some statistics about this variable.

Period	Mean	Median	Min	Max	Range	St. Dev.
2013-1	599.96	498.36	82.2	2636.92	2554.72	519.72
2013-2	591.18	503.72	62.28	2679.8	2617.52	516.08
2014-1	658.31	574	36.84	3123.4	3086.56	565.25
2014-2	668.72	592.32	91.52	2978.28	2886.76	554.98
2015-1	678.68	568.32	38.56	3179.36	3140.8	583.21
2015-2	702.67	607.48	107.76	3014.56	2906.8	567.2
2016-1	722.91	610.68	101.24	3227.84	3126.6	569.05
2016-2	765.72	623.52	107.24	3103.92	2996.68	632.26
2017-1	794.19	637.64	107	3020.4	2913.4	603.31
2017-2	811.16	630.2	122.92	3429.6	3306.68	645.66
2018-1	815.67	634.24	113.4	3141.32	3027.92	627.9
2018-2	832.81	619.96	121.24	3199.76	3078.52	634.21

Table 1.5. Descriptive statistics – Academic Staff

According to Table 1.5, the central tendency presents a non-symmetrical data distribution since there is a significant difference between the mean and median in all periods. Similarly, according to the difference presented between the trimmed and the mean values, we have identified atypical data for all periods. Thus, it is possible to take the median and trimmed as the most representative statistics for the group of analyzed units.

In terms of dispersion measures, the minimum and maximum show a high dispersion that leads to large ranges of values. The standard deviation values reconfirm this dispersion. The distribution indicates a high degree of data concentration around the core values. Figure 1.3. shows the distribution and dispersion of academic staff through the boxplot for each six-month period.

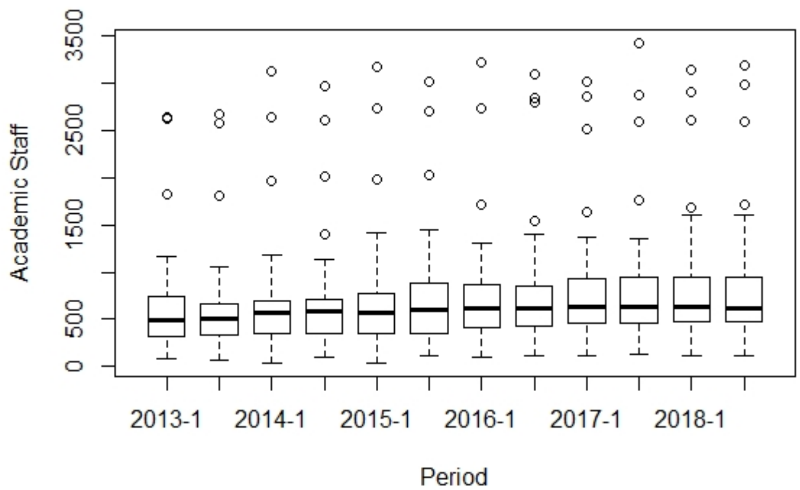

Figure 1.3. Boxplot Academic Staff

Enrolled Students

The students are a crucial part of the available human resources so that universities can carry out their substantive objectives. For this reason, we have collected the database of enrolled students from SNIES in December 2019. This variable concerns the number of students who have completed their enrollment process in diverse cohorts of academic programs in the universities under study. Table 1.6 shows some descriptive statistics related to this data.

Period	Mean	Median	Min	Max	Range	St.Dev.
2013-1	14589.43	12179	1755	51235	49480	9424.27
2013-2	14781.45	12493	1631	50898	49267	9494.31
2014-1	15211.31	13610	1752	50985	49233	9413.9
2014-2	15023.57	12871	1617	51470	49853	9169.6
2015-1	15712.76	13414	1860	52567	50707	9512.27
2015-2	15439.8	13476	1730	52685	50955	9224.41
2016-1	16292.45	14569	1936	53399	51463	9591.63

Period	Mean	Median	Min	Max	Range	St.Dev.
2016-2	15740.53	13786	1793	52601	50808	9308.42
2017-1	16383.37	14300	1996	53807	51811	9556.53
2017-2	15935.24	13915	1859	53010	51151	9351.56
2018-1	16280.33	13819	1940	53709	51769	9432.75
2018-2	15953.1	13339	1936	51811	49875	9144.69

Table 1.6. Descriptive Statistics - Enrolled Students

The statistics in Table 1.6 show a significant difference between the measures of central tendency (mean and median) that make it possible to identify an asymmetric distribution in the number of enrolled students. Also, it is possible to determine in this distribution a positive skewness over all periods and a leptokurtic distribution by their kurtosis values. Finally, the distance between the minimum and maximum values is considerable; these values and the values of the overall standard deviation show a high dispersion in the dataset. This dispersion is possible to see in Figure 1.4; with the presence of atypical values that can alter the central tendency measures, we have proceeded to eliminate the 10% of the outliers.

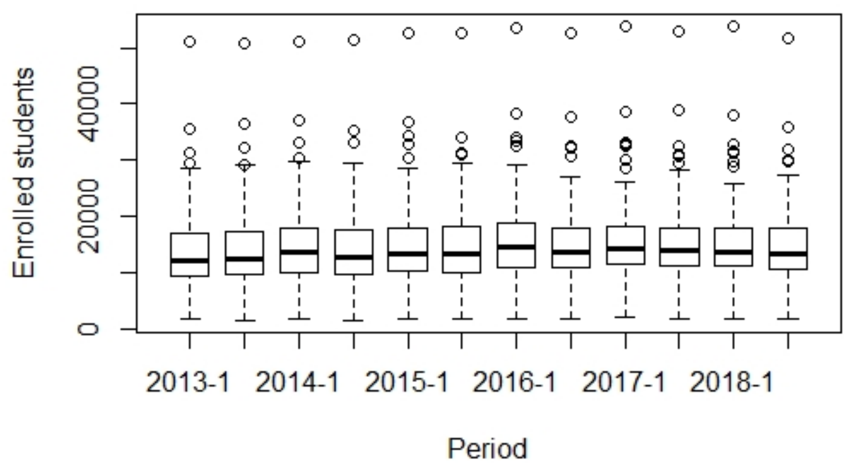

Figure 1.4. Boxplot Enrolled students

The ratio between enrolled students and teachers

The ratio between the number of enrolled students and the number of full-time professors seeks to establish the technical relationship. Thus, we can consider this indicator as an approximation of how many students are related to a professor in the different formation processes. Hence, we get the number of students enrolled in each semester between 2013 and 2018 from SNIES and divide it by the teachers' total number.

In the case of Colombia, there are no guidelines related to the quality in higher education that determine a specific number of students per teacher. CNA (2013) establishes the necessity to have for undergraduate programs enough teachers with the dedication, level of training, and experience required for the optimal development of missional objectives and the capacity to adequately attend to students. Therefore, the CNA has established that the master's and doctorate programs must demonstrate an adequate number of teachers but leaves open the possibility that this number varies from one field of science to another (CNA, 2009). However, if the number of students supported by teachers is smaller, then the students' outcomes should be of better quality. Table 1.7 shows the statistics for this variable.

Period	Mean	Median	Min	Max	Range	St.Dev.
2013-1	41.23	39.7	20.41	110.9	90.49	15.96
2013-2	49.53	39.01	19.95	382.52	362.57	57.99
2014-1	44.6	39.97	20.63	223.64	203.01	31.37
2014-2	51.06	39.69	20.62	427.09	406.47	62.88
2015-1	45.42	37.3	20.61	137.67	117.06	28.01
2015-2	40.43	36.22	20.6	201.8	181.2	27.01
2016-1	40.78	39.5	20.51	147.16	126.65	20.04
2016-2	40.29	35.65	18.04	146.98	128.94	21.87
2017-1	36.48	36.03	18.47	78.52	60.05	11.56
2017-2	35.35	34.63	15.28	74.95	59.67	11.45
2018-1	36.47	34.42	15.99	74.16	58.17	12.79
2018-2	34.59	33.07	14.6	73.77	59.17	11.98

Table 1.7. Descriptive statistics - Enrolled students and teacher ratio

The measures corresponding to the central tendency (mean and median) show a generally more pronounced differentiation in the second half of the year, with some exceptions. After eliminating 10% of the possible atypical data present for the variable, we identified a significant reduction in the mean which brings it closer to the median; but these two statistics better represent the values of most universities.

In all periods under investigation, the positive values of skewness show an asymmetry toward the right (see Figure 1.5). Further, the kurtosis indicate that the data follow a leptokurtic graph, mainly for the period between 2013-1 and 2016-2; for the remaining periods, the distribution is a little more platykurtic.

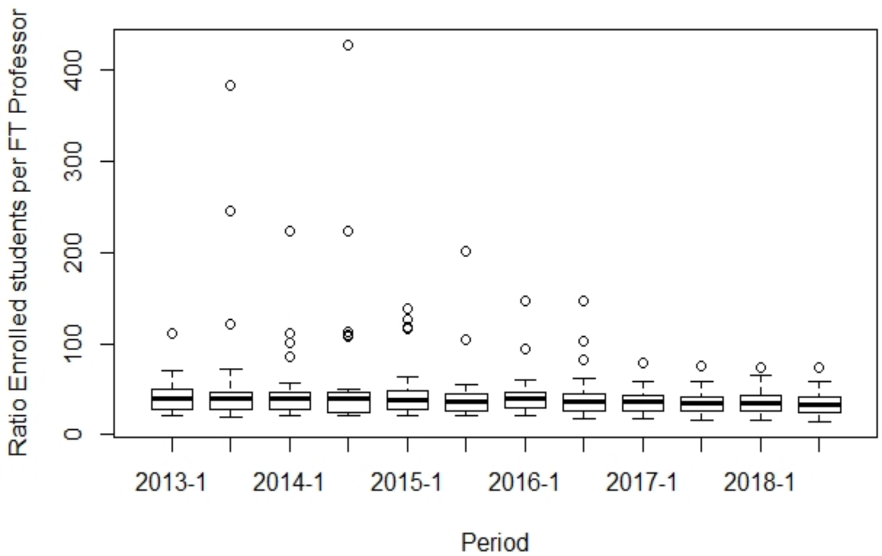

Figure 1.5. Boxplot for enrolled students and teacher ratio.

Non-academic Staff

Another critical input associated with the development of the universities' processes is the non-academic staff. This staff facilitates the proper functioning of the missional objectives and represent the part of the human resources that is available to carry out actions necessary for the adequate development of the administrative processes that support the universities.

The data for this variable comes from the statistics provided by the SNIES (2019). The database contains four types of administrative personnel: "assistant," "technical," "professional," and "manager". In order to construct one indicator, we follow Barra and Zotti (2016c) and assign the following weights: "0.4", "0.6", "0.8", and "1", respectively.

Period	Mean	Median	Min	Max	Range	St. Dev.
2013-1	430.28	303	77.4	1689	1611.6	349.99
2013-2	434.78	304.4	77.4	1689	1611.6	355.1
2014-1	432.54	327.2	83	1690.8	1607.8	323.8
2014-2	445.37	331.4	83	1690.8	1607.8	324.38
2015-1	466.81	345	87.8	1692.6	1604.8	356.23
2015-2	463.97	360.8	87.8	1692.6	1604.8	339.69
2016-1	462.79	374.6	87	1776.8	1689.8	357.3
2016-2	464.89	358.8	72.2	1776.8	1704.6	363.61

Period	Mean	Median	Min	Max	Range	St. Dev.
2017-1	483.52	372.6	72.2	1855	1782.8	395.28
2017-2	506.04	380.8	86	1855	1769	427.52
2018-1	525.73	385.4	85.4	2230.8	2145.4	468.85
2018-2	549.74	417.8	89.4	2769	2679.6	524.68

Table 1.8. Descriptive statistics – Non-academic staff

The data collected show an asymmetric distribution that is skewed to the right and is supported by a leptokurtic type in the different periods due to positive kurtosis values. In turn, the data present high dispersion as evidenced by the high values of range and standard deviation (SD). We calculated the trimmed-mean with a cut in outliers of 10% that identifies an incidence of these atypical data in the central and dispersion measures. Figure 1.6 shows the characteristics of the data distribution graphically.

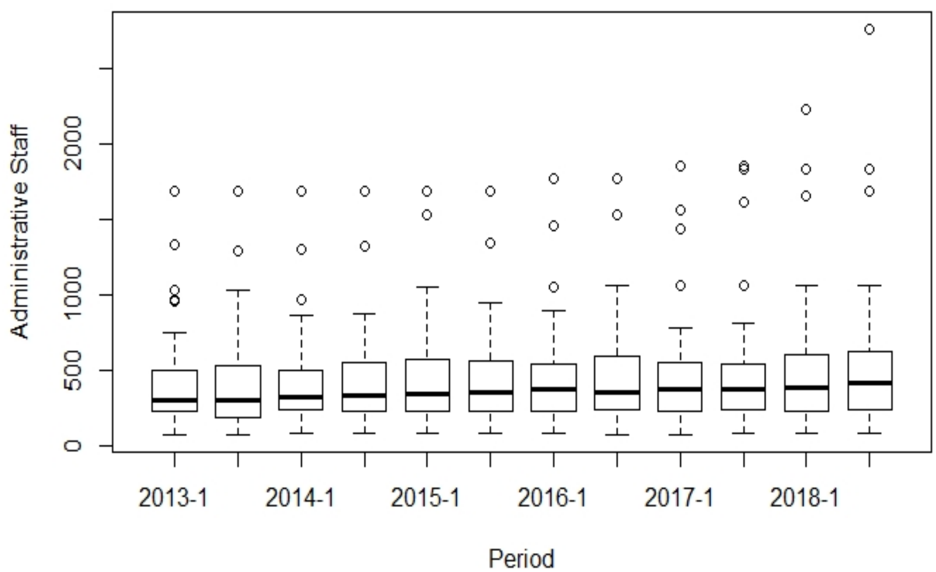

Figure 1.6. Boxplot – Non-academic Staff

1.3.2. Outputs Variables

In this subsection, we identify the output variables for the models. Some studies have analyzed the global mission of the universities by assessing their performance-based to expected outputs for teaching and research (Kudła et al., 2016) and by also adding the knowledge transfer process. For this study, we divide the variables by their respective missional objectives to reflect the differences among the universities' outputs generated by each purpose. Thus, we first identify the variables that are related to the teaching objective and then those related to the research and knowledge transfer objectives.

Substantive objective: Teaching

In the literature, some studies have considered outputs that are focused on the substantive objective of teaching, such as Barra and Zotti (2016c). These authors have proposed undesirable variables for teaching mission as outputs: drop-out, inactive enrollments, and inactive students. Also, they use graduates as an output in common with Mikušová (2017).

Similarly, authors such as Kudła et al. (2016) have analyzed the universities' performance from a global perspective and have considered graduates as an essential output. Studies have used this variable in different ways, sometimes in total amount (Wolszczak-Derlacz, 2017) and sometimes as disaggregated between postgraduate and undergraduate (Mikušová, 2017; Papadimitriou and Johnes, 2019). Barra and Zotti (2016c) have weighted graduates by their degree classification. Indeed González-Garay et al. (2019) use the employability of graduates six months after graduation as a variable.

Authors such as Barra and Zotti (2016a) have analyzed the student's satisfaction with the final degree course. González-Garay et al. (2019) have considered the value-added scores of students from enrollment to graduation by comparing their qualifications on entry to those at the end of their studies. Visbal-Cadavid et al. (2017) examine the finalization of the qualification of the academic program. They consider the students' score on a final exam for their degree without comparing with previous exams to measure the quality of the process. Kudła et al. (2016) use indicators of teaching quality specifically at the academic program level.

We selected four of these variables and adapted them to the Colombian context and the available information from the literature review. Thus, the variables are the years of high-quality accreditation, graduates, drop-out rate, and institutional average in the SABER PRO test. In addition, we generate two more variables to explore their influence on the universities' performance: registered students and institutional average by the level of aggregation in the English SABER PRO.

Table 1.9 presents the set of six outputs for representative teaching activities. For each of these, we present the respective time range with the available data, the period, data source, date of collection, and the number of universities with complete information (CD). Some variables are available in six months periods, which will be represented by "year-1" for the first semester of the respective year and "year-2" for the second one.

Variable	**Available Data**	**Period**	**Source**	**Data Collection**	**CD**
Years of the validity of accreditation in high institutional quality	Unique	Last accreditation obtained	CNA (2020)	January 2020	51
Graduates	2013-2018	Six months	SNIES (2019)	December 2019	51
Registered students	2013-2018	Six months	SNIES (2019)	January 2020	51
Drop-out rate	2013-2018	Six months	SPADIES (2019)	December 2020	51
Institutional average in SABER PRO test	2016-2018	Annual	ICFES (2020)	January 2020	51
Institutional average by level of aggregation in English SABER PRO	2016-2018	Annual	ICFES (2020)	January 2020	51

Table 1.9. Variables focus on the substantive objective of teaching

Henceforth, we justify the choice of each variable, its description, and the respective process of collecting and processing the data. To better understand these variables, the basic descriptive statistics of the data obtained from government sources that are linked to the Ministry of National Education of Colombia are also presented.

Validity of accreditation as a high-quality university

For Colombian universities, the process to obtain accreditation is voluntary. This accreditation represents a relevant result which recognizes the quality of the processes that support their mission. The CNA recommends a period of validity of such certification after the final evaluation. They take into account self-assessment, external assessment, and comments submitted by the University's academic peers.

Thus, university accreditation as high quality has the characteristic of being temporary; therefore, the minimum duration granted corresponds to four years, and the maximum to 10 years. During this time, the university must maintain the quality level in the conditions and components evaluated in the process (National Accreditation Council, 2015). According to the above, the validity becomes a significant result that accounts for the universities' processes quality and ability to hold it.

Figure 1.7 shows the years of validity for the 51 universities in which some had request accreditation for the first time and some had applied for renewal. The majority (37.3%) are universities that applied for the first time and obtained accreditation for four years. The second higher frequency is universities that renewed and received accreditation for 8 and 6 years, 19.6% and 17.6%, respectively.

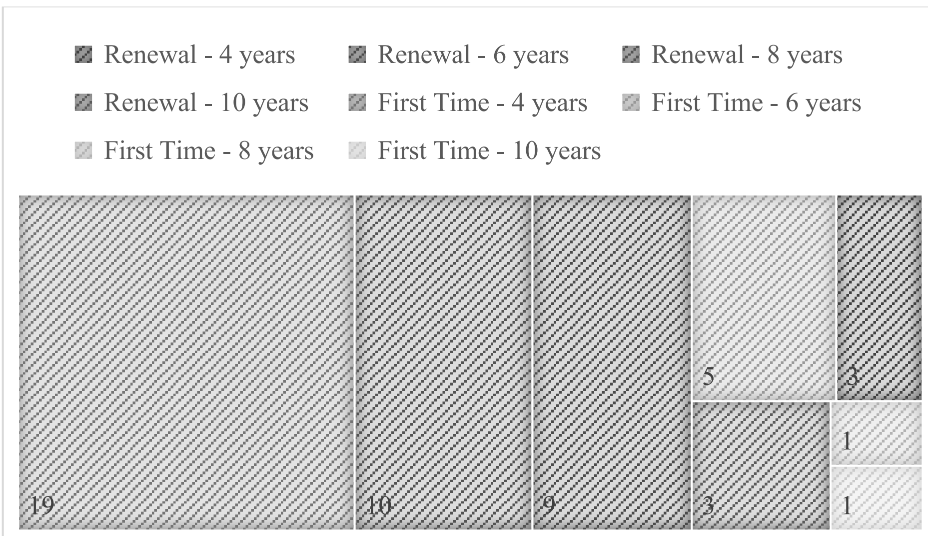

Figure 1.7. Validity of accreditation for universities under study. *Source: The authors based on CNA data.*

Less frequent cases are those where accreditation is granted in the first application for periods longer than four years; there are 9.8% of the cases at six years that is followed by a few at 8 and 10 years. In the renewal process, the least frequency is in the lower and upper limits of the accreditation periods; only 5.9% get validity for four years and the same percentage for 10 years.

Graduates

We use the total number of graduates for each university to represent this variable, regardless of their academic program or level. The data for this variable come from the SNIES statistics. We classified missing values as those that present zero values, and this value does not correspond to the trend in the rest of the data presented by a specific university. EAFIT University and Quindío University showed missing values in some periods. For these missing data, we took the average of the same two semesters corresponding to the previous years because the dynamics of the first and second semesters of the year are diverse. Table 1.10 presents the descriptive statistics corresponding to this variable.

Period	Mean	Median	Min	Max	Range	St. Dev.
2013-1	1090.59	1023	0	3218	3218	779.28
2013-2	1521.73	1386	276	4504	4228	954.31
2014-1	1174.43	1081	0	4176	4176	810.96
2014-2	1474.98	1223	289	4345	4056	954.31
2015-1	1135.47	969	0	4263	4263	843.83
2015-2	1505.27	1312	176	4623	4447	962.42
2016-1	1172.71	1074	0	4701	4701	900.3
2016-2	1706.75	1487	361	4969	4608	1064.21
2017-1	1306.9	1226	0	5272	5272	998.26
2017-2	1889.82	1649	336	5443	5107	1124.71
2018-1	1392.12	1182	0	5065	5065	987.18
2018-2	1904.78	1692	342	5632	5290	1140.11

Table 1.10. Descriptive statistics - Graduates

Table 1.10 shows higher mean values than those for the median that indicates an asymmetric distribution of the data with a bias to the right over time. Also, the positive skewness values and kurtosis indicate a distribution skewed to the right as leptokurtic. Overall, the data are concentrated around the average. However, the difference between the values of trimmed and mean shows higher outliers in this variable. Figure 1.8 displays the outliers and data trends.

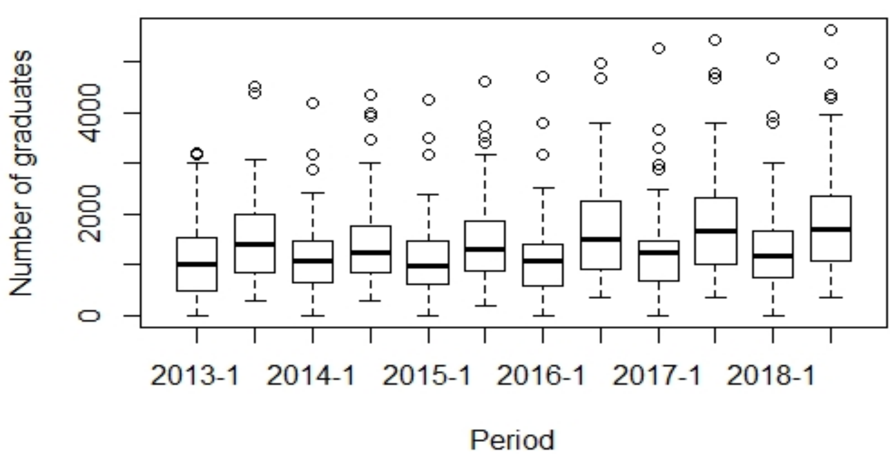

Figure 1.8. Boxplot – Number of graduates

Main institutional variables related to the developing missional objectives of universities

The boxplot displays the data's dispersion that supports the standard deviation and range values in Table 1.10. It shows that the range of the values expands in the first semesters of each year which we consider to be due to graduation policies and market trends.

Registered Students

The number of students registered corresponds to "applications from natural persons for admission to an academic program in an HEI" (SNIES, 2019). We use semester values of the academic years from 2013-2018. This variable shows a person's interest in studying in a specific university. However, it does not mean that this person becomes enrolled because that depends on the HEI's capacity and entry criteria.

This variable is proposed as an output for universities because it can give an idea of students' potential acceptance to academic programs. In addition, it could represent the image and reputation that the university projects as an option to develop professional studies and its general conditions for the educational development of the potential student market.

We identified missing values for the University of the Atlantic for which we used the average of the same semesters in the previous two years. The other missing values correspond to the University of Simón Bolívar in the period 2013-2; for this value, it was impossible to calculate in the same previous way due to the absence of data. So, we calculated the average rate of change in registrations between the semesters in two consecutive years that corresponded to a decrease of 37.7% in the registration number between the first and second semesters for this university. We applied this reduction to the figure recorded for the 2013-1 period to obtain the 2013-2.

The descriptive statistics of the dataset shown in Table 1.11 demonstrate a clear differentiation between the mean values presented in semesters 1 and 2 of each year. One of the facts that can support this difference is that most of the schools in Colombia are of "Calendar A", that is, the school year begins in February and ends in November. So, more students start their vocational studies in the first semester of the year (January - June) to graduate in November - December months.

As in the other variables, outliers are present that can generate a considerable differentiation between the mean and the trimmed mean where the latter is calculated by cutting 10% of the outliers (see Table 1.11). The mean values are larger than those of the median, and the positive skewness values show an asymmetric distribution with a bias to the right that is leptokurtic considering the positive values in kurtosis.

Period	Mean	Median	Min	Max	Range	St. Dev.
2013-1	7935.75	5434	560	75819	75259	11793.88
2013-2	4944.63	3795	244	34836	34592	5250.67
2014-1	6920.57	4822	554	46360	45806	7492.69
2014-2	4659.22	3553	248	32187	31939	4728.41
2015-1	7232	6131	773	48109	47336	7093.88
2015-2	5106.12	4578	232	36349	36117	5260.91
2016-1	8642.76	6781	853	50420	49567	8011.74
2016-2	6363.18	4244	220	40775	40555	7494.21
2017-1	10083.22	6390	773	70765	69992	12609.44
2017-2	6625.65	4243	203	43982	43779	8458.72
2018-1	10099.29	6135	428	68927	68499	13483.34
2018-2	6589.31	4283	303	43625	43322	8436.49

Table 1.11. Descriptive statistics – Registered students

The boxplot of Figure 1.9 shows outliers in the data distribution for each period analyzed. In particular, in both semesters of the year 2017 and the first semester of 2018 and 2013 (2018-1 and 2013-1, respectively), that present also the highest standard deviation, as shown in Table 1.11.

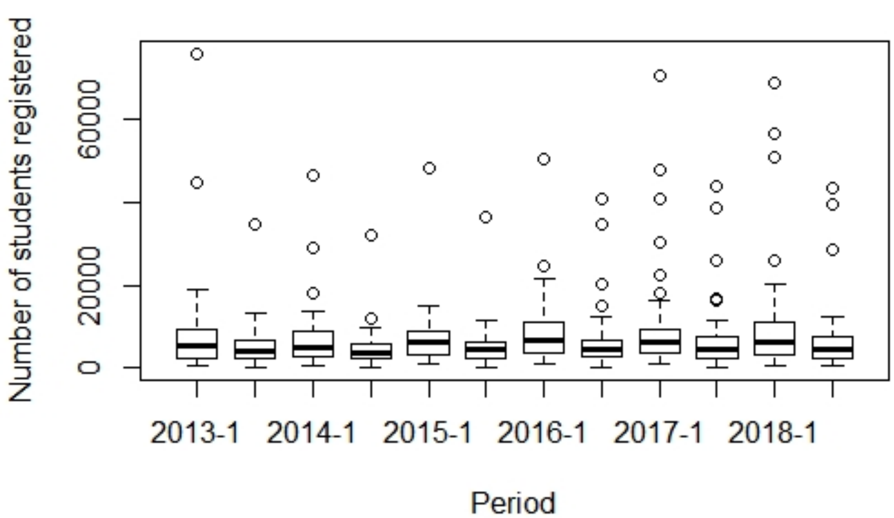

Figure 1.9. Boxplot – Registered students

Drop-out rate

The System for the Prevention of Dropout from Higher Education (SPADIES, 2020) defines a dropout as:

"Status of a student who voluntarily or forcibly fails to register for two or more consecutive academic periods to the program in which he enrolled; and this is not found as a graduate or retired for disciplinary reasons. Dropout results from the effect of different factors such as individual, academic, institutional, and socio-economic."

This undesirable output has its values are in percentage terms and are based on information from SPADIES. Thus, we take the percentages corresponding to the academic semesters of the years between 2013 and 2018; the respective descriptive statistics are in Table 1.12. Unlike other variables, the drop-out variable presents central, median, and mean trend values that coincide in seven semesters and show a symmetrical flared distribution. This distribution is corroborated by the skewness values close to zero and positive kurtosis values. On the other hand, the rest of the semesters present leptokurtic and platykurtic distributions.

Period	Mean	Median	Trimmed	Skew	Kurtosis	Min	Max	Range	St. Dev.
2013-1	0.11	0.11	0.1	1.96	5.64	0.05	0.31	0.26	0.05
2013-2	0.11	0.11	0.11	1.47	4.39	0.06	0.28	0.22	0.04
2014-1	0.1	0.11	0.1	0.22	-0.55	0.05	0.19	0.14	0.03
2014-2	0.11	0.11	0.11	0.72	0.28	0.03	0.23	0.2	0.04
2015-1	0.11	0.1	0.1	1.71	5.11	0.05	0.28	0.22	0.04
2015-2	0.1	0.1	0.1	-0.04	-0.3	0.03	0.17	0.14	0.03
2016-1	0.1	0.1	0.1	1.29	3.5	0.03	0.22	0.19	0.03
2016-2	0.1	0.1	0.1	0.32	-0.06	0.03	0.17	0.14	0.03
2017-1	0.12	0.11	0.11	1.01	1.68	0.04	0.26	0.22	0.04
2017-2	0.12	0.11	0.12	0.83	0.78	0.04	0.24	0.2	0.04
2018-1	0.11	0.11	0.11	1.44	3.62	0.02	0.3	0.28	0.05
2018-2	0.1	0.1	0.1	0.61	0.5	0.03	0.21	0.18	0.04

Table 1.12. Descriptive statistics Drop-out rate

In 9 of the 12 periods, the trimmed value and the mean are equal, which means a low presence of outliers or a concentration closer to the majority of data. However, the range and standard deviation of Table 1.12 (which describe the dispersion) are not high for this variable in general. But, another particularity of this variable is the presence of outliers that make part of the upper mustache and the lower part of the data (Figure 1.10).

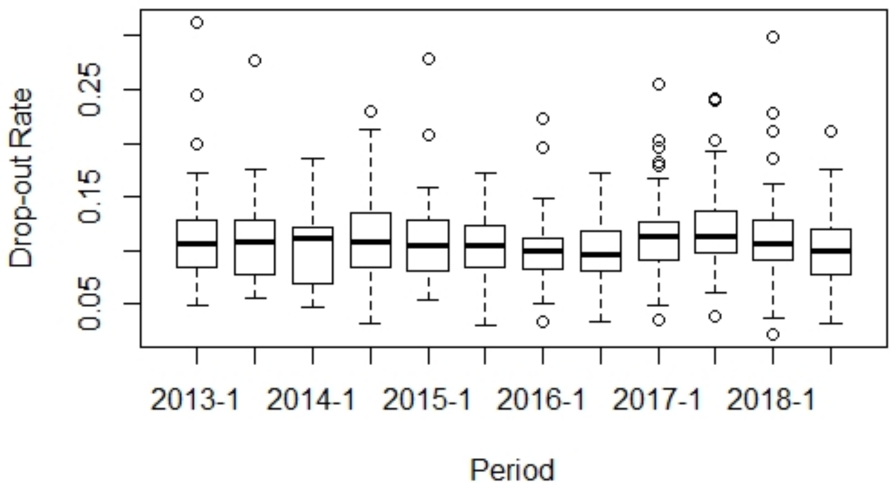

Figure 1.10. Boxplot Drop-out Rate

University average in SABER PRO test

ICFES is a state entity linked to the Ministry of National Education. It is responsible for providing the evaluation services to educational systems at all levels. These services are called "state examinations" and services complementary to research that allows improvement and decision-making for the quality of education (ICFES, 2020).

Thus, for higher education, the presentation of SABERPRO tests is compulsory because this is one of the instruments available to the National Government to evaluate the quality of the educational system. The examination has diverse modules to assess the generic and specific skills provided to future graduates in their training area.

As the variable value, we use the "average of the global score" from the historical reports of the HEIs analyzed by the ICFES. This average is expressed on a scale of 0 to 300 from the results obtained by students in the generic competencies module that is evaluated for all training programs, as it is considered indispensable for academic and work development.

Period	Mean	Median	Min	Max	Range	St. Dev.
2016	159.67	159	139	189	50	12.04
2017	157.24	156	137	189	52	12.31
2018	158.02	156	137	190	53	12.22

Table 1.13. Descriptive statistics – Institutional average SABER PRO test

The measures of central tendency show a distribution with a slight bias to the right for the three years that this variable is analyzed for because there is not a high difference between the mean and the median values. On the other hand, the difference between the average and trimmed mean, although it is not high, represents the meager existence of values that can be considered atypical in the data group. The boxplot displayed in Figure 1.11 shows the distribution and the values that are outliers.

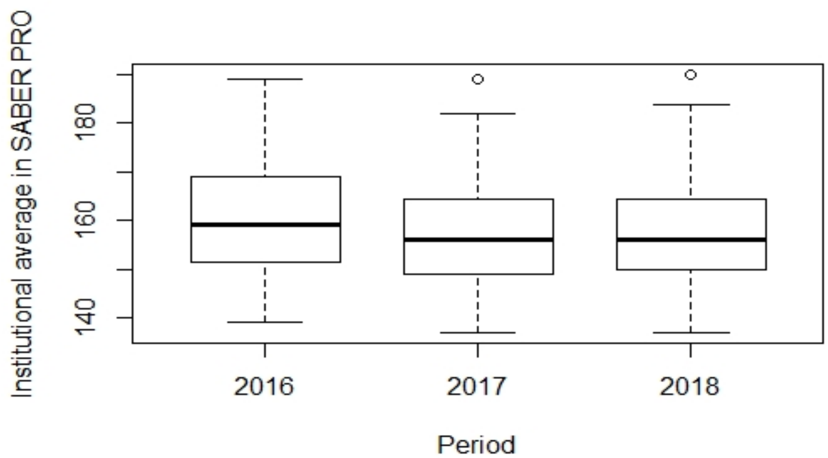

Figure 1.11. Boxplot – Institutional Average SABER PRO Test

The skewness shows a symmetrical curve with a slight tendency for negative values and a platykurtic distribution for this variable (Table 1.13). Finally, there is a low dispersion of the data relative to the mean and a relatively concentrated range of the data in the different periods.

University average by the level of aggregation in English SABER PRO

This variable is proposed in this study because of the Colombian context due to the government's promotion of English through education strategies and programs to drive bilingualism. Mackenzie (2020) asserts that the Ministry of Education uses "bilingualism" to refer to English-Spanish. The English language is the only one evaluated in the state examinations through the SABER PRO test.

Within the generic competencies evaluated in the SABER PRO exam, there is a specific module to measure English performance as a second language that is aligned with the Common European Reference Framework (CEFR) for languages. This measure classifies performance into five levels: -A1, A1, A2, B1, and B2. However, we used the qualification method of the Colombian Institute for the Evaluation of Education (ICFES) that uses a scale of 0 to 300 for the historical results report for this competence. The data are annually obtained for the period from 2016-2018; the main descriptive statistics are in Table 1.14.

Period	Mean	Median	Min	Max	Range	St. Dev.
2016	164.65	164	138	213	75	19.21
2017	164.75	161	139	209	70	18.17
2018	165.67	161	140	210	70	18.16

Table 1.14. Descriptive statistics – Institutional average in English SABER PRO

The statistics show no high variation in the different periods observed, with the mean being higher than the median. The positive skewness values suppose an asymmetric distribution with a bias to the right and platykurtic type by its negative kurtosis values. The difference between trimmed mean and mean shows atypical values that are also visible in Figure 1.12. The dispersion of data tends to be high, supported by the range values.

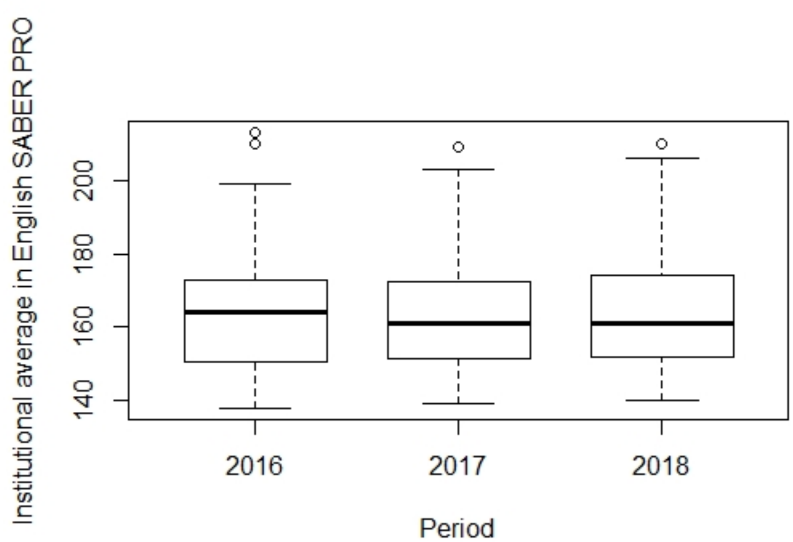

Figure 1.12. Boxplot - Institutional average in English SABER PRO

Substantive Research and Knowledge transfer Objectives

According to Restrepo (2003), the quality of higher education in a knowledge society is intimately associated with the practice of research that can be manifested in two ways: teaching to research and doing research. Research as a substantive component of HEIs is considered by Law 30 of 1992 as the search for knowledge generation. In this way, the selection of variables for this component sought to represent both the process of training new researchers and the generation and socialization of knowledge through different means.

Similarly, in the variables selected, we sought the representativeness of the knowledge transfer (KT) as the third mission of the universities (Laredo, 2007). Research and KT occur together, considering that research is an essential basis for the development of activities that allow the HEIs to interact and contribute to their communities' social, regional, and economic development.

According to the literature, we can identify some outputs as representative of these missional objectives. One of these is the category obtained in the research assessment by groups, faculties, and departments (González-Garay et al., 2019) usually represented by weighted indicators due to the categorization of research activities. The categories of research products or classifications are proportional to the researchers' efforts and the quality of research (Kudła et al., 2016).

The publications are one of the most used outputs to represent the research activities. Usually, its indicator is the quantity and quality of scientific articles expressed as i) proportion (e.g., publications per academic staff member) (Wolszczak-Derlacz, 2017); or ii) a composed indicator for journals, books, or other products weighted according to their importance and impact (Barra and Zotti, 2016a). However, Pastor and Serrano, (2016) show the necessity of considering more indicators than publishing to represent the research production in some contexts because publications probably do not constitute a positive relationship with other possible products, for example, patents.

About the KT outputs, De La Torre et al. (2017) find two leading indicators: the number of spin-offs and the intellectual or industrial property (i.e., licenses on national patents, confidentiality agreements to protect know-how, material transfer agreements, among others).

Thus, we propose different variables in the production set that consider the quality of scientific output can change according to the university specialization and field of science and technology (Pastor and Serrano, 2016). Thus, Table 1.15 shows the selected variables of the HEI's substantive objectives of research and KT; for each of these, the available data are specified for the periods in which the source, time of data collection, and the number of universities for which we have complete data are available.

Variable	Available data	Period	Source	Data collection	CD
Position of the university in SCIMAGO Institutions Rankings	Ranking Scimago 2019	Annual 2019	CNA (2020)	January 2020	51
Research groups in Colciencias	Call Colciencias 2017	Unique for call	Colciencias (2018)	January 2020	51
Publications	Call Colciencias 2017	Unique for call	Colciencias (2018)	January 2020	51
Books result of research	Call Colciencias 2017	Unique for call	Colciencias (2018)	January 2020	51
Invention patents	Call Colciencias 2017	Unique for call	Colciencias (2018)	January 2020	51
Participation in scientific events	Call Colciencias 2017	Unique for call	Colciencias (2018)	January 2020	51
Products of research training	Call Colciencias 2017	Unique for call	Colciencias (2018)	January 2020	51

Table 1.15. Outputs focus on research and KT

The primary data source for the variables is Colciencias (now Ministry of Science, Technology, and Innovation - Minciencias) which is in charge of the National System of Science, Technology, and Innovation (SNCTI). The SNCTI generates calls for resources, training, and measurement as part of its function. Within the calls to measure, they give a category according to the output generated by both researchers and research groups.

The information from Minciencias to categorize the research group comes from the registration made by the researchers of a university from their respective curriculum vitae called "CvLac", and each of these is linked to a research group. Thus, each research group presents their research and KT production resume through a platform called "GrupLac". Similarly, the research groups must be endorsed by a respective university, from their profile "Institulac". In conclusion, the data showed by Minciencias are supplied by the universities' researchers and corroborated in each measurement call.

Hence, we considered the information registered and evaluated in the call "Colciencias 781, recognition of research groups and researchers 2017" (Colciencias, 2017) as being the latest data available on the platform at the date of information collection. The call closed on 25 July 2017, with differentiated observations window depending on research products. This measurement process weights each product according to its relative relevance to other products of the same subtype (Colciencias, 2017). These weights are the basis for establishing the weighted indicators for some research products and are shown in Table 1.16 with their respective categories, relative importance, and the weighting used in this study.

Variable	Category (Colciencias, 2017)	Relative weight (Colciencias, 2017)	Relative weight used
Research group	A1	10	1
	A2	7.5	0.75
	B	5	0.5
	C	2.5	0.25
	Recognized	1	0.1
Scientific events	A	10	1
	B	6	0.6
Invention patents	PA1	10	1
	PA2	7	0.7
	PA3	6	0.6
	PA4	5.5	0.55
Theses	DT_A	10	1
	DT_B	5	0.5
	MT_A	10	0.8
	MT_B	5	0.4
	UT_A	10	0.6
	UT_B	5	0.3
Chapter books	A1	10	1
	A	9	0,9
	B	8	0,8
Book	A1	10	1
	A	9	0.9
	B	8	0.8
Publications	A1	10	1
	A2	6	0.6
	B	3.5	0.35
	C	2	0.2

Table 1.16. Weights for output research variables

Main institutional variables related to the developing missional objectives of universities

Next, we present the concept of each variable, whether weighted or not, and some explicative assumptions to understand the representative data for each. Finally, we develop a general analysis with the descriptive statistics of variables available to represent the research and KT objectives.

Position of the universities in SCIMAGO Institutions Rankings

Scimago Institutions Rankings is an evaluative process applied to institutions and universities focused on research at a global level. The rankings classify the universities according to an indicator that combines representative variables of research performance, results of innovation, and social impact (Scimago, 2020).

The ranking presents the universities' position in a global range and at the national level. For this study, we considered the position at the national level so that the comparison is under a context of similar conditions and scales. In terms of an output variable in a production set, a smaller number indicates the university's better performance.

In Colombia's case, there are 33 institutions from different sectors ranked in Scimago 2019 of which 31 correspond to HEI and 27 are classified as a part of the present research (Figure 1.13) with the remainder absent from the ranking (24 universities). The unranked universities were given a high number, and universities with the same score are ranked the same.

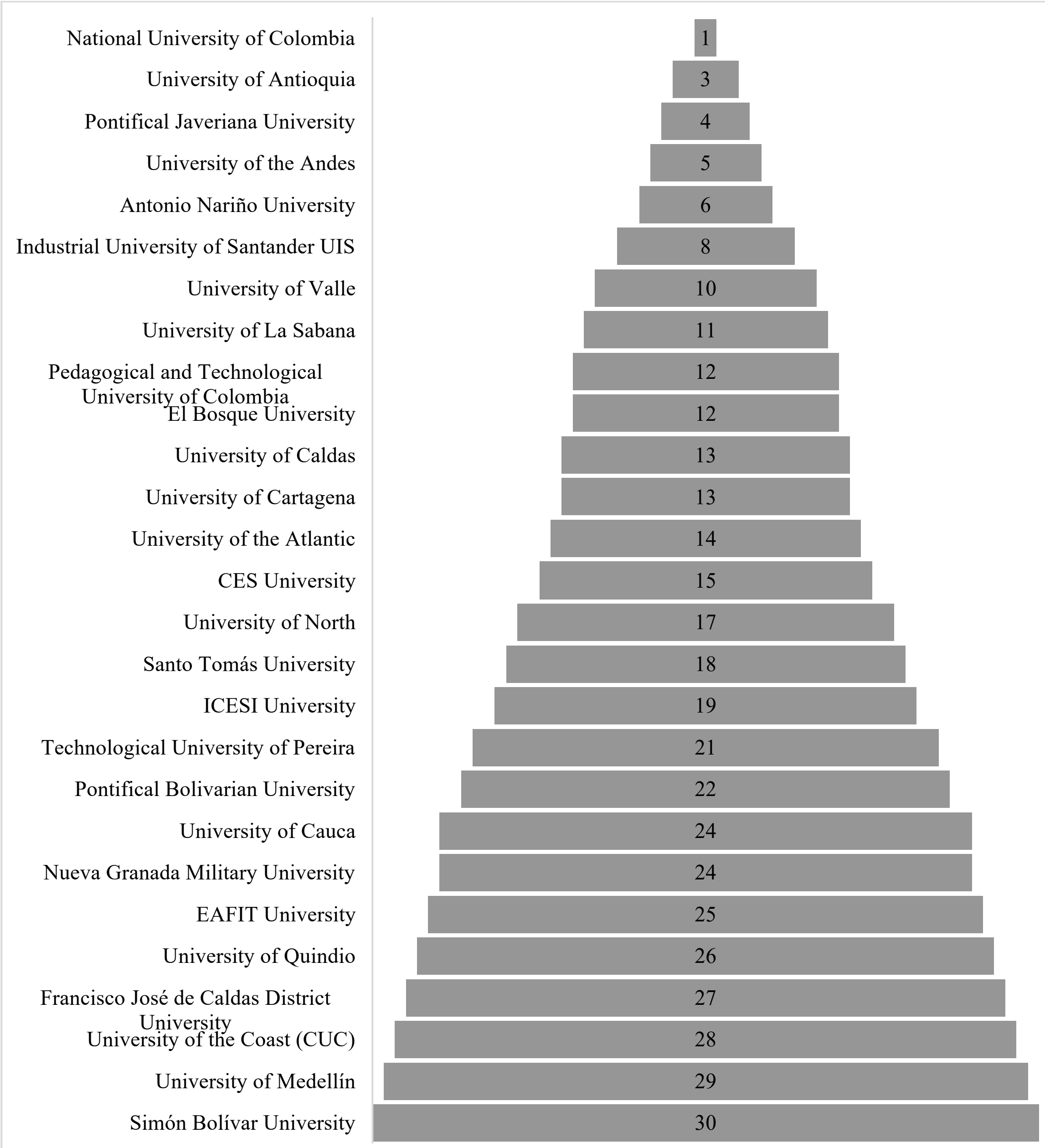

Figure 1.13. National position in Scimago ranking. *Source: The authors based on* (Scimago, 2020).

Research groups

The indicator of the research group is 781 for the measurement in which Colciencias analyzed the production of Colombian research, technological development, and innovation groups (Colciencias, 2017). The categorization of groups depends on the calculation of different indicators due to production, cohesion, cooperation, and compliance with a set of predisposed requirements of existence and researchers. These categories are A1, A, B, C, and recognized.

This hierarchical categorization demonstrates the level of scientific production, cooperation, and cohesion of the research groups. To consolidate only one indicator per the total number of groups of the universities studied, we weighted them with the weights in Table 1.16 that generate proportional scores to categories.

This study considers that research groups (RG) can be input or output depending on the analysis objective. This variable is viewed as an input that corresponds to the heightened capabilities and scientific production experience of the universities. On the other hand, RG can be an output due to researchers' efforts to obtain a category that denotes the quality of the research developed (Kudła et al., 2016).

Publications

Colciencias categorizes publications into five categories according to the journal's impact that they were published in. The journals must be indexed in bases defined by Colciencias to guarantee their scientific quality policies (see Table 1.17). In addition to the categories listed in Table 1.17, there is a category D for publications in journals linked to two or more bibliographical bases contained in the list "Indexing and Summary Systems" (Colciencias, 2017). However, for calculating the publications' indicator, we consider only the categories in Table 1.17 weighted according to Table 1.16 in which category D publications do not have significant national and international impacts.

Category	**Impact**		**Position in databases ISI or SCOPUS**
	International	National	
A1	High	High	First quartile
A2	Middle - High	High	Second quartile
B	Middle - Low	Middle - High	Third quartile
C*	Low	Middle - Low	Fourth quartile

Table 1.17. Publication categories and impacts. *Source: The authors based in information from Bruno Kessler Foundation (2020) and Publindex (2019)*.

*Note: The category C additionally considers ranked in the indexes: Index Medicus, Psyc INFO, Arts and Humanities Citation Index (AandHCI).

Books that result from research

The books that result from research are products of new knowledge generation; thus, they are unpublished and original publications in which the results of the research process are dated. This product must comply with an evaluation process by at least two academic peers and editorial procedures before publication (Colciencias, 2017).

Colciencias (2017) generates three quality levels for this type of product. The categories A1 and A denote a higher quality. A1 has to be cited in category A1, A2, B, or C journals or category B books. A requires being cited in category D journals. Finally, Type B books are those appearing in the Book Citation Index (BCI) ISI, or in effect, books that meet all of the requirements of existence set out in the "Book review guide research result" of Colciencias.

The categories above represent the books' quality levels and impact and have relative weights established by Colciencias, which are the basis for the weights proposed to calculate the indicator representative of this variable in this study (See Table 1.16).

Book chapters

The book chapters are original and unpublished publications that are the result of research processes that make up the whole of a collaboration book and meet evaluation criteria by academic peers of the respective area of knowledge. In addition, the editorial procedures guarantee bibliographic standardization and availability (Colciencias, 2017).

Like the research books, the book chapters have the following categories A1, A, and B. The differentiation for the first category corresponds to chapters cited in A1, A2, B, or C journals, or books in category B. In contrast, the type A chapters are cited in journals of category D. Finally, chapters of book type B are those published in research books present in BCI or that meet all the requirements proposed by Colciencias (2017). According to these categories, Table 1.16 shows the relative weights assigned by Colciencias for the types of book chapters and those used for the representative indicator of this variable in the present study.

Invention patents (IP)

According to De La Torre et al. (2017), the KT can be represented by intellectual and industrial property indicators. Hence, we selected *IP* because they are one of the most used indicators in the literature. In addition, other possible variables that represent KT objectives, such as spin-offs and start-ups, have low or no levels for many Colombian universities.

The invention patents are titles of property granted by the government (in this case Colombian) that confer on its holder the exclusive right to protection of a "new product or process that offers a new way of doing something, or a new solution technique to a problem" (Colciencias, 2017, pp. 44). To gain an invention patent, the product or method must be newfangled, inventive, and capable of industrial application.

The status of the process for an invention patent defines its category. "Type A" is a patent with the process finished and granted, "Type B" is the process of awarding the final concept for patenting, and "Type C" represents an application for obtaining the patent that is supported by an operating contract for the product or method.

For a higher differentiation among the three categories, we took the four subcategories of type A patents that differ from each other according to the method of obtaining the patent (i.e., PCT or traditional) and the existence or absence of the product and contract. Thus, the PA1 and PA3 correspond to invention patents obtained via PCT; PA1 through a product or warrant, and PA3 without a product or a contract. PA2 and PA4 are acquired by traditional means; PA2 through a product or warrant, and PA4 through either. Table 1.16 displays the relative weights assigned by Colciencias for each of the four sub-types of innovation patents. Based on these, we have proposed the weights for the calculation of the representative indicator of this variable.

Participation in scientific events

Participation in scientific events represents the social appropriation of knowledge through circulation, discussion, testing, using, and bringing it to everyday life through strategies of collective participation (Colciencias, 2017).

This kind of circulation of specialized knowledge promotes the socialization among communities of experts and various social actors. With this purpose, the researchers participate in scientific, technological, and innovation events, such as congresses, seminars, forums, discussions, workshops, among other spaces dedicated to analyzing and discussing cases of new knowledge generation. Table 1.16 shows the categories and relative weights.

Research training products

One kind of research practice is teaching research (Restrepo, 2003). Thus, we have selected the advising that professors provide students for their theses or degrees (professional level, master´s, and doctoral) to represent the process of training new researchers through the use of research groups as recommended by Colciencias (2017) as a space to develop these activities.

The measurement model of Colciencias considers two subdivisions to determine the quality of a thesis: Type A is when the work receives an acknowledgment for its contribution and quality, Type B is the case when the job developed garners a certificate or degree without special recognition. These types exist for a thesis at each level of training (doctoral thesis (DT), master's thesis (MT), and undergraduate thesis (UT)).

Again, Table 1.16 shows the differentiated relative weight proposed for the works with recognitions and those that did not obtain them. The weights proposed in this study use the Colciencias weighting as the baseline by maintaining that the ratio between jobs with distinction and those not at the same level is one to two, with the respective differentiation by the level of study, on a scale of zero to one.

Descriptive analysis research variables

This section presents the main descriptive statistics for the variables regarding the objectives of research and KT. Table 1.18 shows the variables considered in this analysis concerning the indicators taken from Colciencias (2017). The data extracted from (Scimago, 2020) were analyzed previously because they are common.

Variable	Mean	Median	Min	Max	Range	St. Dev.
Research Groups	2.24	18.55	4	295.55	291.55	46
Publications	594.49	277.15	10.9	6975.35	6964.45	1151.68
Books	92.5	55.2	0.8	675.9	675.1	108.48
Book chapters	103.92	69.9	2.4	784.6	782.2	131.08
Patent	2.59	0.55	0	18.1	18.1	4.65
Scientific events	1045.39	715.2	106.6	6863.6	6757	1136.69
Theses	721.61	495.6	108.2	4143.3	4035.1	718.39

Table 1.18. General descriptive statistics (research outputs)

The data related to the variable "Research groups" are represented by an asymmetric distribution biased to the right; this is clear since the mean of these data are higher than the median and the skewness has a positive value. According to the kurtosis value, this distribution has a leptokurtic characteristic that means most of the data are located around the mean. Despite having such a concentration, we find a significant difference between the trimmed and the mean that shows the presence of outliers that affect the measures of central tendency and the dispersion measures (Figure 1.14).

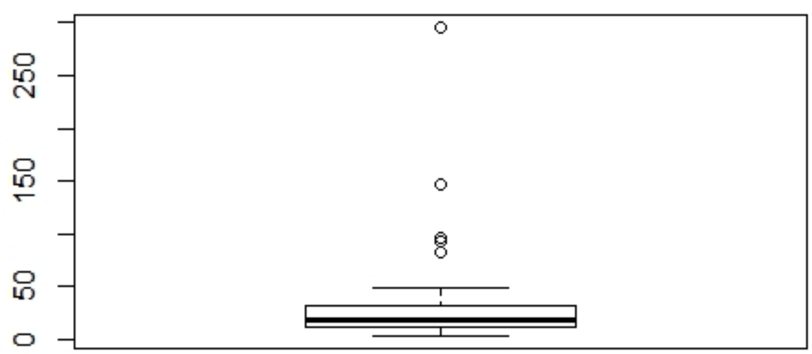

Figure 1.14. Boxplot - Research Groups

On the other hand, the variables "publications" and "participation in scientific events" present the most significant values for the range and the standard deviation that reflects a high dispersion. Moreover, most of the data are around the mean values, as shown by the leptokurtic characteristic and by the positive values of kurtosis. However, the presence of outliers (Figure 1.15) affects their dispersion and central tendency values that also allows the identification of the asymmetric distribution biased to the right for both variables.

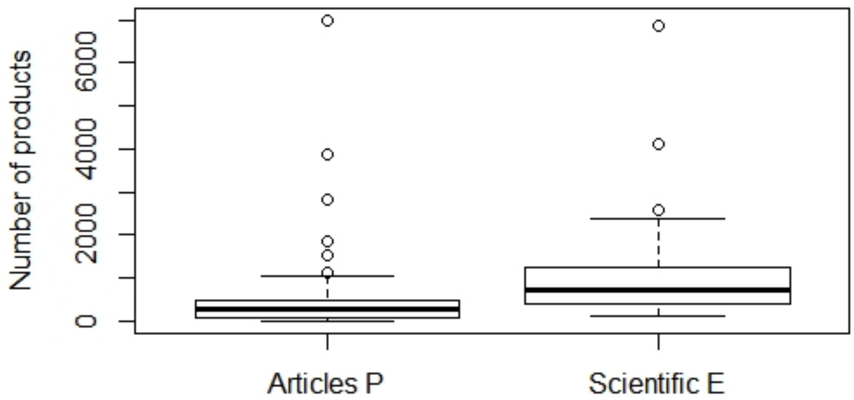

Figure 1.15. Boxplot Publications and Scientific Events

Similarly, the variables “books” and “book chapters” have similar dispersion values. They keep high ranges and high standard deviations that represent a considerable difference in these values among the universities. Their measurement of central tendency allows us to identify an asymmetry biased to the right in both cases that shows a data concentration around the mean value (positive skewness). Moreover, it is possible to see the presence of some outliers (Figure 1.16).

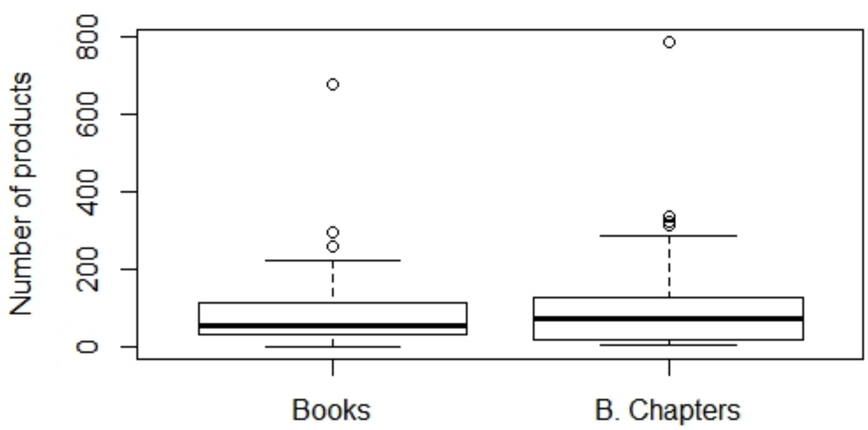

Figure 1.16. Boxplot – Books and Book Chapters.

The data relating to the variable “patents” show the lowest values of the variables considered in this analysis because the research and the patent generation processes were in an early phase when Colciencias measured them. Nowadays, such improvement strategies are still in progress. Thus, the few universities that already had invention patents are mainly considered outliers among the observed universities (see Figure 1.17). However, these data also have large dispersion values and a distribution similar to the previous variables, being asymmetric with a biased to the right and with a considerable concentration of data around the mean value.

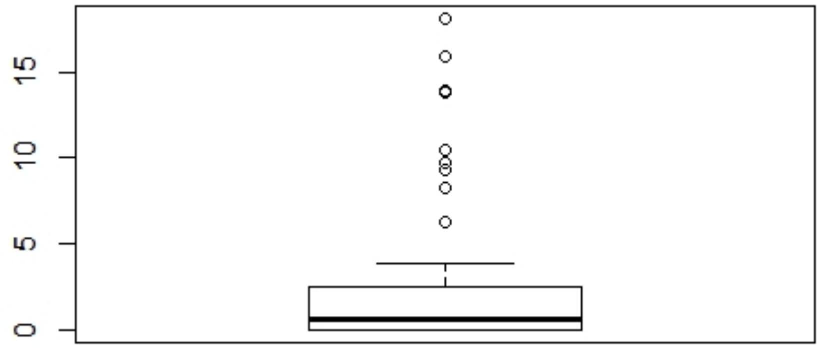

Figure 1.17. Boxplot - Patents

Finally, the variable related to the training in research, named "thesis," presents similar characteristics to the rest of the variables in that it has an asymmetric distribution biased to the right with a considerable concentration of data around the mean. For this case, we also have outliers (Figure 1.18) that generate a remarkable difference in the mean value compared with the trimmed mean that is a central tendency statistic that more properly represents the data.

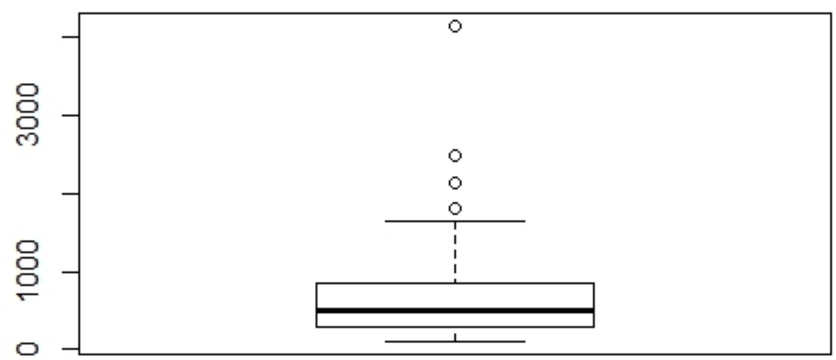

Figure 1.18. Boxplot – Thesis

1.4. Summary

In this chapter, we define the main variables by using the available information to represent the missional objectives of the universities: teaching, research, and knowledge transference. Thus, the information contained in this chapter sets up the possibility to equalize the production sets to analyze the performance of the universities from different perspectives and methodological strategies.

Concerning the decision-making units, we have established that 61 universities have obtained accreditation as high quality by November 2019. However, in the first analysis, we discard 10 institutions as they are not categorized as universities or have a different dynamic due to representing a diverse training mission. Thus, this chapter uses the available information for the 51 universities identified.

Although we selected 51 universities, the variable non-academic staff from SNIES had complete data for only 39. Considering this variable as an essential input to universities' performance, we obtained the data from different information sources for 50 universities. Thus, based on the criteria of missing information, we do not consider the University of Cordoba. To conclude, the dataset for the following analysis refers to 50 Colombian universities with accreditation as high quality by the CNA (66% of them are private, and the remaining 34% are public). According to the data availability, we use the annual figures from the academic years from 2016 to 2018.

We selected the period 2016-2018 according to limitations in the information availability and a change in the guidelines for high-quality institutional accreditation. Regarding the information available, we identify an inconvenience for a critical variable related to a government test that students must take before obtaining an undergraduate title. The Colombian National Institute for Promoting Superior Education (ICFES by its acronym in Spanish) changed the evaluation scale for the Saber PRO exam that is applied for professional academic programs. Thus, from Resolution 892 of 2015, the evaluation scale was zero as the minimum value, a maximum of 300, a Standard Deviation (SD) equal to 30, and a mean of 150. In this order, with a change in the scale, evaluation is not comparable with previous data. On the other hand, the National Accreditation Council (2015) applied changes to the guidelines for high-quality institutional accreditation, which is the common characteristic of the selected analysis group for this study. Finally, the construction of the database was in the first half of the year 2019, so the last year with available information was 2018.

The database was constructed using data from SNIES, Colciencias (currently Ministry of Science, Technology, and Innovation - Minciencias), Colombian National Institute for Promoting Superior

Education (ICFES), SCIMAGO Institutions Rankings, the CNA, and the official websites of the universities.

Among the input variables, we considered five to represent the necessary resources for developing the university´s research, teaching, and KT objectives that are mainly linked to human resources and their expertise to develop processes in the universities. On the other hand, we use 13 variables to represent the three substantive objectives outputs of universities. Table 1.19. shows the descriptive statistics that we explicitly calculated for the period that account for the input and output variables chosen for the combinations of production sets that will support the application of the empirical methodologies selected in this study.

Category	**Variable**	**Min**	**Max**	**Mean**	**SD**
Input	*AS*	104.24	3225	639.386	616.371
	ES	1864.5	53408.5	13786.467	9413.845
	NAS	83.4	2499.9	364.051	401.325
	RST	15.30	88.43	34.447	12.297
Outputs	*VAHI*	4	10	5.616	1.965
	GRA	336	10057	2636.817	1934.038
	RS	731	114747	10530.240	19396.505
	DOR	0.034	0.248	0.104	0.035
	SPT	137	190	158.203	12.025
	SPE	138	213	164.532	18.274
	SCI	1	31	-	-
	PUB	10.9	6975.35	237.102	1155.012
	PRT	108.2	4143.3	508.027	719.341
	PSE	106.6	6863.6	729.775	1136.195
	BRR	0.8	675.9	54.843	108.493
	IP	0	18.1	-	4.653
Input – Output	*RG*	4	295.55	20.380	46.089

Table 1.19. Descriptive Statistics - Selected variables

*Note: *AS* academic staff, *ES* number of enrolled students, *RST* ratio between enrolled students and teachers, *NAS* non-academic staff, *RG* research groups, *VAHI* years of the validity of accreditation as high quality, *GRA* graduates, *RS* registered students, *DOR* drop-out rate, *SPT* university average in SABER PRO test, *SPE* university average by level of aggregation in English , *SCI* position of the university in SCIMAGO Institutions Rankings, *PUB* publications, *BRR* books, *PSE* scientific events, *PRT* teaching activities, and *IP* invention patents.

The statistics and the general analysis presented in this chapter shows that both input and output variables have a high difference in their values for the different universities under study. The high ranges, the values of the standard deviation (SD), and the mean in the input variables show how far one piece of information can be from the others that demonstrates the big differences in the size and level of resources among Colombian universities. Similarly, the output variables present the same differentiation among the values that could be generated by the same asymmetry and inequality of resource levels available in the universities.

2 CHAPTER

Performance of High-Quality Colombian Universities in the Development of their Missional Objectives

2.1. Introduction

In this chapter, we use an efficiency analysis on the accredited universities in Colombia that is based on the empirical methodologies of the data envelopment analysis (DEA) and the Malmquist productivity index (MPI). We implement three different perspectives according to the substantive objectives of the universities. The first perspective considers the variables for all the substantive university missions (i.e., teaching, research, and knowledge transfer). The second and third perspectives correspond to separating the teaching objective from the research and KT activities.

This analysis establishes a benchmark that represents universities' support for making decisions about resources and performance levels and developing the self-assessment necessary for the renewal process of their accreditation, which might guarantee the continuous improvement of the processes in the university. This benchmark could also be helpful for society broadly and for policymakers to make comparisons between HEIs.

We do not intend to use this benchmark to establish differences among universities or to establish hierarchical positions for the universities. We intend to offer a reference group of universities to promote policies and strategies that are useful. Supporting the decision-making with the information from this group of universities with high-quality accreditation means contributing to the continuity of quality education in universities with good performance and resource management. This analysis would impact the involved regions and the country's economic, business, and social development.

According to Prakash (2018), the implementation and continuity of quality in higher education have had positive effects on the satisfaction of students and stakeholders as well as on the efficiency and sustainability of a university's process. Ardila-Rodríguez (2011) asserts that "the relevance and coverage" plays a crucial role when referring to the quality of teaching. The author relates the quality to how accessible education is among different social classes, age groups, and minorities.

Based on this assumption, the same author declares that Colombia faces a crisis in its quality of education.

In this order, Mateos-González and Boliver (2018) say that to increase and maintain a higher level of quality, it is essential to consider how better resource management could be used to generate improvements in outputs in a context of limited resources. Therefore, we can deduce that improved resource management could contribute to universities helping to increase their coverage and relevance for society.

Thus, we identify some methodologies to assess the performance of Colombian universities in this context. Visbal-Cadavid, Martínez-Gómez, and Escorcia-Caballero (2020) applied a Multiple Factors Analysis (MFA). Ramirez-Gutierrez et al. (2020) and Visbal-Cadavid et al. (2017) have applied the DEA as an empirical methodology to public universities as study units. Moreno-Gómez et al. (2019) and Navas et al. (2020) have analyzed both public and private universities in general and have mixed teaching and research variables.

Why to analyze the performance of universities in Colombia differentiated by their substantive objectives?

The differentiation in the outputs and goals of universities generates a particular problem of whether or not they achieve the expected results. Thus, a deeper analysis of each objective can contribute to the improvement measures and highlight situations that can be impossible to see with a general study. Therefore, we develop some contexts for the three different perspectives of the situation in Colombian universities.

From global perspective

The number of enrollments in public and private universities in Colombia have decreased recently. According to SNIES (2019), the country had 952.988 new students in the first semester of 2016; for the same period in 2017, it had 912.468. This decrease was 4.25% and in 2018 the decrease was another 1.5%. This situation indicates an apparent reduction in demand as illustrated by Figure 2.1.

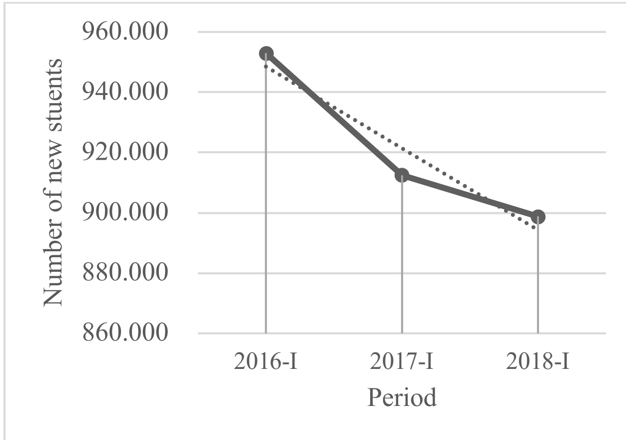

Figure 2.1. Trend of new students in Colombian Universities. *Source: Authors' elaboration based on SNIES (2019)*

The percentage values of the reduced demand are higher for private universities at 11.35% between 2016 and 2017, and at 0.6% for 2018. Thus, for private universities, these decreases mean that not only did they lose students but also resources from tuition payments that cover most of their expenses. This lost revenue represents a problem for these universities because private universities mainly depend on tuitions, while public universities mostly depend on government transfers (Taborda, 2020).

This behavior is the response to demographic changes (shrinking of family nuclei, less young population in the country (DANE, 2018)), competitive conditions (an increase in online courses), economic conditions (an increase in costs above inflation in some universities), political decisions, and strategies such as "Ser Pilo Paga" that produced a bubble effect in the number of enrollments in universities, in particular in the private universities with high-quality accreditation (Londoño-Vélez et al., 2020).

On the other hand, 99 higher education institutions (HEI) were registered in Colombia in the second half of 2019, of which 29.09% (87) corresponded to academic universities. Hence, there is a highly competitive market given the reduction in the number of students. To face this issue, universities need to differentiate themselves from their competition; accordingly, they have to offer higher value services and to increase their reputation in the market (Perreault et al., 2009). But above all, they have to guarantee the quality of service.

Performance of high-quality Colombian universities

In Colombia, there are 61 universities with high-quality accreditation (CNA, 2020). Therefore, 70.11% of all the universities in the country have this recognition about their quality. Thus, accreditation represents a differentiation from 29.89% of the university population. Therefore, it is necessary for universities with accreditation to maintain this recognition and to be efficient in the development of their missional processes to address the current challenges of this market.

From teaching objective

According to the OECD, International Bank for Reconstruction and Development, and The World Bank (2013), Colombia has ambitious plans for its social and economic development. For this reason, Colombia has placed much focus on the quality of human capital that is underpinned by the quality of teaching objectives set within HEIs. Therefore the quality of teaching plays a crucial role in the country's development, as the labor quality exerts a considerable influence on foreign investment (Fung et al., 2002), and it is also linked to an improvement in social mobility and social justice (Turok et al., 2009).

In the case of Colombian universities, the resources come mostly from developing the teaching mission due to the fact that primary sources are related to the enrolled students in academic programs. The tuition for private universities represents between 70 and 80% of their financial structure (Anzola, 2017). Similarly, for public universities, the budget allocation is the absolute variation in the number of enrolled students from one year to the next (Ministry of Education, 2015). This criteria could be unfavorable considering the decrease in the number of enrolled students in the last few years, according to the data from SNIES (2019).

Therefore, the improvements in universities' teaching activities, their quality, and their management of resources can give them competitive advantages with each other in the national but also international market. Further, given the recent increase in global competition that universities are facing today and the transformative process of Covid-19 pandemic, e-learning changes the market conditions for developing teaching (Sá and Serpa, 2020).

From Research and KT

The Colombian Observatory of Science and Technology (n.d.) compares Colombia and South American countries by using information available on R and D investments, such as GDP percentage and the number of researchers per 100,000 members of the workforce. This comparison is also used to produce the overall average for Latin America and OECD member counties (Figure 2.2). Colombia has been a member of OECD since 2020. Figure 2.2 shows the backwardness of Colombia's figures as it has the lowest level in both indicators in all the periods analyzed. This reality presents a challenge for Colombia in terms of improving research and innovation indicators.

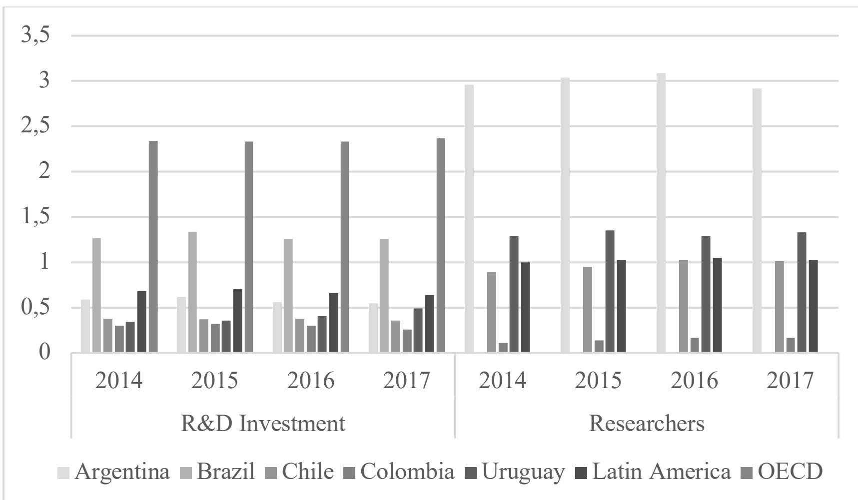

Figure 2.2 Comparison of research indicators. *Source: authors' elaboration based on Colombian Observatory of Science and Technology.*

Research is a relatively recent phenomenon in Colombia compared to other countries (Pineda and Celis, 2017), and its development is driven through different financing and strengthening strategies as well as promotion policies. For example, Colombian Decree 1279 (2002) fosters the scientific production of the faculty at state universities through economic benefits. Furthermore, the creation of the Ministry of Science, Technology, and Innovation (MinCiencias) is an example of generalized policies that seek to benefit public and private universities through greater autonomy from the private sector and the state, and in funding the development and management of research projects and the human resources involved.

Another policy to promote research is incorporating it as a factor to be evaluated in accreditation processes for academic programs and HEI by the CNA. It is worth noting that CNA accreditation stimulates universities to maintain and improve their research and KT activities as the CNA assesses them when granting and renewing such accreditation.

A good performance in research and KT functions represents an improvement in the quality of teaching activities for universities since learning experiences are contextualized within real needs or problems. Further, this performance represents a possibility for universities to diversify their income, considering that the financial structure of Colombian private universities are receive 70 and 80% of their income from tuition payments (Anzola, 2017). The aforesaid can help mitigate the risk some private universities face in terms of quality and continuity due to the decrease in the figures of student enrollment in recent years (SNIES 2019).

Thus, the monitoring of the development of KT and research can contribute to the sustainability of universities by ensuring their quality and progress. Besides, Melo et al. (2018) recognize the importance of universities to knowledge transfer, regional innovation, and societal and economic developments in the surrounding region in which they operate.

2.2. Methods

2.2.1. A Data Envelopment Analysis to measure the universities' efficiency

The first empirical methodology that we used was the DEA (Charnes et al., 1978). This approach has an output orientation which means that the level of inputs remains the same while the outputs are maximized. This model was chosen because in the context of this study, it is more feasible to adjust the output levels to reach the efficiency levels sought. For the scale, we considered the variable return scale (VRS) proposed by Banker et al. (1984) from two perspectives linked to the context and dataset under study:

i) The difference in output and input levels presented by Colombian universities related to their research production.

ii) Understanding the differentiated focus on strategies depending on the vocations and modalities of the universities. Thus, it is understood that the level of research developed by all the universities should not be the same (Pineda and Celis, 2017).

Let $\{\boldsymbol{e}_n, \boldsymbol{s}_n\}_{n=1}^{N}$ be the dataset used, where $\boldsymbol{e}_n \in \mathbb{R}_+^D$ and $\boldsymbol{s}_n \in \mathbb{R}_+^M$ are vectors containing respectively the input and output variables to represent n-th university that in this case corresponds to the universities under study in which N is the total of such universities. Further, D and M are respectively the number of inputs and outputs. Accordingly, the estimated efficiency $\hat{y}_o$ for the UNIVERSITY observed (UNIVERSITY$_o$) is defined in Eq. 1:

$$
\begin{aligned}
max \quad & \eta_o \\
s.t. \quad & \boldsymbol{E}^{\top}\boldsymbol{\lambda} \leq \boldsymbol{e}_o \\
& \eta_o \boldsymbol{s}_o - \boldsymbol{S}^{\top}\boldsymbol{\lambda} \leq \boldsymbol{0} \\
& \boldsymbol{\varphi}^{\top}\boldsymbol{\lambda} = 1 \\
& \boldsymbol{\lambda} \geq \boldsymbol{0},
\end{aligned}
\qquad \text{Eq. 1}
$$

where η_o correspond to $1/\theta_o$ as θ_o is the relation between the virtual outputs and the virtual inputs as represented by Eq. 2:

$$\theta_o = \frac{\text{virtual outputs}}{\text{virtual inputs}} = \frac{u_1 s_{1o} + u_2 s_{2o} + \cdots + u_M s_{Mo}}{v_1 e_{1o} + v_2 e_{2o} + \cdots + v_D e_{Do}} \qquad \text{Eq. 2}$$

where $\boldsymbol{u} = [u_1, u_2, \dots, u_M] \in \mathbb{R}^M$, and $\boldsymbol{v} = [v_1, v_2, \dots, v_D] \in \mathbb{R}^D$ are the input and output weights, respectively. On the other hand, $\boldsymbol{\lambda} \in \mathbb{R}_+^N$ is a vector such that $\lambda_o = 1$ when $\theta_o = 1$, and $\boldsymbol{\varphi} \in R^N$ is an all-ones vector. Finally, $\boldsymbol{E} \in \mathbb{R}^{N \times D}$ and $\boldsymbol{S} \in R^{N \times M}$ are the input and output matrixes, where the n-th row corresponds to $\boldsymbol{e}_n, \boldsymbol{s}_n$ respectively. After the optimization process, we can compute the input excesses $\boldsymbol{\Delta}^- \in \mathbb{R}^D$ and the output shortfalls $\boldsymbol{\Delta}^+ \in \mathbb{R}^M$. Hence, the excesses and shortfalls for the UNIVERSITY$_o$ are given by Eq. 3:

$$\boldsymbol{\Delta}^{-} = \theta \boldsymbol{e}_o - \boldsymbol{E\lambda}, \qquad \boldsymbol{\Delta}^{+} = \theta \boldsymbol{s}_o - \boldsymbol{S\lambda} \qquad \text{Eq. 3}$$

2.2.2. Malmquist Productivity Index

Studies have combined the DEA with methods of time series analysis such as the Malmquist productivity index (MPI) (Färe et al., 1994). We use the concept introduced by Malmquist (1953) as the base which is represented in Eq. 4:

$$\mu^{t+1}(e^{t+1}, s^{t+1}, e^{t}, s^{t}) = \left[\frac{C^{t}(e^{t+1}, s^{t+1})}{C^{t}(e^{t}, s^{t})} \times \frac{C^{t+1}(e^{t+1}, s^{t+1})}{C^{t+1}(e^{t}, s^{t})}\right]^{\frac{1}{2}} \qquad \text{Eq. 4}$$

where the MPI (μ) is calculated according to the C^t that corresponds to the distance function that measures the efficiency in the conversion of inputs e^t to outputs s^t during period t [30]. Applying this concept to the DEA, we can say that the DEA efficiency is a distance that represents the efficiency of conversion of inputs to outputs as explained by Ramanathan (2003):

$$C^{t+1}(e^{t+1}, s^{t+1}) = DEA\ efficiency\ using\ e^{t+1} inputs\ and\ s^{t+1}\ outputs \qquad \text{Eq. 5}$$

Hence, the technical efficiency change (*F*) is determinated by the Eq. 6:

$$F = \frac{C^{t+1}(e^{t+1},\ s^{t+1})}{C^{t}(x^{t},\ s^{t})} \qquad \text{Eq. 6}$$

In this order, if $F>1$ refers to an increase in the technical efficiency of converting inputs to outputs. Otherwise, $F<1$ represent a decrease in the technical efficiency, while the score = 1 means no changes in the efficiency.

The theoretical MPI facilitates the understanding of the change in efficiency through some phenomena that depends on its cause. One is the technological change (TC) which means that the set of feasible combinations expands or contracts, while pure technical efficiency change (PTEC) means that the firm moves closer to or further away from the frontier, and scale efficiency change (SEC) is when the firm has moved to a position on the frontier after being conditioned by its input and output mix. If the SEC is not with a TC and the UNIVERSITY is on the frontier, the SEC corresponds to movement along the frontier (Balk, 2001).

According to these indicators, the necessity and orientation in terms of policies and improvement actions are different. This is because the components allow us to see "the determinants of better performance and provide valuable information for managers and planners" (Mohammadi and Ranaei, 2011) and to understand whether the universities' changes come from external issues or internal measures and changes.

2.3. Specification of the Models

The specification of the models means the combination of input and output variables used to analyze the universities' performance from different perspectives that consider the variables selected in chapter 1 for the development of this research. Thus, we try to find the right combination of variables following the relation established by Dyson et al. (2001): the number of Universities must be at least 2*m*s, where m is the number of inputs and s is the number of outputs. This rule of thumb allows us to obtain meaningful efficiency estimates keeping the correct number of variables in the combinations proposed.

According to the above, we propose the empirical models in Table 2.1. Thus, we consider nine production sets that comprise three for each perspective of analysis from the missional objectives of the universities: i) teaching mission, ii) research-KT, and iii) the global perspective that considers joining the two previous perspectives. We use the three combinations of inputs-outputs for each perspective to analyze the sensitivity of the efficiency scores related to the outputs used or to identify development focuses or mission strengths in the universities under investigation.

For the output combinations we consider the variables as: "indicators", and "set of indicators" or "result of an assessment process". We use these combinations to establish the difference between analyzing the efficiency according to indicators or a set of them (represented by the assessment process). The last option allows taking into account other considerations and factors that could be difficult to assess in a study of this type and, possibly, qualitative criteria that influence evaluation processes.

Teaching				Research and Knowledge transfer				Global			
Models	**1a**	**1b**	**1c**	**Models**	**2a**	**2b**	**2c**	**Models**	**3a**	**3b**	**3c**
Inputs	AS	AS	AS	**Inputs**	AS	AS	AS	**Inputs**	AS	AS	AS
	ES	ES	ES		ES	ES	ES		ES	ES	ES
	NAS	NAS	NAS		NAS	NAS	NAS		NAS	NAS	NAS
	RST	RST			RST	RG	RST			RST	RG
Outputs	GRA	SPE	GRA	**Outputs**	SCI	BRR	PUB	**Outputs**	GRA	SCI	GRA
	SPT	SPT	SPT		RG	PSE	IP		SPT	SPT	SPT
	DOR	DOR	DOR		PUB	PRT			DOR	RG	RS
	RS	VAHI				PUB			PUB	VAHI	PUB
						IP			IP		IP

Table 2.1 Empirical models for “Teaching”, “Research and knowledge transfer” and "Global" production sets

Note: *AS* academic staff, *ES* number of enrolled students, *RST* ratio between enrolled students and teachers, *NAS* non-academic staff, *VAHI* years of the validity of accreditation, *GRA* graduates, *RS* registered students, *DOR* drop-out rate, *SPT* university average in SABER PRO test, *SPE* university average by level of aggregation in English SABER PRO, *SCI* position of the university in SCIMAGO Institutions Rankings, RG research groups, *PUB* Publications, *BRR* books result of research, *IP* invention patents, *PSE* participation in scientific events, and *PRT* products of research training.

About the models for the teaching mission (1a, 1b, 1c), we keep in all of these constant on the input side; the difference is in the output combination. The model 1a uses the output variables of the types mentioned (indicators: *GRA* and *RS*; and results of evaluation processes: *SPT* and *DOR*) and proposes the *RS* as an output that has not been identified by other studies. By contrast, the model 1b uses the outputs of the type “set of indicators” from the results of the following evaluation processes:

- The ICFES evaluates the students’ knowledge acquired in their training process (*SPE* and *SPT*).
- The students evaluate the universities’ conditions to remain and complete the educational process (*DOR*).
- The CNA evaluates the assessment process to give the accreditation of high quality (*VAHI*).

Finally, the model 1c use the variables that we can identify as the most used in the literature review for representing the teaching function in the universities as outputs. These are *GRA*, score in final exam before the graduation (*SPT*), and *DOR*.

On the other hand, for ***the models concerning the research and KT*** we keep constant the inputs in models 2a, 2b, and 2c. Still, model 2a tries to evaluate the research efficiency with the results of the evaluative processes at the national level with the measurement of research groups (*RG*) made by the Ministry of Science, Technology, and Innovation, and at the international level with the classification of universities made by Scimago in which research performance, innovation, and societal impact (*SCI*) were taken into account. In addition, we also consider the publications (*PUB*).

On the other hand, Pastor and Serrano (2016) argue that scientific outputs can change according to a university´s specialization in the knowledge field and its characteristics. In Colombia, there is a markable variety in academic programs, size, and resources of universities. This variety allows us to propose model 2b with a broader range of possibilities of doing research that includes writing (*PUB* and *BRR*), socialization (*PSE*), training (*PRT*), and *IP* as a representation of KT, all of which are in the output vector. The input vector considered the research groups (*RG*) that represent the experience and recognition in research and KT as an essential indicator for obtaining more diverse resources and generating outputs.

Model 2c considers variables most used by authors to analyze academic universities' performance in research and knowledge transfer in its output side, that is *PUB* and *IP*. To conclude, the three models proposed vary their output vector to study efficiency from a perspective of results and categories in evaluation processes (model 2a), a broader range of research and KT products (model 2b), and considering the most used variables in the literature review (model 2c).

Finally, ***the global models*** account for each combination of representative variables from the three missions (3a, 3b, and 3c). On the output side, the model 3a analyzes the efficiency based on the most commonly used variables in literature. Teaching is evaluated according to the number of graduates (*GRA*); the score in the final exam presented before graduation to assess the knowledge, which in the case of Colombia is the SABER PRO test (*SPT*); and the drop-out rate of students of the university (*DOR*). In representing research and innovation, we take article publications (*PUB*) and invention patents (*IP*).

The model 3b like model 3a considers the ratio between enrolled students and full-time teachers (*RST*) on the input side. In this case, the outputs are regarded as the scores and positions in the different evaluation processes to which the Colombian universities' mission processes may be subject. For the case of research and innovation processes, we use the university's position in SCIMAGO Institutions Rankings (*SCI*) and the research groups recognized and classified by Colciencias (*RG*). In addition, the university average in the SABER PRO test (*SPT*) represents the evaluation of the knowledge of their graduates; and finally, the duration of the accreditation as high quality (*VAHI*) by CNA.

Finally, model 3c uses the constant input variables (*AS*, *ES*, and *NAS*) and adds the research groups (*RG*) as an essential resource that denotes experience and capabilities for developing research processes. On the output side, we propose the same variables as in the model 3a but change the *DOR* by the number of registered students (*RS*) as a market recognition response to the coherence and relevance of university offers.

2.4. The empirical evidence

The application of the data envelopment analysis (DEA) model and the Malmquist productivity index (MPI) facilitates the development of the analysis of the performance of high-quality accredited Colombian universities from different perspectives. Thus, in this section we describe university performance in relation to the three diverse perspectives of analysis.

2.4.1. Global perspective

DEA Efficiency Scores

The individual data analysis shows the Colombian universities' sensibility through time and variables that we considered in models 3a, 3b, and 3c. Table 2.2 shows the efficiency score of the universities with each of the models considered. Highlighted in bold are the six universities that remain efficient during all periods in the three proposed models: the National University of Colombia, University of Antioquia, CES University, EIA University, University of the Andes, and Francisco José de Caldas District University.

In most cases, the consistently efficient universities in the model 3a are the same as in the model 3b (62,5%); this is supported by the similarity among the variables after adding *RG* as an input variable and changing the *DOR* to the *RS*. In contrast, model 3b presents the results for the variables on the output side after the evaluation and ranking processes for the different missions. There are a total of 17 universities that maintain their efficiency in the period 2016-2018. Of these, 58,82% are efficient in only this model. These results show the meaningful difference and sensibility in measuring the universities' efficiency based on indicators or results of processes evaluation.

		Model 3a			**Model 3b**			**Model 3c**		
N.	University	2016	2017	2018	2016	2017	2018	2016	2017	2018
1	EAFIT University	1.000	1.000	1.000	1.000	0.975	0.985	1.000	1.000	1.000
2	**National University of Colombia**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3	University of La Sabana	1.000	0.981	1.000	0.977	0.999	0.996	1.000	0.989	0.981
4	North University	1.000	1.000	1.000	0.986	0.968	0.983	1.000	1.000	1.000
5	Colegio Mayor de Nuestra Señora del Rosario University	1.000	0.995	0.984	1.000	1.000	1.000	1.000	0.989	1.000
6	Pontifical Javeriana University	1.000	1.000	1.000	0.997	1.000	1.000	1.000	1.000	1.000
7	Externado University of Colombia	0.932	1.000	1.000	0.993	1.000	1.000	0.989	1.000	1.000
8	Autonomous University de Bucaramanga - UNAB	0.969	0.971	0.968	0.852	0.874	0.875	0.941	0.908	0.912
9	De la Salle University	0.949	0.961	0.964	0.846	0.850	0.852	0.916	0.874	0.871
10	University of Caldas	1.000	0.948	0.995	1.000	1.000	1.000	0.950	0.919	0.931
11	**University of Antioquia**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
12	University of Cauca	1.000	0.924	0.980	1.000	1.000	1.000	1.000	1.000	0.945
13	Technological University of Pereira	1.000	1.000	0.986	1.000	1.000	1.000	1.000	1.000	0.954
14	University of Medellín	1.000	1.000	1.000	1.000	0.945	0.943	1.000	1.000	1.000
15	University of Valle	0.986	0.999	0.974	1.000	1.000	1.000	0.946	0.937	0.972
16	University of Cartagena	0.995	1.000	1.000	0.851	1.000	0.998	1.000	1.000	1.000
17	**CES University**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
18	Industrial University of Santander UIS	0.969	1.000	0.971	1.000	0.996	0.962	0.948	0.979	0.977
19	Sergio Arboleda University	1.000	0.989	0.927	0.868	0.863	0.868	1.000	0.902	0.903
20	ICESI University	0.972	1.000	0.982	1.000	1.000	1.000	1.000	1.000	1.000
21	**EIA University**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
22	**University of the Andes**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
23	Pedagogical and Technological University of Colombia	1.000	1.000	1.000	0.989	1.000	1.000	0.923	1.000	1.000
24	University of Manizales	1.000	1.000	1.000	0.897	0.873	0.862	0.912	0.868	0.895
25	Autonomous University of Manizales	0.987	0.969	0.959	1.000	1.000	1.000	0.839	0.839	0.892
26	Technological University of Bolivar	1.000	1.000	1.000	0.839	0.856	0.858	1.000	1.000	1.000
27	Nueva Granada Military University	1.000	1.000	1.000	0.887	0.908	0.899	1.000	1.000	1.000

		Model 3a			Model 3b			Model 3c		
N.	University	2016	2017	2018	2016	2017	2018	2016	2017	2018
28	Santo Tomás University	0.936	0.907	0.952	0.850	0.903	0.908	0.992	0.902	0.999
29	El Bosque University	0.999	0.964	0.982	1.000	1.000	1.000	0.951	0.882	0.889
30	National Pedagogical University UPN	0.996	1.000	0.991	1.000	1.000	1.000	0.955	0.897	0.888
31	University of Magdalena	1.000	1.000	1.000	0.772	0.782	0.927	1.000	1.000	1.000
32	Libre University	1.000	0.994	1.000	0.805	0.815	0.837	1.000	1.000	1.000
33	Simón Bolívar University	0.933	0.954	0.986	0.793	0.843	0.842	0.788	0.773	0.826
34	**Francisco José de Caldas District University**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
35	Pontifical Bolivarian University	0.921	0.929	0.919	1.000	1.000	0.920	0.924	0.901	0.905
36	University of Nariño	0.964	0.972	0.990	0.905	0.861	0.857	0.896	0.866	0.858
37	San Buenaventura University	0.952	0.912	0.934	0.806	0.817	0.854	0.842	0.829	0.835
38	Autonomous University of West - UAO	0.935	0.949	0.958	0.842	0.850	0.844	0.871	0.864	0.861
39	EAN University	1.000	1.000	1.000	0.854	0.865	0.873	1.000	1.000	1.000
40	Surcolombiana University	1.000	1.000	1.000	1.000	0.830	0.838	1.000	0.902	1.000
41	Jorge Tadeo Lozano University	0.954	0.963	0.969	0.858	0.873	0.888	0.940	0.894	0.958
42	University of Quindio	1.000	1.000	1.000	0.962	0.917	0.866	1.000	1.000	1.000
43	Central University	0.965	0.956	0.968	0.826	0.829	0.839	1.000	1.000	1.000
44	University of the Atlantic	0.959	1.000	1.000	0.852	1.000	1.000	1.000	1.000	1.000
45	Antonio Nariño University	0.956	0.955	0.974	1.000	1.000	1.000	1.000	0.983	1.000
46	University of Sinú - Elias Bechara Zainun - UNISINU	0.981	0.992	0.988	0.763	0.762	0.754	1.000	0.893	1.000
47	Catholic University of the East (UCO)	0.984	1.000	0.996	0.753	0.800	0.780	1.000	0.944	0.930
48	University of the Coast (CUC)	0.957	0.973	0.952	1.000	1.000	1.000	0.793	0.813	0.843
49	Catholic University of Colombia	0.944	0.960	0.988	0.827	0.831	0.829	0.976	0.944	1.000
50	University of Ibagué	0.972	0.994	0.990	0.812	0.821	0.818	1.000	1.000	1.000

Table 2.2. Higher education efficiency using DEA-VRS

According to the aforementioned and the summary presented in Table 2.3, we can determine model 3b as the most demanding for measuring efficiency in the Colombian universities with the lowest average efficiency score (0.928). One possible cause can be the inclusion of the international measure *SCI* for universities that has a more restricted reference group and that is efficient on average 44% of the time as, while the models 3a and 3b are efficient 49.33% and 55.33% of the time, respectively.

	Model 3a			Model 3b			Model 3c		
	2016	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
Average score efficiency	0.981	0.982	0.985	0.925	0.930	0.931	0.966	0.950	0.960
Efficient universities (%)	50%	52%	46%	44%	46%	42%	60%	50%	56%
Universities as reference	32%	34%	36%	26%	26%	22%	34%	36%	44%

Table 2.3. Summary statistics of higher education efficiency using DEA-VRS

The DEA model proposes a target for the Universities to achieve efficiency. In Figure 2.3, the targets are expressed in terms of the average change proposed in each variable per model. In some cases, the outputs' improvement is not enough to reach the efficiency; for this reason, some changes are proposed in the input variables too, but the more significant changes are on the output side due to the model being output-orientated.

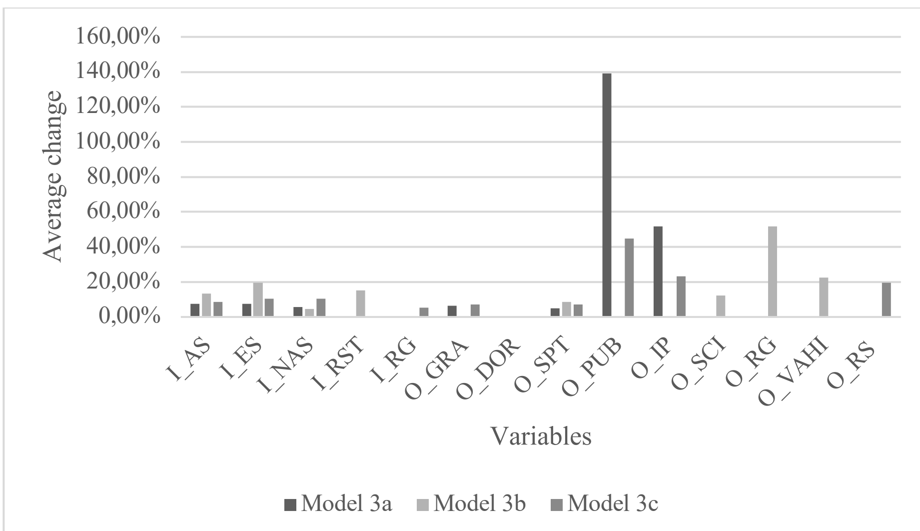

Figure 2.3. Targets for global perspective variables

The research variables in universities are the most affected by the models requiring the highest percentages of increase. In models 3a and 3c with research representation, the publications (*PUB*) variable shows the more representative changes; in model 3b, the same situation applies to research groups (*RG*). The necessary high increments in these variables show a high difference between research generated in Colombia's accredited universities. It can be explained among other factors due to the combination in the DMU group of private and public universities that indicates the national public policies incentivize the teachers' scientific productivity at public universities with increases in wages and salaries.

In line with the above, Figure 2.4 presents the average of universities that need to make efforts in order to improve specific variables. It shows that the universities analyzed need to mainly strengthen the number of invention patents generated, number of publications, and the number and categories of the research groups. In different terms of research variables, it is necessary to decrease the drop-out rate, increase the number of graduates, and improve the score in the SABER PRO exam.

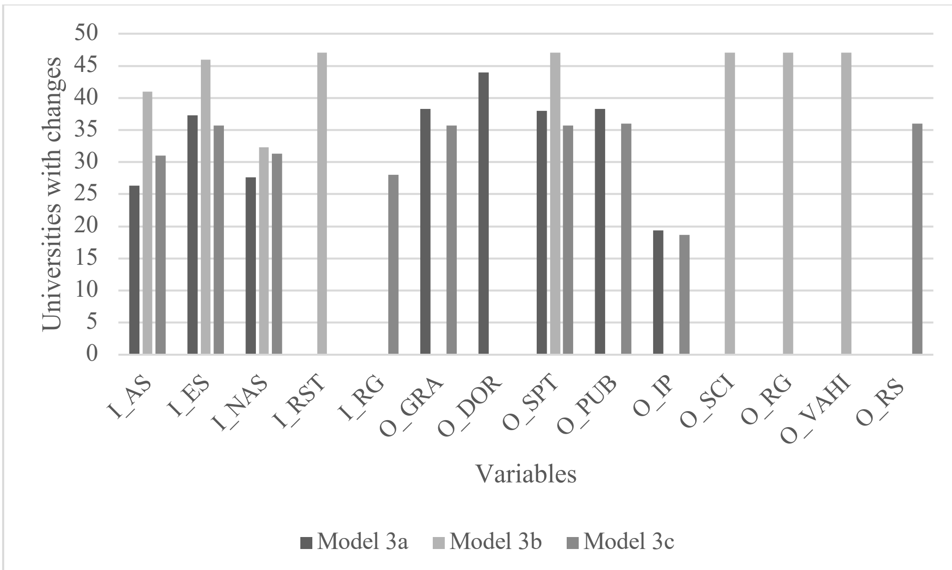

Figure 2.4. Number of university's with changes in variables

The previous targets are proposed based on a reference group for making the projections; this group is made up of efficient universities and can be taken as reference for other ones. In particular, there is evidence that three of the continuously efficient universities are an essential benchmark for other universities and are independent of the other variables that measure those universities: National University of Colombia, EIA University, and the University of the Andes. Figure 2.5 shows the universities taken as a benchmark in more periods (more than 30 accumulated times in the three models) for their peer universities that are more restricted in the number of universities that serve as the reference under the variables of the model 3b.

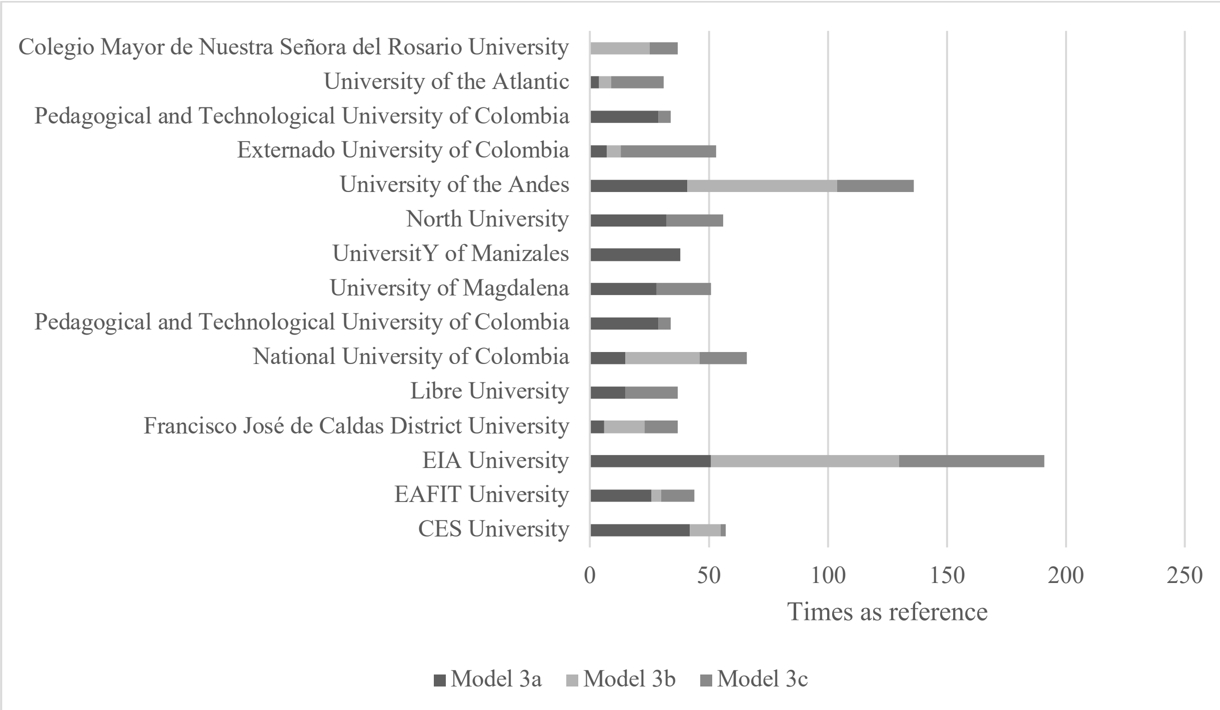

Figure 2.5. Reference group

Efficiency changes over 2016 – 2018 Period: A Malmquist analysis

Table 2.4 shows the results from the Malmquist productivity index (MPI) for the annual mean of the efficiency changes regarding operational efficiency for the period analyzed (2016 - 2018). According to the MPI, the universities presented an increase in the operational efficiency through the time analyzed. This result is independent of the variables used in the different models. A possible explanation is based on the general improvement in a global context for the process of Colombian universities.

This overall positive development for universities can be explained by models 3a and 3c (with operational variables) for the period from 2016 to 2017 by the technological changes (TC), and in 2017-2018 by the decreasing in the university's entry-level for its operation (See the pure technical efficiency change (PTEC)); thus, the technical efficiency of university's is due to a good allocation of its inputs. For model 3b, the improvement presented between 2016-2017 is due to the PTEC, and the TC explains the increase in 2017-2018.

	2016 -2017			2017-2018		
Model	**3a**	**3b**	**3c**	**3a**	**3b**	**3c**
MPI	1.043	1.004	1.038	1.004	1.039	1.006
TC	1.062	0.987	1.064	0.964	1.072	0.983
PTEC	0.980	1.003	0.983	1.012	0.986	1.012
SEC	1.002	1.014	0.992	1.029	0.983	1.012

Table 2.4. Summary of annual means for Malmquist productivity index

Note: Malmquist productivity index (MPI), Technological change (TC), Pure Technical Efficiency Change (PTEC), and Scale Efficiency Change (SEC).

Table 2.5 shows the 10 universities that have achieved the best results in improving their processes according to the different variables that composed the proposed models, which are based on the total factor productivity (MPI). Table 2.5 shows that the universities, The Externado University of Colombia, University of the Atlantic, Jorge Tadeo Lozano University, Autonomous University of West – UAO, and the Catholic University of Colombia markedly improved in the analyzed period regardless of the studied variables. We also highlight the University of Ibagué and the University of Cauca as universities that have improved indicators following the variables in two of the three models.

	Model 3a			Model 3b			Model 3c		
University	R	MPI	TC	R	MPI	TC	R	MPI	TC
Externado University of Colombia	1	1.794	1.158	8	1.088	1.085	2	1.399	1.104
University of the Atlantic	2	1.252	1.111	10	1.078	1.013	1	1.444	1.444
Pedagogical and Technological University of Colombia	3	1.217	1.036	-	-	-	3	1.209	1.040
Simón Bolívar University	4	1.139	1.059	-	-	-	4	1.146	1.051
Jorge Tadeo Lozano University	5	1.111	1.063	3	1.158	1.053	5	1.103	1.061
Antonio Nariño University	6	1.101	1.054	-	-	-	-	-	-
Francisco José de Caldas District University	7	1.097	1.097	-	-	-	-	-	-
Autonomous University of West - UAO	8	1.085	1.023	2	1.162	1.058	8	1.078	1.018
Catholic University of Colombia	9	1.079	1.012	4	1.119	1.075	6	1.090	1.042
University of Ibagué	10	1.075	0.891	5	1.117	1.071	-	-	-
Catholic University of the East (UCO)	-	-	-	1	1.207	1.069	-	-	-
El Bosque University	-	-	-	6	1.103	1.095	-	-	-
De la Salle University	-	-	-	7	1.103	1.053	-	-	-

	Model 3a			Model 3b			Model 3c		
University	R	MPI	TC	R	MPI	TC	R	MPI	TC
University of Cauca	-	-	-	9	1.078	1.078	7	1.080	1.112
Central University	-	-	-	-	-	-	9	1.071	1.071
San Buenaventura University	-	-	-	-	-	-	10	1.064	1.037

Table 2.5. Top 10 universities

Note: Ranking (R), Malmquist productivity index (MPI), and Technological Change (TC).

In contrast, other universities have more noticeable improvements in one type of variable than in another. In the analysis of indicators as outputs are The Pedagogical and Technological University of Colombia, Simón Bolívar University, Antonio Nariño University, Francisco José de Caldas District University, Central University, and San Buenaventura University. On the other hand, the universities with better improvement in variables related to evaluation processes are Catholic University of the East (UCO), El Bosque University, and De la Salle University.

2.4.2. Teaching objectives perspective

DEA-VRS efficiency scores

The individual efficiency scores (Table 2.6) facilitate an understanding of the sensitivity of Colombian universities depending on the change in the levels of the variables over time and, the type of variable used for their measurement. The five universities highlighted in bold are the efficient ones both in the different years and with the different type of variables measured; these universities are National University of Colombia, CES University, EIA University, University of the Andes, and the University of Manizales.

		Model 1a			Model 1b			Model 1c		
N.	University	2016	2017	2018	2016	2017	2018	2016	2017	2018
1	EAFIT University	1.000	1.000	1.000	1.000	0.997	1.000	1.000	1.000	1.000
2	**National University of Colombia**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3	University of La Sabana	1.000	0.987	1.000	0.989	1.000	1.000	1.000	0.981	1.000
4	North University	0.987	0.993	1.000	0.970	1.000	1.000	0.987	0.993	1.000
5	Colegio Mayor de Nuestra Señora del Rosario University	1.000	0.996	0.984	1.000	1.000	1.000	1.000	0.995	0.984
6	Pontifical Javeriana University	1.000	1.000	1.000	0.961	1.000	0.986	1.000	1.000	1.000
7	Externado University of Colombia	0.935	1.000	1.000	0.993	1.000	1.000	0.932	1.000	1.000
8	Autonomous University de Bucaramanga - UNAB	0.974	0.972	0.968	0.952	0.960	0.957	0.969	0.971	0.968

		Model 1a			Model 1b			Model 1c		
N.	University	2016	2017	2018	2016	2017	2018	2016	2017	2018
9	De la Salle University	0.951	0.970	0.970	0.927	0.939	0.964	0.949	0.961	0.964
10	University of Caldas	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.943	0.995
11	University of Antioquia	1.000	1.000	1.000	1.000	1.000	1.000	0.946	0.953	0.960
12	University of Cauca	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.913	0.976
13	Technological University of Pereira	0.967	0.947	0.936	1.000	1.000	1.000	0.967	0.946	0.936
14	University of Medellín	1.000	0.996	1.000	0.977	0.998	0.974	1.000	0.996	1.000
15	University of Valle	0.958	0.974	0.966	1.000	1.000	1.000	0.958	0.974	0.963
16	University of Cartagena	1.000	0.963	0.979	0.938	0.926	0.956	0.969	0.949	0.961
17	**CES University**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
18	Industrial University of Santander UIS	0.964	0.991	0.968	0.958	0.999	0.969	0.964	0.990	0.961
19	Sergio Arboleda University	1.000	0.990	0.929	0.939	0.936	0.915	1.000	0.989	0.927
20	ICESI University	0.972	1.000	0.982	0.972	1.000	0.982	0.972	1.000	0.982
21	**EIA University**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
22	**University of the Andes**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
23	Pedagogical and Technological University of Colombia	1.000	1.000	1.000	0.987	0.990	0.997	1.000	1.000	1.000
24	**University of Manizales**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
25	Autonomous University of Manizales	1.000	1.000	1.000	1.000	1.000	1.000	0.987	0.969	0.959
26	Technological University of Bolivar	1.000	1.000	1.000	0.894	0.924	0.924	1.000	1.000	1.000
27	Nueva Granada Military University	0.935	0.941	0.921	0.915	0.921	0.892	0.933	0.938	0.921
28	Santo Tomás University	1.000	0.938	1.000	0.928	0.929	0.938	0.936	0.907	0.952
29	El Bosque University	1.000	1.000	1.000	1.000	1.000	1.000	0.995	0.964	0.982
30	National Pedagogical University UPN	1.000	1.000	1.000	1.000	1.000	1.000	0.996	1.000	0.991
31	University of Magdalena	1.000	1.000	1.000	0.954	0.984	0.999	1.000	1.000	1.000
32	Libre University	1.000	0.994	1.000	0.951	0.936	0.919	1.000	0.994	1.000
33	Simón Bolívar University	0.938	0.964	1.000	0.926	0.955	0.994	0.932	0.953	0.986
34	Francisco José de Caldas District University	1.000	1.000	1.000	0.995	0.940	0.907	1.000	1.000	1.000
35	Pontifical Bolivarian University	0.933	0.928	0.921	0.955	1.000	0.925	0.909	0.922	0.919
36	University of Nariño	0.972	0.974	0.993	0.961	0.973	0.991	0.964	0.972	0.990
37	San Buenaventura University	0.953	0.921	0.949	0.946	0.893	0.942	0.952	0.912	0.934
38	Autonomous University of West - UAO	0.935	0.949	0.960	0.928	0.941	0.960	0.935	0.949	0.958
39	EAN University	1.000	1.000	1.000	0.944	0.983	0.974	1.000	1.000	1.000
40	Surcolombiana University	1.000	1.000	1.000	1.000	1.000	0.988	1.000	1.000	1.000
41	Jorge Tadeo Lozano University	0.954	0.963	0.969	0.933	0.938	0.935	0.954	0.963	0.969
42	University of Quindio	1.000	0.968	0.986	1.000	0.943	0.981	1.000	0.958	0.986
43	Central University	0.966	0.961	0.973	0.959	0.952	0.972	0.965	0.956	0.968
44	University of the Atlantic	1.000	1.000	1.000	0.955	1.000	0.933	0.956	1.000	1.000

		Model 1a			Model 1b			Model 1c		
N.	University	2016	2017	2018	2016	2017	2018	2016	2017	2018
45	Antonio Nariño University	0.980	0.971	0.983	0.981	0.967	0.982	0.956	0.954	0.971
46	University of Sinú - Elias Bechara Zainun - UNISINU	0.981	1.000	0.994	0.980	1.000	0.994	0.981	0.992	0.988
47	Catholic University of the East (UCO)	0.984	1.000	0.999	0.979	1.000	0.993	0.984	1.000	0.996
48	University of the Coast (CUC)	0.954	0.987	0.960	0.952	0.970	0.956	0.954	0.972	0.952
49	Catholic University of Colombia	1.000	1.000	1.000	0.913	0.927	0.952	0.944	0.960	0.988
50	University of Ibagué	0.972	0.993	1.000	0.971	0.987	0.965	0.972	0.993	0.978

Table 2.6. HE efficiency using DEA-VRS

Table 2.6 highlights the periods in which the universities reach efficiency in the three years analyzed with gray. Moreover, the universities which maintain high levels of efficiency in all the periods in model 1c keep stable this performance also in the model 1a. Model a provides greater stability over time for Colombian universities and shows that 42% of these are efficient in the three years analyzed. While models 1b and 1c show a higher sensitivity index for universities, of between 72% and 74% of the universities that change their efficiency over time.

The difference between models 1a and 1c is that model 1a uses the students served by each full-time professor (*RST*) as an input variable and uses registered students (*RS*) as an output variable that are both favorable for measuring university efficiency. In contrast, model 1c does not use either and therefore is more restrictive leading to universities as only 19% efficient universities in the evaluated period (remaining 23% of the universities as efficient always).

This evidence could be explained from two points of view. First, the *RST* can be an input that contextualizes and benefits the understanding of the results that are correlated to teaching. Second, the *RS* is a beneficial variable for university efficiency because it represents a valid offer from the market according to its conditions.

Referring to model 1b, which presents the analysis only from sets of indicators used as outputs, it represents the most exigent model of those proposed and inhibits universities in their efficiency. Moreover, this model generates the possibility of more efficient universities that are not as easy to identify when utilizing the other models. This possibility could mean that the measurement of the efficiency when only considering results from evaluation processes can bring to further light other aspects that are not possible to see only from indicators (Colegio Mayor de Nuestra Señora del Rosario University, Technological University of Pereira, and the University of Valle).

In concordance with the analysis of the individual efficiency scores, Table 2.7 presents a summary of the performance of universities that allows us to identify the model most exigent for each period. For 2016 and 2018, model 1b represents the average efficiency score and has a lower percentage of efficient universities than the other models. For 2017, the efficiency score (on average) is lower for both models 1b and 1c with model 1c having a smaller group of efficient universities. The third row shows the universities taken as reference for establishing realistic targets for the improvement of the other universities' performance. Representing model 1b, the smaller reference group is an exigent output combination.

	Model 1a			**Model 1b**			**Model 1c**		
	2016	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
Average score efficiency	0.983	0.985	0.986	0.970	0.976	0.974	0.976	0.976	0.979
Efficient universities (%)	58%	50%	58%	34%	48%	34%	42%	36%	38%
Universities as reference	38%	32%	42%	22%	28%	24%	28%	30%	28%

Table 2.7. Summary statistics of DEA

The groups of efficient universities change in their composition depending on the model that indicates their performance depends largely on the variables used for the analysis. The universities displayed in Figure 2.6 are "examples of references" for establishing standards when compared to other universities. The figure shows that some universities were used as positive examples more often or were used as references in two of the three models proposed. In contrast, others like the University of the Andes, EIA University, CES University, University of Manizales, and the North University are used as positive reference cases in the three models that demonstrates these universities are good performers when these variables are considered.

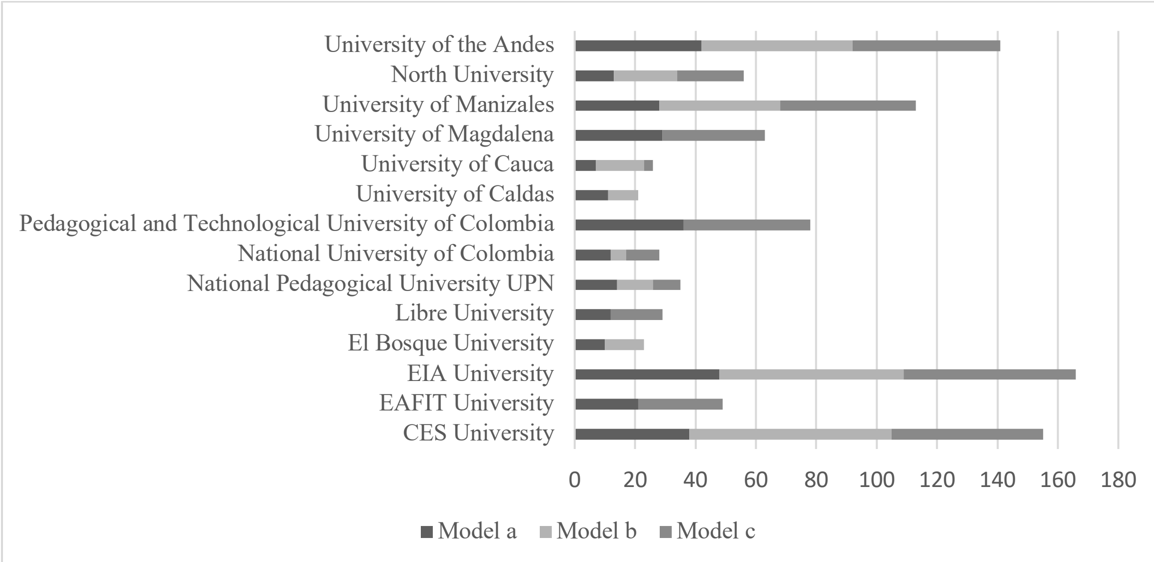

Figure 2.6. Reference group

Based on the levels of the variables in the reference group, DEA proposes changes to the inefficient universities to improve their performance. Figure 2.7 shows the differences in terms of the average percentage that mainly affect the output variables due to the model orientation. However, some changes proposed for the input variables denote that the Colombian universities need to check some resources to reach efficiency.

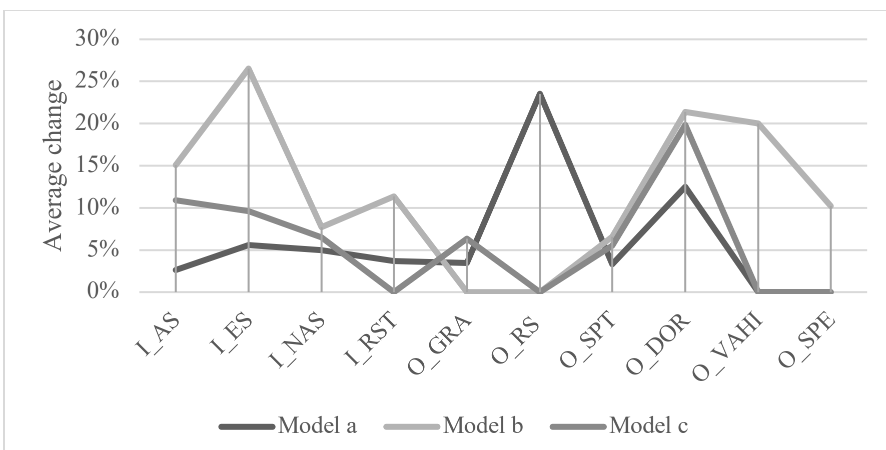

Figure 2.7. Targets for teaching variables

As an output vector, the drop-out variable is one of the most affected variables in models 1b and 1c and needs to be significantly decreased as this is an undesirable output. In the case of model 1a, *RS* presents the highest average percentage of change. This change can be explained due to the big difference in the levels of this variable among the universities analyzed; considering that this variable is more an answer from the students' market, to improve this variable, universities need to check the offer conditions of the academic programs or marketing mix established for them.

With respect to the variable *SPE*, it needs an improvement that is above that required in the general score of *SPT*. This need leads to the conclusion that the scores obtained by the graduates of the universities in the specific English skills are worse than in the overall *SPT* score.

Efficiency changes over 2016 – 2018 Period: A Malmquist analysis

The analysis of change in productivity based on the MPI allows us to better understand what causes these positive or negative changes in the performance of the teaching mission of universities over time. MPI offers three indicators that allow us to capture the changes in the performance from three points of view: i) Technological Changes (TC), ii) the Pure Technical Efficiency Change (PTEC), and iii) Scale Efficiency Changes (SEC). The indicators mentioned are presented in Table 2.8.

The MPI is the annual mean of the efficiency changes for each period considered that indicates the performance of the universities has improved in the variables in the analyzed period. The progress is more obvious from 2016-2017, while from 2017-2018, the positive changes were lower in models 1a and 1c. The variables in model 1b (referred to results of evaluation processes) decreased their performance (in period 2017-2018). The situation described may be due to the implementation of policies that benefited those indicators that can be improved in the short term; while the variables of model 1b are evaluation results, whose changes are reflected in the medium and long term.

	2016 -2017			2017-2018		
Model	**1a**	**1b**	**1c**	**1a**	**1b**	**1c**
MPI	1.081	1.091	1.057	1.006	0.999	1.015
TC	1.154	1.124	1.153	0.979	1.004	0.950
PTEC	0.971	0.989	0.972	1.013	1.006	1.016
SEC	0.965	0.981	0.942	1.013	0.989	1.051

Table 2.8. Malmquist productivity index summary of annuals means

Note: Malmquist Productivity Index (MPI), Technological Change (TC), Pure Technical Efficiency Change (PTEC), and Scale Efficiency Change (SEC).

The TC can explain the generalized improvement in the performance of teaching indicators in Colombian universities for the period from 2016-2017. Compared to the period from 2017-2018, the PTEC and SEC explain the changes in the efficiency of the universities for both positive (in variables of models 1a and 1c) and non-positive (variables model 1b) changes. The variables' improvement in models 1a and 1c comes from measures and strategies for universities, at the same time these lead to a decrease in the performance of the variables in model 1b.

Table 2.9 shows the 10 universities ranked as having the most remarkable improvement in the teaching indicators based on the MPI. The ranking position (R) and the MPI are accompanied by the TC that shows the behavior of these universities is a common factor that influences environmental changes. The ranking position can be analyzed in conjunction with the university character column (C) that indicates whether the universities are public (P) or private (Pri). The table 2.9 shows that the group of universities that present the most improvements in the different models are private as only 33.33% are public universities.

As a possible incentive for positive changes mainly for private universities is the National Government Program called "Ser Pilo Paga" that provides the best college students with the means for the development of their undergraduate professional training. This program has produced a significant preference toward the selection of private universities.

The University of the Atlantic, Francisco José de Caldas District University, and Jorge Tadeo Lozano University improved their efficiency in the models 1a, 1b, and 1c. Further, we can determine that Santo Tomás University, San Buenaventura University, and El Bosque University are universities that respond to the good performance in indicators and the results of evaluative processes, as they rank well in both models 1a and 1b.

		Model 1a			Model 1b			Model 1c		
University	**C**	**R**	**MPI**	**TC**	**R**	**MPI**	**TC**	**R**	**MPI**	**TC**
University of the Atlantic	P	1	1.482	1.482	2	1.344	1.135	2	1.329	1.139
Externado University of Colombia	Pri	2	1.185	1.185	-	-	-	1	1.793	1.158
National University of Colombia	P	3	1.178	1.178	-	-	-	-	-	-
Francisco José de Caldas District University	P	4	1.159	1.159	1	1.366	1.102	5	1.126	1.126
Santo Tomás University	Pri	5	1.155	1.155	6	1.141	1.124	-	-	-
Pedagogical and Technological University of Colombia	Pri	6	1.146	1.146	-	-	-	3	1.241	1.028
University of Cauca	P	7	1.142	1.142	-	-	-	9	1.099	1.033

University	C	Model 1a R	Model 1a MPI	Model 1a TC	Model 1b R	Model 1b MPI	Model 1b TC	Model 1c R	Model 1c MPI	Model 1c TC
San Buenaventura University	Pri	8	1.126	1.111	9	1.115	1.076	-	-	-
Jorge Tadeo Lozano University	Pri	9	1.120	1.082	4	1.162	1.045	7	1.115	1.075
El Bosque University	Pri	10	1.096	1.096	7	1.123	1.123	-	-	-
EAFIT University	Pri	-	-	-	3	1.235	1.037	-	-	-
Libre University	Pri	-	-	-	5	1.158	1.048	-	-	-
Autonomous University of West - UAO	Pri	-	-	-	8	1.119	1.108	-	-	-
Catholic University of the East (UCO)	Pri	-	-	-	10	1.103	1.065	-	-	-
Simón Bolívar University	Pri	-	-	-	-	-	-	4	1.156	1.039
Antonio Nariño University	Pri	-	-	-	-	-	-	6	1.118	1.052
ICESI University	Pri	-	-	-	-	-	-	8	1.109	1.116
University of Antioquia	P	-	-	-	-	-	-	10	1.092	1.126

Table 2.9. Top ten universities

Note: Character (C), Public university (P), Private university (Pri), Ranking (R), Malmquist productivity index (MPI), and Technological Change (TC).

On the other hand, some universities highlighted areas for improvement that depended on the type of variables used. In the case of a combination of results from indicators and evaluative processes (models 1a and 1c), we can establish two groups of universities: i) efficient in both models or ii) efficient in only one of these models. The existence of the second group shows that even having variables of the same type in the models, the performance of the university in question changes by being more sensitive the measure to the variables used compared to the kind of variables. Finally, regarding the type of variables considered in model 1b, universities are identified that perform better if they are specifically measured by the results from evaluation processes.

2.4.3 Research and knowledge transfer perspective

DEA-VRS efficiency scores

The efficiency scores of Colombian universities identify a high sensibility in their performance in research and knowledge transfer processes depending on the variables used for the measurement and the levels of these variables over time. Thus, we can identify seven universities (highlighted in bold) which have maintained their efficiency over time in the three models (2a, 2b, and 2c): the National University of Colombia, Norte University, University of Antioquia, EIA University, Andes University, Nueva Granada Military University, and National Pedagogical University UPN.

According to the efficiency scores highlighted in gray (Table 2.10), model 2b is the most stable one by showing more universities as constantly efficient over time. We rationalize this result from a technical condition where the number of variables in the models can show possible changes in the scale returns (Benicio and De Mello, 2015), with universities having more possibilities for combination weights in their efficiency calculation.

The combination of the *IP* and *PUB* variables in model 2c restricts efficiency through the years for the DMUs. This limitation makes sense because research and KT functions in Colombian universities are in the development phase, so the publications and invention patents are in a growth and consolidation phase, respectively.

By contrast, model 2b opens up the possibility for Colombian universities to be measured as MinCiencias ascertains their research in the national context where, in addition to publications and invention patents, a diverse range of products are considered with regard to training processes, socialization of knowledge, and publication.

Model 2a is at an intermediate level as it is not as demanding as model 2c, but not as favorable as model 2b. It shows that 36% of universities are efficient in the period analyzed. This result may be because the output variables are categories or classifications which vary to a lesser extent for the same university and in their data range, especially the position in *SCI*.

	Model 2a			**Model 2b**			**Model 2c**		
University	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
EAFIT University	1.000	0.931	0.926	1.000	0.972	0.993	0.972	0.699	0.733
National University of Colombia	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
La Sabana University	0.842	0.929	0.885	0.654	0.652	0.637	0.214	0.228	0.214
Norte University	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Colegio Mayor de Nuestra Señora del Rosario University	0.977	1.000	1.000	1.000	1.000	1.000	0.536	0.520	0.493
Pontificia Javeriana University	0.997	0.998	0.999	1.000	1.000	1.000	0.638	0.747	0.610
Externado University of Colombia	0.252	0.253	0.225	1.000	1.000	1.000	0.059	0.060	0.050
Autónoma de Bucaramanga University - UNAB	0.324	0.315	0.308	0.659	0.681	0.700	0.095	0.119	0.108
De la Salle University	0.301	0.315	0.347	1.000	1.000	1.000	0.090	0.098	0.108
University of Caldas	1.000	1.000	1.000	0.541	0.549	0.555	0.430	0.443	0.408
University of Antioquia	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
University of Cauca	1.000	1.000	1.000	0.753	0.799	0.819	1.000	0.970	1.000
Tecnológica de Pereira University	1.000	1.000	1.000	1.000	0.961	0.962	1.000	0.915	0.916
University of Medellín	1.000	0.888	0.959	0.613	0.614	0.638	0.557	0.546	0.591
University of Valle	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.957	0.881
University of Cartagena	0.814	1.000	0.998	0.889	1.000	0.983	0.661	0.749	0.752
CES University	1.000	1.000	1.000	1.000	1.000	1.000	0.784	0.886	0.792

	Model 2a			Model 2b			Model 2c		
University	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
Industrial de Santander University UIS	1.000	1.000	0.950	1.000	1.000	1.000	0.697	0.729	0.733
Sergio Arboleda University	0.254	0.209	0.216	0.625	0.621	0.621	0.064	0.060	0.061
ICESI University	1.000	0.869	0.848	1.000	1.000	1.000	0.577	0.595	0.561
EIA University	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Andes University	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Pedagogica y Tecnólogica University of Colombia	0.912	1.000	1.000	1.000	1.000	1.000	0.345	0.391	0.479
University of Manizales	0.536	0.393	0.405	0.979	0.781	0.873	0.115	0.072	0.089
Autónoma de Manizales University	1.000	1.000	1.000	0.959	0.911	0.930	1.000	1.000	1.000
Technological University of Bolivar	0.455	0.419	0.321	1.000	1.000	1.000	0.310	0.361	0.251
Nueva Granada Military University	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Santo Tomas University	0.193	0.752	0.855	1.000	1.000	1.000	0.063	0.067	0.066
El Bosque University	1.000	1.000	1.000	0.900	0.811	0.861	0.820	1.000	1.000
National Pedagogical University UPN	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
University of Magdalena	0.585	0.562	0.906	0.698	0.700	0.703	0.347	0.352	0.338
Libre University	0.370	0.348	0.682	1.000	1.000	1.000	0.076	0.070	0.055
Simón Bolívar University	0.446	0.879	0.784	0.624	0.629	0.666	0.284	0.449	0.246
Francisco José de Caldas District University	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Pontificia Bolivariana University	1.000	1.000	0.763	1.000	1.000	1.000	1.000	1.000	0.705
University of Nariño	0.706	0.466	0.488	0.932	0.872	0.906	0.212	0.236	0.243
San Buenaventura University	0.501	0.552	0.744	1.000	1.000	1.000	0.234	0.247	0.212
Autónoma del Occidente University - UAO	0.298	0.335	0.338	0.709	0.713	0.714	0.148	0.159	0.164
EAN University	0.306	0.338	0.339	1.000	1.000	1.000	0.033	0.036	0.036
Surcolombiana University	1.000	0.534	0.627	1.000	1.000	1.000	1.000	0.667	0.903
Jorge Tadeo Lozano University	0.311	0.329	0.413	0.892	0.894	1.000	0.191	0.200	0.271
University of Quindio	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.998	0.840
Central University	0.116	0.115	0.123	1.000	0.995	0.989	0.037	0.038	0.041
University of Atlantico	0.649	1.000	1.000	0.916	1.000	1.000	0.708	1.000	1.000
Antonio Nariño University	1.000	1.000	1.000	0.743	0.758	0.848	1.000	0.451	0.591
University of Sinú - Elias Bechara Zainun - UNISINU	0.200	0.192	0.194	1.000	1.000	1.000	0.074	0.078	0.089
Católica de Oriente University (UCO)	0.315	0.393	0.344	1.000	1.000	1.000	0.032	0.041	0.035
Costa University (CUC)	1.000	1.000	1.000	0.779	0.609	0.633	0.342	0.253	0.245
Católica de Colombia University	0.251	0.233	0.224	0.833	0.799	0.821	0.044	0.042	0.041
University of Ibagué	0.272	0.309	0.314	1.000	1.000	1.000	0.165	0.189	0.196

Table 2.10. Higher education efficiency using DEA-VRS

The performance of the models is also seen in the statistical summary of the models in Table 2.11, where model 2c is the most imperative for the Colombian universities with the lowest figures in average efficiency score, efficient universities, and the number of universities that have served as a benchmark for their peers. In contrast, model 2b presents the most beneficial figures; and model 2a remains in the same intermediate position.

	Model 2a			Model 2b			Model 2c		
	2016	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
Average score efficiency	0.724	0.737	0.750	0.914	0.906	0.917	0.539	0.534	0.523
Efficient universities (%)	48%	48%	42%	62%	60%	60%	32%	24%	24%
Universities as benchmark	30%	30%	36%	40%	42%	50%	28%	22%	24%

Table 2.11. Summary statistics of higher education efficiency using DEA-VRS

Model 2c presents the highest peaks in the percentage of improvement, as shown in Figure 2.8. Indeed, the modification rate that corresponds to the publication level in model 2c was eliminated since it was more than double the figure's scale. Model 2a presents improvement averages that may represent great efforts and changes in a university's research production. It increases the RG variable by 103.6% which means the duplication of actions for a better result in the calls for measurement of groups and researchers carried out by MinCiencias.

Model 2b, unlike those already presented, shows reasonable average improvement values for Colombian universities to be able to draw up a work plan aimed at improving the efficiency of research and knowledge transfer processes. The PUB variable requires the most remarkable improvement in the models that consider it in the output vector (models 2b and 2c).

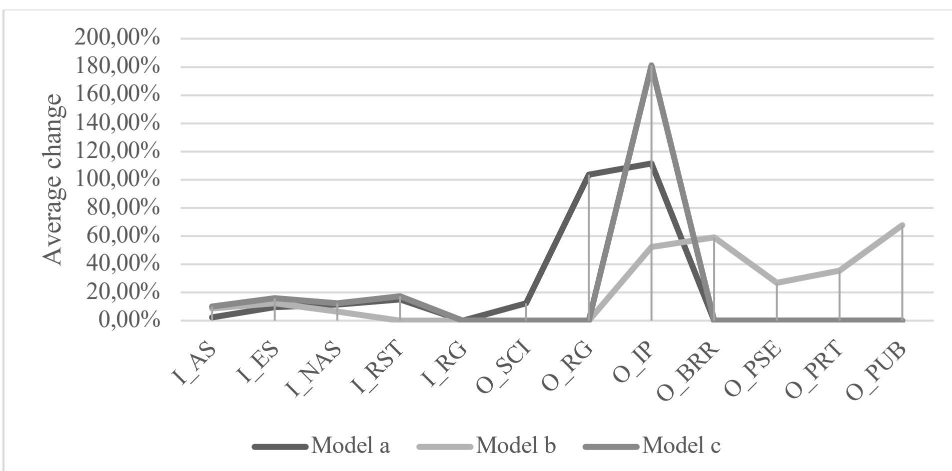

Figure 2.8. Average change for variables

The improvement proposals made by models 2a and 2c are presented for many universities (between 90 and 94%, see Figure 2.9). In comparison, model 2b presents improvements for the 60.8% of the universities analyzed that contrasts the other 39.2% of the universities. Model 2b allows for deducing that it concentrates on the changes in universities that genuinely need to generate improvement strategies.

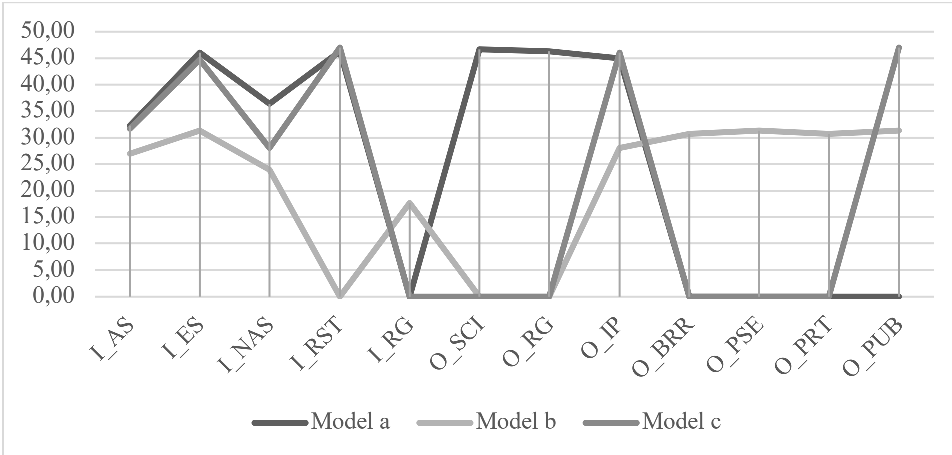

Figure 2.9. Number of universities with changes in variables

Aiming at establishing the targets to reach the frontier (i.e., to be efficient), DEA takes the levels of efficient universities as the point of reference to propose workable and possible targets. Thus, Figure 2.10 shows the universities that are taken 20 times or more as a benchmark for the other HEI in the proposed models. Some universities are used as a point of reference only in specific models because their variables combination is favorable for their performance analysis.

Andes University, Norte University, University of Antioquia, National University of Colombia, National Pedagogical University UPN, Francisco José de Caldas District University and EIA University represent a significative reference for Colombian universities in the models proposed in this study, and Nueva Granada Military University to a lower degree. Alongside are San Buenaventura University, EAN University and ICESI University, which are added to the meaningful benchmark group, but on the grounds of the variables taken into account in model 2b.

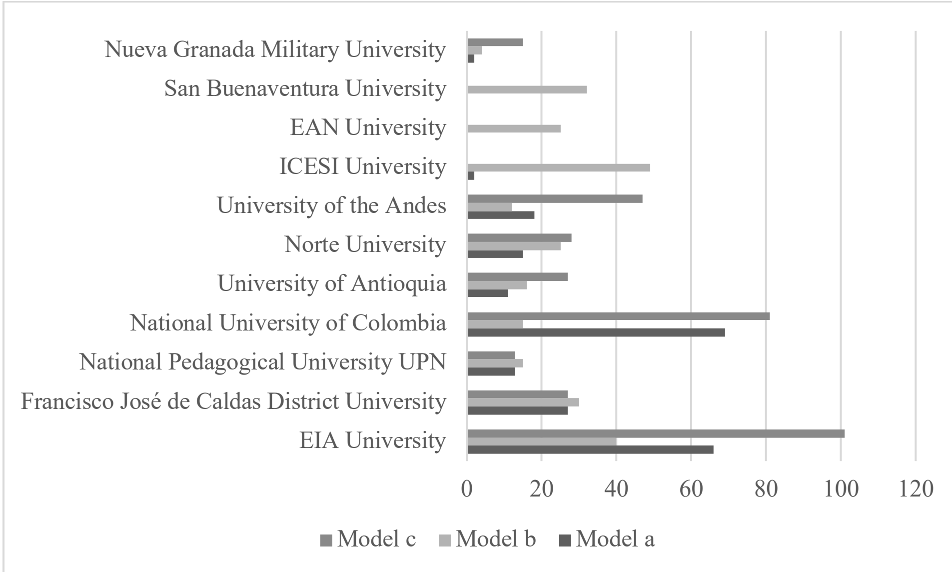

Figure 2.10. Benchmark group

Efficiency changes over 2016 – 2018 Period: A Malmquist analysis applied to Research and KT

Malmquist productivity index (MPI) adds a perspective to the study on the positive or negative changes in efficiency of the universities. Further, it offers three indicators which allow an understanding of policies and actions from which context the changes in efficiency of universities can be explained. TC is generated to present technological changes as explanatory of a certain performance, PTEC refers to Pure Technical Efficiency changes or internal changes by the university, and finally SEC corresponds to the scale efficiency change. These indicators are shown on Table 2.12 for the general group of universities analyzed.

	2016 -2017			2017-2018		
Model	**2a**	**2b**	**2c**	**2a**	**2b**	**2c**
MPI	0.951	0.975	0.955	1.019	0.987	0.982
TC	0.990	0.978	0.970	1.046	0.972	0.990
PTEC	0.980	0.991	1.008	0.948	1.013	0.976
SEC	0.980	1.006	0.977	1.027	1.002	1.016

Table 2.12. Malmquist index summary of annuals means

Note: Malmquist Productivity Index (MPI), Technological change (TC), Pure Technical Efficiency Change (PTEC), and Scale Efficiency Change (SEC).

According to Table 2.12, universities in Colombia have not had a progressive performance in the variables selected for the models proposed in this study, except for model 2a in the period from 2017-2018 in which there were some technological changes (TC) that led to that performance improvement. PTEC can be identified for the strengthening of the variables in model 2c in the period from 2016-2017 and in the period from 2017-2018 for the variables considered in model 2b. The SEC is present among all the variables of the different models in the period from 2017-2018. This presence can represent a general improvement in the efficiency scale of universities in terms of research and knowledge transfer; SEC was also used for the variables in model 2b for the period from 2016-2017.

Table 2.13 presents the universities that had a better improvement in productivity. In particular, the top 10 universities are shown for each model based on the MPI. The ranking position (R) is accompanied by the TC and the PTEC to give an idea of the origin of this improvement movement in the productivity of private (Pri) or public (P) universities with higher changes in their performance.

It can be seen that the university groups with the most significant improvements are mostly made up of private universities, especially in model 2a, where 80% are of this type; in models 2b and 2c, this percentage corresponds to 60%. Regarding the origin of the changes, since PTEC is equal to or greater than one for all universities, efforts and strategies are considered as the explanatory factor for the improvements in the three models' variables. This factor applies except for Antonio Nariño University in model 2c, whose improvement is explained exclusively by SEC with a value of 1.410.

TC is more influential in model 2a, which considers the positioning or categorization variables at the national and international level. With respect to the variables of model 2c, which consider the most frequent variables in the literature such as *PUB* and *IP*, they do not significantly register changes in the performance of universities in terms of research.

Finally, it is essential to highlight that only three universities show substantial changes in their performance in the three models: Jorge Tadeo Lozano University, De la Salle University, and the Pedagogical and Technological University of Colombia.

		Model 2a					Model 2b					Model 2c				
University	**C**	**R**	**MPI**	**TC**	**PTEC**	**SEC**	**R**	**MPI**	**TC**	**PTEC**	**SEC**	**R**	**MPI**	**TC**	**PTEC**	**SEC**
Católica del Oriente University (UCO)	Pri	1	1.207	1.069	1	1.129										
Autónoma del Occidente University - UAO	Pri	2	1.184	1.065	1	1.112	7	1.006	0.987	1.004	1.015					
Jorge Tadeo Lozano University	Pri	3	1.178	1.066	1	1.105	2	1.039	0.963	1.059	1.018	2	1.131	0.968	1.190	0.982
University of Nariño	Pri	4	1.140	1.030	1.344	.823										
Católica de Colombia University	Pri	5	1.124	1.080	1	1.041										
University of Ibagué	Pri	6	1.117	1.071	1	1.043						8	1.007	0.956	1.091	0.966
Externado de Colombia University	Pri	7	1.114	1.073	1	1.039										
De la Salle University	Pri	8	1.111	1.055	1	1.053	4	1.016	1.016	1	1	5	1.022	0.953	1.091	0.983
University of Cauca	P	9	1.091	1.031	1	1.058										
Pedagogical and Technological University of Colombia	P	10	1.087	0.965	1.147	.983	6	1.010	1.010	1	1	3	1.099	0.986	1.179	0.945
University of Atlántico	P						1	1.096	1.027	1.045	1.022	1	1.242	1.024	1.189	1.020
Antonio Nariño University	Pri						3	1.031	0.95	1.069	1.015	4	1.070	0.987	0.769	1.410
University of Sinú - Elias Bechara Zainun - UNISINU	Pri						5	1.011	0.989	1	1.022	9	1.005	0.967	1.100	0.945
University of Antioquia	P						8	1.006	1.006	1	1	7	1.008	1.008	1	1
Francisco José de Caldas District University	P						9	1.002	1.002	1	1	6	1.011	1.011	1	1
San Buenaventura University	Pri						10	1.001	1.001	1	1					
National Pedagogical University UPN	Pri											10	1.001	0.991	1	1.011

Table 2.13. Top 10 universities based on MPI

Note: Character (C), Public university (P), Private university (Pri), Ranking (R), Malmquist Productivity index (MPI), Technological Change (TC), Pure Technical Efficiency Change (PTEC), and Scale Efficiency Change (SEC).

2.5. Summary

The DEA-VRS model and the DEA-based MPI model establish a proper understanding of the efficiency of Colombian universities that helps define the targets and possible reference groups that could improve the rest of the universities. Also, the MPI shows continuous improvement in these universities' processes; similarly, the MPI's indicators show if such advance in the processes' development comes from external or internal causes.

The mixing of the methods, variables, and diverse perspectives of analysis can establish views of policies and market conditions that specifically affect the performance indicators of those activities. Considering the results for the three proposed perspectives, we present the final comments for each in this summary.

Global perspective

For models 3a, 3b, and 3c, we can deduce that models 3b and 3c are appropriate for the analysis of the efficiency of Colombian universities with accreditation as high quality. These models generate workable targets for the representative indicators of all the universities' substantive functions and give relevant information about the possible reference groups to analyze their processes and improvement measures. The selection between model 3b or 3c will depend on the purpose of the analysis with relation to the types of variables and on which possible improvements are being analyzed.

Regardless of the applied model, the variables of the substantive functions of research and knowledge transfer are those that require the most significant change in the universities analyzed.

Teaching perspective

Concerning the proposed models, all of them could be used for the performance analysis of the Colombian universities in their teaching mission; however, each model has may contribute to a bias view of the universities' behavior. Thus, the researcher's perspective and the variables over which we want to focus on the improvement measures significantly influences the model selection. Also, it is crucial to consider the exigency level that the researchers intend to establish since it is evident that universities have a high sensitivity to the variables used to measure their efficiency.

In conclusion, we identify the main characteristics for each model that we proposed and provide some highlights about the model selection for future analysis of the teaching mission:

- The variable combination in model 1a gives more stability to the analysis over time so that more universities can maintain their efficiency. Further, this model uses *RST* as an input which is favorable for the efficiency measurement since it contextualizes the teaching outputs.
- Model 1b can be used to explain how the efforts and resources of the universities are related to the results of evaluative processes. This kind of output presents additional factors that the organizations which do the evaluation processes can consider.

In general, we find a continued improvement in the efficiency of the teaching mission in the universities accredited by the CNA for the period from 2016-2018 that is explained in part by technological changes disclosed by the MPI. We show that private universities have the most significant improvements over time in their efficiency. These high-quality accredited private universities lead us to identify that the government's Ser Pilo Paga program has possibly influenced technological change in the performance of universities, which is in accordance with secondary sources that analyzed this phenomenon and that have also agreed with this conclusion.

Research and KT Perspective

From the perspective of research and KT, model 2c is more restrictive on efficiency scores by requiring high levels of improvements in the variables considered (*PUB* and *IP*). The high disparity in outputs levels produces these gaps in improvement percentages that is evident when considering the differences in the means available for the development of research processes, particularly in private universities where the funding of these projects is significantly dependent on their own resources.

Thus, we have concluded that the access to resources for developing research processes is not the same for all the universities. What is more, calls for resources consider the experience of the research groups as selecting criteria. In this case, the resources from the government should consider the cooperation among groups from different categories to promote training for scientific production.

We find that model 2a on evaluation processes as outputs is not as demanding as model 2c, nor as favorable as model 2b is for Colombian universities. Model a identifies some efficient universities that are not visible in the other models. This identification is evidence that the use of measures and evaluation processes like accreditation or categorizations of the output vector involve the evaluators' criteria and perceptions. These factors are so robust that models 2b and 2c cannot identify them merely based on production indicators.

Model 2b is most benevolent in terms of efficiency score and workable improvement percentages since the output vector considers a broader range of products from the research. This model shows that research can be carried out from different perspectives and that not all universities focus their efforts on the generation of the same products that promotes heterogeneity in the higher education sector. This heterogeneity in turn indicates that the measurement of efficiency in research and KT must encompass environmental conditions and university characteristics.

The analysis that uses Malmquist Productivity Index (MPI) shows the remarkable presence of university efforts to improve the performance variables under study. Likewise, the high presence of private universities in the ranking of universities with the most significant performance improvements for the period assessed is noteworthy.

3 CHAPTER

How much Do External Variables Influence the Universities' Efficiency?

3.1. Introduction

The social service of the education provided by universities is influenced by market regulations and actions from the ministries or regional authorities. This statement is supported by Fried *et al.* (2002) who conclude that environmental variables can influence the variation in the universities' performance. Thus, in this chapter, we analyze the efficiency scores obtained by the universities as the dependent variable of five exogenous factors that we selected based on practical considerations, such as the availability of data. Accordingly, the performance of a given university is related to factors such as the GDP, population size, unemployment, the Gini coefficient of the university's location, and the university's age.

For the analysis, we used a double-bootstrapped data envelopment analysis to measure the impact of exogenous variables on the universities' performance. We remark that the universities cannot control such exogenous variables because they correspond to socio-economic aspects of the region where each university is located. Many studies have concluded that using the student's socio-economic status as a contextual variable helps in understanding the performance of educational evaluation processes (OECD, 2016) and therefore, is part of the universities' outputs.

In addition, some of these exogenous variables are controlled by different actors or sectors; still, these affect the universities´ performance. For example, the triple helix model uses the industry, the state government, and the universities as a network in which their components interact, connect, and mutually complement and reinforce each other (Carayannis and Campbell, 2009); hence, the performance in one of the components can affect the others. Thus, "contextual data places academic attainment into the context of the circumstances in which the results were obtained" (Thiele et al., 2014).

The exogenous variables can affect the performance of universities in different ways like through missional orientation (Bruni et al., 2020) as in the disciplinary fields (Bonaccorsi and Secondi, 2017). Thus, we perform this analysis from three perspectives. The first is global, where we consider performance variables from the three missional functions (teaching, research and, knowledge transfer). In the second perspective, we focus exclusively on the teaching function. Third, we perform an analysis in which we consider both the research functions and the knowledge transfer (KT).

We highlight that this analysis can be important for both the policymakers from an institutional perspective and for decision-making from an interinstitutional perspective by contributing to the functioning of these universities by using a quadruple helix model: government, business, industry, and society (Carayannis and Campbell, 2009). Further, our analysis can benefit the agencies in charge of quality processes for evaluations and university performances since it furthers an understanding and contextualization of the indicators and levels of efficiencies presented by a particular university.

Thereby, this chapter is presented as follows: In the first section, we perform a contextualization about our last chapter (2) to justify from its results the current analysis and the external variables chosen for this analysis. Then, we analyze the relationship and separability between the external variables and the level of efficiency for the universities studied from a parametric and non-parametric approach.

3.2. Evidence from the DEA and Malmquist Analysis of the influence of external variables

Chapter 2 computed the efficiency scores for each studied university with three models from three perspectives (See subsections 2.1., 2.2., and 2.3. for more details). Namely, the first approach studies efficiency from a global perspective by considering the whole university's functions. The second is focused on the teaching mission. The third model is built from two functions under development in Colombia: research and knowledge transfer.

We proposed the three perspectives by prioritizing and strengthening the development of specific missional objectives based on their conditions and necessities for advancing science, technology, and industrial environment (Aghion et al., 2010). Thus, heterogeneity is considered a critical issue in assessing the universities' performance because the organizational efforts are diverse for the outputs related to their missional orientation (Bruni et al., 2020). Concurrently, according to the evaluation perspective, the universities' performance can be affected at a higher or lower level by specific exogenous determinants (Agasisti and Bertoletti, 2019).

To calculate the universities' performance, we applied the DEA analysis with VRS model (Banker et al., 1984) as this approach represents and evaluates in a better way the performance of the Colombian universities, which present high differentiation in the levels of input and output variables (Smirlis et al., 2006). Moreover, the model was orientated to the outputs which means that the level of inputs remained the same while the outputs were maximized; we chose this orientation because the universities are more likely to adjust the output levels to reach efficiency.

The application of the model allowed us to identify variables that affect the universities' inefficiency. This identification required significant efforts by them for their improvement and thus favor the general performance regarding substantive functions. Therefore, the registered students (*RS*), dropout rates (*DOR*), and enrolled students (*ES*) are the variables with a significant effect on the inefficiency of the universities from a teaching perspective. Furthermore, such variables can be highly permeated by the environment's economic, political, and social situations in which the student population exists. These aspects can affect the permanence and completion of educational processes.

From the research and KT perspective, patents and publications are the variables that influence university inefficiency at a general level. These two variables highly depend on the macroeconomic situations of the regions and countries where the universities reside. The relationship between external factors and research and knowledge transfer occurs in two ways: the development of university functions that influence economic indicators and vice versa.

Similarly, the possible influence of exogenous variables on the universities' efficiency can also be corroborated from the Malmquist-DEA results in chapter 2 that show the presence of technological changes as an explanatory indicator of the changes in the efficiency of the universities in the years analyzed and under the different perspectives of analysis.

3.3. External variables affecting university (in)efficiency

In this subsection, we explain the concept of the external variables used, its relationship with education, and how they affect universities' efficiency levels. The data for the graphics and analysis come from the departmental level of the universities. As the principal data source for the socioeconomic and population variables, we use the National Administrative Department of Statistics of Colombia (DANE, by its Spanish translation). The analyzed universities' websites were the data sources for their age variable.

Thus, the variables included in the current analysis are shown in Table 3.1 with their respective descriptive statistics to get an idea about their level in the Colombian context. Only the three first variables correspond to the dependent variables obtained from the results of the DEA analysis in the second chapter. The last five variables are the independent and exogenous variables proposed for this chapter.

About the dependent variables, according to the statistics from Table 3.1, the efficiency scores in research and KT have the highest variance with the widest range and the most significant standard deviation (SD). They also represent the lowest average performance. Conversely, the teaching efficiency scores have a lower range and SD and a higher average; for its part, efficiency performance from a global perspective remains between the previous two.

Furthermore, related to the independent variables, the statistics in Table 3.1 for "university's age" can partly show the heterogeneity of the academic offerings in Colombian higher education. Also, it is possible to see the high disparity of socio-economic variables between the Colombian departments according to the wide ranges and data dispersion with respect to the mean. These variables will be defined and represented graphically to better understand their variation.

Variables	Mean	SD	Min	Max
Teaching Eff.	0.983	0.020	0.923	1.000
Research Eff.	0.929	0.077	0.760	1.000
Global Eff.	0.959	0.056	0.795	1.000
Unemployment rate	9.337	1.506	6.333	13.833
Gini index	0.484	0.024	0.430	0.513
Gross domestic product	108753.075	84537.085	7564.539	236917.344
University's age	92.580	94.625	33.000	437.000
Population density	4613139.550	2626196.359	534587.000	7350311.000
Observations	50			

Table 3.1. Summary of statistics – External variables

3.3.1. Independent Variables

Unemployment rate

The employment in education studies has different perspectives. One of the most common is the employability of university graduates in the labor market (Morrison, 2019; Macias, Valencia and Montoya, 2018). These studies have examined its effect on unemployment (Horner, Zhang and Furlong, 2018; Al-Manaseer and Al-Qudah, 2018) as well as that on graduates' unemployment (Hwang, 2017). Specifically, they identify the factors that influence unemployment among new graduates (Hossain et al., 2018) as well as the effect of entrepreneurship programs on the unemployment rate of university graduates (Febriani et al., 2019).

In Colombia, the global participation rate and the employment and unemployment rates are indicators of the country's workforce, regions, departments, cities, or municipalities. The base for calculating these is the "Large Integrated Household Survey". In this study, we use the unemployment rate as an independent variable that is representative of the labor force that can affect the efficiency of accredited universities of high quality. Thus, the unemployment rate is given as the percentage relationship between the number of people looking for work and the number of people who are part of the economically active population or labor force (DANE, 2021).

Figure 3.1 represents the average unemployment rate in the departments (forms of regions) where the 50 universities analyzed in this study operate during the period from 2016-2018. The department of Quindío (geographic unit located in the center-west of Colombia) has the highest unemployment rate, followed by the departments of Tolima and Valle del Cauca, with the department of Bolívar having the lowest level of unemployment.

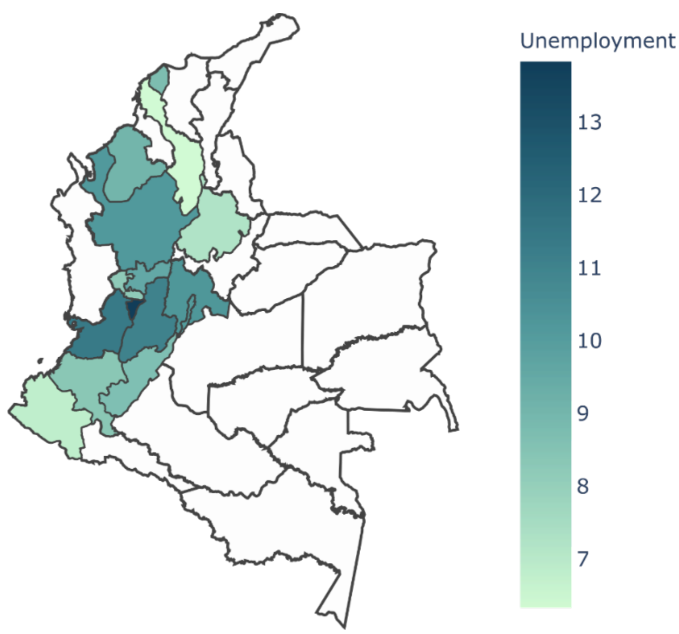

Figure 3.1. Unemployment rate. *Source: The authors based on DANE data.*

Gini index

The Gini index is an inequality indicator that measures the concentration of wealth in a geographic area. In this case, we consider the Gini index at the departmental level. The Gini coefficient measures the distance between the Lorenz curve and the equidistributional line.

Depending on the distance between these lines, the Gini coefficient has a value between zero and one, where zero represents absolute equality and one absolute inequality (DANE, 2019).

According to Winkler and Sackmann (2020), the Gini coefficient is the most used indicator for analyzing social inequality. These authors analyzed the link between this indicator and the social selectivity of HEIs in Germany and France. In the same way, Banzragch et al. (2019) have studied the education inequality by using the Gini and find it is a common tendency to focus on educational attainment (Beaulac and Rosenthal, 2019) and geographic accessibility (Walsh et al., 2016).

This study intends to analyze the relationship between the Gini index and the universities' performance according to their missional functions. The data of the Gini indicator in Colombia are calculated by DANE (DANE, 2019); we used the data corresponding to the years 2016, 2017, and 2018 of the 15 departments in which the selected universities are concentrated. Figure 3.2 shows that the average of the analyzed period shows higher coefficients in the departments located in the southwest of Colombia: Nariño, Cauca, Huila.

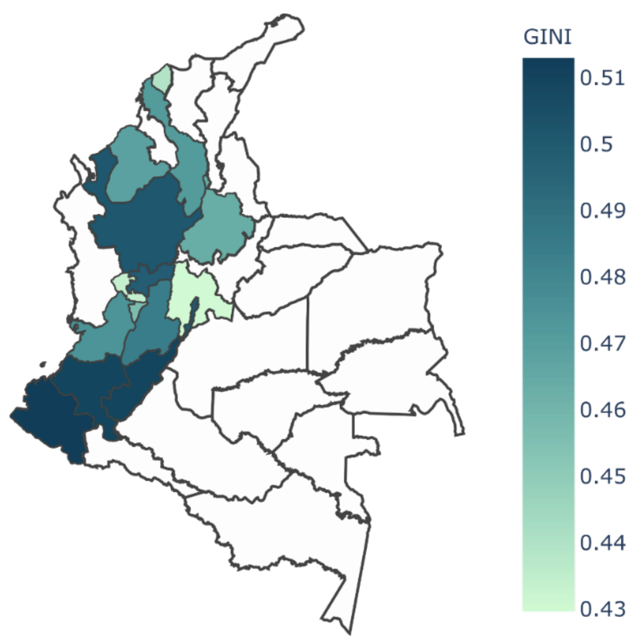

Figure 3.2. Index Gini. *Source: The authors based on data from DANE.*

Gross domestic product (GDP)

GDP is an economic indicator that reflects the monetary value of finals goods and services produced by a country or region in a specified period. Several authors have analyzed the relationship between GDP and education due to the bi-directional contributions between the local economic development and the different levels of education. In particular, they relate it to higher education as an essential factor in the creation and regional innovation through research and technology transfer, but also because it contributes to the development of human resources linked to the teaching function (OECD, 2012).

Thus, studies have analyzed GDP as an indicator of economic growth as having a causal relationship with education from the perspective of the public expenditure on education (Ifa and Guetat, 2018), enrollment in higher education (Dahal, 2010), human capital development, and university efficiency (Barra and Zotti, 2016b). In Colombia's context, we identified the analysis by OECD (2012) about the link between development of cities and HE in the Antioquia department.

This study is based on annual time series data on the GDP expressed as thousands of millions of pesos for each university according to its location. Figure 3.3 shows the GDP averages of Bogotá D.C., Antioquia, and Valle del Cauca as having the highest values.

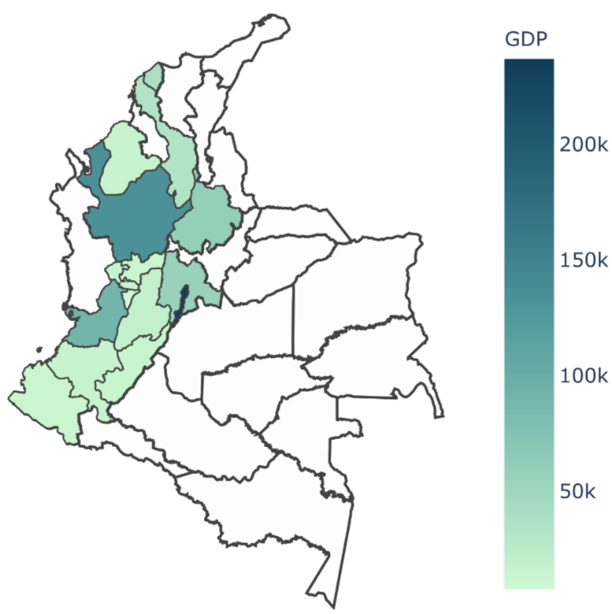

Figure 3.3. GDP level in location of universities under study

Population

The size of the population and its different indicators of dispersion have generated various economic theories around employment and costs related to daily life and services (García L. and Muñiz O., 2007). Also, in some cases, population sizes and densities are an indicator of the development in urban centers, businesses, productive cultures, government support or aid (Mozas M. and Bernal J., 2006), among other aspects. Therefore, we consider it relevant to analyze the relationship between the population size of the department where the universities operate and the levels of efficiency presented by the latter.

Thus, the census population adjusted for coverage at the departmental level comes from the 2018 National Population and Housing Census carried out by DANE (2018). We only consider the departments corresponding to the headquarters of at least one university under study. Accordingly, the population varies between 534,587 people corresponding to the department of Quindío and a maximum of 7,350,311 people in the capital city of Bogotá. The distribution of the population for the selected departments is presented in Figure 3.4.

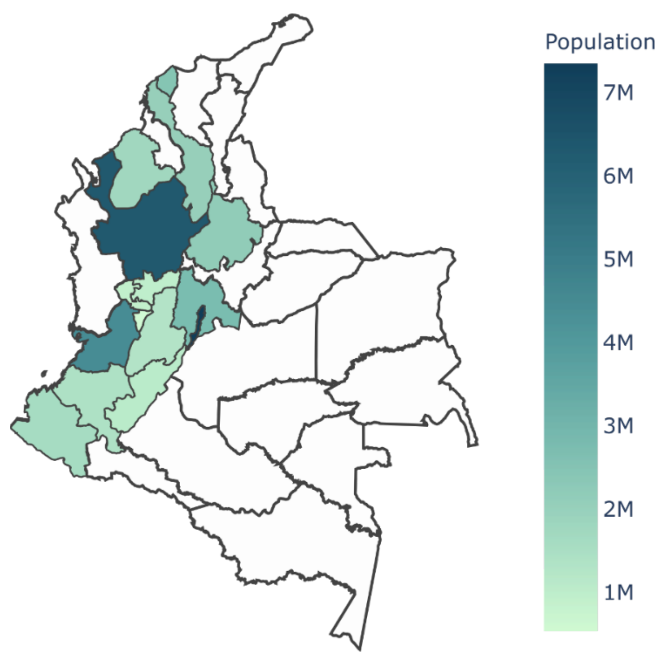

Figure 3.4. Departmental population. *Source: The authors based on data DANE*

University's age

The years of operation of the universities, called in the present study "age of the university," indicate experience developing their missionary processes. This expertise we can link with the level of establishment and improvement of organizational processes and educational services and universities' position in the market that entails a reputation and relationship with strategic allies (Warning, 2004). Therefore, we can establish a hypothesis that this variable can influence the efficient performance of universities.

Some studies use the times of efforts directed specifically on a missionary function as a representation of experience, for example, Agasisti, Barra and Zotti (2019), where the "age" of the transfer office is used to measure performance in research and KT-related functions. For our study, we prefer the experience based on the number of years since the foundation of each university as accredited with high quality, represented in Figure 3.5.

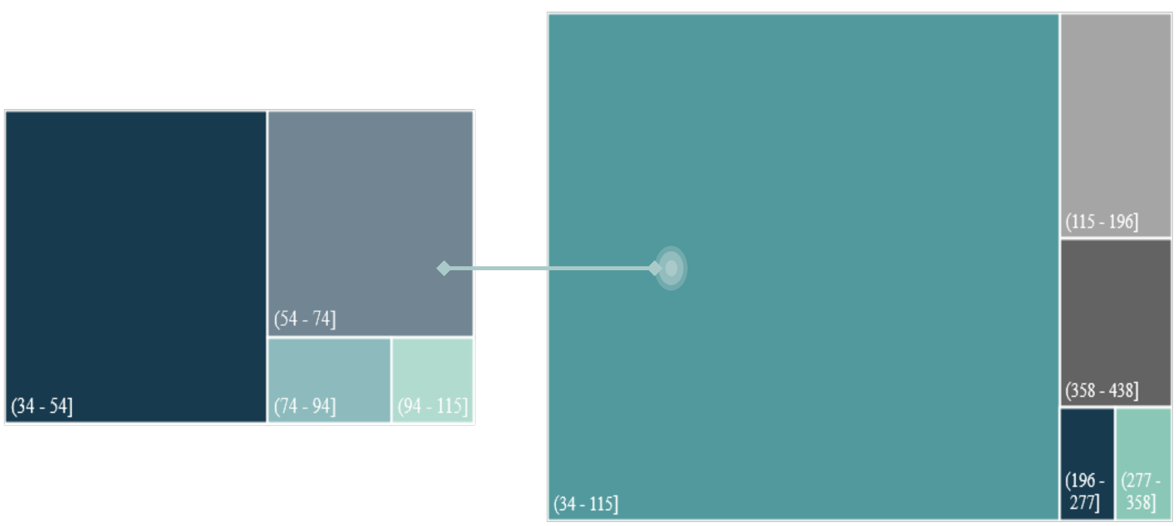

Figure 3. 5. Age of universities. *Source: The authors based on universities' site web*

The right-hand side of Figure 3.5 represents the frequency of universities in the age ranges with a high variance in which universities range from a minimum of 34 years of operation to 358 years of operation in Colombia. Most of the data (82%) are concentrated in the lower range between 34 and 115 years of operation. Due to the age and to better illustrate experience, the graph on the left side shows the range with the highest mode broken down into four ranges.

The graph located on the left side shows that 46% of the total accredited universities in Colombia are relatively new universities (between 34 and 54 years old) compared to other older universities with a marked differentiation of experience in terms of years.

3.3.2 Dependent variables

The dependent variables were calculated according to the universities' missional objectives by using them jointly (global perspective) or separately (teaching, research, and KT models) and considering that each objective has different outputs variables. At the same time, the outputs of their processes can be of different types among these: indicators or results of processes evaluation; thus, we considered three possible combinations of the production set. In this way, we analyzed the sensitivity of the university's performance according to its missional objectives and the type of variables used to evaluate them.

Teaching models

Aiming to analyze the performance of teaching at the university from an efficiency perspective, we consider three settings. For each configuration, we choose a particular combination of inputs and outputs variables which were defined in the previous chapter and can be consulted in Table 3.2. The combination of variables used in models 1a and 1c establish indicators such as the number of graduates and registered students as output variables; more complex variables correspond to outcomes from evaluative processes such as *SPT* and *DOR*. On the other hand, model 1b is formed exclusively by outputs variables that are the product of evaluation processes performed by external government entities and the students.

Models	Inputs				Outputs			
Model 1a	*AS*	*ES*	*NAS*	*RST*	*GRA*	*SPT*	*DOR*	*RS*
Model 1b	*AS*	*ES*	*NAS*	*RST*	*SPE*	*SPT*	*DOR*	*VAHI*
Model 1c	*AS*	*ES*	*NAS*		*GRA*	*SPT*	*DOR*	

Table 3.2. The teaching model specification: The production set

Research and KT models

The universities' performance from a perspective of missionary functions of research and KT is focused on the combinations shown in Table 3.3; thus, three different models arise. Model 2a uses outputs categories or levels from evaluation processes that measure aspects such as the research quality and KT. Second, model 2b is based on a set of products considered by the Ministry of Science, Technology, and Innovation of Colombia to assess different aspects (e.g., Scientific events and training activities) of Colombian universities. Third, model 2c uses publications and patents as outputs.

Models	Inputs				Outputs				
Model 2a	*AS*	*ES*	*NAS*	*RST*	*SCI*	*RG*	*IP*		
Model 2b	*AS*	*ES*	*NAS*	*RG*	*BRR*	*PSE*	*PRT*	*PUB*	*IP*
Model 2c	*AS*	*ES*	*NAS*	*RST*	*PUB*	*IP*			

Table 3.3. The research model specification: The production set

Global models

In the previous chapter, we analyzed the universities' efficiency when considering variables representative of all their missional objectives (Table 3.4). Hence, models 3a and 3c evaluate the efficiency from a mixed perspective by using indicators from teaching, research, and KT processes. Specifically, model 3c introduces a variable that has not been identified in the literature review, *RS*, as we want to analyze it to answer the question about the market interest in the academic offer of the universities. Model 3b has only the results of evaluation processes applied to all the objectives of the universities on its output side.

Models	Inputs				Outputs				
Model 3a	*AS*	*ES*	*NAS*		*GRA*	*SPT*	*DOR*	*PUB*	*IP*
Model 3b	*AS*	*ES*	*NAS*	*RST*	*SCI*	*SPT*	*RG*	*VAHI*	
Model 3c	*AS*	*ES*	*NAS*	*RG*	*GRA*	*SPT*	*RS*	*PUB*	*IP*

Table 3.4. The Global model specification: The production set

3.4. Previous Analyses

3.4.1. Pearson's correlations between variables

We implemented a Pearson correlation analysis to see the association between the variables selected for the study. Thus, Table 3.5 shows the correlation's coefficients between the variables involved in this analysis, the dependent variables obtained from the DEA implementation for each substantive objective of universities, and the independents corresponding to the environmental variables.

	TE	RE	GE	UR	Gini	GDP	UA	PD
Teaching Eff. (TE)	1.00							
Research Eff. (RE)	0.24^{*}	1.00						
Global Eff. (GE)	0.61^{***}	0.22	1.00					
Unemployment rate (UR)	0.06	0.10	0.15	1.00				
Gini index (Gini)	-0.04	0.11	0.08	0.32^{**}	1.00			
GDP	-0.04	0.13	0.18	0.43^{***}	0.47^{***}	1.00		
University's age (UA)	-0.21	0.13	0.07	-0.04	0.17	0.06	1.00	
Population density (PD)	-0.10	0.07	0.21	0.38^{***}	0.43^{***}	0.87^{***}	0.22	1.00

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.5. Pearson correlations

According to Table 3.5, it is possible to identify a few significant associations between the variables. The population density and the GDP present the highest positive association which means that a higher population density creates higher values in GDP and vice versa. The other relationships between variables are weakly positive: population density with unemployment rate and Gini index, and the GDP with the unemployment rate and the Gini index.

3.4.2. Testing separability

For this study of universities' efficiency, we related some inputs (E) versus specific outputs (S) of developing university missions. However, the relation among these variables that represent the performance of the universities can be influenced by some exogenous variables (X) which are not typically under management's control.

Simar and Wilson, (2007) have described the assumption that is related to the influence of environmental variables on the distribution of efficiency and the production possibilities through a separability condition. If the separability condition does not hold, unconditional DEA estimators are not a good representation of efficiency estimates because they do not estimate meaningful model features. Thus, for each explicative variable and model analyzed, we propose the following hypothesis:

H_0 : $f_{ESX}\ (e, s, x) = f_{ES|X}(e, s|x)\ f_X(x)$ separability

H_1 : $\vartheta^x = \{(E, S) \mid E\ can\ produce\ Y\ when\ X = x\}$

where, ϑ^x represents the production sets for a university facing the environmental conditions $X = x$

Therefore, we test the null hypothesis of separability against its complement (H_1) following Daraio et al. (2018). We test the separability condition for the total sample of the 50 universities with DEA estimators in the output direction. The test was developed by separately considering each continuous explanatory variable (i.e., Gini, GDP, university's age, population, and unemployment rate).

Table 3.6 shows the results for this analysis, the first element of vector tau contains the test statistic obtained by averaging the Daraio et al. (2018) statistics across 10 sample splits (NSPLIT= 10), and the second element is the Kolmogorov-Smirnov statistic. The vector in the second row “pval” contains the corresponding p-values estimated by the bootstrap method.

	Teaching			Research			Global		
	Model 1a	Model 1b	Model 1c	Model 2a	Model 2b	Model 2c	Model 3a	Model 3b	Model 3c
Unemployment rate	$tau [1] -0.701 0.371 $pval [1] 0.879 0.290	$tau [1] -2.654 0.500 $pval [1] 1.000 0.078	$tau [1] 0.356 0.319 $pval [1] 0.308 0.378	$tau [1] -0.182 0.231 $pval [1] 0.704 0.649	$tau [1] 0.813 0.296 $pval [1] 0.153 0.506	$tau [1] -0.964 0.303 $pval [1] 0.978 0.423	$tau [1] 0.780 0.379 $pval [1] 0.158 0.290	$tau [1] -0.220 0.272 $pval [1] 0.682 0.650	$tau [1] 0.173 0.314 $pval [1] 0.438 0.450
Gini index	$tau [1] 0.320 0.393 $pval [1] 0.347 0.215	$tau [1] 1.451 0.614 $pval [1] 0.025 0.022	$tau [1] -0.036 0.350 $pval [1] 0.573 0.285	$tau [1] 0.379 0.345 $pval [1] 0.299 0.271	$tau [1] 1.050 0.332 $pval [1] 0.073 0.361	$tau [1] -0.612 0.262 $pval [1] 0.901 0.513	$tau [1] 0.976 0.456 $pval [1] 0.082 0.118	$tau [1] 0.535 0.473 $pval [1] 0.235 0.110	$tau [1] 0.794 0.275 $pval [1] 0.153 0.597
Gross Domestic Product	$tau [1] -2.089 0.589 $pval [1] 0.998 0.013	$tau [1] -1.129 0.474 $pval [1] 0.966 0.114	$tau [1] 0.810 0.492 $pval [1] 0.097 0.044	$tau [1] 0.914 0.481 $pval [1] 0.069 0.046	$tau [1] -0.805 0.236 $pval [1] 0.915 0.744	$tau [1] -0.837 0.271 $pval [1] 0.966 0.490	$tau [1] 0.578 0.486 $pval [1] 0.241 0.081	$tau [1] 0.093 0.437 $pval [1] 0.506 0.150	$tau [1] -0.135 0.336 $pval [1] 0.640 0.389
University's age	$tau [1] -1.280 0.364 $pval [1] 0.980 0.336	$tau [1] 3.089 0.721 $pval [1] 0.000 0.003	$tau [1] -1.467 0.504 $pval [1] 0.997 0.042	$tau [1] 0.499 0.300 $pval [1] 0.205 0.391	$tau [1] -0.371 0.309 $pval [1] 0.777 0.455	$tau [1] -0.288 0.238 $pval [1] 0.798 0.626	$tau [1] 0.282 0.340 $pval [1] 0.367 0.411	$tau [1] 0.424 0.351 $pval [1] 0.291 0.375	$tau [1] -0.806 0.305 $pval [1] 0.914 0.492
Population Density	[1] -0.605 0.295 $pval [1] 0.856 0.555	$tau [1] -1.256 0.451 $pval [1] 0.980 0.151	$tau [1] 0.841 0.416 $pval [1] 0.097 0.142	$tau [1] -0.882 0.374 $pval [1] 0.961 0.209	$tau [1] -0.314 0.222 $pval [1] 0.768 0.803	$tau [1] 0.398 0.277 $pval [1] 0.264 0.462	$tau [1] -1.353 0.450 $pval [1] 0.980 0.135	$tau [1] -1.351 0.558 $pval [1] 0.986 0.031	$tau [1] 0.467 0.373 $pval [1] 0.301 0.293

Table 3.6. Test separability

As is possible to see in Table 3.6, the p-values different from zero do not reject the H_0, and therefore we can say that all the factors considered must be excluded from the production. Thus, the test statistics illustrate the significance that can represent a second-stage regression for this study to understand the universities' performance better; for this reason, we consider the effects of these factors as efficiency scores by using a double-bootstrapped DEA and SFA in the following sections.

3.5. Empirical Strategy

In this section, we analyze the selected external variables and their influence on the efficiency levels of the universities. In order to avoid the possible influence of time and heterogeneity shocks and have the same information about the universities present in our sample, we use a 3-year (period: 2016-2018). Considering that the values for the variables, unemployment rate, GDP, Gini and population, vary at the departmental level and some universities operate in different departments in the national territory, we calculate the standard deviation of the departments where these types of universities operate to select an appropriate representative measure. Thus, if the standard deviation is greater than or equal to one, then the representative measure is the median for the "multi-campus" university; otherwise (<1), the mean is used.

The analysis is discriminated by the models proposed for each of the three approaches according to the missionary functions of the universities, teaching, research, and KT, as well as a global perspective. For such an analysis, we use efficiency levels obtained in chapter 2 that correspond to universities with a special feature as the dependent variable: the accreditation as high quality. Thus, as we do not consider the total of Colombian universities and as the possible values for the university efficiency is between zero and one, then the dependent variable can be truncated. Accordingly, we use a ***truncated regression***.

Let $\{\boldsymbol{x}_n, \hat{y}_n\}_{n=1}^{N}$ be the dataset used, where $\boldsymbol{x}_n$ is a vector containing the five external variables considered (unemployment rate, Gini index, GDP, population, and university's age), and $\hat{y}_n$ being the dependent variable related to the estimated efficiency for the n-th universities; N is the total of universities considered in this study (N=50). A typical linear regression model is defined as, $\hat{y}_n = \boldsymbol{x}_n\boldsymbol{\beta}^T + \varepsilon$, where $\boldsymbol{\beta}$ are the regression coefficients which represent the effects of each independent variable over the efficiencies y_n, and $\varepsilon \sim \mathcal{N}(0, \sigma^2)$. Assuming that the efficiencies (y_n) are independent and identically distributed, the likelihood function is defined as:

$$P(\hat{y}_1, \hat{y}_2, \dots, \hat{y}_n | \boldsymbol{x}_1, \boldsymbol{x}_2, \dots, \boldsymbol{x}_N, \boldsymbol{\beta}, \sigma^2) = \prod_{n=1}^{N} \mathcal{N}(\hat{y}_n | \boldsymbol{x}_n \boldsymbol{\beta}^T, \sigma^2). \qquad \text{Eq. 7}$$

Usually, the parameters $\boldsymbol{\beta}$ and σ^2 are calculated by maximizing the likelihood function.

However, this type of regression is not applicable if the dependent variable is truncated (as in our case). In that sense, considering that the dependent variable is truncated to the left of δ, we resort to a special case of a truncated regression in which the likelihood function is defined as:

$$P(\hat{y}_1, \hat{y}_2, \ldots, \hat{y}_n | \boldsymbol{x}_1, \boldsymbol{x}_2, \ldots, \boldsymbol{x}_N, \boldsymbol{y} > \delta, \boldsymbol{\beta}, \sigma^2) = \prod_{\boldsymbol{n}=\boldsymbol{1}}^{\boldsymbol{N}} \frac{\mathcal{N}(\hat{y}_n | \boldsymbol{x_n} \boldsymbol{\beta}^{\boldsymbol{T}}, \sigma^2)}{1 - \phi_n(\delta)} \qquad \text{Eq.8}$$

where $\phi_n(\delta) = P(y_n \leq \delta)$ is the cumulative probability for a Gaussian distribution,

$$\phi_n(\delta) = P(y_n \leq \delta) = \int_{-\infty}^{\delta} \mathcal{N}(\hat{y}_n | \boldsymbol{x_n} \boldsymbol{\beta}^{\boldsymbol{T}}, \sigma^2) \boldsymbol{d y_n} \qquad \text{Eq. 9}$$

For the truncated regression, the parameters $\hat{\boldsymbol{\beta}}$ and $\hat{\sigma}^{\boldsymbol{2}}$ are estimated by likelihood functions as in a typical linear regression model. Considering these concepts, we implement the ***double-bootstrapped Data Envelopment Analysis*** in this work to analyze the relationship between technical efficiency and the exogenous variables. The relationship is measured as follows: First, the universities' efficiency is computed by solving the DEA optimization problem in Eq. 1; then, in the second stage, the DEA scores are used in a regression framework as target values, where the independent variables correspond to the environmental variables (Barra et al., 2018).

However, according to Simar and Wilson (2007), there are some problems related to that kind of two-stage method because they do not consider the correlations between the environment variables and the input-output variables used to represent the universities' behavior. Accordingly, the DEA estimations and the regression results may be biased. Further, the efficiency scores are biased in the presence of a finite number of samples.

Then, aiming to obtain an unbiased estimation for the DEA efficiencies $\hat{\boldsymbol{y}}$ and the regression parameters $\hat{\boldsymbol{\beta}}$ (which capture the dependencies between the DEA scores and the environment variables), we use two bootstrapping procedures for the two-stage efficiency estimation problem. The first approach aims to improve the regression results through the following algorithm:

Algorithm 1: Bootstrap stage 1

Compute $\hat{y}_n$ *using the data* $\{\boldsymbol{e}_n, \boldsymbol{s}_n\}_{n=1}^{N}$ *and solving the optimization problem in Eq 1*
Estimate the parameters $\widehat{\boldsymbol{\beta}}$ *and* $\widehat{\sigma^2}$ *by using the truncated regression of* $\hat{y}_n$ *over* $\boldsymbol{x}_n$ *in Eq 7*
Predefine the number of iterations L for the bootstrap procedure
for *l = 1 to L* ***do***
  for *n= 1 to N* ***do***
    Draw ϵ_n *from* $\mathcal{N}(0, \widehat{\sigma^2})$ *distribution with left truncation.*
    Compute $y_n^* = \boldsymbol{x}_n \widehat{\boldsymbol{\beta}}^T + \epsilon_n$.
  end
  Compute the parameters $\widehat{\boldsymbol{\beta}_l^*}$ *and* $\widehat{\sigma^2}_l^*$ *by solving the truncated regression of* y_n^* *over* $\boldsymbol{x}_n$
end

Use the bootstrap values $\left\{\widehat{\boldsymbol{\beta}_l^*}, \widehat{\sigma^2}_l^*\right\}_{l=1}^{L}$ *and the originals estimators* $\widehat{\boldsymbol{\beta}}$ *and* $\widehat{\sigma^2}$ *to compute the confidence intervals for the parameters* $\boldsymbol{\beta}$ *and* σ^2

Then, aiming to compute the bias-corrected estimator for $\hat{\hat{y}}_n$, $\hat{\hat{\boldsymbol{\beta}}}$, and $\hat{\hat{\sigma}}$, we use the following algorithm:

Algorithm 2 Bootstrap stage 2

Compute $\hat{y}_n$ *using the data* $\{\boldsymbol{e}_n, \boldsymbol{s}_n\}_{n=1}^{N}$ *and solving the optimization problem in Eq 1*
Estimate the parameters $\widehat{\boldsymbol{\beta}}$ *and* $\widehat{\sigma^2}$ *by using the truncated regression of* $\hat{y}_n$ *over* $\boldsymbol{x}_n$ *in Eq 7*
Predefine the number of iterations L_1 *and* L_2 *for the bootstrap procedure*
for *b= 1 to* L_1 ***do***
  for *n= 1 to N* ***do***
    Draw ϵ_n *from* $\mathcal{N}(0, \widehat{\sigma^2})$ *distribution with left truncation.*
    Compute $y_n^* = \boldsymbol{x}_n \widehat{\boldsymbol{\beta}}^T + \epsilon_n$.
    Define $\boldsymbol{e}_n^* = \boldsymbol{e}_n$, $\boldsymbol{s}_n^* = \boldsymbol{s}_n \widehat{y_n} / y_n^*$
    Compute $\hat{y}_{n,b}^*$ *using* $\{\boldsymbol{e}_n^*, \boldsymbol{s}_n^*\}_{n=1}^{N}$ *and solving the problem in Eq 1*
  end
end
for *n= 1 to N* ***do***
  Compute the Bias-corrected estimator $\hat{\hat{y}}_n = \hat{y}_n - \mathrm{BIAS}(\hat{y}_n)$, *based on the set* $\{\hat{y}_{n,b}^*\}_{b=1}^{L_1}$
End
Compute the parameters $\hat{\hat{\boldsymbol{\beta}}}$ *and* $\hat{\hat{\sigma}}$ *by solving the truncated regression of* $\hat{\hat{y}}_n$ *over* $\boldsymbol{x}_n$
for *b= 1 to* L_2 ***do***

for *n= 1 to N* ***do***

Draw ϵ_n *from* $\mathcal{N}\left(0, \widehat{\widehat{\sigma^2}}\right)$ *distribution with left truncation.*

Compute $y_n^{**} = \boldsymbol{x}_n \widehat{\widehat{\boldsymbol{\beta}}}^T + \epsilon_n$.

end

Compute the parameters $\widehat{\widehat{\boldsymbol{\beta}}}_b^*$ *and* $\widehat{\widehat{\sigma^2}}_b^*$ *by solving the truncated regression of* y_n^{**} *over* $\boldsymbol{x}_n$

End

Use the bootstrap values $\left\{\widehat{\widehat{\boldsymbol{\beta}}}_b^*,\ \widehat{\widehat{\sigma^2}}_b^*\right\}_{b=1}^{L_2}$ *and the originals estimators* $\widehat{\widehat{\boldsymbol{\beta}}}$ *and* $\widehat{\widehat{\sigma^2}}$ *to compute the confidence intervals for the parameters* $\boldsymbol{\beta}$ *and* σ^2

3.6. Empirical Evidence

3.6.1. Double-bootstrapped Scores Efficiency

We implemented the double-bootstrapped method with the DEA analysis to analyze the possible effects of exogenous variables on the university's performance. To do so, we followed the procedure suggested by Simar and Wilson (2007) with the output orientation approach. Thus, the dependent variables are the average efficiency scores obtained from the three defined models (a, b, and c) proposed for each mission (Teaching, Research and KT, and Global perspective).

On the other hand, we consider the social, economic, and demographical variables on the independent side of the department where the university is located, such as the unemployment rate, Gini index, GDP, and population density. Moreover, we use two other variables for the universities: their age and type (private or public). Table 3.7 shows the double-bootstrapped results in which the relationships with more significance are highlighted in gray.

As shown in Table 3.7, environmental variables have a significant role in explaining the inefficiency of the universities analyzed. It shows that the Gini index, GDP, and the university's age are the variables that most influence the university's performance. In particular, an increase in the Gini index causes a higher inefficiency for the universities. In contrast, a negative sign like in the case of GDP and the university's age indicates that when these variables increase, they correspond to lower inefficiency (greater efficiency) in the analyzed units.

	Teaching Model 1a	Teaching Model 1b	Teaching Model 1c	Research Model 2a	Research Model 2b	Research Model 2c	Global Model 3a	Global Model 3b	Global Model 3c
Determinant of inefficiency									
ln(Unemployment rate)	0.0617	0.137^{*}	0.0619	1.165	1.258	10.36	-0.0584	0.135	-0.243^{***}
	[0.0649]	[0.0747]	[0.0589]	[1.304]	[0.778]	[36.03]	[0.0717]	[0.104]	[0.0642]
ln(Gini index)	0.492^{**}	0.582^{**}	0.460^{**}	-8.276^{*}	0.407	633.6^{***}	1.122^{***}	0.699^{*}	0.750^{***}
	[0.217]	[0.267]	[0.183]	[4.287]	[1.935]	[242.3]	[0.273]	[0.379]	[0.207]
ln(Gross Domestic Product)	-0.0432^{**}	-0.0636^{***}	-0.0193	-0.639^{*}	-0.476^{*}	-46.82^{***}	-0.0403^{**}	-0.0274	0.0332^{*}
	[0.0215]	[0.0206]	[0.0183]	[0.352]	[0.271]	[17.15]	[0.0203]	[0.0271]	[0.0182]
ln(University's age)	-0.0445^{***}	-0.0434^{***}	-0.0316^{**}	0.341	-0.281	-28.05^{***}	-0.0565^{***}	-0.0143	-0.0423^{***}
	[0.0149]	[0.0162]	[0.0123]	[0.221]	[0.318]	[10.81]	[0.0137]	[0.0182]	[0.0111]
ln(Population Density)	0.0172	0.0253^{*}	0.00427	0.0369	-0.0406	6.754	0.0376^{**}	0.0524^{**}	0.0270^{*}
	[0.0132]	[0.0145]	[0.0119]	[0.194]	[0.0995]	[7.813]	[0.0154]	[0.0206]	[0.0139]
Private	0.0311	0.0118	0.000159	-0.0578	0.189	199.6^{***}	0.0831^{***}	-0.0405	0.0932^{***}
	[0.0202]	[0.0218]	[0.0174]	[0.367]	[0.254]	[74.75]	[0.0215]	[0.0302]	[0.0163]
Constant	1.905^{***}	2.044^{***}	1.654^{***}	-3.508	5.662	844.5^{***}	2.498^{***}	1.431^{***}	1.781^{***}
	[0.292]	[0.321]	[0.247]	[5.876]	[4.038]	[314.6]	[0.301]	[0.457]	[0.212]
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Period	2016-2018	2016-2018	2016-2018	2016-2018	2016-2018	2016-2018	2016-2018	2016-2018	2016-2018
Observations	150	150	150	150	150	150	150	150	150
Observations (inefficient)	108	116	112	116	72	126	108	100	89

Standard errors in brackets; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.7. Determinants on Efficiency Scores: Simar and Wilson (2007) output-orientated

Influence of Gini index

The Gini index represents income inequality or wealth inequality; hence, an increase in inequality produces higher inefficiency in the universities. Table 3.7 shows that the influence of the Gini index on teaching processes, on research in model 2c, and on the global perspective in models 3a and 3c.

The effect of the index on ***teaching processes*** shows that its value directly affects the access, continuity, and the finalization of people in the higher education process: people with low inequality are more likely to own the necessary educational resources to develop their education processes.

Due to the Gini index influence, it is plausible to consider that the income inequality in the market affects variables such as drop-out rate (*DOR*), the number of registered students (*RS*), and enrolled students (*ES*). In fact, according to the DEA analysis, the named variables are more necessary for improvement in the models related to teaching. Thus, it is remarkable that Table 3.7 shows the Gini index mainly influences teaching models 1a and 1c that include at least two of the three previously mentioned variables as the most affected (*DOR*, *RS*, and the input: *ES*).

Related to the influence of Gini on the model 2c of ***research and KT processes*** in which the outputs variables are the publications (*PUB*) and patents (*IP*). It is possible to see that higher inequality in income and wealth can restrict opportunities for more people to access education and less human capacity to generate knowledge; this translates as higher inefficiency levels in research and KT.

Finally, the index shows a significative influence on the global performance because the teaching and research and KT variables are on the output side, while the model 3b which is not so affected by the Gini index because it considers variables related to evaluation processes but not to particular indicators like the other models.

The GDP influence

The empirical evidence shows that the level of GDP in a specific region affects the performance of the universities in teaching and in research and KT processes as these relations are preceded by a negative sign. The negative sign means that a higher GDP can be represent a lower inefficiency (higher efficiency) in the performance of the universities.

This link is in concordance with the models of recent years about the interactions between the universities and industry in which the "third mission" of the university is to transfer knowledge through technology, assessing and protecting intellectual property, and making it available to industry (Geuna and Muscio, 2009). This transfer to industry, and companies in general, is one of the drivers of innovation and business productivity in regional innovation systems, and it generates competitive advantages (Geuna and Muscio, 2009). This transfer exists in a context of the emergence of new technology and growing demand for a more skilled workforce that motivates the teaching and training processes.

This development in the production of goods and services encourages and motivates the realization of teaching, research activities, and knowledge transfers in universities that are represented by the recruitment of university graduates to personnel exchanges, cooperative joint research, contract research, consulting, patents, publications, among other activities.

In this order, studies as developed by Barra and Zotti (2016b) suggest that at the same time, university efficiency is a significant determinant of the local GDP per capita, presenting a positive effect. Thus, the authors show that productivity gains "are larger in areas in which efficient universities are located, meaning that the closer an area is to an efficient university, the higher is the effect of the level of efficiency of the university on the economic development of that area" (pp. 663).

Other works specifically relate the universities and the GDP from the only presence of the universities in a region and not from the university's efficiency. Valero and Van Reenen (2019) show that university growth strongly correlates with later GDP per capita increase at the sub-national level. This relation is partially explained by the authors due to the increasing supply of human capital and by raising innovation, that is coherent with the influences identified of GDP on the "teaching" and "research and KT" in Table 3.7. representing the possible existence of a reciprocal influence between the universities and the increasing of GDP.

Influence of university's age

The independent variable "university's age" presents in Table 3.7 a significant coefficient with a negative sign that indicates that a higher experience in terms of working time is associated with lower levels of inefficiency in the missional objectives of the universities. This variable has significant values in all the teaching models, model 2c for the research and KT, and in some models from the global perspective. To analyze this finding, we need to contextualize how the perception of universities has evolved from being traditionally conceived as teaching universities. However, current educational and economic models go further by adding the functions of the generation of knowledge and valuable solutions in the environment through research processes and generating alliances between universities, the state, private industry, and society (Carayannis and Campbell, 2009).

Going from the traditional model to the model that includes research and transfer of this generated knowledge suggests great effort in providing physical and human resources, and about structural and organizational changes to develop in a good way the processes of 1) communication between the producers of knowledge and the users of knowledge, 2) brokering and negotiating knowledge transfer arrangements, and 3) the delivery of knowledge (Jacobson et al., 2016).

This process of adaptation of universities can be more accessible and with a higher probability of success for experienced and established universities that suggests empirical knowledge of organizational and structural aspects. Then, we can consider the coherent relationship: more years of operation equals higher performance in the processes related to research and KT.

Therefore, it is valid to add that research such as that of Siegel *et al.* (2004) suggest that for excellent performance, especially in the knowledge transfer, universities also require a good patent and research portfolio and a reputation given by experience to be more proactive in marketing especially in the cases when the reputation of the university is not sufficient to draw attention to its services of transferring knowledge.

In concordance, Berbegal-Mirabent, Lafuente and Solé (2013) have concluded that the universities have to provide the marketplace with new knowledge, experience, and technology solutions. Thus, the variable which we analyze as "university's age" can denote this necessary experience of the universities for coordinating the activities related to the third mission and indicates the accumulated knowledge, experience, and transfer resources that lead to the creation of knowledge.

Thus, we can deduce that universities with accumulated experience that is represented by the "university's age" will have better performance in the research and knowledge transfer processes because they have a better capacity to develop the appropriate policies, managerial capabilities, infrastructures and services necessary to develop academic entrepreneurship (Berbegal-Mirabent et al., 2013) and processes to generate knowledge. Additional to these processes and links with the companies, societal organizations can generate a reputation that makes a specific university an interesting place to develop a person, and that allows that university to select students with some initial quality.

Double-bootstrapped efficiency scores

The previous analysis shows that the exogenous variables influence the inefficiency levels. That means the efficiency scores might be overestimated; therefore, we present in this subsection the bias-corrected efficiencies using the double-bootstrapped DEA algorithm proposed by Simar and Wilson (2007).

Thus, the bootstrapped DEA scores are shown in appendices A.1, A.2, and A.3 for the teaching, research and KT, and global perspective, respectively. In addition, Table 3.8 shows some values to see how the efficiency scores are affected when obtained with the minimized influence of exogenous variables. Thus, Table 3.8 shows a strong influence of the exogenous variables in the universities' performance after restricting the efficiency levels and the number of universities on the efficiency frontier.

Model		Efficiency scores						Bias		
		Minimum value		Average score efficiency		Efficient universities		Average	Maximum	Minimum
		No-boot	Boot	No-boot	Boot	No-boot	Boot			
Teaching	1a	0,928	0,762	0,984	0,925	21 -> (42%)	4 -> (8%)	0,059	0,230	-0,016
	1b	0,909	0,760	0,973	0,901	14 -> (28%)	7 -> (14%)	0,072	0,232	-0,056
	1c	0,917	0,760	0,977	0,918	13 -> (26%)	4 -> (8%)	0,059	0,226	-0,042
Research and KT	2a	0,118	0,365	0,732	0,767	18 -> (36%)	3 -> (6%)	-0,035	0,595	-0,816
	2b	0,549	0,524	0,912	0,899	28 -> (56%)	21 -> (42%)	0,013	0,066	0,000
	2c	0,035	0,036	0,530	0,495	9 -> (18%)	4 -> (8%)	0,034	0,366	-0,009
Global	3a	0,923	0,760	0,983	0,919	18 -> (36%)	7 -> (14%)	0,064	0,226	-0,023
	3b	0,760	0,755	0,929	0,934	17 -> (34%)	7 -> (14%)	-0,005	0,245	-0,175
	3c	0,795	0,771	0,959	0,941	21 -> (42%)	11 -> (22%)	0,017	0,056	0,00

Table 3.8. Bootstrapped efficiency scores

We can identify the remarkable influence of exogenous variables in the teaching models which present the highest average in the bias values and changes in the number of efficient universities. This significant influence can be justified since the output variables involved in the teaching models are the ones that most react to the environmental variables by directly affecting the student market and their conditions to develop professional training.

Furthermore, Table A.1 shows The EIA University, and the National University of Colombia are the only ones that manage to remain efficient in the three combinations of production set for the teaching models. In addition, the EAN University and National Pedagogical University UPN maintain their efficiency in models 1a and 1c. Finally, in model 1b, the Technological University of Pereira, the University of Antioquia, the University of Valle, and the University of the Andes remain on the efficiency frontier together with the Externado University of Colombia, which without the influence of environmental variables manage to raise its efficiency from 0.998 to 1.

The table 3.8 shows that the research and KT models have the most significant changes in model 2a that restricts the possibilities for the universities to obtain efficiency in their performances. Only two of the 18 universities remain on the efficiency frontier (Francisco José de Caldas District University and the National University of Colombia), and the University of the Atlantic rises from 0,866 to efficiency.

Model 2a uses the positions and categories in the evaluation processes of the research and KT production as outputs (*SCI*, *RG*, and *PUB*). These outputs represent a more general vision about the criteria and general impact of these university's objectives whereby environmental factors can affect the performances more. In the same line, models 2b and 2c are also affected by the double-bootstrapped process by allowing fewer universities to remain on the efficiency frontier. However, it is necessary to highlight that model 2c was already demanding for Colombian universities; therefore, the changes are not as noticeable as in the other models.

Finally, Table 3.8 shows the effect of environmental variables on efficiency levels in the global models with the most significant changes in models 3a and 3c, which consider variables more susceptible to market conditions such as graduates, drop-out rate, and registered students.

3.6.2. From the parametric perspective

The literature review identified two main methods for measuring technical efficiency: the parametric (e.g., stochastic frontier analysis - SFA) or non-parametric (e.g., data envelopment analysis - DEA); some studies have compared these two approaches (Barra et al., 2018; Mikušová, 2020) by using HEIs (Timovski and Atanasova-Pacemska, 2021).

Thus, in chapter 2, we developed the performance analysis of the Colombian universities with high-quality accreditation by using a DEA model with a VRS orientated to outputs. However, this method does not impose a specific functional form and considers some a priori hypothesis about the technology (Agasisti et al., 2019b). The previous assumptions can generate inconsistent estimates in the inefficiency levels of the units analyzed due to the size of the sample or the presence of outliers.

Therefore, we propose using the SFA by following Battese and Coelli (1995) to offer another perspective and compare the performance of the universities according to the methods used. This parametric method needs the imposition of a specific functional form. It establishes some assumptions on the error distributions that make this approach not so sensitive to extreme values (Agasisti et al., 2019b).

Thus, in this subsection, we strengthen our empirical exercise by analyzing the effect of external factors on inefficiency by using the SFA that is based on a recent procedure suggested by Kumbhakar et al. (2014) that assumes the inefficiency component is distributed as a truncation at zero. The peculiarity of this model is that it splits the error term into four components: higher education fixed effects, time-varying inefficiency, time-invariant inefficiency, and a stochastic component that captures random shocks. Additional to the external factors considered, we added the private or public nature of the university as a dummy variable that takes the value "1" if the university is private and "0" if it is public.

Related to the production function, we assume a Cobb-Douglas functional form because it can be less susceptible to multicollinearity and degrees of freedom problems than other methods (Zellner et al., 1966). Therefore, this method can be useful to model exogenous variables in processes related to human capital formation (Laureti, 2007), as we are studying in this case with the universities objectives.

For the purpose of comparison between parametric and non-parametric methods, we use the same production sets established in the previous chapter for the development of the DEA model. Thus, for the application of SFA to the dataset we identify the necessity to deal with the multidimensional nature of the production (i.e., multiple outputs) that is necessary to obtain one indicator to represent the output set for this combination in the production sets. Consequently, we propose two solutions for this situation: i) the mean of the output variable for each case and, ii) the Benefit-of-Doubt approach (BoD) (Melyn and Moesen, 1991).

In the case of the mean giving the same weights to all the variables which compose the output vector, we consider that the strengths of the universities can be diverse. Therefore, the weights on the representative variables of their performance should be different also. Thus, a solution is to give differentiated weights to the outputs; however, it is necessary to be objective in this process. To supply this requirement some methods like BoD have been proposed.

The BoD determines the weights endogenously by the performance of the observed units that means the index is the result of a liner combination of observed best performances in the groups of DMU under study (Nardo et al., 2005). Thus the BoD is based on the "best set of weights" idea in the context of productive efficiency analysis (Van Puyenbroeck, 2018). In this sense, Nardo et al. (2005) consider that in the field of policy analysis, policymakers cannot argue there is an unfair weighting.

Appendices A.4 and A.5 explain the influence of the determinants on the efficiency scores obtained using the BoD indexes and the mean, respectively. The scores whose output side is represented by the mean of the variables is more affected by the environmental variables selected than the scores with BoD indexes as they show more significant relations. Therefore, to contrast the application of bootstrapped SFA vs DEA efficiency scores, we use the scores calculated with the composite index BoD.

Concerning the SFA scores based on index BoD, it is possible to see in Table A.4 that the university's age and the dummy variable private/public university presented a strong relationship with at least one of the models per each perspective analysis (teaching, research and KT, and global). The university's age presents a negative relationship, which means a high university's age can represent a lower inefficiency level in the universities (models: 1a, 2b, 2c, 3b). The character of private/public university has a positive relationship with the inefficiency score (models: 1a, 2c, and 3c), meaning that the character "private" is related to higher levels of inefficiency.

Thus, Table 3.9 shows the minimum, maximum, and average efficiency levels obtained by applying the SFA method using a Cobb-Douglas functional form. The individual efficiency scores can be found in appendices A.1, A.2, and A.3. The following columns display the efficiency average from the bootstrapped and no-bootstrapped DEA scores to facilitate a first comparison between the methods.

		SFA eff. scores (Cobb-Douglas)			Comparison	
		Min.	Max.	Average	Average score efficiency (No-boot)	Average score efficiency (Boot)
Teaching	1a	0,529	0,998	0,936	0,984	0,925
	1b	0,594	0,996	0,941	0,973	0,901
	1c	0,613	0,998	0,942	0,977	0,918
Research and KT	2a	0,073	0,928	0,389	0,732	0,767
	2b	0,764	0,998	0,946	0,912	0,899
	2c	0,031	0,923	0,389	0,53	0,495
Global	3a	0,563	0,937	0,837	0,983	0,919
	3b	0,707	0,999	0,939	0,929	0,934
	3c	0,040	0,717	0,245	0,959	0,941

Table 3.9. Summary SFA efficiency scores

According to the previous descriptive values, the table 3.9 shows that the average efficiency levels in the teaching models are between those shown by the other methods used. About the research and KT models, the average obtained is the lowest in the production sets 2a and 2c and the highest in model 2b with respect to the other methods with significant differentiation.

Finally, in the models from a global perspective, the variable combination proposed in model 3b shows a better performance when viewing the average as a reference in the SFA method; however, the difference between efficiency levels is not significantly different from that generated by the methods in the other models. Concerning the models 3a and 3c, the efficiency averages are lower than those in the other techniques analyzed, presenting a high gap in model 3a. To see in a better way the comparison between the used methods, Figures 3.6 – 3.8 display the Kernel distributions of the efficiency scores for each analysis perspective.

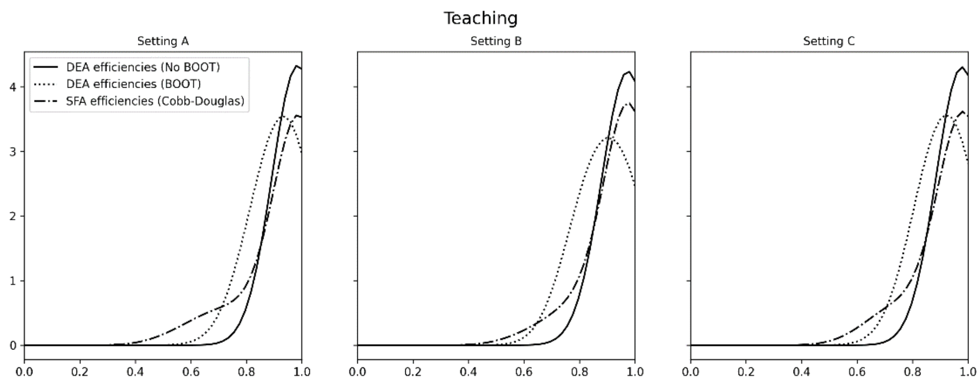

Figure 3.6. Comparison efficiency levels in teaching models among methods used

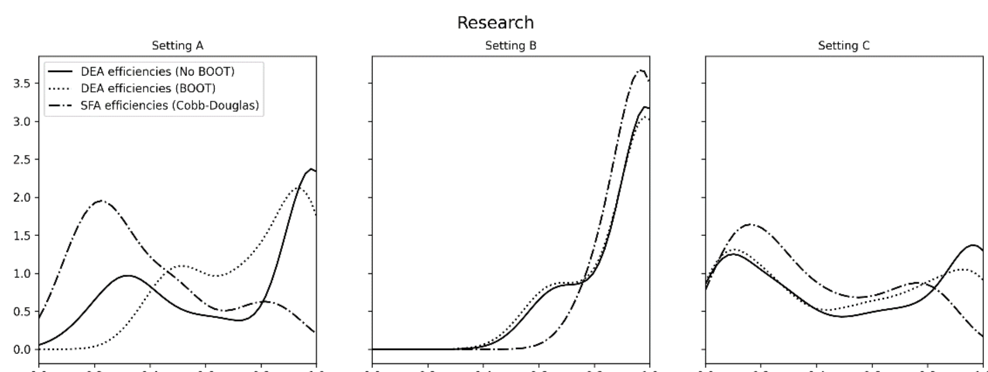

Figure 3.7. Comparison efficiency levels in research and KT models among methods used

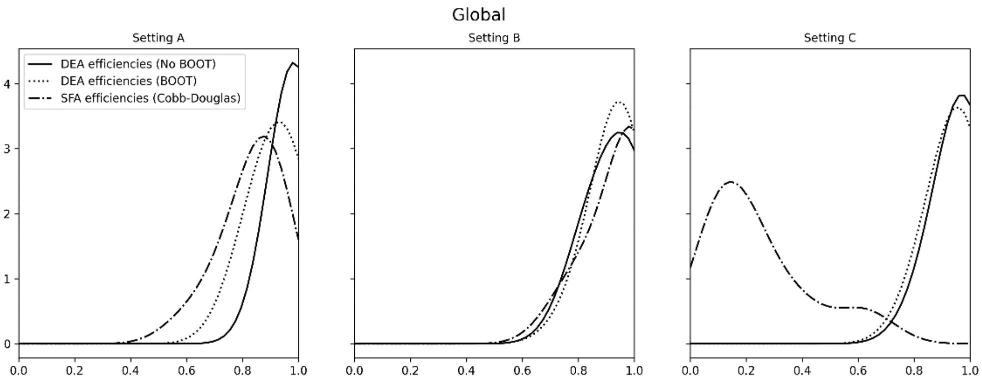

Figure 3.8. Comparison efficiency levels in models from global perspective among methods used

Figure 3.6 shows similar distributions from the different methods analyzed in all the models with a concentration of universities in the highest values of efficiency; however, the widest range is presented by the SFA due to its minimum values. Conversely, the distributions in the models related to the research and KT objectives (3.7) show a high difference in particular in model 2a. Similarly, the global perspective (Figure 3.8) in model 3c shows this differentiation is only presented by the SFA method; nevertheless, in the 3a and 3b models, the distributions from the three techniques implemented are similar.

3.7. Summary

In this chapter, we analyzed the influence of five exogenous variables on the performance of Colombian universities. These variables are the GDP, population size, unemployment, and the Gini coefficient, and the university's age. Further, we studied the exogenous variable's correlation and separability.

Thus, the separability test allowed us to prove the significance that represents for this study a second-stage regression to analyze the performance of Colombian universities. That proof is the lack of rejection of the null hypothesis of separability that indicates the selected exogenous variables must be excluded from the production function to measure the efficiency.

Thus, we developed a double-bootstrap data envelopment analysis to identify the different influences of the variables on the efficiency levels that depend on the perspective analysis. The combinations for teaching and global perspective are the most affected by the environmental variables.

The environmental variables with a significant role in explaining the inefficiency of the universities are the Gini index, GDP, and the university's age. These variables are related to income inequality or wealth inequality in the environment of the student market, production of goods and services, and prestige and experience of the universities, respectively. We explained and related this finding with previous studies for each significant relation.

Next, we analyzed the bootstrapped efficiency scores to see the change concerning the efficiency levels influenced by exogenous variables. Thus, it was possible to identify a substantial effect on the teaching models justified from the behavior and decisions of the student market according to their environmental factors. However, from all the perspectives analyzed, the efficiency levels and efficient universities are generally restricted.

Finally, we implemented a stochastic frontier approach (SFA) with a Cobb-Douglas function to provide another analysis focus from a parametric method. In particular, we used the model suggested by Kumbhakar et al (2014) in the case of Cobb-Douglas specification and assumed that the inefficiency component is distributed as a truncation at zero. For comparative effects with respect to the non-parametric results, we took the indicator calculated with the Benefit-of-Doubt approach. The difference in efficiency levels is analyzed by implementing a Kernel density estimation.

4 FINAL REMARKS

4.1. Discussion and Policy Implications

By considering the differences evidenced in the results and influences according to the analyses' perspectives, we now conduct a discussion on the individual missional objectives of universities.

Research and knowledge transfer

The asymmetries in the research levels of Colombian universities' affect the models' proposed targets that generates a high percentage in the possible improvement measures related to the representative variables of the research mission. The asymmetry comes from the inequality in the availability of resources to develop research projects and products, some conditions that favor the performance of some universities, and others policy implications.

Decree 1279 of 2002

First, we identified that national public policies motivate professors at public universities to be scientifically productive. Decree 1279 (2002) establishes the wage and salary system for teachers at public universities that indicates lifetime wage points associated with scientific productivity issues. In this line, some private universities have implemented incentive policies to motivate their teachers' development of the research mission.

This situation generates a trend toward prioritizing incentive policies to research while marginalizing the teaching mission, in which the incentives are not as representative as those for research. The prioritizing leads to a quantitative approach for these research products which in the future, may represent a preference for short-term research projects (Osterloh and Frey, 2008). Further, these incentives aimed at public universities generate gaps between their production levels and those of private ones, since in the latter, the strategies of promotion and strengthening of research should the university decide to implement them are funded mainly with their own resources.

Thus, it is necessary to discuss this topic when thinking about incentive policies institutionally. In this order, some universities must make more significant efforts to motivate the quality of teaching by establishing measurement qualifications and improvement measures that can generate teaching-learning processes with high standards and educational innovation as a fundamental requisite.

Resource calls

Second, the Ministry of Science, Technology, and Innovation has called for developing research projects that represent the universities' training of researchers and monetary resources. An essential criterion for selecting the universities to benefit is the classification of research groups. This classification as a criterion represents an advantage for the better classified groups over the others that are barely in their learning and development process; this deficiency makes their progress more difficult because of the financial cost of research in Colombia is mainly dependent on institutional resources.

Thus, universities with higher qualifications and human resource experience are more likely to access resources from the Ministry of Science, Technology, and Innovation for research development that makes categorizing research groups one of the selection criteria in calls for resources. This situation generates an area that makes it difficult for universities to access external resources to do research projects.

CAN Guidelines accreditation

We can deduce a particular interest in the development of research activities since 2013 when the National Accreditation Council (2013) added factors to evaluate “Research and artistic and cultural creation” and “National and international visibility” to the guidelines for getting an accreditation of high quality. These criteria generate inertia in universities on assessing these aspects with a specific own weight; in previous CNA models, these factors were immersed in the element of academic processes.

Discussion and policy implications

Gaps in resources and missional objectives

All Colombian universities are teaching universities that do research to the extent of their institutional capabilities. In this sense, it is understandable to find asymmetries in the research levels produced since the outputs to be generated depend mainly on the institutional resources. Therefore, the universities are equally asymmetrical in resources and sizes, but also in their model such as publics, privates, mixed, regional, sectional, confessional, military, more than 20.000 students, and less than 3.000 students.

Therefore, the gaps in the levels of the variables related to research reflect these differences among the universities. Indeed, the resources and sizes within private universities themselves vary according to the respective economic and strategic capacities. This university autonomy is granted by law 30, where each university can allocate resources in a differentiated way according to its mission scope. The difference in levels in the exposed variables reflects the data's descriptive statistics with a high variation in the levels of both the input and output variables.

Patents development

The quality of research in a university suggests greater possibilities of transferring knowledge as both substantive missions are linked. Likewise, the limitations of the research processes restrict the transfer of knowledge. But since the mid-1980s universities have opened a new form of commercialization of knowledge by modifying their role in innovation systems (Del Socorro L. et al. 2009). This new role of universities has one of its representative variables in publications and innovation patents as new ways of generating income and promoting and supporting the technological development of companies in their region and country.

The commercialization of patents represents an opportunity to diversify the income of Colombian universities, which present an economic dependence of up to 80% on student enrollment values (Anzola, 2017), and in the context of a decreasing trend in the number of students registered in the last few years (SNIES, 2019). According to the Superintendency of Industry and Commerce (n.d.), there was a growing trend in the number of patents filed by residents between 2015 and 2019. This ever-increasing trend is seen in patents granted to universities which stand at 34.09% of those processed in 2015 by residents in Colombia and was 50.16% for 2019. Thus, there is evidence of a significant improvement of these processes from the universities. However, the relatively low number of patents is one of the variables that significantly punishes the efficiency levels of Colombian universities, which indicates that it is necessary to significantly improve this area.

Therefore, we consider that although the number of granted patents for universities shows a growing trend, it is necessary to maintain this trend and enhance it with greater and equitable access to resources. Increased access to resources opens the possibility for more universities to generate patents as only 47 of these obtained patents in 2020 out of the 275 universities in operation in Colombia (Superintendency of Industry and Commerce, n.d.). Simultaneously, the gap presented between universities in number of patents would decrease which would lead the models of this study to establish lower percentages and workable goals for inefficient universities, while recognizing that there are universities that have not obtained their first patent yet.

This chasm between universities in terms of experience and the number of patents obtained may nurture further efforts for universities wishing to start generating them. Siegel et al., (2003) establish that the costs of patents are not only related to the previous research process and application to obtain them but also involve the costs related to the marketing and negotiation process of the patent already granted and whose values vary according to the position of the university holding the patent (Siegel et al., 2004).

The preceding denotes that the high number of patents established by the models that are needed to improve the performance and impact of Colombian universities in the business sector depends on the market recognition of the university as a generator of technology and knowledge. Ultimately, a significant improvement in the establishment of technical expertise, marketing skills, and developing and strengthening research processes in universities is greatly needed.

Teaching

From this analysis, we can deduce some significant policy implications for developing the teaching mission in the universities under study. Hence, we establish three discussion points:

Market perspective

The proposed models withal indicate that the drop-out rate (*DOR*) is the most significant average change variable. At the same time, registered students also present substantial changes. These two variables are similar because they can be considered market responses to start or continue with their training process. This situation can represent a problem regarding the lack of knowledge of the market conditions and restrictive conditions of various kinds that the student market presents to universities when developing their training process. The student market information is crucial for establishing the offer characteristics of the academic programs.

On the other hand, the teaching models are the most affected by the environmental variables analyzed in the third chapter, specifically the variables related to the socio-economic conditions of the student market. Thus, we can assert that the influence on teaching models is related to student market conditions, which could establish base information to prevent unfinished education processes and motivate their initiation.

Chalela-Naffah et al. (2020) assert that to mitigate drop-out rates, it is necessary to address the strategies of universities and the group that supports the students (generally the family nucleus). For the strategies, it is essential to implement research marketing that focuses on obtaining information that allows the development of actions and strategies for the satisfaction and quality of the service. In this aspect, Navarro et al. (2017) establish another critical challenge for universities: the relevance and updating of their academic offerings that are necessary to make them attractive to students.

From the group's perspective, the significant factors that influence the drop-out rate in the Colombian context are economic difficulties and personal and familiar history (Navarro et al., 2017). In concordance, González et al. (2014) identify the inverse relationship between the low gross coverage rate for universities and the high level of income inequality represented by the Gini index. As for registered students, DANE (2018) identifies trends in the Colombian population as the shrinking of the family nuclei, fewer young people, and more adults in the country, which means the reduction in the potential market for universities.

Equal access to English courses

Another observation related to the variables is the improvement for the general score of the SABER PRO test. Specifically, we can observe that when the score is specific to English skills, the average improvement necessity is almost doubled concerning the general SABER PRO score. Thus, the score shows the difference in English skills among universities and how far behind some are in their ability in relation to others. In these cases, their performances are supported in the global score by the other skills analyzed in the state exam.

To understanding the score, it is necessary to analyze whether students come from public or private schools. Mejía-Mejía (2016) explains the difference in the English as being significantly higher in students from private schools. Although the government has applied strategies to motivate and improve the learning process of students to improve the English level in public schools, the gap still exists and is substantial.

This gap means that the entering freshman of Colombian universities already come with significant differences in English levels that depend on market segmentation of the universities (students from private or public school). In this way, it is possible to implement evaluation methods based on the added value to evidence the student's actual progress during their university training process considering that a teaching process that has allowed the introduction and progress in new skills is more admirable than the skill maintained.

Favorable policy for teaching variables

Some findings lead us to believe that in the period analyzed, there was a policy or external strategy that benefited high-quality accredited universities, and to a greater extent, was reflected in private universities. Therefore, we identify the government program as Ser Pilo Paga which gave access to universities to about 40.000 students between 2014 and 2018. The students had three specific characteristics: first, they had top scores on SABER 11 (state exam for high-school graduates); second, had more social conditions in disadvantage; and third, studied in universities with a high-quality accreditation.

Londoño-Vélez et al. (2020) state that Ser Pilo Paga changed the preference in the student market, particularly from low-quality to high-quality universities. Also, the preference from the public to private universities is due to the students perceiving that the last option is more reputable and can produce more significant value-added.

Therefore, we can assert that Ser Pilo Paga had a significant influence on improving the performance of high-quality accredited universities, particularly on private ones. This influence shows that these universities expanded their student population by increasing the number of undergraduate applications (*RS*). But also, these universities have more outstanding quality and socioeconomic conditions, and high-ability students who would allow a better performance of teaching activities and evaluations.

4.2. Conclusion

The models proposed in this study have two types of outputs variables (i.e., indicators and set of them represented by assessment processes) show us that the efficiency results in Colombian universities depend on the combination and type of variables used for such measurement. A model based on a set of indicators is more restrictive related to efficiency scores and the reference groups.

The significant impact that the research variables represent in the DEA’s targets minimizes the visibility of possible improvements in other variables representative of the teaching function. The minimal visibility validates the necessity to separately analyze the teaching from the research and knowledge transfer objectives.

The separate analyzations can also establish a discussion point about how the universities' missionary objectives are balanced regarding the importance and priority of developing them. This balance can represent a topic for reflection in the quality assurance entities in which the Ministry of Education and the universities regulate the incentives for the activities of the three missional functions of the universities considering their respective particularities of context and development.

The asymmetries identified in resources and outputs represent the great differences among the universities in terms of size, available resources, research and KT production, results in teaching activities, among other features that can affect the measurement performance of universities. These differences make the models like the variable return scale appropriate for these conditions. Even though many universities are not efficient in the models, they continuously improve themselves in many cases. It can be attributed to the study group taken: the Colombian universities with accreditation as high quality by the CNA that develop a culture of constant improvement of their missional process.

This university's performance is influenced by environmental variables such as the Gini index, GDP, and university's age that demonstrate the wealth inequalities, levels of production of goods and services, and the prestige and experience of the universities in their performance. Although there is talk of the influence of exogenous variables from the regions and departments where the universities are located on the performance of the universities; it is necessary to highlight the active role that needs to assume the universities to transform the environment where they work because they have transformative capacities in the contexts.

About the methods used in this study, we could see a coherent relationship among these that justifies the results of a model and the implementation of the next. In the first part, we developed the analysis from the data envelopment analysis with variable return scale and the Malmquist-DEA; the technological changes allow us to establish the next step of analyzing the external factors that influence the universities' performance. According to the DEA, we implemented a separability test, and motivated the double-bootstrapped data envelopment analysis, we adjusted the efficiency scores to the exogenous influences. Finally, we viewed this analysis from a parametric perspective with a stochastic frontier approach (SFA) with a Cobb-Douglas function.

4.3. Future work

This study analyses a complex topic of the performance of social services in universities. The analysis is focused on the substantive objectives of the universities (teaching, research, and knowledge transfer) from a set of representative information in national systems. This information corresponds to indicators that allow the study of technical efficiency; nevertheless, we do not provide an analysis from the economic efficiency perspective. Thus, we establish that the future work can be orientated to propose an analysis from an economic point of view to complement the outcomes provided by the current work.

Concerning the variables, we have identified a lack of available information for the KT function in Colombian universities. Accordingly, a broader diversity of KT representative variables is proposed for future studies, which can give an idea of the impact of these activities in external sectors, such as contracts.

On the other hand, this study presents the findings from correlational studies and associations between selected variables. From those, it is possible to develop a cause-and-effect analysis applied to the education evaluation in order to strengthen the understanding of the identified relationships. In addition, we offer analysis from the non-parametric approach to solving the DEA optimization problem and a double-bootstrap DEA that considers two-stage optimization. From the parametric perspective, we implemented SFA. Thus, we suggest as an interesting development for the comparison between methods the implementation of a one-stage DEA method that simultaneously estimates the non-parametric frontier and the coefficients of the environmental variables (Johnson and Kuosmanen, 2012).

Related to the units analyzed, we use universities accredited as high quality by considering their disposition to improve the quality levels in the diverse functions developed and, by extension, the adoption of a culture of continuous improvement. Thus, the non-accredited universities are not included in the analysis proposed which means that some universities were excluded but also Colombian departments and regions because some of these do not have universities with the feature that we considered. This exclusion allows considering the non-accredited universities either separately or in combination with those already studied in future works.

Finally, this study provides information for decision-making in the universities. Thus, as an essential future step, we consider evaluating the findings of this study by the universities involved and the consideration to adopt the pertinent information in their organizational action plans and strategic routes.

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University	Teaching_1a DEA eff. scores (no_boot)	Teaching_1a DEA eff. scores (boot)	Teaching_1a SFA eff. scores (Cobb-Douglas)	Teaching_1b DEA eff. scores (no_boot)	Teaching_1b DEA eff. scores (boot)	Teaching_1b SFA eff. scores (Cobb-Douglas)	Teaching_1c DEA eff. scores (no_boot)	Teaching_1c DEA eff. scores (boot)	Teaching_1c SFA Eff. scores (Cobb-Douglas)
Antonio Nariño University	0,978	0,852	0,994	0,977	0,835	0,989	0,961	0,849	0,997
Autonomous University de Bucaramanga - UNAB	0,971	0,889	0,866	0,956	0,862	0,991	0,970	0,888	0,993
Autonomous University of Manizales	1,000	0,974	0,884	1,000	0,990	0,990	0,972	0,972	0,900
Autonomous University of West - UAO	0,948	0,854	0,998	0,943	0,854	0,995	0,948	0,854	0,756
CES University	1,000	0,922	0,996	1,000	0,921	0,962	1,000	0,922	0,997
Catholic University of Colombia	1,000	0,987	0,994	0,931	0,845	0,990	0,964	0,985	0,997
Catholic University of the East (UCO)	0,994	0,835	0,996	0,991	0,784	0,966	0,993	0,834	0,997
Central University	0,967	0,834	0,994	0,961	0,832	0,990	0,963	0,833	0,997
Colegio Mayor de Nuestra Señora del Rosario University	0,993	0,968	0,996	1,000	0,992	0,992	0,993	0,967	0,997
De la Salle University	0,964	0,867	0,994	0,943	0,852	0,989	0,958	0,867	0,997
EAFIT University	1,000	0,982	0,996	0,999	0,974	0,962	1,000	0,982	0,997
EAN University	1,000	1,000	0,994	0,967	0,870	0,989	1,000	1,000	0,997
EIA University	1,000	1,000	0,996	1,000	1,000	0,977	1,000	1,000	0,997
El Bosque University	1,000	0,980	0,994	1,000	0,969	0,990	0,980	0,979	0,997
Externado University of Colombia	0,978	0,993	0,995	0,998	1,000	0,990	0,977	0,993	0,997
Francisco José de Caldas District University	1,000	0,994	0,996	0,947	0,957	0,977	1,000	0,987	0,997
ICESI University	0,985	0,956	0,998	0,985	0,955	0,995	0,985	0,956	0,725
Industrial University of Santander UIS	0,974	0,902	0,986	0,975	0,901	0,982	0,971	0,902	0,992
Jorge Tadeo Lozano University	0,962	0,886	0,916	0,935	0,875	0,975	0,962	0,886	0,997
Libre University	0,998	0,999	0,644	0,935	0,817	0,737	0,998	0,999	0,997
National Pedagogical University UPN	1,000	1,000	0,996	1,000	0,984	0,981	0,996	1,000	0,997
National University of Colombia	1,000	1,000	0,994	1,000	1,000	0,934	1,000	1,000	0,997
Nueva Granada Military University	0,932	0,884	0,996	0,909	0,877	0,970	0,931	0,879	0,996
Pedagogical and Technological University of Colombia	1,000	0,971	0,618	0,991	0,846	0,963	1,000	0,961	0,993
Pontifical Bolivarian University	0,928	0,875	0,997	0,959	0,936	0,968	0,917	0,875	0,997
Pontifical Javeriana University	1,000	0,980	0,995	0,982	0,954	0,989	1,000	0,980	0,997
San Buenaventura University	0,941	0,837	0,998	0,927	0,826	0,996	0,933	0,836	0,977
Santo Tomás University	0,979	0,973	0,529	0,932	0,945	0,958	0,932	0,973	0,997
Sergio Arboleda University	0,973	0,903	0,972	0,930	0,876	0,975	0,972	0,897	0,996

Appendix

University	Teaching_1a			Teaching_1b			Teaching_1c		
	DEA eff. scores (no_boot)	DEA eff. scores (boot)	SFA eff. scores (Cobb-Douglas)	DEA eff. scores (no_boot)	DEA eff. scores (boot)	SFA eff. scores (Cobb-Douglas)	DEA eff. scores (no_boot)	DEA eff. scores (boot)	SFA Eff. scores (Cobb-Douglas)
Simón Bolívar University	0,967	0,866	0,755	0,958	0,798	0,976	0,957	0,866	0,979
Surcolombiana University	1,000	0,902	0,949	0,996	0,871	0,964	1,000	0,899	0,837
Technological University of Bolivar	1,000	0,985	0,993	0,914	0,970	0,973	1,000	0,985	0,903
Technological University of Pereira	0,950	0,881	0,673	1,000	1,000	0,834	0,950	0,879	0,925
University of Antioquia	1,000	0,994	0,998	1,000	1,000	0,680	0,953	0,904	0,998
University of Caldas	1,000	0,989	0,990	1,000	0,998	0,977	0,979	0,873	0,922
University of Cartagena	0,980	0,903	0,997	0,940	0,799	0,806	0,960	0,862	0,959
University of Cauca	1,000	0,985	0,997	1,000	0,999	0,983	0,962	0,962	0,686
University of Ibagué	0,988	0,908	0,992	0,974	0,830	0,991	0,981	0,907	0,833
University of La Sabana	0,996	0,959	0,998	0,996	0,982	0,809	0,994	0,953	0,991
University of Magdalena	1,000	0,969	0,981	0,979	0,774	0,594	1,000	0,957	0,976
University of Manizales	1,000	0,845	0,902	1,000	0,871	0,987	1,000	0,845	0,923
University of Medellín	0,999	0,956	0,996	0,983	0,882	0,963	0,999	0,956	0,997
University of Nariño	0,980	0,846	0,995	0,975	0,843	0,954	0,975	0,841	0,613
University of North	0,993	0,929	0,781	0,990	0,926	0,974	0,993	0,929	0,981
University of Quindio	0,984	0,840	0,721	0,975	0,780	0,805	0,981	0,840	0,924
University of Sinú - Elias Bechara Zainun - UNISINU	0,992	0,762	0,994	0,991	0,760	0,945	0,987	0,760	0,712
University of Valle	0,966	0,872	0,998	1,000	1,000	0,993	0,965	0,872	0,746
University of the Andes	1,000	0,999	0,995	1,000	1,000	0,990	1,000	0,999	0,997
University of the Atlantic	1,000	0,966	0,983	0,962	0,886	0,726	0,985	0,950	0,976
University of the Coast (CUC)	0,967	0,801	0,766	0,959	0,775	0,973	0,959	0,798	0,976

Table A.1. Scores Teaching models

University		**Research_2a**			**Research_2b**			**Research_2c**	
	DEA eff. scores (no_boot)	DEA eff. scores (boot)	SFA Eff. scores (Cobb-Douglas)	DEA eff. scores (no_boot)	DEA eff. scores (boot)	SFA Eff. scores (Cobb-Douglas)	DEA eff. scores (no_boot)	DEA eff. scores (boot)	SFA Eff. scores (Cobb-Douglas)
Antonio Nariño University	1,000	0,485	0,254	0,782	0,747	0,972	0,643	0,485	0,265
Autonomous University de Bucaramanga - UNAB	0,316	0,934	0,216	0,680	0,640	0,996	0,107	0,103	0,173
Autonomous University of Manizales	1,000	0,934	0,348	0,933	0,909	0,996	1,000	0,634	0,216
Autonomous University of West - UAO	0,323	0,934	0,169	0,712	0,706	0,968	0,157	0,146	0,132
CES University	1,000	0,774	0,524	1,000	0,992	0,878	0,819	0,774	0,709
Catholic University of Colombia	0,236	0,934	0,128	0,818	0,790	0,975	0,042	0,040	0,062
Catholic University of the East (UCO)	0,349	0,934	0,129	1,000	1,000	0,875	0,036	0,044	0,031
Central University	0,118	0,934	0,109	0,995	0,988	0,973	0,038	0,036	0,057
Colegio Mayor de Nuestra Señora del Rosario University	0,992	0,503	0,495	1,000	1,000	0,975	0,516	0,501	0,617
De la Salle University	0,321	0,934	0,171	1,000	1,000	0,978	0,098	0,089	0,142
EAFIT University	0,952	0,563	0,380	0,988	0,951	0,874	0,793	0,752	0,483
EAN University	0,327	0,934	0,190	1,000	1,000	0,970	0,035	0,038	0,061
EIA University	1,000	0,990	0,800	1,000	1,000	0,865	1,000	0,995	0,709
El Bosque University	1,000	0,809	0,248	0,857	0,824	0,975	0,936	0,761	0,259
Externado University of Colombia	0,243	0,934	0,094	1,000	1,000	0,974	0,056	0,055	0,064
Francisco José de Caldas District University	1,000	1,000	0,900	1,000	1,000	0,988	1,000	1,000	0,845
ICESI University	0,903	0,560	0,510	1,000	1,000	0,981	0,578	0,559	0,697
Industrial University of Santander UIS	0,983	0,543	0,647	1,000	1,000	0,997	0,719	0,674	0,769
Jorge Tadeo Lozano University	0,348	0,934	0,202	0,927	0,905	0,921	0,218	0,212	0,172
Libre University	0,445	0,782	0,096	1,000	1,000	0,957	0,067	0,065	0,067
National Pedagogical University UPN	1,000	0,996	0,222	1,000	0,999	0,987	1,000	0,820	0,133
National University of Colombia	1,000	1,000	0,928	1,000	1,000	0,991	1,000	1,000	0,800
Nueva Granada Military University	1,000	0,430	0,261	1,000	1,000	0,987	1,000	1,000	0,297
Pedagogical and Technological University of Colombia	0,970	0,733	0,245	1,000	1,000	0,998	0,401	0,391	0,218
Pontifical Bolivarian University	0,914	0,404	0,211	1,000	1,000	0,878	0,890	0,863	0,244
Pontifical Javeriana University	0,998	0,457	0,326	1,000	1,000	0,972	0,662	0,618	0,327
San Buenaventura University	0,590	0,804	0,276	1,000	1,000	0,981	0,231	0,226	0,267
Santo Tomás University	0,499	0,531	0,073	1,000	1,000	0,987	0,066	0,064	0,059
Sergio Arboleda University	0,225	0,934	0,122	0,622	0,622	0,798	0,062	0,058	0,090
Simón Bolívar University	0,675	0,623	0,167	0,639	0,620	0,764	0,315	0,242	0,144
Surcolombiana University	0,694	0,970	0,797	1,000	0,962	0,997	0,844	0,795	0,817
Technological University of Bolivar	0,394	0,935	0,492	1,000	0,984	0,987	0,304	0,291	0,453

University		Research_2a			Research_2b			Research_2c	
	DEA eff. scores (no_boot)	DEA eff. scores (boot)	SFA Eff. scores (Cobb-Douglas)	DEA eff. scores (no_boot)	DEA eff. scores (boot)	SFA Eff. scores (Cobb-Douglas)	DEA eff. scores (no_boot)	DEA eff. scores (boot)	SFA Eff. scores (Cobb-Douglas)
Technological University of Pereira	1,000	0,789	0,773	0,974	0,967	0,977	0,943	0,933	0,865
University of Antioquia	1,000	0,945	0,701	1,000	1,000	0,958	1,000	1,000	0,721
University of Caldas	1,000	0,670	0,385	0,549	0,524	0,997	0,427	0,410	0,416
University of Cartagena	0,933	0,688	0,873	0,956	0,891	0,991	0,719	0,662	0,923
University of Cauca	1,000	0,684	0,391	0,790	0,754	0,997	0,990	0,825	0,407
University of Ibagué	0,297	0,934	0,268	1,000	1,000	0,996	0,183	0,167	0,196
University of La Sabana	0,885	0,365	0,192	0,648	0,640	0,801	0,219	0,212	0,231
University of Magdalena	0,668	0,783	0,483	0,700	0,667	0,898	0,346	0,326	0,545
University of Manizales	0,440	0,935	0,260	0,874	0,860	0,996	0,091	0,088	0,156
University of Medellín	0,948	0,495	0,301	0,621	0,597	0,849	0,564	0,550	0,323
University of Nariño	0,544	0,806	0,339	0,903	0,850	0,996	0,230	0,209	0,348
University of North	1,000	0,405	0,479	1,000	1,000	0,774	1,000	0,999	0,587
University of Quindio	1,000	0,530	0,476	1,000	0,995	0,996	0,943	0,923	0,529
University of Sinú - Elias Bechara Zainun - UNISINU	0,195	0,934	0,213	1,000	1,000	0,995	0,080	0,077	0,122
University of Valle	1,000	0,732	0,589	1,000	1,000	0,987	0,945	0,905	0,630
University of the Andes	1,000	0,978	0,879	1,000	1,000	0,976	1,000	0,978	0,857
University of the Atlantic	0,866	1,000	0,763	0,971	0,962	0,913	0,891	0,894	0,799
University of the Coast (CUC)	1,000	0,490	0,341	0,670	0,627	0,779	0,277	0,265	0,403

Table A.2. Scores Research and KT models

University	Global_3a			Global_3b			Global_3c		
	DEA eff. scores (no_boot)	DEA eff. scores (boot)	SFA eff. scores (Cobb-Douglas)	DEA eff. scores (no_boot)	DEA eff. scores (boot)	SFA eff. scores (Cobb-Douglas)	DEA eff. scores (no_boot)	DEA eff. scores (boot)	SFA eff. scores (Cobb-Douglas)
Antonio Nariño University	0,962	0,778	0,748	1,000	0,820	0,999	0,994	0,953	0,254
Autonomous University de Bucaramanga - UNAB	0,970	0,888	0,930	0,867	0,945	0,900	0,920	0,892	0,160
Autonomous University of Manizales	0,972	0,847	0,832	1,000	0,998	0,999	0,856	0,820	0,717
Autonomous University of West - UAO	0,948	0,855	0,635	0,845	0,935	0,999	0,865	0,851	0,345
CES University	1,000	0,910	0,894	1,000	0,921	0,999	1,000	0,998	0,567
Catholic University of Colombia	0,964	0,927	0,900	0,829	0,934	0,999	0,973	0,947	0,239
Catholic University of the East (UCO)	0,993	0,817	0,714	0,778	0,934	0,999	0,958	0,911	0,604
Central University	0,963	0,833	0,614	0,831	0,934	0,999	1,000	0,988	0,225
Colegio Mayor de Nuestra Señora del Rosario University	0,993	0,967	0,911	1,000	0,984	0,945	0,996	0,989	0,065
De la Salle University	0,958	0,867	0,837	0,849	0,947	0,999	0,887	0,867	0,220
EAFIT University	1,000	0,990	0,932	0,986	0,964	0,999	1,000	0,990	0,426
EAN University	1,000	1,000	0,929	0,864	0,934	0,999	1,000	1,000	0,234
EIA University	1,000	0,995	0,917	1,000	1,000	0,999	1,000	1,000	0,605
El Bosque University	0,982	0,866	0,835	1,000	0,967	0,999	0,906	0,874	0,264
Externado University of Colombia	0,977	0,993	0,747	0,998	1,000	0,999	0,996	0,986	0,124
Francisco José de Caldas District University	1,000	1,000	0,855	1,000	1,000	0,999	1,000	1,000	0,095
ICESI University	0,985	0,956	0,772	1,000	0,950	0,999	1,000	1,000	0,401
Industrial University of Santander UIS	0,980	0,922	0,917	0,986	0,888	0,864	0,968	0,933	0,078
Jorge Tadeo Lozano University	0,962	0,889	0,904	0,873	0,943	0,999	0,931	0,894	0,166
Libre University	0,998	0,999	0,936	0,819	0,894	0,850	1,000	0,996	0,065
National Pedagogical University UPN	0,996	0,870	0,767	1,000	1,000	0,999	0,913	0,884	0,107
National University of Colombia	1,000	1,000	0,935	1,000	1,000	0,980	1,000	1,000	0,040
Nueva Granada Military University	1,000	1,000	0,860	0,898	0,845	0,999	1,000	1,000	0,146
Pedagogical and Technological University of Colombia	1,000	0,951	0,887	0,996	0,931	0,994	0,974	0,958	0,093
Pontifical Bolivarian University	0,923	0,946	0,837	0,973	0,918	0,998	0,910	0,899	0,337
Pontifical Javeriana University	1,000	0,988	0,895	0,999	0,936	0,801	1,000	0,998	0,044
San Buenaventura University	0,933	0,825	0,781	0,826	0,893	0,997	0,835	0,817	0,133
Santo Tomás University	0,932	0,879	0,810	0,886	0,906	0,817	0,963	0,937	0,040
Sergio Arboleda University	0,972	0,894	0,900	0,866	0,939	0,999	0,934	0,910	0,210
Simón Bolívar University	0,958	0,772	0,827	0,826	0,818	0,844	0,795	0,771	0,217
Surcolombiana University	1,000	0,921	0,779	0,886	0,967	0,999	0,966	0,957	0,419
Technological University of Bolivar	1,000	0,985	0,922	0,851	0,934	0,995	1,000	1,000	0,532

University	Global_3a DEA eff. scores (no_boot)	Global_3a DEA eff. scores (boot)	Global_3a SFA eff. scores (Cobb-Douglas)	Global_3b DEA eff. scores (no_boot)	Global_3b DEA eff. scores (boot)	Global_3b SFA eff. scores (Cobb-Douglas)	Global_3c DEA eff. scores (no_boot)	Global_3c DEA eff. scores (boot)	Global_3c SFA eff. scores (Cobb-Douglas)
Technological University of Pereira	0,995	0,976	0,924	1,000	0,999	0,727	0,984	0,978	0,123
University of Antioquia	1,000	1,000	0,879	1,000	1,000	0,882	1,000	1,000	0,092
University of Caldas	0,980	0,878	0,891	1,000	0,998	0,998	0,933	0,897	0,240
University of Cartagena	0,998	0,976	0,928	0,947	0,781	0,744	1,000	0,997	0,109
University of Cauca	0,967	0,870	0,664	1,000	0,993	0,999	0,981	0,926	0,095
University of Ibagué	0,985	0,870	0,737	0,817	0,934	0,999	1,000	1,000	0,658
University of La Sabana	0,994	0,953	0,926	0,990	0,975	0,757	0,990	0,972	0,242
University of Magdalena	1,000	0,958	0,928	0,824	0,873	0,750	1,000	0,966	0,094
University of Manizales	1,000	0,845	0,883	0,878	0,959	0,999	0,892	0,846	0,647
University of Medellín	1,000	0,990	0,937	0,962	0,880	0,999	1,000	0,991	0,387
University of Nariño	0,975	0,841	0,563	0,874	0,924	0,999	0,873	0,853	0,151
University of North	1,000	1,000	0,910	0,979	0,917	0,817	1,000	1,000	0,200
University of Quindio	1,000	0,981	0,860	0,914	0,777	0,814	1,000	0,998	0,078
University of Sinú - Elias Bechara Zainun - UNISINU	0,987	0,760	0,593	0,760	0,934	0,965	0,963	0,917	0,339
University of Valle	0,986	0,943	0,767	1,000	1,000	0,999	0,951	0,941	0,132
University of the Andes	1,000	1,000	0,921	1,000	1,000	0,999	1,000	1,000	0,182
University of the Atlantic	0,986	0,953	0,828	0,948	0,993	0,707	1,000	0,966	0,080
University of the Coast (CUC)	0,960	0,802	0,763	1,000	0,755	0,834	0,816	0,796	0,213

Table A. 3. Scores Global perspective

	Global	Teaching	Research	Global	Teaching	Research	Global	Teaching	Research
	Model 3a	Model 1a	Model 2a	Model 3b	Model 1b	Model 2b	Model 3c	Model 1c	Model 2c
Determinants of inefficiency									
ln(Unemployment rate)	0.246	-0.347	-1.465	-2.695	2.463***	1.496***	0.183	0.926*	-0.0258
	[0.237]	[0.294]	[3.503]	[1.649]	[0.582]	[0.367]	[0.664]	[0.560]	[1.336]
ln(Gini index)	-1.249	-0.0415	22.21*	16.88*	1.694	0.564	9.069*	0.502	23.27***
	[0.852]	[0.764]	[12.03]	[9.469]	[1.042]	[0.960]	[4.680]	[0.656]	[3.852]
ln(Gross Domestic Product)	-0.0985	0.0717	-1.685**	-3.381***	-0.513**	-0.168*	-1.093**	0.260	-1.582***
	[0.0840]	[0.0750]	[0.773]	[1.028]	[0.242]	[0.0961]	[0.466]	[0.483]	[0.352]
ln(University's age)	-0.283**	-0.181***	-1.286	-1.772***	-0.440**	-0.431***	-0.656**	-0.0442	-0.907***
	[0.121]	[0.0484]	[1.389]	[0.518]	[0.175]	[0.125]	[0.277]	[0.415]	[0.255]
ln(Population Density)	-0.179**	0.0660	0.420	1.141**	0.185**	-0.274***	0.151	-0.0184	-0.0925
	[0.0708]	[0.0470]	[0.282]	[0.557]	[0.0811]	[0.0660]	[0.178]	[0.205]	[0.184]
Private	-0.173**	0.729***	4.179	-1.112**	-0.358*	0.424**	2.016***	-0.202	4.942***
	[0.0800]	[0.0940]	[2.991]	[0.489]	[0.187]	[0.176]	[0.640]	[0.424]	[0.674]
Central	0.332*	-0.536***	0.0871	4.479***	1.695***	1.240***	-2.031**	0.499	1.396*
	[0.179]	[0.187]	[1.050]	[1.230]	[0.452]	[0.290]	[0.817]	[0.651]	[0.719]
Northern	-0.0999	-0.535***	-1.727*	4.016***	0.930***	1.090***	-0.216	0.309	-1.622**
	[0.115]	[0.196]	[1.007]	[1.240]	[0.293]	[0.246]	[0.418]	[0.281]	[0.699]
Southern	0.344***	0.175	-0.0721	0.662	-0.0156	0.927***	0.878	1.084**	-1.140*
	[0.125]	[0.151]	[1.343]	[0.673]	[0.301]	[0.192]	[0.628]	[0.545]	[0.591]
West Central	-0.257	0.144	-2.526**	-1.331	0.491*	1.585***	0.228	1.049	-3.374***
	[0.178]	[0.196]	[1.140]	[1.017]	[0.261]	[0.245]	[0.460]	[1.070]	[0.868]
Western	0.103	-0.218	-1.587	7.690***	1.257*	0.958***	1.705*	0.631*	-4.598***
	[0.167]	[0.157]	[1.128]	[2.442]	[0.653]	[0.231]	[0.901]	[0.343]	[0.738]
Macro fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Period	2016-2018	2016-2018	2016-2018	2016-2018	2016-2018	2016-2018	2016-2018	2016-2018	2016-2018
Observations	150	150	150	150	150	150	150	150	150

Standard errors in brackets; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A. 4. SFA- CD- BOD

	Global	Teaching	Research	Global	Teaching	Research	Global	Teaching	Research
	Model 3a	Model 1a	Model 2a	Model 3b	Model 1b	Model 2b	Model 3c	Model 1c	Model 2c
Determinants of inefficiency									
ln(Unemployment rate)	0.638	1.696***	0.0573	0.120	1.779***	0.744**	0.731**	0.219	0.605
	[0.830]	[0.346]	[0.284]	[0.130]	[0.482]	[0.292]	[0.324]	[0.229]	[0.521]
ln(Gini index)	6.111	2.695**	2.104**	4.234***	3.848**	6.262***	4.252***	-2.305	7.744***
	[8.196]	[1.093]	[0.933]	[1.014]	[1.591]	[1.424]	[1.035]	[2.084]	[2.041]
ln(Gross Domestic Product)	-0.224	-0.761***	-0.655***	-0.0732	-1.698***	0.307***	-0.368***	-0.106	-1.075***
	[0.233]	[0.178]	[0.137]	[0.0975]	[0.347]	[0.100]	[0.122]	[0.0692]	[0.252]
ln(University's age)	-0.161	-0.134*	-0.210***	-0.245***	-0.338*	-0.0001	-0.653***	-0.255	-0.482***
	[0.104]	[0.0752]	[0.0768]	[0.0666]	[0.188]	[0.0640]	[0.112]	[0.196]	[0.185]
ln(Population Density)	0.0797	0.637***	0.210***	-0.0128	0.153***	0.0812**	0.259***	-0.283*	0.300***
	[0.158]	[0.173]	[0.0594]	[0.0301]	[0.0358]	[0.0399]	[0.0506]	[0.170]	[0.116]
Private	0.149	0.359***	1.067***	-0.0482	-1.556***	0.169*	-0.671***	-0.135	1.856***
	[0.358]	[0.103]	[0.189]	[0.0767]	[0.351]	[0.0979]	[0.157]	[0.147]	[0.410]
Central	0.278	-2.035***	-0.122	0.0100	3.071***	0.910**	-0.702***	0.0882	-0.197
	[0.813]	[0.686]	[0.243]	[0.0997]	[0.870]	[0.446]	[0.245]	[0.734]	[0.478]
Northern	0.852	-1.476***	-1.103***	-0.0328	0.945**	0.931**	-1.088***	1.224**	-1.555***
	[1.253]	[0.365]	[0.207]	[0.0983]	[0.417]	[0.451]	[0.217]	[0.613]	[0.358]
Southern	0.951	-1.603***	-0.289*	-0.305**	-0.823**	1.185*	-0.935***	1.653***	-0.709**
	[1.185]	[0.453]	[0.165]	[0.119]	[0.337]	[0.639]	[0.234]	[0.602]	[0.307]
West Central	0.0523	-0.803***	-1.409***	-0.150	-0.868***	1.076**	-1.544***	1.021*	-2.332***
	[0.578]	[0.244]	[0.312]	[0.214]	[0.309]	[0.421]	[0.319]	[0.615]	[0.492]
Western	0.144	-0.390	-0.239	0.0817	4.648***	1.664***	-0.648*	-1.746	-0.636
	[0.580]	[0.457]	[0.293]	[0.139]	[1.009]	[0.503]	[0.376]	[0.435]	[0.501]
Macro fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Period	2016-2018	2016-2018	2016-2018	2016-2018	2016-2018	2016-2018	2016-2018	2016-2018	2016-2018
Observations	150	150	150	150	150	150	150	150	150

Standard errors in brackets; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A. 5. SFA – CD – MEAN

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