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Efficiency in higher education. Empirical study in public universities of Colombia and Spain

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In recent decades, Iberoamerican universities have introduced new quality assessment and accountability schemes, inspired by the New Public Management (NGP) model. In this context, efficiency in the distribution of public funds and obtaining the maximum possible return are a priority. Thus, measuring efficiency in the public sector, and specifically in higher education, has become a challenge for accounting science. The objective of this work is a proposal to calculate efficiency indices with Data Envelopment Analysis (DEA) models, introducing a previous step through the Analysis of Canonical Correlation (ACC). Using this technique, the aim is to improve discrimination capacity and overcome monodimensionality and lack of reliability in the representativeness of the chosen input and output variables. The study is applied in the public universities of Colombia and Spain during the years 2015 and 2016. The results obtained demonstrate the convenience of applying this preliminary step in the multivariate analysis. This reinforces the need to explore more rigorous methodologies in stages before and after the calculation of the efficiency indices. This practice increases confidence when using the indices to formulate policies and manage resources for the sector.
Keywords: higher education; canonical correlation analysis; data envelopment analysis DEA; efficiency; university rankings.

Eficiência no ensino superior. Estudo empírico em universidades públicas da Colômbia e Espanha

Nas últimas décadas, as universidades iberoamericanas introduziram novos esquemas de avaliação e prestação de contas, inspirados no modelo da Nova Gestão Pública (NGP). Nesse contexto, a eficiência na distribuição de recursos públicos e a obtenção do máximo retorno possível são uma prioridade. Assim, medir a eficiência no setor público, e especificamente no ensino superior, tornou-se um desafio para a ciência contábil. O objetivo deste trabalho é uma proposta para o cálculo de índices de eficiência com os modelos DEA (Data Envelopment Analysis), introduzindo uma etapa anterior da Análise de Correlação Canônica (ACC). O objetivo dessa técnica é melhorar a capacidade de discriminação e superar a monodimensionalidade e a falta de confiabilidade no quão representativas são as variáveis de entrada e saída escolhidas. O estudo é aplicado nas universidades públicas da Colômbia e Espanha durante os anos de 2015 e 2016. Os resultados obtidos demonstram a conveniência de aplicar esta etapa preliminar na análise multivariada. Isso reforça a necessidade de explorar metodologias mais rigorosas nas etapas antes e depois do cálculo dos índices de eficiência, os quais gerarão confiança, para serem utilizados na formulação de políticas e gestão de recursos para o setor.
Palavras-chave: ensino superior; análise de correlação canônica; análise de envelope de dados DEA; eficiência; produtividade; qualidade educacional; ranking universitário.

Eficiencia en la educación superior. Estudio empírico en universidades públicas de Colombia y España

En las últimas décadas, las universidades de Iberoamérica han introducido nuevos esquemas de evaluación de calidad y rendición de cuentas, inspirados en el modelo de la nueva gestión pública (NGP). En este contexto, la eficiencia en el reparto de los fondos públicos y la obtención del máximo rendimiento posible son una prioridad. Así, medir la eficiencia en el sector público, y específicamente en la educación superior, se ha convertido en un desafío para la ciencia contable. El objetivo de este trabajo es una propuesta para el cálculo de índices de eficiencia con modelos de análisis envolvente de datos (DEA), introduciendo un paso previo a través del análisis de correlación canónica (ACC). A través de esta técnica se pretende mejorar la capacidad de discriminación y superar la monodimensionalidad y falta de confiabilidad en la representatividad de las variables input y output elegidas. El estudio se aplicó en las universidades públicas de Colombia y España durante los años 2015 y 2016. Los resultados obtenidos demuestran la conveniencia de aplicar este paso preliminar en el análisis multivariante. Con ello, se refuerza la necesidad de explorar metodologías más rigurosas en etapas previas y posteriores al cálculo de los índices de eficiencia, que permitan generar confianza, a efectos de ser utilizados en la formulación de políticas y gestión de recursos para el sector.
Palabras clave: educación superior; análisis de correlación canónica; análisis envolvente de datos (DEA); eficiencia; productividad; calidad educativa; rankings universitarios.

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1. INTRODUCTION

In recent decades, society has increasingly demanded an increase in transparency and accountability from public organizations. In response to this, and aiming to improve quality and ensure efficient use of public resources (C. R. M. Silva & Crisóstomo, 2019), most countries have introduced new management models in their institutions, inspired by the principles of new public management (NPM) (Andrews, Beynon, & McDermott, 2019; Broucker, De Wit, & Verhoeven, 2018; Lane, 2002), introducing management techniques from the private sector.

Within this new paradigm, public higher education institutions have been pressured to improve their performance. Thus, many governments have implemented new regulations to professionalize universities in search of excellence. This market approach has fostered an interest in analyzing and comparing results between different universities, with particular emphasis on research (Mateos-González & Boliver, 2019).

However, the increase in university quality should not be linked only to the university's effectiveness, that is, achieving its objectives in terms of the number of publications, citations, or graduates (De-Juanas Oliva & Beltrán Llera, 2013; Giménez-Toledo & Tejada-Artigas, 2015), regardless of the cost or effort required. It is also important to consider efficiency, that is, the relationship between resources used and output produced, something indisputable given extreme resource constraints (Gómez-Sancho & Mancebón-Torrubia, 2005; Mateos-Gonzalez & Boliver, 2019).

In the public sector, the concepts of quality and efficiency should be inseparable. As stated by Gómez-Sancho & Mancebón-Torrubia (2005), it is hard to imagine that a high-quality university could be inefficient. Quality should also be associated with optimizing resource use, thus improving the services provided to the population and contributing to socioeconomic development (Debnath & Shankar, 2014; Tiana Ferrer, 2018).

On this background, this study aims to calculate efficiency scores using data envelopment analysis (DEA) by applying a preliminary calculation with canonical correlation analysis (CCA). Our main interest lies in multivariate methodological questions that are conducive to overcoming the unidimensionality and unreliable representativeness of the selected input and output variables, to improve the discriminatory power of efficiency analysis. The study considers Colombian and Spanish public universities in 2015 and 2016. Its key contribution is not so much the numerical results obtained (efficiency scores) for each university evaluated but the discussion of various methodological aspects arising from the evaluation process: formulation, delimitation, significance, and representativeness of inputs and outputs specific to public universities; technique selection; model evaluation; and selection of the units of analysis.

The results obtained show the convenience of using CCA in a preliminary step in multivariate analysis to provide reliability and representativeness to the variables used for efficiency calculations in the public higher education sector. Colombian universities obtain high average efficiency scores (0.7107 and 0.7911) in 2015 and 2016 along with high inefficiency scores (0.2280 and 0.3792), with a high dispersion of the input and output data used in the calculation. Spanish universities show lower average efficiency (0.6537 and 0.5865) and dispersion levels. Eleven out of 32 Colombian universities and six out of 48 Spanish universities are fully efficient, showing that data refinement and the selection of appropriate methods increase the reliability of the final results and therefore their usefulness.

This study is subdivided into four sections: the first reviews the literature on the subject of public management and efficiency in higher education; the second describes the CCA and DEA models applied in the study and the variables and units of analysis involved; the third describes and analyzes the empirical results obtained; finally, the fourth proceeds to the discussion and conclusions.

2. NEW PUBLIC MANAGEMENT AND EFFICIENCY IN HIGHER EDUCATION

NPM emerged at the end of the 20th century from the need to use public resources with maximum efficiency, meet citizens' demands, take advantage of the opportunities of a globalized and competitive world, and make societies more aligned with the collective will (Frey & Jegen, 2001; Agasisti & Haelermans, 2016). Thus, NPM aims to create a more efficient and effective administration in areas where a better supplier is not found, eliminating bureaucracy, adopting more rational processes, and having greater administrative autonomy (García Sánchez, 2007).

In this context, measuring public sector efficiency, specifically in higher education, becomes a challenge for accounting (A. F. Silva, J. D. G. Silva, M. C. Silva & 2017). However, measuring university efficiency is not trivial; in fact, obtaining an easy and objective measurement is one of the main problems (Moreno-Enguix, Lorente-Bayona, & Gras-Gil, 2019).

Efficiency has been a widely addressed topic in the context of private and for-profit organizations and generally implies doing things well, i.e., ensuring adequate distribution of the means utilized relative to the outcomes achieved (Álvarez, 2001). In the public sector, efficiency consists in optimizing resource use to obtain the maximum of goods and services in both quantitative and qualitative terms (Hauner & Kyobe, 2010; Mukokoma & Dijk, 2013; Peña 2008; A. F. Silva et al., 2017; Soto Mejía & Arenas Valencia, 2010).

To assess organizational efficiency, it is necessary to specify a production function reflecting the process by which the entities under evaluation transform inputs into outputs (Johnes, 2006; Kuah & Wong, 2013; A. F. Silva et al., 2017). To construct a production function for universities, their normal activities must be considered (Moncayo-Martínez, Ramírez-Nafarrate, & Hernández-Balderrama, 2020). The productive efforts of universities involve simultaneously performing several activities of different kinds (activities related to the creation of knowledge—research activities—and its dissemination through teaching, transfer, and extension activities, along with other activities that universities perform as social agents) while sharing most resources (faculty, administrative and service staff, facilities, equipment, supplies, etc.).

Like any other public organization, universities find it difficult to assign monetary values to the inputs and outputs of their production process given that they both generate multiple outputs (e.g., graduates and publications) and use multiple inputs (e.g., speakers and facilities) (Kuah & Wong, 2013).

Many studies have sought to facilitate efficiency calculation in higher education from various perspectives (Abbott & Doucouliagos, 2003; Avkiran, 2001; Bougnol & Dulá, 2006; Cloete & Moja, 2005; Fandel, 2007; Johnes, 2006; Johnes & Li, 2008; Moncayo-Martínez et al., 2020; Shi & Wang, 2004). In the Ibero-American context, Colombia and Spain — which have undergone important transformations in the public management of their universities (Brunner & Miranda, 2016) — have specifically seen the emergence of studies addressing efficiency measurement in higher education (García & González, 2011; González, Ramoni, & Orlandoni, 2017; Maza-Ávila, Quesada-Ibargüen, & Vergara-Schmalbach, 2013; Maza Ávila, Vergara-Schmalbach, & Román Romero, 2017; Melo-Becerra, Ramos-Forero, & Hernández-Santamarí, 2014) that have aimed to assess and classify institutions, either to inform citizens or the government or to disclose their management capacity, impact, coverage, or social mission.

It should be noted many of these papers focus more on the relationship between institutional inputs and outputs than on their overall performance since they compare universities by the units with best practices, based on their ability to maximize outputs given some available inputs (Johnes, 2006). The present study aims to provide a comprehensive view of both inputs and outputs — which must be relevant and significant — of the processes they engage in, by using appropriate methods, and of the results that ultimately allow the assessment and classification of the institutions. We finally aim to propose options for improvement and put forward individual and sector management policies.

4. METHODS AND DATA

4.1 CCA

A previous step before using DEA in efficiency analysis is to select the most representative variables. This step is very important since the variables used directly affect the final score. The selection of these variables seeks to obtain good discrimination between efficient and inefficient units and set a boundary that best fits the observed data. Despite their significance, few studies propose preliminary methods to construct the variables that best represent the set of inputs and outputs used for efficiency analysis (Azor Hernández, Sánchez García, & DelaCerda Gastélum, 2018; Friedman & Sinuany-Stern, 1997; Moreno Sáez & Trillo del Pozo, 2001; Sabando Vélez, & Cruz Arteaga, 2019). To optimize this process, as a previous step before using DEA, the present study applies CCA to analyze the significance and representativeness of the selected variables (inputs, outputs) to calculate efficiency scores.

CCA is a linear, multivariate statistical analysis method (Hotelling, 1935) used to identify, measure, and analyze associations between two sets of variables. While multiple regression predicts a single dependent variable from a set of independent variables, CCA facilitates the study of the interrelationships between multiple criterion variables (dependent) and multiple predictor variables (independent) (Badii & Castillo, 2007; Soto Mejía, Vásquez Artunduaga, & Villegas Flórez, 2009; Soto Mejía & Arenas Valencia, 2010). The mathematical expression of CCA is:

$$Y_1 + Y_2 + Y_3 + \dots + Y_n = X_1 + X_2 + X_3 + \dots + X_n \quad (1)$$

CCA is a valuable tool in human factor research, as it involves a clear distinction between independent and dependent variables, multiple dependent variables, and the potential for multidimensional relationships between these two sets of variables.

4.2 Data and Variables

According to Gómez-Sancho and Mancebón-Torrubia (2005), it has not been possible to specify a generally accepted production function of higher education. Inputs are usually proxies of capital and labor factors. While for the labor factor there seems to be agreement on using the number of full-time equivalent faculty (Chang, Chung, & Hsu, 2012; Johnes, 2006; Laureti, Secondi, & Biggeri, 2014; Rhodes & Southwick, 1993; Sarafoglou & Haynes, 1996; Sav, 2012), in the case of capital, the approaches are sufficiently different (infrastructure, technology, operating expenses, among others) that it continues to be an open topic for discussion. Outputs in all cases are related to the results of the two main activities in universities: teaching and research (Pérez-Esparrels & Gómez-Sancho, 2011), measured, for example, by the number of graduates (Athanassopoulos & Shale, 1997; Avrikan, 2001; Laureti et al., 2014; Rhodes & Southwick, 1993) and the number of publications (Chang et al., 2012; García-Aracil, 2013; Kao & Hung, 2008; Munoz, 2016; Kuah & Wong, 2013), respectively. The conclusion is there is no definitive standard to guide the selection of inputs and outputs in assessing university efficiency (Kuah & Wong, 2013). According to Buitrago-Suescún et al. (2017), the literature reports approximately 254 inputs and 230 outputs to measure education efficiency worldwide.

In the present study, starting from the bibliometric and systemic analysis in Ramírez-Gutiérrez, Barrachina-Palanca, and Ripoll-Feliu (2019) of the existing literature within the area of efficiency in higher education, we have selected those variables (see Table 1) that have had the most impact in previous studies and were available in the databases (National System of Higher Education Institutions of Colombia – SNIES, for its initials in Spanish, and Integrated University Information System of Spain – SIIU, for its initials in Spanish) of Colombia and Spain. The study periods are 2015 and 2016.

To formulate canonical functions, the smallest number of variables is considered, i.e., five for Colombia and three for Spain (see Table 1), since the number of possible canonical random variables (canonical dimensions) is equal to the number of variables in the smallest set (Badii & Castillo, 2007).

TABLE 1 **INPUT AND OUTPUT VARIABLES FOR MEASURING THE EFFICIENCY OF COLOMBIAN AND SPANISH PUBLIC UNIVERSITIES**

COLOMBIA				SPAIN			
INPUT VARIABLES (Independent) (Prdedictive) (Explicative)		**OUTPUT VARIABLES (Dependent) (Criterion) (Explained)**		**INPUT VARIABLES (Independent) (Predictive) (Explicative)**		**OUTPUT VARIABLES (Dependent) (Criterion) (Explained)**	
PROF_TCE:	Full-Time Equivalent (FTE) Faculty	GRAD_PREG	Degree graduates	PROF_TCE	Full-Time Equivalent research and teaching staff	GRAD_PREG	Degree graduates
ICAL_PDI	Quality index of teaching and research staff	GRAD_POST	Postgraduate graduates	ICAL_PDI	Percentage of pdi doctor	GRAD_POST	Masters graduates
NUM_ADM	Full-Time Equivalent Administrative Staff	GRUP_INV	Research Groups	NUM_ADM	Administrative and service staff PAS	PUB_WOS	Publications in Scopus and Web of Science
M2_USO_ MISIONAL	Missionary space in m2	REV_INDEX	Indexed Journals	TRANSF_EST	Total public transfers		
TRANSFER_NACION	Resources transferred by the State in COP	TOTAL_PUB_ SCOPUS	Cumulative total number of Publications in Scopus				
TOTAL: 10 Variables	(5 inputs - 5 outputs)			TOTAL: 7 Variables	(4 inputs - 3 outputs)		
INPUT VARIABLES				OUTPUT VARIABLES			
Variable name	Description			Variable name	Description		
Full-Time Equivalent Faculty PROF_TCE	The conversion of time dedicated by professors to the universities is carried out. Per hour of teaching equivalent to 0.25 FTE, part-time equivalent to 0.5 FTE, and full-time to 1 FTE.			Degree graduates GRAD_PREG	Total students graduated from university undergraduate programs during each academic year.		

Continue

COLOMBIA		SPAIN	
INPUT VARIABLES (Independent) (Prdedictive) (Explicative)	**OUTPUT VARIABLES (Dependent) (Criterion) (Explained)**	**INPUT VARIABLES (Independent) (Predictive) (Explicative)**	**OUTPUT VARIABLES (Dependent) (Criterion) (Explained)**
Quality index of the teaching and research staff ICAL_PDI	This indicator is made taking into account the level of professor training. A rate is calculated = (graduates*5 + specialists*6 + masters*8 + doctors*10)/TotalFTE. This percentage or rate is already established in the Spanish university information system, but only for professors with doctoral training.	Postgraduate graduates GRAD_POST	Total students graduated from postgraduate programs (specializations, Masters, and Doctorates) during each academic year.
FTE administrative staff NUM_ADM	The information is contained in the information systems, and is reported by the Planning Offices. It is the number of people dedicated to the administrative functions of the universities.	Research Groups GRUP_INV	Total Research Groups categorized by Colciencias in Colombia, by university. A direct relationship is found between productivity in research terms and the number of categorized research groups. This variable is not used for the Spanish universities, since it does not operate in the same sense as previously described.
Missionary space in m2 M2_USO_ MISIONAL	It is considered an important resource, and a proxy of capital (installed capacity) for the universities. It must be reported from the Planning offices to the Ministry of National Education. Many studies in Colombia use it as an input (Garcia & Gonzalez, 2011; Maza Avila, Vergara Schmalbach, & Roman Romero, 2017; Melo, Ramos, & Hernandez, 2014; Ramos, Morero, Almanza, Picon, & Rodriguez, 2015; Rodriguez Murillo, 2014). This variable can only be obtained in the SNIES database of the Colombian Ministry of Education. For the Spanish universities, this variable is not available.	Indexed Journals REV_INDEX	Total Indexed Journals by university in Colombia. A direct relationships is found between productivity in research terms and the number of indexed journals, since in Colombia the journals are attached to university institutions. For the Spanish universities this variable is not used, since most of the journals are attached to entities of a different nature.
Resources transferred by the State in COP TRANSFER_ NACION	It is the monetary value of the public transfers to each of the public universities. Also known as current transfers or transfers of the autonomous communities.	Total number of publications accumulated in Scopus NUM_PUB_ SCOPUS	Total number of publications in the Scopus database. It only works for Colombian universities, since it is the database that consolidates production for most of them in terms of research articles.

Source: Elaborated by the authors.

4.3 DEA

This model, developed by Charnes, Cooper, and Rhodes (1978), is a nonparametric and deterministic procedure to assess the relative efficiency of a set of homogeneous production units. Using the number of inputs consumed and outputs produced by each unit, and by linear programming techniques, DEA constructs, from the current best practice, the efficient production frontier against which the efficiency of each unit is evaluated (Salinas-Jiménez & Smith, 1996).

The conceptual foundations of DEA were laid by Farrel (1957), who defined technical (relative) efficiency as the ability to achieve certain objectives through the desirable combination of certain inputs and products (Ramos Ruiz, Moreno Cuello, Almanza Ramírez, Picón Viana, & Rodríguez Albor, 2015). Following Farrel (1957), DEA calculates efficiency from the following equation:

$$h_{j0} = \frac{\sum_{r}^{s} = 1 u_r y_{rj} 0}{\sum_{i}^{m} = 1 v_i x_{ij} 0} \tag{2}$$

Where:

r = 1…s	Subscript identifying an output
j = 1…n	Subscript identifying the different decision-making units (DMUs)
i = 1…m	Subscript identifying the input
j_o	Subscript identifying the decision-making unit (DMU) for which the efficiency is being calculated.
h_{j0}	Efficiency of the decision-making unit (DMU) that is being calculated
u_r	Relative weight of the output yr for the DMU j0 that is being calculated.
v_i	Relative weight of input xi in the DMU j0 that is being calculated.

The weights obtained (U_r and V_i) represent the values attributed to each input and output that provide the highest possible efficiency index to each decision-making unit (DMU). This weight combination, when applied to the rest of the DMUs must yield an efficiency indicator between 0 and 1. Thus, the objective is to find the DMUs producing the highest output levels from the lowest input levels. To do this, it maximizes the ratio of weighted outputs and weighted inputs for each DMU under consideration (Ray, 1991).

Since 1978, according to Soto Mejía and Arenas Valencia (2010), many multivariate models have been developed. The two basic models, named after the initials of their innovators, are CCR (Charnes, Cooper, & Rhodes, 1981) and BCC (Banker, Charnes, & Cooper, 1984), which may differ in their orientation (inputs, outputs, or none), diversification, returns to scale (CRS: constant returns to scale; NIRS: nonincreasing returns to scale; NDRS: nondecreasing returns to scale; and VRS: variable returns to scale), measurement type (radial, nonradial, additive, multiplicative, hyperbolic, etc.), and other features. Equations (3), (4), (5), and (6) in Box 1 show the linear programming models for CCR (constant returns) and BCC (variable returns to scale), with input orientation and output orientation.

BOX 1 CCR (CHARNES, COOPER AND RHODES) AND BCC (BANKER, CHARNES, AND COOPER) MODELS FOR DATA ENVELOPMENT ANALYSIS

CCR-I model Input-oriented	CCR-O model Output-oriented
Min_θ Subject to: $\theta\,\chi_0 - X\lambda \geq 0$ $Y\lambda \geq y_0$ $\lambda \geq 0$ $\lambda = (\lambda_1, \lambda_2, \ldots, \lambda_n)^T$ (3)	Max_η Subject to: $\chi_0 - X_\mu \geq 0$ $\eta y_0 - Y_\mu \leq 0$ $\mu \geq 0$ (4)
BCC-I model **Input-oriented**	**BCC-O model** **Output-oriented**
Min_θ_B Subject to: $\theta_B\,\chi_0 - X\lambda \geq 0$ $Y\lambda \geq y_0$ $e\lambda = 1$ $\lambda \geq 0$ $\lambda = (\lambda_1, \lambda_2, \ldots, \lambda_n)^T$ (5)	Max_η_B Subject to: $\chi_0 - X\lambda \geq 0$ $\eta_B\, y_0 - Y\lambda \leq 0$ $e\lambda = 1$ $\lambda \geq 0$ (6)

Source: Elaborated by the authors.
Note: The BCC-O model aims to determine how much output could be obtained from the same level of inputs if all the DMUs were efficient, once the scale effects are removed.

The BCC model is designed to measure efficiency under variable returns. In this procedure, the inefficient DMUs are compared only with efficient units operating on a similar scale (Soto Mejía & Arenas Valencia, 2010). The output-oriented BCC model is the best suited to evaluate the efficiency of public universities (Ramos Ruiz et al., 2015; Visbal-Cadavid, Mendoza Mendoza, & Causado Rodríguez, 2016), as these may have different sizes in terms of the number of students, faculty, and/or financial resources allocated, may not control their inputs, and may rely on models of state funding and budget allocation. Thus, the BCC-O model aims to determine how much output could be obtained from the same level of inputs if all DMUs were efficient, once scale effects were eliminated.

4.4 Units of Analysis or DMUs

A DMU is the unit subject to efficiency measurement compared to others of its kind or typology. The DMU controls the process of transforming resources (inputs) into products. To identify the DMU, it must comply with an essential homogeneity characteristic, which is evident when it is verified that all DMUs use the same type of resource (inputs) to obtain the same type of output, albeit in different amounts (Soto Mejía & Arenas Valencia, 2010).

Thus, Colombian and Spanish public universities can be seen as production units transforming resources into products. Each institution—treated as a DMU—can be considered a multiproduct organization (Ray, 1991). This study focuses on 32 DMUs (Colombian public universities) and 48 DMUs (Spanish public universities) belonging to the public university system (SUE, for its initials in Spanish) of each country (see Table 2).

TABLE 2 DMUS. UNIVERSITIES OF THE COLOMBIAN AND SPANISH PUBLIC UNIVERSITY SYSTEMS

COLOMBIA - SUE			SPAIN - SUE		
No.	University Name (DMU)	Acronym	No.	University Name (DMU)	Acronym
1	University of Antioquia	udea	1	A Coruña	UDC
2	University of Caldas	unicaldas	2	Alcalá	UAH
3	University of Cartagena	unicart	3	Alicante	UA
4	University of Córdoba	unicord	4	Almería	UAL
5	University of Cundinamarca	udecun	5	Autonomous U. of Barcelona	UAB
6	University of the Amazon	uniamaz	6	Autonomous U. of Madrid	UAM
7	University of the Guajira	uniguajira	7	Barcelona	UB
8	University of the Llanos	unillanos	8	Burgos	UBU
9	University of Nariño	unariño	9	Cádiz	UCA
10	University of Pamplona	unipamp	10	Cantabria	UNICAN
11	University of Sucre	unisucre	11	Carlos III de Madrid	UC3M
12	University of the Atlantic	uniatlantico	12	Castilla-La Mancha	UCLM
13	University of Cauca	unicauca	13	Complutense U. of Madrid	UCM
14	University of Magdalena	unimag	14	Córdoba	UCO
15	University of the Pacific	unipac	15	Extremadura	UNEX
16	University of Quindio	uniquindio	16	Girona	UDG
17	University of Tolima	udetol	17	Granada	UGR
18	University of Valle	univalle	18	Huelva	UHU
19	Francisco José de Caldas University	udist	19	Illes Balears (Les)	UIB
20	Francisco de Paula Santander University - Cúcuta	ufpsc	20	Jaén	UJAEN

Continue

COLOMBIA - SUE			SPAIN - SUE		
No.	University Name (DMU)	Acronym	No.	University Name (DMU)	Acronym
21	Francisco de Paula Santander University - Ocaña	ufpso	21	Jaume I de Castellón	UJI
22	Industrial University of Santander	uis	22	La Laguna	ULL
23	Military University - Nueva Granada	militar	23	La Rioja	UNIRIOJA
24	National Open and Distance University UNAD	unad	24	Las Palmas de Gran Canaria	ULPGC
25	National university of Colombia	unal	25	León	UNILEON
26	National Pedagogical University of Colombia	upnal	26	Lleida	UDL
27	Pedagogical and Technological University of Colombia - UPTC	uptc	27	Málaga	UMA
28	Popular University of Cesar	upoc	28	Miguel Hernández de Elche	UMH
29	Surcolombiana University	unisur	29	Murcia	UM
30	Technological University of Pereira	utp	30	National University of Distance Education	UNED
31	Technological University of Chocó	utch	31	Oviedo	UNIOVI
32	University - College of Cundinamarca	ucolm	32	Pablo de Olavide	UPO
			33	Basque Country/Euskal Herriko Unibertsitatea	EHU
			34	Polytechnic U. of Cartagena	UPCT
			35	Polytechnic U. of Catalonia	UPC
			36	Polytechnic U. of Madrid	UPM
			37	Polytechnic U. of Valencia	UPV
			38	Pompeu Fabra	UPF
			39	Public U. of Navarra	UPNA
			40	Rey Juan Carlos University	URJC
			41	Rovira i Virgili	URV
			42	Salamanca	USAL
			43	Santiago de Compostela	USC
			44	Sevilla	US
			45	València (Estudi General)	UV
			46	Valladolid	UVA
			47	Vigo	UVIGO
			48	Zaragoza	UNIZAR

Source: Elaborated by the authors.

5. RESULTS

5.1 Significance Analysis by CCA

Table 3 shows the canonical correlation scores and the multivariate dimensional analysis for five independent and five dependent variables selected for the Colombian SUE and four independent and three dependent variables processed for the Spanish SUE.

The most important canonical correlation index for each country is that of Function 1 (0.9078 for Colombia and 0.8779 for Spain). A significant relationship between the two sets of variables is established at the 1% level, representing the greatest possible correlation between any linear combination of independent variables (faculty, teaching quality, administrative staff, and public transfers) and any linear combination of dependent variables (graduates, postgraduates, and publications).

TABLE 3 OVERALL MODEL FIT MEASURES FOR CCA (COLOMBIAN SUE, SPANISH SUE)

Colombia					Spain				
Canonical Function	Canonical Correl.	Canonical R2	F-Statistic	Prob.	Canonical Function	Canonical Correl.	Canonical R2	F-Statistic	Prob.
1	0,908	0,824	37,032	0.000*	1	0,878	0,771	55,299	0.000*
2	0,522	0,273	10,910	0	2	0,236	0,056	3,905	0,001
3	0,398	0,159	7,659	0	3	0,124	0,015	2,472	0,086
4	0,217	0,047	3,747	0,05					
5	0,038	0,001	0,425	0,515					
Multivalent contrast of significance					Multivalent contrast of significance				
Statistical	Value	Approx F-Statistic	Probability		Statistical	Value	Approx F-Statistic	Prob.	
Wilks' Lambda	0,102	37,032	0		Wilks' Lambda	0,213	55,299	0	
Pillai's Trace	1,304	21,023	0		Pillai's Trace	0,842	30,999	0	
Hotelling's Trace	5,299	61,972	0		Hotelling's Trace	3,436	90,105	0	
Roy's Largest Root	4,685	279,204	0		Roy's Largest Root	3,362	267,267	0	

Source: Authors' calculation (Stata Software) based on data from the Colombian Ministry of National Education (2015-2016) and the University Information System of Spain SIIU (2015-2016).
Note: The statistical test used to evaluate the significance of the respective correlation indices is Wilks' Lambda, contrasted with the F-test.

Note that the highest coefficient of determination (canonical R^2) corresponds to the first pair of canonical variables (U_1, V_1) (R^2 can = 0.8241 for Colombia and 0.7707 for Spain), which are high values indicating high practical significance (Badii & Castillo, 2007). These results mean 82.41% of the variability of U_1 (linear combination of dependent variables) is explained by V_1 (linear combination of independent variables). This preliminary approach demonstrates for each public university system the importance and representativeness of the selected variables and the explanatory power of the set of independent variables with respect to the set of dependent variables. Both sets of variables (inputs, outputs), specifically selected for each university system, have interdependencies with each other and a high explanatory value, which corroborates their selection as proxies to perform efficiency calculations using DEA models.

5.2 CCA Redundancy Analysis

Amount of shared variance. Table 4 shows the correlation between the first dependent canonical variable and each original dependent variable. Each correlation is interpreted as a factor loading, which identifies the value of each item's relative contribution to its canonical item.

TABLE 4 SIMPLE LINEAR CORRELATIONS (CANONICAL LOADINGS), BETWEEN DEPENDENT VARIABLES AND THE FIRST CANONICAL VARIABLE (U1)

Colombia - SUE	
Variable	Canonical Function 1
GRAD_PREG	0,84
GRAD_POST	0,712
GRUP_INV	0,79
REV_INDEX	0,637
TOTAL_PUB_SCOPUS	0,915

Spain - SUE	
Variable	Canonical Function 1
GRAD_PREG	0,738
GRAD_POST	0,833
PUB_WOS	0,977

Source: Authors' calculation (Stata Software) based on data from the Colombian Ministry of National Education (2015-2016) and the University Information System of Spain SIIU (2015-2016).
Note: For both countries the variable with the greatest relative contribution is Scopus publications (Colombia) and WOS publications (Spain), followed by the graduates variables, indicating the two output variables most representative of two university activities (research and teaching).

Redundancy rates. In Table 5, the canonical Function 1 for Colombia shows a percentage of 50.78%, which is high, indicating the explanatory power of the input variables (independent) in the variances of the original (dependent) output variables. For Spain, this percentage is 57.06%, showing the variables associated with Spanish universities have a high explanatory power for the variability of their original outputs (Soto Mejía et al., 2009; Badii & Castillo, 2007)

TABLE 5 **REDUNDANCY ANALYSIS OF THEORETICAL VALUES DEPENDENT AND INDEPENDENT OF CANONICAL FUNCTIONS (COLOMBIAN SUE, SPANISH SUE)**

Colombia						Spain					
Standardized variance of dependent variables explained by:						Standardized variance of dependent variables explained by:					
	Own Theoretical Value (Shared Variance)			Opposite Theoretical Value (Redundancy)			Own Theoretical Value (Shared Variance)			Opposite Theoretical Value (Redundancy)	
Canonical Function	%	% Accum.	Canonical R2	%	% Accum.	Canonical Function	%	% Accum.	Canonical R2	%	% Accum.
1	61,62	61,62	82,41	50,78	50,78	1	74,04	74,04	77,07	57,06	57,06
2	11,40	73,02	27,26	3,11	53,89	2	9,78	83,82	5,56	0,54	57,61
3	8,06	81,08	15,85	1,28	55,16	3	7,26	91,08	1,53	0,11	57,72
4	13,09	94,17	4,73	0,62	55,78						
5	5,83	100,00	0,14	0,01	55,79						

Standardized variance of independent variables explained by:						Standardized variance of independent variables explained by:					
	Own Theoretical Value (Shared Variance)			Opposite Theoretical Value (Redundancy)			Own Theoretical Value (Shared Variance)			Opposite Theoretical Value (Redundancy)	
Canonical Function	%	% Accum.	Canonical R2	%	% Accum.	Canonical Function	%	% Accum.	Canonical R2	%	% Accum.
1	73,20	73,20	82,41	60,32	60,32	1	74,12	74,04	77,07	57,12	57,12
2	6,87	80,07	27,26	1,88	62,19	2	9,49	83,53	5,56	0,53	57,65
3	7,25	87,32	15,85	1,15	63,34	3	16,47	100,00	1,53	0,25	57,90
4	8,18	95,50	4,73	0,38	63,72						
5	3,95	99,45	0,14	0,00	63,73						

Source: Authors' calculation (Stata Software) based on data from the Colombian Ministry of National Education (2015-2016) and the University Information System of Spain SIIU (2015-2016).

Thus, for the first canonical correlation (Function 1), the independent canonical variables explain 82.41% (Colombia) and 77.07% (Spain) of the variance of the dependent canonical variables, while the first variables predict 50.78% and 57.06% of the variance in the original dependent variables, respectively. Dependent canonical variables predict 61.62% and 74.04% of the variance in the original dependent variables, and independent canonical variables predict 73.20% and 74.12% of the variance in the original independent variables. The above shows, in percentages, all the relationships and interdependencies between the two sets of variables and their respective linear combinations, providing reliability (Azor Hernández et al., 2018; Friedman & Sinuany-Stern, 1997; Moreno Sáez &

Trillo del Pozo, 2001; Sabando Vélez & Cruz Arteaga, 2019) and encouraging researchers to continue using the proposed sets of variables to perform further efficiency calculations using DEA models.

Regarding independent theoretical values (canonical loadings), as seen in Table 6, the three items that significantly contribute to teaching and research activities in Colombian universities are the number of full-time faculty (prof_tce), the space available for missionary use (m2_uso_misional), and the resources transferred from the state (transfer_nacion). These variables imply high representativeness and significance as inputs and as explanatory variables for the outputs in each country.

The most significant dependent variables are degree graduates (grad_preg) and total Scopus publications (total_pub_scopus) for Colombia and postgraduates (grad_post) and total Web of Science publications (pub_wos) for Spain, consistent with previous studies (Kao & Hung, 2008; Kuah & Wong, 2013; Chang et al., 2012; García-Aracil, 2013; Munoz, 2016), as they are representative variables for teaching and research activities in universities.

TABLE 6 STANDARDIZED CANONICAL COEFFICIENTS, CANONICAL LOADINGS, AND CANONICAL CROSS-LOADINGS FOR THE FIRST CANONICAL FUNCTION (COLOMBIAN SUE, SPANISH SUE)

Colombia				Spain			
Variables	Standar. Canon. Coeff. Function1	Canonical Loadings Function 1	Canonical cross Loadings Function 1	Variables	Standar. Canon. Coeff. Function 1	Canonical Loadings Function 1	Canonical cross Loadings Function 1
Dependent				Dependent			
GRAD_PREG	0,391	0,840	0,763	GRAD_PREG	0,220	0,738	0,647
GRAD_POST	0,099	0,712	0,646	GRAD_POST	0,167	0,833	0,731
GRUP_INV	0,105	0,791	0,718	PUB_WOS	0,715	0,977	0,858
REV_INDEX	0,031	0,637	0,578				
TOTAL_PUB_SCOPUS	0,545	0,915	0,830				
Independent				Independent			
PROF_TCE	0,507	0,926	0,841	PROF_TCE	0,149	0,975	0,856
ICAL_PDI	0,269	0,758	0,688	ICAL_PDI	0,093	0,363	0,319
NUM_ADM	-0,056	0,790	0,717	NUM_ADM	0,210	0,949	0,833
M2_USO_MISIONAL	0,307	0,897	0,814	TRANSF_EST	0,629	0,990	0,869
TRANSFER_NACION	0,113	0,851	0,773				

Source: Authors' calculation (Stata Software) based on data from the Colombian Ministry of National Education (2015-2016) and the University Information System of Spain SIIU (2015-2016).

5.3 DEA: BCC-O results

Following the preliminary results obtained with CCA, two models (sets of variables) are proposed to calculate efficiency in higher education using DEA.

Model 1. This method aims to perform efficiency calculations using DEA based on the representative and/or significant input and output variables explained by the results obtained from the canonical loadings shown in Table 6. Table 7 shows the descriptive details. The inferences are made for each set of universities (Colombian and Spanish) independently and to characterize their specific components, variables, data, and efficiency results, considering the aim is not to compare them but to demonstrate that the proposed method applies to the university sector of any country.

TABLE 7 DESCRIPTION OF THE INPUT AND OUTPUT VARIABLES MODEL 1. COLOMBIAN SUE, SPANISH SUE

Colombia						
Input Variables	Average		Min		Max	
	2015	2016	2015	2016	2015	2016
PROF_TCE	591	648	59	91	2.426	2.501
M2_USO_MISIONAL	117.732	117.732	20.278	20.278	491.956	491.956
TRANSFER_NACION*	78.800	84.400	16.000	17.000	610.000	650.000
Output Variables						
GRAD_PREG	2.199	1.593	218	124	6.793	5.705
TOTAL_PUB_SCOPUS	1.115	1.445	-	-	13.704	17.419

Spain						
Input Variables	Average		Min		Max	
	2015	2016	2015	2016	2015	2016
PROF_TCE	1.462	1.460	329	332	4.124	4.099
TRANSF_EST**	141.000	147.417	36.100	36.000	363.000	400.000
Ouput Variables						
GRAD_POST	1.054	1.260	122	131	3.306	4.622
PUB_WOS	1.108	1.308	142	218	4.722	5.273

Source: Authors' calculation (Stata Software) based on data from the Colombian Ministry of National Education (2015-2016) and the University Information System of Spain SIIU (2015-2016).
Descriptive note: in Colombia, the number of full-time equivalent professors increased from 2015 to 2016, while infrastructure remained the same and graduates decreased. For the Spanish system, little variation is noted in the professors variable, while the graduates and publications increased. For both countries, transfers increased from one period to another: in Colombia an increase of 2.1% and in Spain an increase of 4.6%.
** Measured in thousands EUR.
*Measured in millions COP.

Model 2. The prediction of the variables U_1 and V_1, corresponding to the canonical Function 1, is made with a coefficient of determination of 82.4% for the Colombian SUE and 77.07% for the Spanish SUE. This study proposes transforming the input and output variables into fictitious variables, a product of the canonical Function 1, as explained in the methods and data section using CCA. The variable U_1 will be named U_{input}, and V_1 will be $V_{output.}$ The prediction model for each variable is shown in Table 8.

From raw canonical coefficients and canonical correlations, and based on the most representative variables (Model 1) and transformed variables (Model 2), efficiency scores are calculated using DEA models to facilitate the analysis.

TABLE 8 PREDICTION OF INPUTS AND OUTPUTS, MODEL 2 (COLOMBIAN SUE, SPANISH SUE)

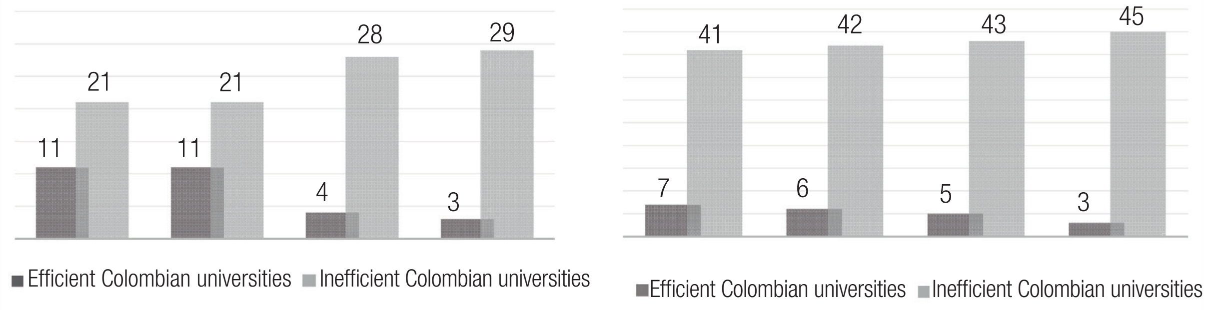
Colombia		Spain	
Input Variable (U_{input})	Output Variable (V_{output})	Input Variable (U_{input})	Output Variable (V_{output})
U_{input} = 0.6941prof_tce + 0.4802ical_pdi- 0.0735num_adm + 0.3520m2_uso_misional + 0.1169transfer_nacion	V_{output} = 0.5050grad_preg + 0.0435grad_post + 0.0824grup_inv + 0.0206rev_index + 0.2840total_pub_scopus	U_{input} = 0.2541prof_tce + 0.0097ical_pdi + 0.3524num_adm + 1.06transfer_nacion	V_{output} = 0.2539grad_preg + 0.2286grad_post + 0.9576pub_wos

Source: authors' calculation (Stata Software) based on data from the Colombian Ministry of National Education (2015-2016) and the University Information System of Spain (SIIU) 2015-2016.

The coefficients shown for each variable, both input and output, are obtained as unrotated or raw canonical coefficients, for each set of variables (dependent and independent), and they will be the *a priori* weights for each input and output, leaving a single variable as the input and another as the output.

Data are processed in Stata and DEA-solver software. Figure 1 shows the aggregate results from efficient and inefficient universities. Tables 10 and 11 show the disaggregated efficiency scores for each model, method, period, and university.

FIGURE 1 **AGGREGATE OF EFFICIENT AND INEFFICIENT UNIVERSITIES (COLOMBIAN SUE, SPANISH SUE) (MODELS 1 AND 2 USING DEA BCC-O)**



Source: Elaborated by the authors, based on efficiency scores.

Figure 1 shows that, in Colombia, in 2015 and 2016, 34% of universities are fully efficient (11/32). In Spain, 14.5% (7/48) and 12.5% (6/48) of the public universities are considered fully efficient for 2015 and 2016, respectively.

Model 1 shows more efficient universities than Model 2. Its higher number of inputs and outputs limits the discriminatory power of the model, where some variables considered critical might be zero-weighted so that they do not affect relative calculations (Pedraja Chaparro, Salinas Jimenez, & Smith, 1994).

The importance of the results shown by Model 2 is that, using a single input variable and a single output variable (transformed variables), it groups items with their respective weight coefficients, using the canonical function described in the method section above.

Table 15 shows that the average efficiency of Colombian universities is 0.7107 in 2015 and 0.7911 in 2016 (Model 1 BCC-O, 2015-2016; see Table 15). The average efficiency of Spanish universities, using the same model and periods, is 0.6537 and 0.5865.

Table 9 lists Colombian and Spanish universities with recurring relative efficiency, these being universities with scale effects. For Colombia, they are the Francisco de Paula Santander University-Ocaña and University of the Llanos; the latter is not considered efficient by any of the recent efficiency studies conducted on Colombian public universities (García & González, 2011; Ramos Ruiz et al., 2015; Rodríguez-Varela & Gómez-Sancho, 2015; Visbal-Cadavid et al., 2016). For Spain, the consistent results of the University of La Rioja stand out, a university also deemed efficient by Parellada and Duch (2006) for the years 2003 and 2004.

TABLE 9 UNIVERSITIES WITH RELATIVE EFFICIENCY, ORDERED BY SIZE (VARIABLE RETURNS)

COLOMBIA - SUE UNIVERSITIES			
Year 2015		Year 2016	
Model 1	Model 2	Model 1	Model 2
Militar	Udetol	Upoc	Udist
Udecun	Uniquindío	Udecun	Unillanos
Ufpso	Ufpso	Ufpso	
Utch		Unillanos	
Unillanos			

SPAIN - SUE UNIVERSITIES			
Year 2015		Year 2016	
Model 1	Model 2	Model 1	Model 2
UB	UAB	UB	UAL
UCM	UIB	UCM	UMH
Unirioja	Unirioja	Unirioja	
UV	UPF		

Source: Elaborated by the authors.

TABLE 10 COLOMBIAN PUBLIC UNIVERSITIES' EFFICIENCY SCORES (2015-2016)

DMU	MODEL 1				MODEL 2			
	Efficiency Score CCRO		Efficiency Score BCCO		Efficiency Score CCRO		Efficiency Score BCCO	
	2015	2016	2015	2016	2015	2016	2015	2016
udea	1,000	1,000	1,000	1,000	0,979	0,964	0,979	0,968
unicaldas	0,562	0,773	0,653	0,793	0,926	0,901	0,928	0,917
unicart	0,536	0,628	0,564	0,636	0,921	0,896	0,923	0,912
unicord	0,396	0,380	0,409	0,410	0,866	0,798	0,868	0,815
udecun	0,546	0,862	1,000	1,000	0,756	0,775	0,791	0,806
uniamaz	0,198	0,561	0,273	0,632	0,774	0,813	0,841	0,895
uniguajira	0,293	0,356	0,437	0,379	0,784	0,754	0,822	0,771
unillanos	0,381	0,776	1,000	1,000	0,829	0,850	0,980	1,000
unariño	0,326	0,561	0,348	0,573	0,848	0,853	0,850	0,869
unipamp	0,502	0,423	0,539	0,457	0,881	0,826	0,883	0,839
unisucre	0,305	0,774	0,679	0,952	0,760	0,838	0,881	0,961
uniatlantico	0,345	0,476	0,384	0,770	0,842	0,832	0,844	0,844
unicauca	0,386	0,439	0,400	0,458	0,880	0,871	0,881	0,884
unimag	1,000	0,710	1,000	0,710	0,968	0,876	0,979	0,895
unipac	0,125	0,157	1,000	1,000	0,631	0,585	0,933	0,909
uniquindio	0,797	0,383	0,871	0,450	0,939	0,781	1,000	0,797

Continue

DMU	MODEL 1				MODEL 2			
	Efficiency Score CCRO		Efficiency Score BCCO		Efficiency Score CCRO		Efficiency Score BCCO	
	2015	2016	2015	2016	2015	2016	2015	2016
udetol	1,000	0,731	1,000	0,777	0,998	0,872	1,000	0,891
univalle	0,877	0,948	0,885	0,949	0,967	0,954	0,968	0,962
udist	1,000	1,000	1,000	1,000	0,966	0,978	0,969	1,000
ufpsc	0,702	1,000	0,735	1,000	0,900	0,883	0,944	0,948
ufpso	0,552	0,765	1,000	1,000	0,618	0,612	1,000	1,000
uis	1,000	1,000	1,000	1,000	0,974	0,945	0,977	0,957
militar	0,955	0,867	1,000	0,908	0,897	0,897	0,899	0,913
unad	0,700	1,000	0,762	1,000	0,810	0,818	0,812	0,832
unal	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
upnal	0,217	0,584	0,228	0,624	0,827	0,825	0,833	0,841
uptc	0,245	0,401	0,323	0,496	0,894	0,890	0,895	0,903
upoc	0,411	0,903	0,519	1,000	0,858	0,856	0,907	0,913
unisur	0,351	0,588	0,380	0,593	0,850	0,837	0,874	0,860
utp	0,561	0,796	0,623	0,853	0,930	0,911	0,932	0,927
utch	0,542	1,000	1,000	1,000	0,848	0,838	0,955	0,942
ucolm	0,340	0,708	0,729	0,897	0,821	0,799	0,909	0,881

Source: Authors' calculation (Stata Software) based on data from the Colombian National System of Information for Higher Education SNIES (2016-2016).

TABLE 11 SPANISH PUBLIC UNIVERSITIES' EFFICIENCY SCORES (2015-2016)

DMU	MODEL 1				MODEL 2			
	Efficiency Score CCRO		Efficiency Score BCCO		Efficiency Score CCRO		Efficiency Score BCCO	
	2015	2016	2015	2016	2015	2016	2015	2016
EHU	0,386	0,335	0,553	0,528	0,927	0,921	0,937	0,995
UA	0,477	0,397	0,552	0,417	0,871	0,865	0,907	0,999
UAB	1,000	1,000	1,000	1,000	0,992	0,904	1,000	0,911
UAH	0,634	0,502	0,638	0,506	0,873	0,850	0,932	0,919
UAL	0,517	0,483	0,593	0,560	0,814	0,869	0,904	1,000
UAM	0,842	0,791	0,853	0,799	0,966	0,908	0,983	0,914
UB	0,976	0,882	1,000	1,000	1,000	0,910	1,000	0,986

Continue

DMU	MODEL 1				MODEL 2			
	Efficiency Score CCRO		Efficiency Score BCCO		Efficiency Score CCRO		Efficiency Score BCCO	
	2015	2016	2015	2016	2015	2016	2015	2016
UBU	0,367	0,341	0,664	0,720	0,764	0,903	0,964	0,968
UC3M	0,540	0,525	0,615	0,574	0,868	0,896	0,922	0,922
UCA	0,347	0,304	0,378	0,306	0,826	0,932	0,878	0,947
UCLM	0,382	0,329	0,392	0,334	0,867	0,894	0,898	0,917
UCM	0,593	0,542	1,000	1,000	0,950	0,917	0,977	0,930
UCO	0,551	0,420	0,595	0,426	0,878	0,919	0,937	0,930
UDC	0,460	0,369	0,490	0,384	0,852	0,861	0,910	0,934
UDG	0,579	0,561	0,811	0,751	0,874	0,860	0,992	0,978
UDL	0,510	0,463	0,782	0,704	0,834	0,921	0,996	0,927
UGR	0,568	0,445	0,852	0,733	0,941	0,961	0,953	0,979
UHU	0,385	0,363	0,476	0,450	0,790	0,959	0,901	0,980
UIB	0,670	0,600	0,883	0,786	0,880	0,783	1,000	1,000
UJAEN	0,473	0,452	0,533	0,471	0,838	0,784	0,920	0,974
UJI	0,520	0,375	0,561	0,436	0,849	0,927	0,931	0,929
ULL	0,399	0,357	0,442	0,382	0,863	0,942	0,905	0,949
ULPGC	0,297	0,247	0,308	0,250	0,813	0,922	0,864	0,925
UM	0,587	0,464	0,666	0,506	0,898	0,843	0,928	0,950
UMA	0,358	0,372	0,436	0,509	0,872	0,951	0,885	0,990
UMH	0,884	0,668	0,915	0,675	0,878	0,960	0,985	1,000
UNED	1,000	1,000	1,000	1,000	0,864	0,841	0,918	0,942
UNEX	0,454	0,396	0,463	0,409	0,849	0,855	0,902	0,973
UNICAN	0,510	0,453	0,640	0,567	0,860	0,928	0,943	0,942
UNILEON	0,426	0,371	0,546	0,488	0,830	0,931	0,933	0,931
UNIOVI	0,459	0,408	0,471	0,411	0,885	0,905	0,908	0,941
UNIRIOJA	0,348	0,349	1,000	1,000	0,759	0,917	1,000	0,918
UNIZAR	0,416	0,415	0,421	0,435	0,907	0,940	0,913	0,943
UPC	0,409	0,411	0,414	0,469	0,894	0,928	0,898	0,944
UPCT	0,296	0,288	0,583	0,505	0,755	0,924	0,948	0,991
UPF	1,000	1,000	1,000	1,000	0,917	0,925	1,000	0,931
UPM	0,332	0,333	0,351	0,395	0,884	0,922	0,886	0,936
UPNA	0,443	0,372	0,641	0,526	0,813	0,948	0,947	0,967
UPO	0,753	0,632	0,968	0,794	0,825	0,910	0,970	0,946
UPV	0,401	0,361	0,504	0,469	0,897	0,930	0,901	0,936
URJC	0,877	0,784	0,898	0,842	0,873	0,946	0,949	0,968

Continue

DMU	MODEL 1				MODEL 2			
	Efficiency Score CCRO		Efficiency Score BCCO		Efficiency Score CCRO		Efficiency Score BCCO	
	2015	2016	2015	2016	2015	2016	2015	2016
URV	0,597	0,547	0,734	0,650	0,888	1,000	0,995	1,000
US	0,409	0,350	0,592	0,524	0,914	0,879	0,926	0,893
USAL	0,536	0,427	0,552	0,428	0,895	0,983	0,927	0,998
USC	0,491	0,417	0,566	0,438	0,897	0,889	0,907	0,904
UV	0,698	0,529	1,000	0,807	0,964	0,911	0,968	0,932
UVA	0,350	0,276	0,350	0,280	0,857	0,911	0,887	0,933
UVIGO	0,594	0,479	0,701	0,515	0,878	0,940	0,922	0,943

Source: Authors' calculation (Stata Software) based on data from the University Information System of Spain SIIU (2016-2016).

6. ANALYSIS OF RESULTS

To complement the analysis of the efficiency scores shown in Tables 11 and 12, these are distributed in quartiles (see Table 13) for each higher education system analyzed.

In Model 1, efficiency scores are lower than in Model 2, due to the sensitivity shown in the number of inputs and outputs, and variable transformation by previous CCA weighting.

As for the Colombian university system, Table 13 shows that 37.5% of the Colombian universities went from having scores above 0.88854 in 2015 to above 0.9517 in 2016 (Model 1), which shows improved efficiency, analyzed among the last 12 universities. Universities with low efficiency scores, located in the first quartile (8 institutions) showed scores below 0.4093 in 2015 and less than 0.5925 in 2016.

Of the Spanish universities, as shown in Table 13, 25% went from having scores above 0.852 in 2015 to higher than 0.733 in 2016 (Model 1), which implies a worsening from one period to the next for universities in the last quartile. Institutions with low efficiency scores, corresponding to the first 25%, showed scores below 0.4755 in 2015 and less than 0.4275 in 2016, confirming the downward trend in efficiency scores in 2016.

TABLE 12 ANALYSIS OF EFFICIENCY SCORES DISTRIBUTED BY QUARTILES.

COLOMBIA - SUE				
QUARTILE	EFFICIENCY SCORES			
% ACCUM	BCC-O 2015		BCC-O 2016	
DMU	MODEL 1	MODEL 2	MODEL 1	MODEL 2
25%	0,409	0,868	0,593	0,844
50%	0,729	0,909	0,853	0,903
62,50%	0,885	0,944	0,952	0,925

SPAIN - SUE				
QUARTILE	EFFICIENCY SCORES			
% ACCUM	BCC-O 2015		BCC-O 2016	
DMU	MODEL 1	MODEL 2	MODEL 1	MODEL 2
25%	0,476	0,905	0,428	0,930
50%	0,593	0,928	0,509	0,943
75%	0,852	0,968	0,733	0,978

Source: Authors' calculation (Stata Software) based on data from the Colombian Ministry of National Education (2015-2016) and the University Information System of Spain SIIU (2015-2016).

The efficiency scores are categorized in Table 14 to classify each public university, both in Colombia and Spain, for each model and period (2015-2016), into the following groups: fully efficient (index = 1), highly efficient (1 > index > average), and low-efficiency or inefficient (index < average).

TABLE 13 UNIVERSITIES CLASSIFIED BY EFFICIENCY CATEGORIES (COLOMBIAN SUE, SPANISH SUE)

	COLOMBIA - SUE			
	BCC-O 2015		BCC-O 2016	
	MODEL 1	MODEL 2	MODEL 1	MODEL 2
AVERAGE EFFICIENCY INDEX	0,711	0,914	0,791	0,902
FULLY EFFICIENT (EF= 1)	udetol	udetol	udea	unal
	udecun	ufpso	udecun	unillanos
	unal	unal	udist	udist
	unillanos	uniquindio	ufpso	
	udist		uis	
	ufpso		unal	
	unimag		unillanos	
	udea		utch	
	uis		unad	
	utch		ufpsc	
	militar		upoc	
HIGH EFFICIENCY (EF > AVERAGE)	unipac	unillanos	unipac	ufpso
	univalle	udea	unisucre	udea
	uniquindio	unimag	univalle	univalle
	unad	uis	militar	unisucre
	ufpsc	udist	ucolm	uis
	ucolm	univalle	utp	ufpsc
		utch	unicaldas	utch
		ufpsc		utp
		unipac		unicaldas
		utp		militar
		unicaldas		upoc
		unicart		unicart
				unipac
				uptc

Continue

COLOMBIA - SUE				
	BCC-O 2015		BCC-O 2016	
	MODEL 1	MODEL 2	MODEL 1	MODEL 2
NOT EFFICIENT (EF < AVERAGE)	unisucre	ucolm	udetol	udetol
	unicaldas	upoc	uniquindio	ucolm
	utp	militar	unimag	uniquindio
	unicart	uptc	unicart	unimag
	unipamp	unipamp	uptc	unipamp
	upoc	unisucre	unipamp	unicauca
	uniguajira	unicauca	unicauca	unisur
	unicord	unisur	unisur	unicord
	unicauca	unicord	unicord	unariño
	uniatlantico	unariño	unariño	uniatlantico
	unisur	uniatlantico	uniatlantico	uniamaz
	unariño	uniamaz	uniamaz	upnal
	uptc	upnal	upnal	uniguajira
	uniamaz	uniguajira	uniguajira	unad
	upnal	unad		udecun
		udecun		

SPAIN - SUE				
	BCC-O 2015		BCC-O 2016	
	MODEL 1	MODEL 2	MODEL 1	MODEL 2
AVERAGE EFFICIENCY INDEX	0,654	0,937	0,587	0,951
FULLY EFFICIENT (EF= 1)	UAB	UAB	UAB	UMH
	UB	UB	UB	URV
	UNED	UNIRIOJA	UNIRIOJA	UAL
	UNIRIOJA	UPF	UPF	
	UPF	UIB	UNED	
	UCM		UCM	
	UV			
HIGH EFFICIENCY (EF > AVERAGE)	UPO	UDL	URJC	UIB
	UMH	URV	UV	UA
	URJC	UDG	UAM	USAL
	UIB	UMH	UPO	EHU

Continue

SPAIN - SUE				
	BCC-O 2015		BCC-O 2016	
	MODEL 1	MODEL 2	MODEL 1	MODEL 2
	UAM	UAM	UIB	UPCT
	UGR	UCM	UDG	UMA
	UDG	UPO	UGR	UB
	UDL	UV	UBU	UHU
	URV	UBU	UDL	UGR
	UVIGO	UGR	UMH	UDG
	UM	URJC	URV	UJAEN
	UBU	UPCT		UNEX
		UPNA		URJC
		UNICAN		UBU
		UCO		UPNA
		EHU		
NOT EFFICIENT (EF < AVERAGE)	UPNA	UNILEON	UC3M	UM
	UNICAN	UAH	UNICAN	ULL
	UAH	UJI	UAL	UCA
	UC3M	UM	EHU	UPO
	UCO	USAL	UPNA	UPC
	UAL	US	US	UVIGO
	US	UC3M	UVIGO	UNIZAR
	UPCT	UVIGO	UMA	UNED
	USC	UJAEN	UAH	UNICAN
	UJI	UNED	UM	UNIOVI
	EHU	UNIZAR	UPCT	UPV
	UA	UDC	UNILEON	UPM
	USAL	UNIOVI	UJAEN	UDC
	UNILEON	USC	UPV	UVA
	UJAEN	UA	UPC	UV
	UPV	ULL	UHU	UNILEON
	UDC	UAL	USC	UPF
	UHU	UNEX	UJI	UCO
	UNIOVI	UHU	UNIZAR	UCM
	UNEX	UPV	USAL	UJI

Continue

SPAIN - SUE				
	BCC-O 2015		BCC-O 2016	
	MODEL 1	MODEL 2	MODEL 1	MODEL 2
	ULL	UCLM	UCO	UDL
	UMA	UPC	UA	ULPGC
	UNIZAR	UVA	UNIOVI	UC3M
	UPC	UPM	UNEX	UAH
	UCLM	UMA	UPM	UNIRIOJA
	UCA	UCA	UDC	UCLM
	UPM	ULPGC	ULL	UAM
	UVA		UCLM	UAB
	ULPGC		UCA	USC
			UVA	US
			ULPGC	

Source: Elaborated by the authors.
Note: For the Colombian university system there are 11 fully efficient universities, 6 with high efficiency and 15 with low efficiency, for both periods (2015-2016), under model 1, and with all the representative input-output variables. The Colombian universities with the lowest score in 2015 and 2016 are upnal and uniguajira (0.2280 and 0.3792). In the Spanish system, 3 efficient universities in the years 2015 and 2016 stand out, both in constant and variable returns: the UB, the UNED and the UPF. The ULPGC is the institution with the lowest score in both periods (0.3083 and 0.2503).

For the Colombian SUE, Ramos Ruiz et al. (2015) calculate efficiency scores under DEA BCC-O models, classifying 13 and 15 institutions in the efficient category for the years 2007 and 2013, with average efficiency scores of 0.836 and 0.827, respectively. Some of these universities are still in that category in 2015 and 2016 in the present study (unal, udea, udetol, ufpso, and ufpsc). Visbal-Cadavid et al. (2016) classified 20 Colombian universities as fully efficient in 2011, also with the BCC-O model, and five universities (unal, udea, uis, ufpso, and udist) are still in that category. García and González (2011) classified 17 Colombian universities as efficient in the period 2003-2009, with an average efficiency index of 89%, and three of those classified in the present study as fully efficient (uis, udetol, and udist) are still in the top 10. Rodríguez-Varela and Gómez-Sancho (2015), by applying variable returns, calculated efficiency scores for 2015 and found only three Colombian universities (unicord, uniatlantic, and udetol) to be fully efficient, of which only udetol appears in the classification for 2015 made in the present study, while the other two universities are considered to have low efficiency (below average).

Regarding the Spanish university system, Table 12 details the efficiency scores calculated for each university. For the year 2016, under the BCC-O method, there are only three efficient universities (UAL, URV, and UMH), which are also considered by Gómez-Sancho and Mancebón-Torrubia (2012) as efficient in research, and although they differ from those present in Model 1, this is surely due to the transformation of variables by CCA.

Although few studies have been published in the last 5 years at the level of Spanish public higher education institutions (Parellada & Duch, 2006; Vásquez Rojas, 2010; Gómez-Sancho & Mancebón-Torrubia, 2012; Martí-Selva, Puertas-Medina, & Calafat-Marzal, 2014), since most have been conducted at the departmental level within universities, the most recent study (Martí-Selva et al., 2014) stands out because it classified 18 Spanish universities as efficient for the year 2006, of which URV and UMH are still efficient in the present study in both 2015 and 2016.

Vásquez Rojas (2010) reports average efficiency scores for Spanish universities for 2005 and 2007 that are very close to each other, 0.9608 and 0.9378, respectively, while the two values in the present study differ substantially, with average efficiency scores in 2015 and 2016 of 0.6537 and 0.5865, respectively.

Table 14 shows the aggregate of the calculated efficiency scores, for each public university system (Spain and Colombia), to evaluate the methods and models used in both periods (2015, 2016).

Colombian public universities show highly variable results, with high average efficiency and inefficiency scores, indicating high inequality in the public higher education system. The average efficiency score with Model 1 BCC-O was 0.7107 and 0.7911 in 2015 and 2016, respectively. The minimum efficiency was 0.1250 and 0.1568 for the same years.

Spanish public universities show low variability in the results and low average efficiency and inefficiency scores, indicating homogeneity in grouping data. The average efficiency index with Model 1 BCC-O was 0.6537 and 0.5865 in 2015 and 2016, respectively, and the minimum efficiency was 0.3083 and 0.2503.

TABLE 14 COMPARATIVE EFFICIENCY LEVELS OF THE CCRO-BCC-O METHODS BETWEEN COLOMBIAN AND SPANISH PUBLIC UNIVERSITIES (2015-2016)

	CCR-O METHOD (Charnes, Cooper, and Rhodes. Constant returns - output-oriented)							
	MODEL 1				MODEL 2			
	SPAIN		COLOMBIA		SPAIN		COLOMBIA	
	2015	2016	2015	2016	2015	2016	2015	2016
Average Efficiency	0,544	0,483	0,567	0,705	0,873	0,909	0,867	0,848
Standard Deviation	0,196	0,189	0,284	0,240	0,054	0,044	0,094	0,089
Minimum	0,296	0,247	0,125	0,157	0,755	0,783	0,618	0,585
Maximum	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
	BCC-O METHOD (Banker, Charnes, and Cooper. Variable returns - output-oriented)							
	MODEL 1				MODEL 2			
	SPAIN		COLOMBIA		SPAIN		COLOMBIA	
	2015	2016	2015	2016	2015	2016	2015	2016
Average Efficiency	0,654	0,587	0,711	0,791	0,937	0,951	0,914	0,902
Standard Deviation	0,214	0,214	0,275	0,221	0,039	0,030	0,062	0,063
Minimum	0,308	0,250	0,228	0,379	0,864	0,893	0,791	0,771
Maximum	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000

Source: Elaborated by the authors, based on the results processed in DEA-solver.

7. DISCUSSION AND CONCLUSIONS

Higher education has been facing challenges, not only in terms of its contribution to the generation and dissemination of knowledge to society but also in its use of limited resources to generate and disseminate knowledge. Challenges for this and the coming decades, such as internationalization and mobility, the empowerment of Ibero-American identity, and university social responsibility, are only possible if combined with a strengthening of university autonomy, governance, and funding through accountability, along with efficiency and effectiveness in resource use.

Thus, to be efficient and to appear as such — in terms of quality and excellence — to citizens and governments, is a challenge that has been raised by applying NPM methods to all kinds and categories of universities.

This study has sought to apply efficiency measurement to the Colombian and Spanish public higher education institutions, entering a field of research with all its complexities related to the very nature of this type of organization, which performs multiple activities, with multiple shared resources, to deliver multiple results.

Thus, the relevant contribution of the present study has been to put forth a specific method to specify a production function that can be applied in higher education, delving into the typology and quantification of relevant inputs and outputs and the mathematical description of their relationship.

For this purpose, CCA was used as a multivariate analysis method. CCA has been little used in this field but is useful to give significance and representativeness to the variables considered in order to calculate relative efficiency using DEA models. This study confirms the usefulness of this method in higher education systems in one or more countries (Wolszczak-Derlacz & Parteka, 2011; Rodríguez-Varela & Gómez-Sancho, 2018; Agasisti & Wolszczak-Derlacz, 2015).

The results obtained allow us to contrast some hypotheses previously put forth about the number of universities classified as efficient with each method and model. With the BCC method, efficient DMUs always exceed those obtained with CCR (Ramos Ruiz et al., 2015; Visbal-Cadavid et al., 2016).

As for higher education systems for each country, there is a close relationship with context and public policy. In Colombia, inequality stands out in terms of resources vs. products, as it has a higher number of efficient universities than Spain but a greater difference between efficient and inefficient universities. In Spain, there is greater data homogeneity, with lower and more clustered efficiency scores and a smaller difference between efficient and inefficient universities.

Other results on the efficiency of Colombian and Spanish higher education institutions differ significantly from the results obtained in this study, mainly due to methodological and sample aspects (delimitation of inputs and outputs of university activity, selection of the technique and evaluation model, and selection of the sample and periods). This corroborates the difficulty in making such comparisons (Gómez-Sancho & Mancebón-Torrubia, 2012) and reinforces the great criticisms made of the homogenizing classifications that have prevailed since the beginning of the century.

Another contribution of this study lies in demonstrating that, even with independent and not necessarily related systems of public higher education in Ibero-America, a preliminary step of analysis can be performed with CCA to provide representativeness to the input and output variables necessary to calculate efficiency using DEA models. At this preliminary step, CCA can transform variables to reduce their number and generate *a priori* weightings, thereby improving their ability to discriminate and providing more accurate, reliable, and meaningful scores.

The most important conclusion is that, when addressing efficiency measurement in higher education, special care should be taken when selecting variables, methods, periods, and units to be evaluated. The stated objective should always be kept in mind, allowing comparability of resource management, improvement plans, and monitoring strategies. Therefore, this study highlights alternative research paths for efficiency measurement in higher education, as a public management priority.

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