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Research and knowledge transfer performance in Colombian universities

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Abstract

This study analyzes the performance of Colombian universities in their research and knowledge transfer (KT) objectives in the period 2016–2018. The methodology was based on Data Envelopment Analysis models with Variable Return Scale and a Malmquist Productivity Index (MPI) using different combinations of variables, considering the sensitivity of performance according to the type of variables used for its measurement. The results allowed us to identify significant gaps in research output among the studied universities. Publications and patents are the main variables that influence these differences in university performance and impact their scores. On the other hand, the MPI analysis made it possible to identify that most of the universities with the most significant improvements in the analyzed period correspond to private universities, and it was possible to recognize the importance of institutional efforts and strategies as an explanatory factor for progress in the performance of universities in the studied objectives. The results obtained formed the starting point for the discussion about the implications of some incentive policies at the national and institutional level for academic production. We also refer to the KT opportunities for Colombian universities and the measures required to promote their development.

Keywords Higher education institutions · Data envelopment analysis · Malmquist index · Research · Knowledge transfer

JEL Classification C14 · C44 · I21 · I23 · O54

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1 Introduction

According to the knowledge triangle, the main function of universities encompasses teaching, research, and knowledge transfer (KT). Such functions have to systematically and continuously interact to improve the commercialization of new technologies and promote economic development and entrepreneurial activities (Siegel et al. 2004). Thus, the universities are considered critical socio-economic development actors because they contribute to their local communities via the triple helix system (Dzisah and Etzkowitz 2008).

In this order, the universities as actors in the Triple helix system produce new knowledge and technology and transfer them to other sectors benefiting the economic, societal, and technological development (Farinha and Ferreira 2013). Also, the KT activities represent benefits at the institutional level for the universities, increasing the probability of accessing to external financial resources through intellectual property licensing services, staff training courses, and other opportunities arising from the commercialization of research results (González and Campins 2017).

According to data from the Colombian Observatory of Science and Technology (2021), Colombia and South American countries are compared using information available on R&D investment indicators, 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 (Fig. 1).

Figure 1 shows the backwardness of Colombia's figures compared to other countries and OECD, of which Colombia has been a member since 2020, being the country with the lowest level in both indicators in all the periods analyzed. The above represents a challenge for Colombia in terms of improving research and innovation indicators.

In this order, Colombia has encouraged the development of research and innovation in universities through different financing and strengthening strategies and promotion policies. For example, 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 seeking greater autonomy in the articulation between universities, the private sector, and the State, and in funding the development and management of research projects and the human resources involved.

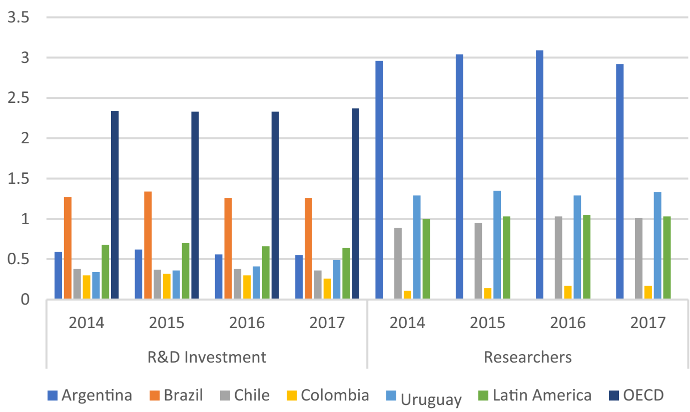

Fig. 1 Comparison of research indicators. *Source*: authors' elaboration

Another policy to promote research is incorporating it as a factor to be evaluated in high quality accreditation processes for academic programs and HEI by the National Committee of Accreditation (CNA in Spanish). It is worth noting that CNA accreditation stimulates universities to maintain and improve their research and KT activities, considering the fact that such aspects are assessed by CNA to grant and/or renew such accreditation.

A good performance in research and KT functions represents an improvement of the quality of teaching activities for universities since learning experiences are contextualized within real needs or problems. Besides, this represents a possibility for universities to diversify their income, considering that Colombian HEI's financial structure is supported between 70 and 80 per cent by tuition payments (Anzola Montero 2017). The aforesaid can help mitigate the risk some HEI's face in terms of quality and continuity due to the decrease in the figures of student enrolment in recent years (SNIES 2019).

Concerning the above, the monitoring of the development of KT and research function processes can contribute to the sustainability of HEIs, ensuring their quality and progress. Besides, Melo et al. (2018) and Agasisti and Bertoletti (2020) recognize the importance of HEI in knowledge transfer, regional innovation, and societal and economic developments in the surrounding region where the universities operate.

Due to this importance, KT and research process measurements have been analyzed separately or jointly from different perspectives to understand how they develop in HEI and thus determine influencing factors in their performance. Studies focusing on the research function were identified in some universities, seeking to explain and take apart the differences in output research according to the environmental conditions in the respective country and their science field, among other criteria (Pastor and Serrano 2016). Other studies have specifically been developed on knowledge transfer to study its influence on HEI's efficiency (De La Torre et al. 2017).

Agasisti et al. (2019) performed a study considering both functions intended to analyze the effect of efficiency in the activities related to research and KT on the local economic development. On the other hand, in the Colombian context, most of the studies analyzed these functions, together with the teaching function and exclusively for state universities, Visbal-Cadavid et al. (2017). Similarly, Navas et al. (2020) mixed the university functions' variables, this time considering both state and private universities, concluding that Colombian HEIs have need of a most significant investment in the research dimension to improve their efficiency.

Among the studies in the scientific literature, the following approaches are identified: Literature Reviews (Macias et al. 2018), Categorical-Based Evaluation Technique (Vaz de Almeida et al. 2019), Index Fit (Jaeger and Kopper 2014), Benefit-of-Doubt Model BoD (Melyn and Moesen 1991) and the Data Envelopment Analysis ((Charnes et al. 1978).

Considering the studies developed in Colombia, it is necessary to stress the differentiated analysis of research and KT from the teaching function. Although the universities must develop the three objectives (Law No. 30, 1992), including teaching in a joint study with research and KT can skew universities' performance analysis and the improvement targets for the variables related to the research and KT. Similarly, the teaching variables can affect the identification of possible causes on the universities' performance from the perspective of the functions analyzed (research and KT).

On the other hand, the related studies show the analysis of universities generally separated according to whether they are private or public. In this study, we consider as necessary to analyze state and private institutions together because the diverse opportunities to obtain resources from the research or knowledge transference are open to both types in general, which requires universities to be competitive in a broad market of universities.

Thus, we proposed to analyze the universities' technical efficiency with high-quality institutional accreditation representing 70.11% of the universities in the country. We select this group of universities because, through the accreditation by CNA, it is possible to validate the adoption of continuous improvement in their organizational culture.

In this order, our study can provide information for the renewal processes of the current accreditation, and in addition for other processes of high-quality certification that can give competitive advantages (e.g., international accreditations). We refer to more remarkable competitive advantages, considering that the accreditation of this group of universities 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, this study pretends to offer a broad perspective about: *How are high-quality accredited universities performing from a research and KT perspective?*

For that purpose, Data Envelopment Analysis (DEA) with Variable Return Scale (VRS) and Malmquist Productivity Index (MPI) for the period 2016–2018, are used. The mixture of methodologies allows to view each university´s performance, identify benchmark groups, critical variables to be improved, and possible explanations for the changes in efficiency from external or internal actions. It allows to the universities to pinpoint what aspects they need to improve on and define the best investment policy for available resources, enabling efficient resource management through informed decision-making.

The rest of the article is organized as follows. Section 2 describes the research design used to assess efficiency scores in the Colombian context (subSect. 2.1). Similarly, we expose in subSect. 2.2 the sources, definitions of our variables, and specifications of the models. Key findings are set out in Sect. 4, while Sect. 5 discusses policy implications. Finally, Sect. 6 brings forth the conclusions.

2 Research design

A good and broad understanding of the performance of accredited Colombian universities in high institutional quality from a research and KT functions perspective would allow information-based decision-making, which would lead to a good investment of available resources in the universities. Thus, this section exposes the selected methods to achieve the proposed objective. In addition, it outlines the variables to represent the inputs and outputs related to the university functions of research and KT and how these variables can be combined to provide different analysis perspectives.

2.1 Methods

The empirical methodology proposed is based on two techniques. The first is DEA (Charnes et al. 1978) with an output orientation which implies 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.

The frontier with Variable Return Scale (VRS) restricting the production region forms a downward concave efficient frontier (Banker et al. 1984). The above implies that the efficient DMUs, in this case, universities, do not need to present the same productivity; thus, observing different local returns to scale is possible (Benicio and De

Mello 2015). We considered the VRS 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, tending to maintain a varied offer of HEI (Pineda and Celis 2017).

The second technique is the DEA and Malmquist Productivity Index (MPI) conjunction (Färe et al. 1994), where a distance function measures the efficiency of conversion of inputs into outputs during a specific period taking as base methods of time series analysis like the concept introduced by Malmquist (1953).

2.1.1 Data envelopment analysis

To define the Variable Return Scale DEA, let be $\{\boldsymbol{E}, \boldsymbol{S}\}$ an input–output dataset used to represent the universities under study, where $\boldsymbol{E} \in \mathbb{R}^{N \times D}$ is the input matrix whose n-th vector is $\boldsymbol{e}_n \in \mathbb{R}^D$, which contains the input information for the university $n \in \{1, \dots, N\}$, being N the number of universities (Decision Making Unit, DMU). In addition, $\boldsymbol{S} \in \mathbb{R}^{N \times M}$ is the output matrix conformed by row vectors $\boldsymbol{s}_n \in \mathbb{R}^M$. Besides, D and M are respectively the number of inputs and outputs. Thereby, the efficiency for the observed DMU ($\mathrm{DMU_o}$) is defined as in the Eq. 1 (Ramanathan 2003):

$$\begin{aligned} &\max \quad \eta_o \\ &s.t. \quad \boldsymbol{E}^\top \boldsymbol{\lambda} \le \boldsymbol{e}_o \\ &\eta_o \boldsymbol{s}_o - \boldsymbol{S}^\top \boldsymbol{\lambda} \le 0 \\ &\boldsymbol{\varphi}^\top \boldsymbol{\lambda} = 1 \\ &\boldsymbol{\lambda} \ge 0, \end{aligned} \tag{1}$$

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

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

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. After the optimization process, we can compute the input excesses $\boldsymbol{\Delta}^- \in \mathbb{R}^D$, and the output shortfalls $\boldsymbol{\Delta}^+ \in \mathbb{R}^M$. Thus, the excesses and shortfalls for the $\mathrm{DMU_o}$ are given by the Eq. 3:

$$\boldsymbol{\Delta}^- = \theta_o \boldsymbol{e}_o - \boldsymbol{E}\lambda, \qquad \boldsymbol{\Delta}^+ = \theta_o \boldsymbol{s}_o - \boldsymbol{S}\lambda \tag{3}$$

2.1.2 Malmquist productivity index—DEA

In the context of DEA analysis, the technical efficiency change (F) is determinated by the Eq. 4 (Ramanathan 2003):

$$F = \frac{C^{t+1}\left(\boldsymbol{E}^{t+1}, \boldsymbol{S}^{t+1}\right)}{C^{t}\left(\boldsymbol{E}^{t}, \boldsymbol{S}^{t}\right)}, \tag{4}$$

where, $C^{t+1}\left(\boldsymbol{E}^{t+1}, \boldsymbol{S}^{t+1}\right)$ is the DEA efficiency for the period $t+1$, which is computed based on the input–output dataset $\left\{\boldsymbol{E}^{t+1}, \boldsymbol{S}^{t+1}\right\}$. In this sense, $F>1$ refers to an increase in the technical efficiency of converting inputs to outputs. Otherwise, $F<1$ represents a decrease in the technical efficiency, while the score $=1$ means any changes in the efficiency (Cooper et al. 2016).

The Malmquist implementation allows to identify possible causes of efficiency changes through three indicators: Technological changes (TC) when the set of variables expands or contracts, the Pure Technical Efficiency Change (PTEC) meaning that a specific observation unit moves closer to or further from the frontier, and finally, the Scale Efficiency Change (SEC), which represents the movement of a unit observation to a position in the frontier (Balk 2001).

2.2 Data

The dataset refers to the Colombian universities accredited with high institutional quality by CNA; we established 61 institutions registered as such until November 2019. Eleven of these institutions have not been considered due to the following criteria: (i) institutions not categorized as universities according to the SNIES classification; (ii) institutions with a mission different to the academic, such as military training (Admiral Padilla Naval Cadets College); (iii) they present missing values in crucial variables for this research. Thus, the dataset comprises 50 universities between private (66%) and public (34%) institutions.

Regarding the universities studied, there are eight denominated “multi-campus” because they are located in different Colombian cities. For such universities, the data related to their performance are available by headquarter. Accordingly, it is necessary to apply a methodology to obtain a unique value per variable for “multi-campus” universities. For specific testing, we sum the levels of inputs and outputs available in each location. Concerning the Scimago ranking, we highlight that the previous methodology was not applied because Scimago offers a unique scale for each institution.

With regard to the variables, eleven are considered linked to the research function of Colombian universities for the period 2016–2018, taking the information from the National System of Information of Higher Education (SNIES), National System of Science, Technology, and Innovation (SNCTI), SCIMAGO Institutions Rankings, and Official websites of universities. Table 1 presents the main descriptive statistics of the dataset.

Among the input variables, five are considered to represent necessary resources to develop a university´s research function, mainly linked to human resources and their expertise to develop research processes in the institutions.

The first is an academic staff (*AS*) indicator weighted by two criteria: the highest level of training of the faculty (doctorate, master, specialization, or undergraduate) (Papadimitriou and Johnes 2019), and their position (Full-tenure professor, associate professor, and lecturer) (Agasisti et al. 2016). The second input is the non-academic staff (*NAS*) considering the types of administrative personnel: “Assistant,” “Technical,’ ‘Professional,’ and ‘Manager’. The hierarchical weights for the indicators of *AS* and *NAS* were assigned following (Agasisti et al. 2016) where ‘1.0’ is the maximum value with differentiation of ‘0.2’ between each level.

Table 1 Descriptive Statistics of the variables. *Source*: authors' elaboration

Category	Variable	Min	Max	Mean	SD
Input	*AS*	104.24	3225	639.386	616.371
	ES	1864.5	53,408.5	13,786.467	9413.845
	NAS	83.4	2499.9	364.051	401.325
	RET	15.30	88.43	34.447	12.297
Output	BK	0.8	675.9	54.843	108.493
	PSE	106.6	6863.6	729.775	1136.195
	TRAI	108.2	4143.3	508.027	719.341
	SCIM	1	31	–	–
	PUB	10.9	6975.35	237.102	1155.012
	IP	0	18.1	–	4.653
Input–Output	RG	4	295.55	20.380	46.089

AS Academic staff, *ES* Number of enrolled students, *NAS* Non-academic Staff, *RET* Ratio between enrolled students and teachers, *BK* Books, *PSE* Scientific events, *TRAI* Teaching activities, *SCIM* Position of the university in SCIMAGO Institutions Rankings, *PUB* Publications, *IP* Invention patents, *RG* Research groups

The third human resource considers the students who have completed their enrollment process in all the academic program cohorts in the institutions analyzed (ES). The ES represents, together with academic staff, the university's human resources to develop the research processes, which are the input to the knowledge transference activities. The fourth variable is the ratio between the number of enrolled students and the number of full-time professors (*RET*), taking as reference González-Garay et al. (2019), and considering that a more extensive staff per student could translate into higher quality research processes. In fact, Arias-Pérez et al. (2019) exposed that the research results in the universities depend on the human capital inventory that considers among other factors the full-time professors.

Finally, research groups (RG) are represented by a weighted indicator according to the categories established by Colciencias (2017) in its '781 Call' for the measurement of research production. 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).

The output vector considers seven variables, including *RG* and the universities' position in the SCIMAGO Institution ranking (*SCIM*), as indicators of institutional recognition in calls for measurement and rankings. It is pointed out that the *SCIM* indicator is taken as an undesirable output because a smaller number in position is due to better performance; the universities that are not in the ranking were penalized with a high number. The rest of the variables are linked to research products.

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. In this way, the selection of variables for this component sought to represent both the process of training new researchers (*TRAI*), represented by the advising provided to thesis or degree works (in a professional level, master´s, and doctoral degree), and the generation and socialization of knowledge through different means as participation in scientific events (*PSE*), books (*BK*), and publications (*PUB*).

To represent a university´s knowledge transfer, De La Torre et al. (2017) have two leading indicators: intellectual and industrial property. Thus, invention patents (IP) were selected as an indicator of this function. It is remarked that other variables like spin-offs and start-ups have low or no levels for many Colombian universities; accordingly, they were excluded from the present study.

Considering some studies that represent the research variables with a weighted indicator according to their importance and impact (Agasisti et al. 2016), we represented the variables: *RG*, *PSE*, *IP*, *TRAI*, *BK*, and *PUB* with an indicator composed of the number of these products in each of their categories weighted by the relative weights that we established based on the weights imposed by Colciencias (2017) per products and their categories as is possible to see in Table 2.

2.3 Specification of the models

The combinations of variables shown in Table 3 were proposed to analyze the sensitivity of a university´s performance. To obtain meaningful efficiency estimates keeping the correct number of variables in the combinations proposed, we followed the relation established

Table 2 Weights for output variables. *Source*: authors' elaboration

Variable	Category	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
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	0.2	0.2

Table 3 The model specification. Inputs and outputs. *Source*: authors' elaboration

Models	Inputs			Outputs				
Model 'a'	*AS*	*ES*	*NAS*	*RET*	*SCIM*	*RG*	*IP*	
Model 'b'	*AS*	*ES*	*NAS*	*RG*	*BK*	*PSE*	*TRAI*	*PUB*	*IP*
Model 'c'	*AS*	*ES*	*NAS*	*RET*	*PUB*	*IP*		

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.

Thus, each combination corresponds to a different model that pretends to measure efficiency from different perspectives as explained below.

Model 'a' 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 (*SCIM*) were taken into account. In addition, we also consider the invention patents (*IP*).

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 'b' with a broader range of possibilities of doing research that includes writing (*PUB* and *BK*), socialization (*PSE*), training (*TRAI*), 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 'c' 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 'a'), a broader range of research and KT products (model 'b') and considering the most used variables in the literature review (model 'c').

3 Results

3.1 DEA 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 which have maintained their efficiency over time in the three models ('a', 'b', and'c'); 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, model 'b' 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 ‘c’ 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 ‘b’ 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 ‘a’ is at an intermediate level as it is not as demanding as model ‘c’, but not as favorable as model ‘b’. 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 *SCIM*.

The performance of the models is also seen in the statistical summary of the models in Table 4, where model ‘c’ 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 ‘b’ presents the most beneficial figures; and model ‘a’ remains in the same intermediate position. Model ‘c’ presents the highest peaks in the percentage of improvement, as shown in Fig. 2a, b and c.

Indeed, the modification rate that corresponds to the publication level in model ‘c’ was eliminated since it was more than double the figure’s scale. Model ‘a’ 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 ‘b’, 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 ‘b’ and ‘c’).

The improvement proposals or changes in the current levels of the variables that the models ‘a’ and ‘c’ affect between 90 and 94% of the universities (see Fig. 3a, b and c). In comparison, model ‘b’ presents improvements for the 60.8% of the universities analyzed that contrasts the other 39.2% of the universities. Model ‘b’ allows for deducing that it concentrates on the changes in universities that genuinely need to generate improvement strategies.

Table 4 Summary statistics of higher education efficiency using DEA-VRS. *Source*: authors’ elaboration

	Model ‘a’			Model ‘b’			Model ‘c’		
	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%
DMU’s as benchmark	30%	30%	36%	40%	42%	50%	28%	22%	24%

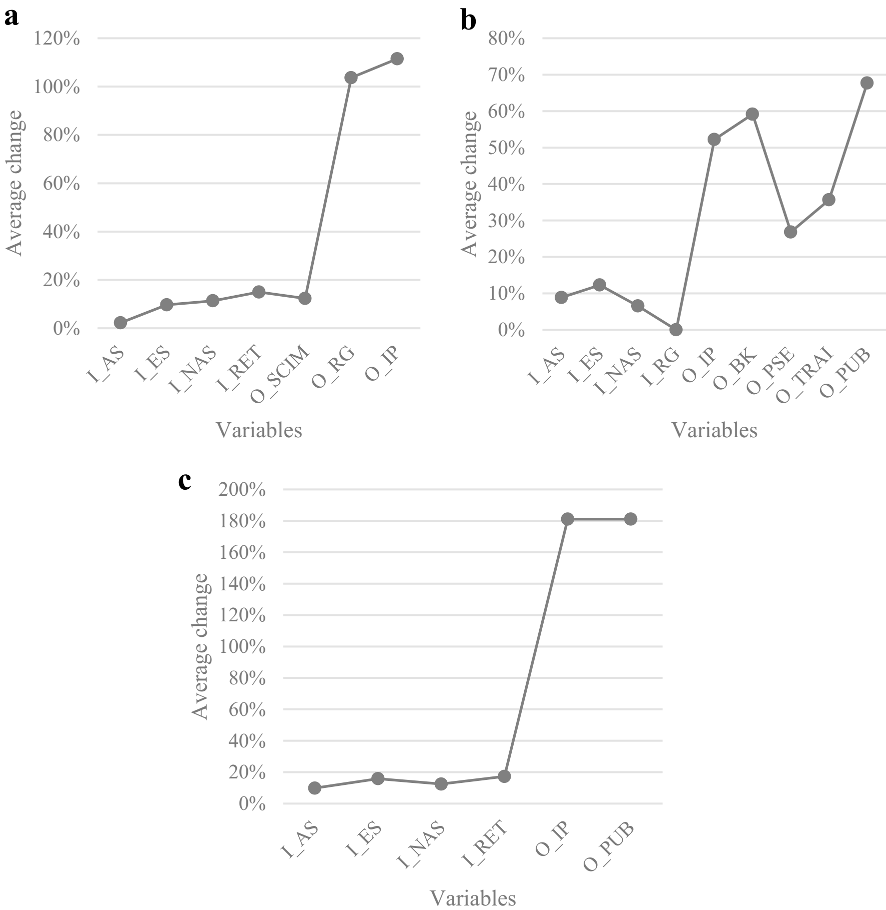

Fig. 2 **a** Average change for variables—model a. **b** Average change for variables—model b. **c**. Average change for variables—model c. *Source*: authors' elaboration

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, 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 significant benchmark for Colombian universities in the models proposed in this study. Also, the Nueva Granada Military University is a referent but with a lower degree than the previous universities.

Some universities are used as a point of reference only in specific models because their variables combination is favorable for their performance analysis. For example, San Buenaventura University, EAN University, and ICESI University are added to the influential benchmark group, but on the grounds of the variables taken into account in Model 'b.'

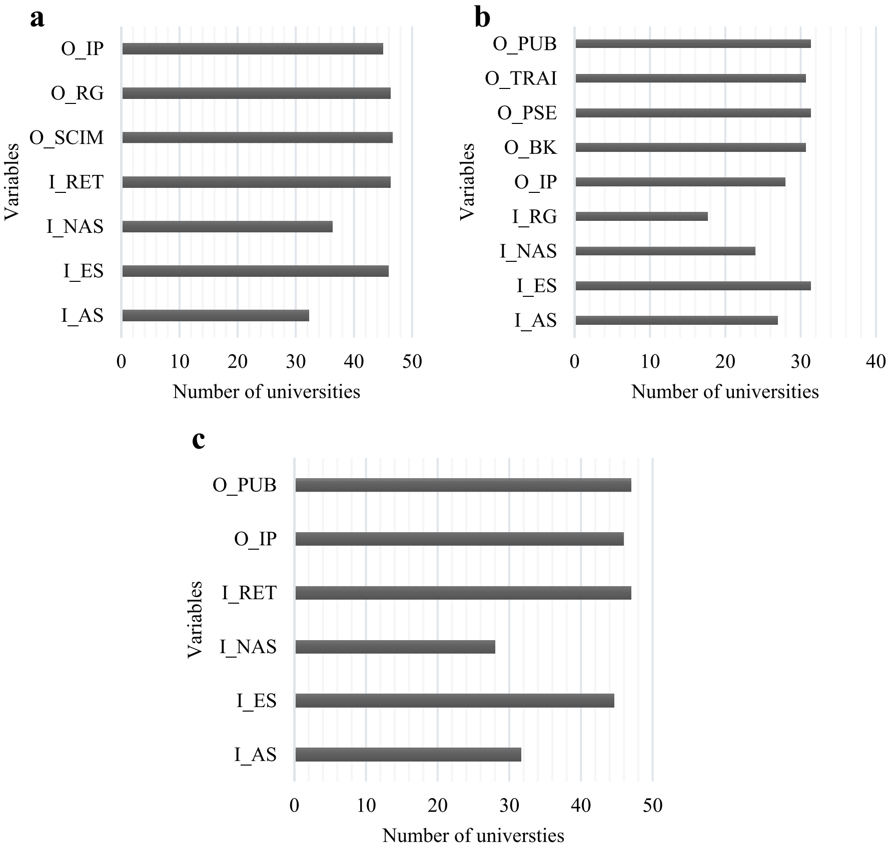

Fig. 3 **a** Number of DMU's with changes in variables—model a. **b.** Number of DMU's with changes in variables—model b. **c.** Number of DMU's with changes in variables—model c. *Source*: authors' elaboration

3.2 Efficiency changes over 2016–2018 period: a Malmquist analysis

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 6 for the general group of universities analyzed.

According to Table 5, universities in Colombia have not had a progressive performance in the variables selected for the models proposed in this study, except for model 'a' 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 'c' in the period from 2016–2017 and in the period from 2017–2018 for the variables considered in model 'b'. The SEC is present among all the variables of the different models in the period from 2017–2018. This presence can represent a general

Table 5 Malmquist index summary of annuals means. *Source*: authors' elaboration

Model	2016–2017			2017–2018		
	'a'	'b'	'c'	'a'	'b'	'c'
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

MPI Malmquist productivity index, *TC* Technological change, *PTEC* Pure technical efficiency change, *SEC* Scale efficiency change

improvement in the efficiency scale of universities in terms of research and knowledge transfer; SEC was also used for the variables in model 'b' for the period from 2016–2017.

Table 6 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 (P) or state (S) 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 'a', where 80% are of this type; in models 'b' and 'c', 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 'a', which considers the positioning or categorization variables at the national and international level. With respect to the variables of model 'c', 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.

4 Discussion

This discussion is developed in three points identified from the outstanding findings that the used methodologies exposed about the university's performance related to their research and KT objectives. The first discussion perspective is given by the result related to the most affected variables (publications and invention patents), which means they are the variables that require the highest percentages of improvement by the universities to reach efficiency.

The second discussion point is established from the gaps identified in the research and KT production levels among the universities and how the governmental and institutional policies can incentivize and influence the differences in production levels. Finally, the third discussion point is about the possibilities that represent the knowledge transference for the Colombian universities, which can impact at the same time the research

Table 6 Top ten universities based on Malmquist index. *Source*: authors' elaboration

University	C	Model 'a'					Model 'b'					Model 'c'				
		R	MPI	TC	PTEC	SEC	R	MPI	TC	PTEC	SEC	R	MPI	TC	PTEC	SEC
Católica del Oriente University (UCO)	P	1	1.207	1.069	1	1.129										
Autónoma del Occidente University -UAO	P	2	1.184	1.065	1	1.112	7	1.006	0.987	1.004	1.015					
Jorge Tadeo Lozano University	P	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	P	4	1.140	1.030	1.344	.823										
Católica de Colombia University	P	5	1.124	1.080	1	1.041										
University of Ibagué	P	6	1.117	1.071	1	1.043						8	1.007	0.956	1.091	0.966
Externado de Colombia University	P	7	1.114	1.073	1	1.039										
De la Salle University	P	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	S	9	1.091	1.031	1	1.058										
Pedagogical and Technological University of Colombia	S	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	S						1	1.096	1.027	1.045	1.022	1	1.242	1.024	1.189	1.020
Antonio Nariño University	P						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	P						5	1.011	0.989	1	1.022	9	1.005	0.967	1.100	0.945
University of Antioquia	S						8	1.006	1.006	1	1	7	1.008	1.008	1	1
Francisco José de Caldas District University	S						9	1.002	1.002	1	1	6	1.011	1.011	1	1
San Buenaventura University	P						10	1.001	1.001	1	1					
National Pedagogical University UPN	P											10	1.001	0.991	1	1.011

C Character, *S* State university, *P* Private university, *R* Ranking, *MPI* Malmquist productivity index, *Tc* Technological change, *PTEC* Pure Technical Efficiency change, *SEC* Scale efficiency change functions generating more resources to the development of research processes. This final discussion point is proposed to incentivize the development of KT activities in the Colombian universities considering the gap between universities in the number of patents and other essential research products to generate transference of knowledge.

4.1 Publications and invention patents as critical variables for the university's performance

As we noticed in the results, there exists a strong relationship between the technical performance and the variables related to KT and research. Such an outcome is not uncommon because similar conclusions can be observed in different works. For instance, Fan et al. (2019) argue that faculty and students at universities in Taiwan are encouraged to commercialize patents, which favors the immediate commercial potential. Besides, such patents encourage to use of university knowledge as the basis for new sources of industrial innovation. On the other hand, from a Colombia context, we recognize the work in Cricelli et al., (2018), which statistically demonstrates that universities with the best performances are related to better innovation variables, including the number of Scopus journal articles.

4.2 Governmental and institutional policies that generate gaps among the universities in research and KT production levels

The gaps in the variable levels related to research and KT reflect the differences among the resources and sizes of Colombian universities. These gaps can be fostered by national and institutional policies that motivate professors at universities to be scientifically productive, generating higher levels in the outputs that change the scale of efficiency under which the performance of the other universities is measured.

In the case of public universities, the Decree 1279 (2002) establishes the wage and salary system for teachers at public universities that indicates lifetime wage points associated with scientific productivity issues. 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 are implemented and funded mainly with their own resources. These incentive strategies from the universities can be a possible explanation for the finding from the MPI that shows the strong influence of institutional strategies and efforts related to the top ten universities' performance (Table 6).

In addition, national entities related to higher education as the CNA that demonstrates a particular interest in the development of research activities since 2013 when they 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 in academic programs (National Accreditation Council 2013) and since 2015 for the institutional accreditation process (National Accreditation Council 2015). 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.

4.3 Possibilities from the knowledge transference for the Colombian universities

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 López 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 Montero 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 (2021), 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, 2021). 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. The efforts for developing these necessary skills and infrastructure in the research and KT processes must be institutionalize in the universities.

Hence, one of the strategies of the universities is the incorporation of administrative structures such as the Office for Transfer of Research Results (OTRI) that moderate the relationship between scientists and business in the technology management process

(Stankevičienė et al. 2017). In this order, the OTRIs should have the necessary entrepreneurial abilities to commercialize universities' intellectual property connecting the university objectives to those of the industry.

In the current study, we considered the invention patents as the only representative variable of the KT processes in the universities because it was the output with more universities advancing in its development and with data available. However, the OTRIs and in general knowledge transference processes can generate the link with the industry from diverse outputs such as the publication of research results with applications in companies, agreements or contracts, creation of start-ups and spin-offs, mobility of human resources, among other services derivate from the research processes.

5 Conclusion

Three different perspectives (models 'a', 'b', and 'c') were taken as reference for the efficiency measure of Colombian universities, specifically in their research and KT processes. Each of these models yields a different conclusion about the object of study. The perspective from outputs, 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 'a' based on evaluation processes results as outputs (that are not considered in the other models) is not as demanding as model 'c', nor as favorable as model 'b' is for Colombian universities. Model 'a' identifies some efficient universities that are not visible in the other models. The differences in the performance shown by the universities in the model 'a' can be evidence that the output variables based on results and categories from evaluation processes are not only composed of the number of products but also include criteria and perceptions of the evaluators. These qualitative factors are so robust that models 'b' and 'c' cannot identify them merely based on production indicators.

Model 'b' 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.

Despite the universities, in general, have not had a progressive performance according to the Malmquist Productivity Index (MPI), in particular, the universities that had a better improvement in productivity (Table 6) show as a key to their improvement the remarkable presence of university efforts (PTEC $\geq$ 1). Likewise, the high presence of private universities in the ranking of universities with the most significant performance improvements for the period assessed is noteworthy.

In this order, it is possible to assert that despite the efforts from the public and private universities is necessary to increment the research and KT outputs as the publications and invention patents. However, it is essential to highlight that this type of improvement needs to be planned for the medium and long term due to the initial point for these outputs are the research projects. Thus, the availability of necessary resources and research ideas linked with the environment is the starting point for strengthening the research results that, in turn, bring categorization in this field and the capacity to think in the development of knowledge transference. The previous actions need to consider the necessary connection and the university's role as an actor of the triple helix system (Dzisah and Etzkowitz 2008).

As limitations for this study, the lack of available information for the KT function in Colombian universities is identified. 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. Similarly, concerning the research function, we suggest implementing a model that considers the effects of research projects, products, and processes as variables, instead of the amount of these parameters.

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