Vol. 5, No. 1, 2025, 1-19. DOI: 10.47909/ijsmc.173

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ORIGINAL ARTICLE

Research efficiency in Chilean universities: A look from data envelopment analysis

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ABSTRACT

Objective. The objective is to analyze Chilean universities' efficiency in using some research-related inputs to determine their impact on the results of their scientific production.

Design/Methodology/Approach. To achieve the outlined objective, some strategic resources are used as inputs, such as financial income, full-time equivalent academic staffing, and the number of enrolled students, and, as output, the number of publications in journals indexed in the Scopus database between 2020 and 2022. This is a descriptive and quantitative research using the data envelopment analysis technique.

Results/Discussion. Valuable information for university management and governance was identified, including that three universities reached 100 % efficiency and seven others exceeded 90 %. The Mann-Whitney U and Student's t-tests, which show significant and favorable results for public entities, evidence the differences between public and private universities.

Conclusion. The analysis suggests that multiple factors should be considered when evaluating the efficiency of academic institutions, especially their context and mission, especially regarding scientific production.

Keywords: data envelopment analysis; university rankings; higher education; governance of educational institutions; research evaluation; scientific output.

1. INTRODUCTION

Universities are a fundamental pillar of society, as they generate knowledge, are committed to innovation, and encourage critical thinking, all framed in the promotion of fundamental values such as the permanent search for excellence in teaching, the link with their environment, institutional management, and, of course, research. Therefore, scientific dissemination and outreach play a crucial role in this context, allowing for deeper exploration

Received: 22-10-2024. **Accepted:** 28-12-2024. **Published:** 28-01-2025.

How to cite: Ganga-Contreras, F., Romero, J. B. A., González, P. V., Cifras, N. A., & Amaya, W. S. (2025). Research efficiency in Chilean universities: A look from data envelopment analysis. *Iberoamerican Journal of Science Measurement and Communication; 5*(1), 1-19. DOI: 10.47909/ijsmc.173

and open dialogue around relevant topics. These conversations subsequently become valuable tools conducive to advancement in academia and university management (Peña, 2015; Gaete Quezada, 2016; Chankseliani *et al.,* 2021; Ganga-Contreras *et al.,* 2024). Given this reality, institutions are expected to be efficient in managing their resources and evaluating the impact on the fulfillment of their mission (Etzkowitz, 2008; 2016; Bugaj & Rybkowski, 2018; Bitencourt *et al.,* 2021; Loganathan & Subrahmany, 2023; Maral & Çetin, 2024)

In an organizational context characterized by the complexity and heterogeneity of higher education, the university institution has gone from being an entity intended for a small elite to a university with a clear tendency to increase mass enrollment (Brunner, 2012; Brunner and Ganga-Contreras, 2016; Chankseliani *et al.,* 2021). This phenomenon was not homogeneous across countries, as in some, it was done by the hand of the State, through new institutions or the expansion of existing ones. In contrast, in other places, this was done through new private universities, which generated a market of students, academics, and even prestige (Brunner and Ganga, 2016; Brunner and Ganga-Contreras, 2018; Labraña and Brunner, 2022). Therefore, these organizations must differentiate themselves from each other to stand out.

Universities face increasing financial pressures due to expanding student enrollment, the need to maintain modern and technologically advanced facilities, and the demand for research and academic development resources. Lack of adequate investment can translate into decreased education quality, reduced accredited programs, and limited research opportunities (Marginson, 2018; Abramo and D'Angelo, 2021). The scarcity of funding has led institutions to consider the university an entrepreneurial institution that seeks ways to generate extra income with activities related to businesses or the state, selling products or services (Etzkowitz, 2016; Nations, 2021). Understanding this reality, the possibility of obtaining more income becomes complex, so these entities need to be more efficient in the use of their resources and seek alliances or other measures that allow them to achieve this goal (Martínez-Campillo and Fernández-Santos, 2020; Peralta-González and Gregorio-Chaviano, 2022; Lehmann *et al.,* 2024).

In this sense, university governance is fundamental for their proper functioning and for achieving their academic and social objectives. University governance encompasses decision-making, resource allocation, policy definition, and strategic direction of the institution (Ganga *et al.,* 2016; Ganga-Contreras and Pérez, 2018). Effective governance ensures transparency, accountability, and participation of different stakeholders, such as students, faculty, administrative staff, and the community in general. In addition, it facilitates adaptability to changes in the educational, economic, and social environment. It allows universities to respond effectively to society's demands and maintain high academic quality standards (Acosta-Silva *et al.,* 2021). Governance also plays a crucial role in preserving the values and identity of the institution, thus contributing to the strengthening of its reputation and academic excellence in the long term (Asimiran and Ismail, 2019; Mok, 2021; Escandón-Barbosa and Salas-Páramo, 2023).

Within this efficiency, indicators, and transparency framework, an enormous interest has arisen in comparing higher education institutions, particularly universities. University rankings, such as the World University Rankings (QS), Academic Ranking of World Universities (ARWU), Times Higher Education (THE), and Scimago, among others, have played a significant role in the global perception of educational and research quality (Hazelkorn, 2011; 2014; Easley *et al.,* 2021). However, these rankings often do not reflect the totality of institutional performance. This is where data envelopment analysis (DEA) emerges as a valuable tool that can provide a complementary approach to assess the efficiency and effectiveness of universities. Thanks to DEA, it is possible to perform a multidimensional assessment that considers various factors, allowing for a fairer and more accurate comparison of university performance.

For institutional purposes, research evaluation is a complex challenge that involves several dimensions (Peña, 2015). Evaluating a scientific journal (using the impact factor), a university (analyzing its production, projects, and patents), a department (considering senior staff), or a researcher (reviewing their projects, publications, and patents) requires specific approaches and criteria in each case (Abramo

and D'Angelo, 2015; Abramo, D'Angelo and Soldatenkova, 2016; Praus, 2019). The variability in production and citations according to the field of knowledge highlights the importance of approaching evaluation in a contextualized manner and considering the particularities of each discipline (Abramo and D'Angelo, 2015; Asiedu *et al.,* 2020).

When evaluating the performance of individual researchers, the aim is to analyze their performance and the specific contributions of each one, considering elements such as the quantity and quality of their publications, their participation in research projects, and the impact they generate in the academic community. However, an additional difficulty arises when comparing the performance of researchers operating in different fields, each with varying publication and citation rates. This diversity of approaches and disciplinary foci adds a layer of complexity to individual evaluation, as previous studies have highlighted (Abramo *et al.,* 2013; Abramo and D'Angelo, 2021; Choy and Jang, 2023).

The main objective of this research is to analyze the efficiency of Chilean universities in using specific research resources to determine their impact on the results of their scientific production. To this end, a methodology encompasses the selection of criteria, data collection, and the application of the online efficiency analysis (DEA). The results offer a valuable perspective on the efficiency of Chilean universities in research. The discussion explores the practical implications of these results and their relevance for institutional decision-making.

1.1. Chilean University System

As of December 2023, the Chilean university system was composed of 58 universities, according to data from the Higher Education Information System (SIES, 2023a). It is necessary to indicate that, of these 58 universities, 51 have obtained accreditation by August 2024, according to information from the National Accreditation Commission (CNA, 2024), which underlines the commitment to educational quality. In terms of enrollment, the higher education system has 1,341,439 students, of which 785,273 are in universities (SIES, 2023b), representing a significant increase over the 776,838 students in 2007 (SIES, 2023b).

Universities rely heavily on student tuition fees for funding. Public resources complement this funding model through scholarships, free tuition, and private credits, a demand subsidy for public and private institutions (Salazar and Leihy, 2013; Rodríguez-Garcés and Padilla-Fuentes, 2021).

In the area of research, it is essential to note that although there is funding, it is relatively minor compared to other aspects of the university system. According to the Ibero-American Network of Science and Technology Indicators (RICYT), in 2020, Chile allocated only 0.34% of its GDP to research and development. This figure highlights the need to increase the resources allocated to research to boost the generation of knowledge and innovation in academia and thus strengthen the contribution of the university system to the country's scientific and technological progress.

1.2. Data Envelopment Analysis in Universities

Data envelopment analysis is a methodology used to indicate efficiency as a function of the inputs and outputs selected about the topic to be studied. This technique, specifically the classical radial model proposed by Charnes, Cooper, and Rhodes in 1978, measures efficiency with constant returns to scale, implying that a proportional input variation will generate a proportional output variation. Through the application of dynamic programming and without the need to impose restrictions on the functional form of the data, it can measure and compare the relative efficiency of a series of elements dedicated to a specific sector with similar tasks. Initially, this model was implemented exclusively in non-profit organizations; however, it is currently used for multiple cases and different types of organizations, including for-profit organizations (Charnes *et al.,* 1978; Coll and Blasco, 2000). This model can be oriented to inputs or results, but, as in this work, the aim is to determine the efficiency of using inputs to achieve the desired results; the orientation is to the selected inputs (Boussofiane *et al.,* 1991).

Efficiency in resource use is essential in higher education, given the situation and mission of these institutions, especially given resource scarcity and limitations. Public universities

must manage the resources allocated to them well and obtain external funding sources that allow them to grow, maintain, or improve their level. In this sense, the AED provides educational institutions with a solid analytical framework for strategic decision-making and continuous improvement.

1.3. Justification of Selected *Inputs* and *Outputs*

Inefficiency analyses using the DEA technique, commonly used in research focused on institutional performance, use some recurrent elements as input variables. These include specific economic indicators, the number of researchers, the proportion of academics dedicated to research, support personnel, and the number of students (see Table 1). The number of publications, projects, patents, or graduate students is usually an output variable.

Public spending is an essential indicator of investment in higher education, and allocating financial resources is fundamental to supporting research in academic institutions. According to Salmi (2009), for an institution to be considered world-class, three key elements are required: robust funding in terms of financial resources, the presence of talent represented by students and academics, and, finally, sound governance. Along the same lines, Abramo *et al.* (2008) incorporate research funding as one of the input elements in their analysis.

Authors	Year	Country	Inputs	Outputs
Abbott & Doucouliagos	2003	Australia	• Number of academics (Full-time equivalent) • Number of non-academic employees (Full Time Equivalent) • Operating expenses • University equity (accumulated capital)	• Number of full-time students • Number of enrolled undergraduate and graduate students • Number of undergraduate and graduate graduates. Public funding to universities according to number of publications (Australia).
Abramo, G., D'Angelo, C. A., & Pugini	2008	Italy	• Number of full-time professors • Number of associate professors • Number of researchers • Research funding	• Number of publications • Contributions to publications. • Scientific strength (weightings of publications according to the impact factor of the journals in which they are published).
Pino-Mejías, J.-L., Solís-Cabrera, F. M., Delgado-Fernández, M., & Barea-Barrera, R.	2010	Spain	• Human resources • Number of doctors • Number of graduates • Number of graduates • Auxiliary personnel • Fellows • Financial Resources	• Human resources • Web of Science (WoS) publications • Conference contributions • Thesis • Intellectual Property • Projects • Total number of contracts
Ramirez & Alfaro	2013	Chile	• Operating expenses	• Student enrollment • WoS publications
Cáceres Kristjanpoller & Tabilo.	2014	Chile	• Operating expenses • Personnel expenses • Full academic staff equivalent days • Full-day equivalent of academic support personnel	• Number of undergraduate enrollments • New undergraduate student enrollment • Own income • WoS and Scielo publications (1/3 value) • Undergraduate tuition revenue
Muñoz	2016	Chile	• Number of undergraduate students enrolled • Number of undergraduate students • Fee charged annually • Number of university professors • Number and percentage of professors with doctorate degrees • Full-time equivalent of teachers • Student grade point average (NEM, in Spanish) • Average university entrance exam score	• Number of university publications • Amount of public funds awarded in Fondecyt research

Authors	Year	Country	Inputs	Outputs
Quispe Fernández, G. M., & Jordán Minaya	2017	Bolivia	• Total number of teachers • Total number of administrative workers	• Total number of enrollees • Total number of graduates • Total number of new registrations
Alcaraz-Ochoa & Bernal-Domínguez	2017	Mexico	• Ordinary and extraordinary federal financing	• New students • Alumni • Percentage of accredited programs • Academic bodies
Peñate, Y., Rivero, J. L., & Lozada	2017	Ecuador	• Proportion of teaching activity • Proportion of research activity • Proportion of research activity	• Proportion of teaching activity • Proportion of research activity • All associated with value of importance
Expósito-García, A., & Velasco-Morente	2018	Spain	• Expenditure per student • Spending per academic • Average number of years of academic research	• Total number of publications (per 100 academics) • Number of publications in Q1 journals (per 100 academics) • Number of publications not cited, expressed as %
Salas-Velasco	2020	Spain	• Total number of credits enrolled • Ratio of credits enrolled in technical degrees over the total number of credits enrolled. • Full-time equivalent teaching staff • Administrative and service personnel	• Total number of credits passed or approved • Liquid revenues from applied research • Weighting of health sciences graduates over the total number of graduates as an indicator of resource attraction
Villegas, J. G., Carolina, C. P., & Gómez	2021	Colombia	• No inputs as they are evaluations within the same university	• Number of lecture sections taught during the year • Number of courses given during the year • Total number of students in these courses. • Total number of hours taught during the year. • Weighted average evaluation of the quality of teaching provided by students
Chen, Y., Ma, X., Yan, P., & Wang	2021	China	• Total number of full-time professors • Total fixed assets • Funding for scientific research • Number of master's and doctorate students	• Number of monographs published • Number of articles published • Number of awards • Actual revenues from patent sales
Cossani, Codoceo, Cáceres & Tabilo	2022	Chile	• Operating expense • Academic staff • Infrastructure in square meters constructed • Direct fiscal contribution (AFD, in Spanish	• Publications in Scopus • Quality of publications according to CiteScore • Income from research grants

Table 1. Studies on data envelopment analysis in universities.
Source: Own elaboration based on reviewed articles.

This practice is consistently observed in various studies, as research funding is an input element in efficiency analyses. Given that it plays a critical role in evaluating the quality and performance of academic institutions, it is essential to assess their quality and performance (Abbott and Doucouliagos, 2003; Pino-Mejías *et al.,* 2010; Ramírez and Alfaro, 2013; Cáceres *et al.,* 2014; Alcaraz-Ochoa and Bernal-Domínguez, 2017; Expósito-García and Velasco-Morente, 2018; Chen *et al.,* 2021).

2. METHODOLOGY

The non-parametric tool DEA was applied, enabling efficiency classifications that reflected how relevant factors behaved when expressed in a result, such as the *output* to be studied. All Chilean universities with their financial

information updated at the Superintendence of Higher Education were selected. In total, 54 universities are listed in Table 2.

The input variables adopted were the operating income of the universities, the number of students enrolled, and the full-time equivalent (FTE), which reflected the proportion of academics dedicated to research. For the output variables, we chose to use the number of publications indexed in Scopus since it is the most extensive database with more excellent coverage compared to WoS, especially in areas such as social sciences and humanities (Andalia, Labrada and Castells, 2010; Pranckutė, 2021). This approach sought to maximize the accuracy and comprehensiveness of the results by taking advantage of the breadth of Scopus in terms of content and scope.

Taking into account the contribution of previous research and the purpose of this work, the decision was made to use the academic component as an input variable; more specifically, we chose to use the full-time equivalent so that the time per staff would be more representative and reflect the actual value of each university. This choice is based on previous research supporting the validity and relevance of this variable (Abbott and Doucouliagos, 2003; Abramo, D'Angelo, and Pugini, 2008; Cáceres, Kristjanpoller and Tabilo, 2014; Muñoz, 2016; Peñate *et al.,* 2017; Salas-Velasco, 2020; Chen *et al.,* 2021).

On many occasions, students collaborate with their professors in conducting research, either as assistants or as part of their graduate theses. This component was incorporated for this research based on the number of students enrolled as a relevant input. This choice was based on the observation that this practice was recurrent and on evidence from other DEA studies, which indicated that efficiency may vary proportionally to the size of the university (Muñoz, 2016; Salas-Velasco, 2020; Chen *et al.,* 2021).

As for the product of this research, it was decided to focus exclusively on publications indexed in Scopus. This choice was based on the relevance of this database, considered one of the most important worldwide, and its ease of filtering articles associated with scholars at each university (Pranckutė, 2021). When analyzing other studies that use scientific publications as a result, it was observed that the tendency to interpret them is recurrent due to their ease of association with each institution (Pino-Mejías *et al.,* 2010; Ramírez and Alfaro, 2013; Cáceres *et al.,* 2014; Muñoz, 2016; Expósito-García and Velasco-Morente, 2018; Chen *et al.,* 2021; Cossani *et al.,* 2022).

For data collection, we considered, as a result, the publications in journals indexed in Scopus (average between 2020 and 2022), that is, up to the last year for which complete information on articles published in each university was available. This criterion was used since Scopus is the database with the most indexed journals (Pranckuté, 2021). It is interesting to know the performance in the scientific production of Chilean universities, which is a significant factor in expanding information and knowledge and advancing better management and efficient processes. For operating income, data were taken for 2020 to 2022, according to the information provided by the Superintendence of Higher Education for each university. Enrollment data were obtained from the Higher Education Information System (SIES) database of the Ministry of Education for each institution between 2020 and 2022 and averaged. The same source was used for the full-time equivalent academic staff data, and the results were averaged by year.

Considering the above, the Scopus publications reflected scientific production and its extreme significance in the university academy, resulting in the convergence of the chosen inputs. These were the "Decision-Making Units" (DMUs), which were evaluated by the program and could later be "ranked" according to their performance and selected criteria (Bowlin, 1998).

We worked with three inputs that were related to Scopus publications. In addition to containing reliable data, these were measured quantitatively to obtain consistent results from which relevant conclusions and interpretations were obtained. The above can be summarized in the following expressions that characterized the inputs and outputs used for the entire analysis, the overall results, and the conclusions of this study:

Input = Operating income (40%) + *Enrolled students* (10%) + *Full-time equivalent academicians* (50%)

Output = Average Scopus publications (2020-2022)

Acronym	Name	Acronym	Name	Acronym	Name
UCH	University of Chile	UVM	University of Viña del Mar	UCSH	Silva Henriquez Catholic University
PUC	Catholic University of Chile	UV	University of Valparaíso	UAHC	Academy of Christian Humanism University
UDEC	University of Concepción	UNAB	Andrés Bello University	USEK	SEK University
PUCV	Catholic University of Valparaíso	UAI	University U. Adolfo Ibáñez	INACAP	National Vocational Training Institute
UTFSM	Universidad Técnica Federico Santa María.	UDP	Diego Portales University	UDALBA	Alba University
USACH	University of Santiago	UMAYOR	Universidad Mayor	UGM	Gabriela Mistral University
UFRO	Universidad de la Frontera	UANDES	Universidad de los Andes	UMC	Miguel de Cervantes University
UTA	University of Tarapacá	UST	Santo Tomas University	ULL	Los Leones University
UNAP	Arturo Prat University	UBO	Bernardo O'Higgins University	UTALCA	University of Talca
UA	University of Antofagasta	UDLA	University of the Americas	UCM	Catholic University of Maule
UCN	Catholic University of the North	UAH	Alberto Hurtado University	UDD	Universidad del Desarrollo
UDA	University of Atacama	UTEM	Metropolitan Technological University	UBB	University of Bio-Bio
ULS	University of La Serena	UFT	Finis Terrae University	UCSC	Universidad Católica de la Santísima Concepción
UPLA	Playa Ancha University of Education Sciences	UCEN	Central University of Chile	USS	San Sebastian University
UACON	University of Aconcagua	UMCE	Metropolitan University of Education Sciences	UOH	University of O'Higgins
UADVEN	Adventist University	UACH	Austral University of Chile	UATO	Universidad Autónoma de Chile
UCT	Catholic University of Temuco	ULAGOS	University of Los Lagos	UAYSEN	University of Aysén
UMAG	University of Magallanes	UNIACC	University of Arts, Sciences and Communication	BU	Bolivarian University

Table 2. Universities that were part of the study sample.
Source: Own elaboration based on data from SIES 2023a.

The first data selected was the average operating income (years 2020 to 2022). This factor was relevant since no institution can produce without research funds. An income makes it possible to propose interesting projects for open discussion and work within each educational community and extrapolate the conclusions or results obtained so that other entities can know them. In this way, knowledge and research can be expanded to more people. Then, we have the average student enrollment in the same years (2020-2022), a relevant factor for a university since a more significant number of students can provide more opportunities for development and growth for the respective house of studies, managing to build bases for scientific production in different branches of each area such as management, medicine, economics, education, among thousands of other research options.

The last input factor was full-time academics on average (years 2020 to 2022). Like monetary income and enrollment, the number of academics at the university was another critical factor that directly impacted the number of Scopus publications. Academics have the necessary tools for scientific production, so their presence is essential for research to exist. In addition, it was specified that these staff members should be full-time since, in this way, we ensured that

their commitment and trajectory were explicitly linked to one of the 54 Chilean universities (Navarro-Cabrera, 2022).

For this work, specific weightings were chosen for each input according to their relevance in scientific dissemination. That said, the income from the year's operation is 40%, while student enrollment has the lowest percentage of incidence, with only 10%. Finally, full-time academics, as mentioned before, were essential for creating and disseminating knowledge in these scientific journals, so they captured 50 % of the incidence on the final product. This made it possible to highlight the factors that had the most significant impact and to make the universities comparable, leaving aside the differences in size that caused the same numbers to be repeated in the different national and international rankings. The impact of these factors on Scopus publications was justified theoretically. Still, whether these three independent variables had a statistically significant relationship with the result (dependent variable) was also supported. This was done using a regression in the Stata 17 program.

This calculation was performed in the statistical program R and R Studio with the *makedeadata* command, using the classical *CCR model_basic* method. CCR is the classical version devised by Charnes, Cooper, and Rhodes, which measures efficiency with constant returns to scale; a proportional variation in inputs will generate a proportional variation in outputs. On the other hand, the BCC model (Banker, Charnes, and Cooper) is an extension of CCR since it allows variable returns to scale when there are different efficiency frontiers, while in CCR, there is only one efficiency frontier. In this case, the efficient units constituted a single frontier that was the parameter for all decision units (Fancello *et al.,* 2020). Considering the main feature of both models, the constant returns to scale option was used, which is the most common to compare performances.

3. RESULTS AND DISCUSSION

A regression is performed in the Stata 17 program to check whether the chosen parameters significantly affect *Scopus* publications. An R-squared value of 0.9282 indicates that the three parameters are the model's independent variables. These variables explain 93 % of the variability in the chosen result. The regression also provides statistically significant values for all inputs at 1 %. This reaffirms that these variables significantly affect the outcome, making their use valid and valuable.

As shown in Table 3, the coefficients indicate that tuition would hurt Scopus publications, while JCE academics and operating income positively impact the dependent variable.

Scopus publications	Coefficient	Std. error	t	P > |t|
Registration	-.0378921	.0116195	-3.26	0.002
JCE Academics	.7717744	.2978371	2.59	0.013
Operating income	6.59e-09	6.37e-10	10.35	0.000
Constant	51.06727	44.03416	1.16	0.252

Table 3. Results of regression inputs on average Scopus publications 2020-2022.
Source: Own elaboration with regression data in *Stata 17.*

Table 4 shows the order of the universities based on the input data for this study in terms of operating income, enrollment, and number of full-time equivalent (FTE) academics. The data show a significant disparity in the financial capacity of these institutions. For example, the Pontificia Universidad Católica de Chile and the Universidad de Chile stand out as the universities with the highest revenues, reaching figures of 507,757 and 505,657 million pesos, respectively (543 and 541 million dollars approximately). These amounts reflect their ability to obtain both public and private funding and income from tuition and other associated services. On the other hand, universities such as Universidad Los Leones and Universidad Miguel de Cervantes operate with considerably fewer financial resources, suggesting limitations in their economic capacity to develop their academic and research activities.

University	Revenues	Registration	JCE Academics
Catholic University of Chile	507.757.457.667	41.848,00	2.265,96
University of Chile	505.657.780.000	41.913,67	2.358,38
University of Concepción	242.081.524.333	29.701,33	1.475,33
Andrés Bello University	228.834.194.000	54.615,00	2.365,65
Universidad de los Andes	183.395.385.333	15.664,67	536,21
San Sebastian University	164.343.397.667	40.531,33	1.712,97
Catholic University of Valparaíso	121.751.625.333	18.161,00	669,80
University of Santiago de Chile	120.144.233.000	24.336,33	1.189,01
Universidad del Desarrollo	109.743.747.000	19.402,00	1.074,12
Federico Santa María Technical University	108.501.166.000	21.477,67	729,87
Universidad Autónoma de Chile	106.199.693.000	29.892,67	1.160,04
Austral University of Chile	101.100.900.667	18.015,00	955,23
Universidad Mayor	99.218.197.333	23.148,67	937,63
University of Santo Tomás	88.498.534.333	27.149,33	1.231,70
Adolfo Ibáñez University	84.033.494.000	12.519,67	533,05
Universidad de la Frontera	83.841.488.000	11.753,33	512,15
University of Valparaíso	81.882.369.333	17.057,67	888,44
Diego Portales University	77.044.699.333	19.350,33	736,01
University of the Americas	73.472.777.333	25.228,33	1.040,06
University of Talca	70.315.116.667	12.056,67	598,82
Catholic University of the North	64.222.648.333	11.261,33	549,02
Universidad del Bío-Bío	53.838.313.333	12.105,33	498,77
University of Tarapacá	52.789.833.333	10.081,67	352,02
Universidad Católica de la Santísima Concepción	51.309.272.333	14.523,00	605,47
University of Antofagasta	48.493.570.667	7.980,33	428,14
Catholic University of Temuco	46.879.629.667	12.361,67	557,88
Catholic University of Maule	46.434.594.333	11.313,33	538,51
Central University of Chile	43.282.200.000	13.878,33	492,74
Metropolitan Technological University	39.858.521.333	9.087,00	375,20
University of Los Lagos	39.506.093.000	9.499,33	468,33
Arturo Prat University	39.024.345.667	11.233,00	420,79
Finis Terrae University	36.339.018.667	10.081,67	474,84
Technological University of Chile INACAP	34.524.060.000	15.858,67	449,24
University of La Serena	32.892.368.000	7.600,67	308,15
Alberto Hurtado University	32.432.022.333	8.315,33	287,52
Playa Ancha University of Education Sciences	30.776.814.667	7.255,67	416,54
University of Viña del Mar	28.607.221.333	9.288,00	388,90
Bernardo O'Higgins University	25.551.827.333	8.438,67	373,18
University of Atacama	24.727.636.333	7.431,67	375,51
University of Magallanes	24.613.524.333	3.981,67	283,28
University of O'Higgins	23.768.436.667	4.154,33	193,74
Metropolitan University of Education Sciences	23.655.926.667	4.330,33	298,26
Cardenal Raúl Silva Henríquez Catholic University	21.269.617.667	6.854,67	307,57
Alba University	17.403.681.667	6.030,67	228,71
University of Arts, Sciences and Communication UNIACC	13.597.343.000	5.953,67	203,63
Academy of Christian Humanism University	10.281.883.667	3.821,00	163,93
University of Aconcagua	9.679.218.000	5.808	167,23
Adventist University of Chile	8.144.864.333	2.517,67	175,41

University	Revenues	Registration	JCE Academics
University of Aysén	7.336.264.667	523,00	58,38
Gabriela Mistral University	6.991.893.667	1.439,00	56,52
Sek University	6.794.497.333	2.727,67	139,51
Miguel de Cervantes University	3.806.776.000	3.777,67	69,92
Bolivarian University	3.137.814.333	2.376,33	59,91
Los Leones University	518.689.000	765,33	10,47

Table 4. Inputs for each university (annual averages 2020 to 2022, in Chilean pesos). Source: Own elaboration based on SIES for enrollment and academics (2020 to 2022) and Operational income Superintendence of Higher Education (2020 to 2022) *Dollar value observed 19-12-24 (USD 1 US dollar is equal to 990.87 Chilean pesos.).

Universidad Andrés Bello leads with 54,615 students enrolled, followed closely by Universidad de Chile, with 41,913 students. In contrast, smaller institutions such as Universidad de Aysén and Universidad Gabriela Mistral have considerably lower enrollments, with 523 and 1439 students, respectively. In the case of the Universidad de Aysén, this is explained by the fact that it is a university located in the least populated region of the country, with a population of only 103 158 inhabitants (INE, 2017), so in this study, both universities should benefit, given that their inputs are small and what the study seeks is to measure efficiency.

The number of academics in JCE also varies significantly from one university to another. Universidad Andrés Bello and Universidad de Chile have the most academics in JCE, with 2366 and 2358, respectively. This high number of academics could reflect these institutions' capacity to offer a wider variety of academic programs and their strong focus on research. In contrast, universities such as Universidad Los Leones and Universidad Gabriela Mistral have significantly fewer academics in JCE, indicating smaller academic structures and possibly a lower capacity to conduct large-scale research.

Regarding scientific production, Scopus publications for the last three years (2020-2021-2022) show that the Universidad de Chile has an average of 3740 publications. It is followed by Pontificia Católica de Chile and, in third place, Universidad de Concepción. On the other hand, Universidad de Los Leones is the only one that did not register any publications during the period (see Table 5).

3.1. Data Envelopment Analysis

The data envelopment analysis obtains a standardized efficiency level for each study center, where the levels range from 0 to 1, or similarly, from 0 % to 100 %. The term "efficiency" is used in the economic analysis to indicate that no resources are wasted in this economic activity. In this case, the definition is technical efficiency, which reflects the organization's ability to produce the maximum output in publications from 2020-2022.

From the table ordered by efficiency results of the universities in their performance in Scopus publications, considering income, enrollment, and full-time academics, three universities with complete efficiency are obtained. These entities are Universidad de la Frontera, Universidad Católica del Maule, and Universidad de Chile. The three universities present an efficiency of 100%, so it can be affirmed that these educational institutions have a correct performance in using inputs and how these are reflected in the results. In the second group of efficiency are the universities of Tarapacá (very close to entering the first group), the Catholic University of Chile and the Catholic University of the North, and closing the group, the Pontifical Catholic University of Valparaíso. In the last places, marked in red, are private institutions focusing more on teaching than research.

These data can explain the functioning of the DEA, since this method does not seek to find the universities with the best results in Scopus publications, but rather the most efficient in the management of the resources (inputs) used in the research production of the Scopus journal, in an average of three years.

Pos.	University	Scopus Output	Pos.	University	Scopus Output
1	University of Chile	3.740,00	28	University of La Serena	271
2	Catholic University of Chile	3.434,67	29	University of Santo Tomás	241,67
3	University of Concepción	1.799,67	30	University of Atacama	235,33
4	Andrés Bello University	1.344,33	31	University of the Americas	225,33
5	University of Santiago de Chile	1.172,33	32	Alberto Hurtado University	214,33
6	Catholic University of Valparaíso	1.045,00	33	Metropolitan Technological University	190,67
7	Austral University of Chile	1.035,33	34	University of Magallanes	182,33
8	Universidad de la Frontera	886	35	Arturo Prat University	181,67
9	Federico Santa María Technical University	810,33	36	University of O'Higgins	169,67
10	Universidad Autónoma de Chile	729	37	Playa Ancha University of Education Sciences	165,33
11	University of Valparaíso	710,67	38	Finis Terrae University	164,67
12	University of Talca	693	39	Central University of Chile	137
13	Catholic University of the North	683	40	Metropolitan University of Education Sciences	127,33
14	Catholic University of Maule	597	41	Cardenal Raúl Silva Henríquez Catholic University	77,33
15	University of Tarapacá	561,67	42	University of Viña del Mar	66,67
16	Universidad Del Desarrollo	543,33	43	Adventist University of Chile	53,67
17	Adolfo Ibáñez University	529	44	Academy of Christian Humanism University	46,67
18	Diego Portales University	517	45	University of Aysén	37,67
19	Universidad Mayor	474	46	Sek University	28,67
20	Universidad del Bío-Bío	470,67	47	Technological University of Chile INACAP	21
21	Universidad Católica de La Santísima Concepción	451,33	48	Alba University	13,33
22	Universidad De Los Andes	438,33	49	Gabriela Mistral University	9,33
23	University of Antofagasta	394	50	Miguel de Cervantes University	4,33
24	San Sebastian University	385,33	51	University of Aconcagua	3,67
25	Catholic University of Temuco	357,67	52	University of Arts, Sciences and Communication UNIACC	1,33
26	Bernardo O'Higgins University	288,67	53	Bolivarian University	1,33
27	University of Los Lagos	277,67	54	Los Leones University	-

Table 5. Universities by average publications (years 2020 to 2022).
Source: Own elaboration based on Scopus database (2020 to 2022).

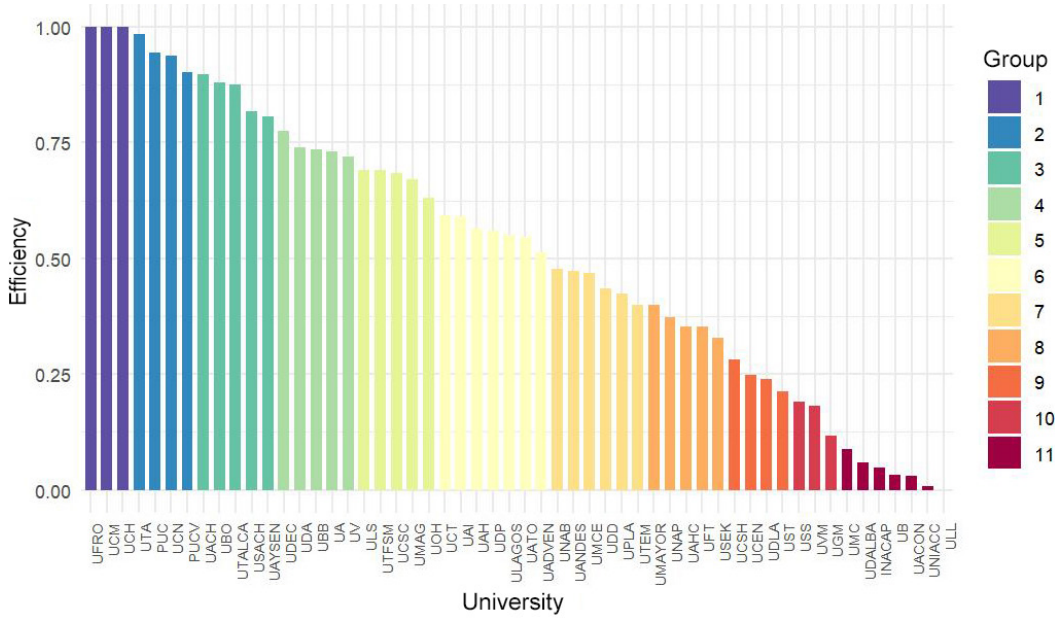

Figure 1. Efficiency of Chilean universities (2020-22). Source: Own elaboration, using R software.

As can be seen in Table 6 (which complements the information in Figure 1), the study detected entities that obtained 0 efficiency in DEA, which is mainly due to the scarcity of published articles. For example, the Universidad Gabriela Mistral (with 4 publications on average), the Universidad de Aconcagua (with 3.6 publications on average) and, in last place, the Universidad de Artes, Ciencias y Comunicación UNIACC (with an average of 1.3 publications). Within these universities, the database shows that UNIACC has a high operating income (13,597,343,000), but it is not an institution that focuses on scientific production, so for this type of analysis its efficiency will be null in the use of its resources to produce output.

In this analysis, the results and positions in the rankings of Chilean universities were examined, also considering the type of institution to which they belong. Among the public universities, the Universidad de Chile and the Universidad de la Frontera stand out with percentages of 100 % in the DEA result; other public institutions that stand out are Tarapacá and Talca with percentages above 87 %. A special case is the Universidad de Aysén, which was created in 2015; as can be seen, it appears in fifth position, which is explained by the fact that it has a low enrollment of 523 students and an average of 58.38 full-time equivalent academics, which gives an average of practically 9 students per academic. These factors contribute to the high level of efficiency in the analysis.

In private universities that are part of the Council of Rectors of Chilean Universities (CRUCH), the Universidad Católica del Maule leads the group of universities with 100% efficiency. In comparison, the next on the list is the Pontificia Universidad Católica de Chile, with 94.42% in the DEA Result, and the Universidad Católica del Norte, with 93.73% efficiency. Other private institutions of the CRUCH, such as the Pontificia Universidad Católica de Valparaíso and the Universidad Austral, also present high percentages and outstanding positions in the ranking.

On the other hand, some private universities that do not belong to the CRUCH also stand out in the analysis. Universidad Bernardo O'Higgins stands out with an efficiency of 87.87 %, followed by Universidad Adolfo Ibáñez, which shows a percentage of 59.02 % in the DEA result. The Universidad Autónoma de Chile has a rate of 54.58 %. Finally, some private universities such as Bolivariana, Universidad de Artes, Ciencias y Comunicación UNIACC, and Universidad de Los Leones exhibit very low percentages in the DEA score. This could be explained by the fact that they are in the process of closing or because they do not specialize in research, which limits the results in these areas.

As Table 6 shows, the analysis provides an overview that suggests that public and private universities belonging to the CRUCH tend to show more potent results than independent private universities. However, it emphasizes that this analysis is based on general trends and that each university should be evaluated according to its characteristics, mission, and the specific environment in which it is located.

Pos.	University	DEA	Type of institution	Pos.	University	DEA	Type of institution
1	Universidad de la Frontera	100%	Public	26	Autonomous University	54,58%	Private
1	Catholic University of Maule	100%	Private CRUCH	27	Adventist University	51,24%	Private
1	University of Chile	100%	Public	28	Andrés Bello University	47,63%	Private
2	University of Tarapacá	98,50%	Public	29	Universidad de los Andes	47,25%	Private CRUCH
3	Pontifical Catholic University of Chile	94,42%	Private CRUCH	30	Metropolitan University of Education Sciences	46,74%	Public
4	Catholic University of the North	93,73%	Private CRUCH	31	Universidad del Desarrollo	43,51%	Private
5	Catholic University of Valparaíso	90,18%	Private CRUCH	32	Playa Ancha University of Educational sciences	42,35%	Public
6	Austral University of Chile	89,76%	Private CRUCH	33	Metropolitan Technological University	40,04%	Public
7	Bernardo O'Higgins University	87.87%	Private	34	Universidad Mayor	39,94%	Private
8	University of Talca	87,52%	Public	35	Arturo Prat University	37,19%	Public
9	University of Santiago de Chile	81,66%	Public	36	Academy of Christian Humanism University	35,30%	Private
10	University of Aysen	80,71%	Public	37	Finis Terrae University	35,24%	Private
11	University of Concepción	77,44%	Private CRUCH	38	SEK University	32,81%	Private
12	University of Atacama	74,02%	Public	39	Cardenal Raúl Silva Henriquez Catholic University	28,27%	Private
13	University of Bio Bio	73,56%	Public	40	Central University of Chile	24,79%	Private
14	University of Antofagasta	73,14%	Public	41	University of the Americas	23,85%	Private
15	University of Valparaíso	71.87%	Public	42	University of Santo Tomás	21,23%	Private
16	University of La Serena	69,07%	Public	43	San Sebastian University	18,95%	Private
17	Federico Santa María Technical University	68,98%	Private CRUCH	44	University of Viña del Mar	18,12%	Private
18	Universidad Católica de la Santísima Concepción	68,41%	Private CRUCH	45	Gabriela Mistral University	11.71%	Private
19	University of Magallanes	67,06%	Public	46	Miguel de Cervantes University	8,85%	Private
20	University of O'Higgins	62,98%	Public	47	Alba University	5,95%	Private
21	Catholic University of Temuco	59,34%	Private CRUCH	48	Technological University of Chile INACAP	4,73%	Private
22	Adolfo Ibáñez University	59,02%	Private	49	Bolivarian University	3,30%	Private
23	Alberto Hurtado University	56,40%	Private CRUCH	50	University of Aconcagua	2,94%	Private
24	Diego Portales University	55,90%	Private CRUCH	51	University of Arts, Sciences and Communication UNIACC	0,76%	Private
25	University of Los Lagos	54,96%	Public	52	Los Leones University	0,00%	Private

Table 6. DEA results for Chilean universities.
Source: Own elaboration based on universities' DEA results.

Using *Stata 17,* two tests are performed to test for differences between public and private universities: the Mann-Whitney U test and the t-test. The Mann-Whitney U test compares whether there are differences in the distributions of two independent groups. In this case, the null hypothesis that the AED scores of the two groups have no significant differences is rejected. Since the Z value is negative (z = -3.101) and significant, it is concluded that public universities obtain better results than private universities.

As shown in Table 7, the t-test, which evaluates the mean of two populations through hypothesis testing, is consistent with previous results. The application of this statistical tool reveals that private institutions have an AED score of 0.267 units lower than public entities.

Group	obs	mean	std error	std dev
Private	36	.4432	.0514	.3088
Public	18	.7104	.0471	.1998
Diff		-.2671	.080	

Table 7. Application of the Test-t.
Source: Own elaboration using Stata 17.

4. CONCLUSIONS

As institutions in charge of training advanced human capital, universities face several challenges, one of which is scientific production, where they stand out for their contribution to the expansion and creation of knowledge, which opens the way to new opportunities for improvement and problem-solving. On the other hand, the efficiency of higher education spending is crucial due to its high social cost, especially in the case of Chile, which is the OECD country that invests the most in higher education, with 2.65% of GDP in public and private spending (OECD, 2024). Whether qualitative or quantitative, research can provide relevant information for decision-making and enrich education by raising questions and seeking in-depth answers (Gil, 2014).

Data envelopment analysis provides insight into the efficiency of decision-making units in using inputs and how these are reflected in the results chosen. In this case, Scopus publications were used to illustrate the efficient use of the university budget, enrollment, and full-time academics. These inputs were weighted according to their incidence in the result, which also helps to balance the sample of universities and to ensure that university size is not a bias that benefits more prominent universities (Cossani *et al.,* 2022). This analysis shows three Chilean universities that stand out for their efficiency: Universidad de Chile, Universidad Católica del Maule, and Universidad de la Frontera. On the other hand, other universities presented very low-efficiency levels: Bolivarian University, the University of Arts, Sciences, and Communication, UNIACC, and the University of Los Leones.

By the premise that systems that allocate research funds based on competitive incentives are more efficient in the use of resources, Auranen and Nieminen (2010) point out that this statement does not apply uniformly in all cases; the reality is more complex than simply having incentive systems to finance science. In this same sense, when this work considers the data envelopment analysis in Chilean universities as an example of competitive funds, significant variability in efficiency among universities is observed even though they all compete for research funds.

It has been observed that the inputs chosen are essential to obtaining these results. If other variables are selected, the inefficient universities could lead to the new list. Changing the weights can also modify the positions of the universities, completely changing the resulting top.

One of the key elements to be considered with this type of technique is the need for scientific information systems that provide detailed and reliable data on results and inputs. In the case of Chile, the legislation requires the delivery of information associated with the inputs, both for public and private universities. This requirement is not present in all higher education systems globally. Although it may be iterative, it is essential to highlight the fundamental role of universities in society and the great challenge they face when it comes to distributing and using their resources in the best possible way to obtain results that allow them to raise their level of quality and achieve better levels of accreditation.

This work is the result of a first approach to this type of measurement, which implies recognizing that there are margins that allow

complementing this inquiry with measurements that, in the future, could consider factors such as the leadership of scientific article authors, the quality of the publications (quartile of the journal), and the impact factor, among other variables. The application of research in patents, bills, or other initiatives that have a positive impact on society could also be added to the analysis.

Conflict of interest

The authors declare that there is no conflict of interest.

Contribution statement

Conceptualization, methodology, validation, formal analysis, research, resources, data curation, writing-original draft preparation, writing-revision and editing, visualization, supervision, project management, acquisition of funds: Francisco Ganga-Contreras.

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Conceptualization, validation, formal analysis, writing-original draft preparation, writing-revision and editing: Wendolin Suárez Amaya.

Data Consent Statement

Data supporting the results of this study are available from the corresponding author upon request.

Ethical Statement

This study was conducted according to the ethical standards of the institutional research committee, the 1964 Declaration of Helsinki and its subsequent amendments, or comparable ethical standards.

Financing

The authors would like to thank the Agencia Nacional de Investigación y Desarrollo (ANID, Chile) for the sponsorship received through the FONDECYT Regular Project Nº 1231766, which allowed the preparation of this article.

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