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Performance of Education and Research in Latin American Countries through Data Envelopment Analysis (DEA)

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Abstract

Fifteen Latin American countries are analyzed considering six factors that reflect their progress with respect to research and development, science and technology, education and innovation. These factors are studied as inputs and outputs in a technical efficiency analysis of their economies using Data Envelopment Analysis (DEA). As inputs, the percentage of Gross Domestic Product (GDP) contributed to education and research and development expenses, in addition to the number of universities in each country. while ouputs are Information and Communication Technologies (ICT) services and high-tech exports, as well as the Global Innovation Index. The data were collected from the World Bank, Economic Commission for Latin America and the Caribbean (ECLAC), World Intellectual Property Organization (WIPO) and the Webometrics Ranking of Universities. It was obtained that the Latin American countries present different performances considering the contribution of the GDP for research and development expenses, being this the main input that contributes with the High-technology exports in the studied Latin American countries.

Keywords: Latin America, efficiency, science and technology, innovation, ICT, DEA.

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1. Introduction

The World Trade Organization, in its annual statistical report, provides a detailed analysis of recent developments in world trade, reporting on global exports of telecommunications, computer and information services, by region. In 2015, this service sector grew rapidly, especially in Costa Rica, which became the main provider of IT services in South and Central America, followed by Brazil and Argentina. However, regional figures are low for Latin America (2.2%), with Europe (58.8%) and Asia (23.6%) being the leaders [1][2][3][4]. By 2018, these figures changed, with Europe (57.1%), Asia (25.2%), and South and Central America and the Caribbean (1.5%) [5]. The volume of exports to our region has decreased, affecting its competitiveness and productivity [6][7][8]. In this regard, it is worth asking what factors contribute to technology exports, and consequently, improve the positioning of countries as innovators. Innovation is not limited to the most advanced economies, nor to high-tech sectors, but is a global phenomenon that affects all sectors of the economy [9].

Among the World Development Indicators published by the World Bank [10], compiled from officially recognized international sources, are exports of information and communication technology (ICT) services and expenditure on research and development. These indicators are extremely important for the countries, which have been compiled in this study to conduct a technical efficiency analysis of the GDP and education investments of Latin American countries, and also to learn about their contributions to innovation and exports in technology, applying the Data Envelopment Analysis (DEA) method.

The first part of the paper presents the methodology employed for the selection and collection of variables and data, and then presents the results achieved and the academic discussion. At the end, the conclusions and bibliographical references are shown. The results show the performance of countries with respect to technology exports and their development in innovation, through differentiable clusters. It is concluded that Latin America presents inefficiencies in the progress of Research and Development, compared to the international framework.

2. Development

2.1. Selection of variables, countries and data for the analysis

For the analysis of technical efficiency using DEA, data published from Latin American countries in recognized databases such as the World Bank, ECLAC, WIPO and SNRC are considered, with complete data for the six selected variables (Tables 1 and 2). Of 23 countries reviewed, 15 had the required data for the six indicators under study. The countries were grouped into two clusters, the first consisting of eight countries whose percentage of GDP for Research and Development (R&D) is greater than 0.2%. In the second cluster there are seven countries with percentages of GDP for Research and Development (IPIBI &D) below 0.2% (Table 3). Fig. 1 shows the distribution of countries in the quadrants of ratio of IPIBI&D to %GDP in education (IPIBEDU), Universities by population (IUNIPOB) and the Global Innovation Index (OGIIRAN). The upper quadrants correspond to countries in Cluster 1 and the lower quadrants to Cluster 2. Three analyses were conducted per cluster, corresponding to the efficiency of the countries in using the three inputs with respect to each output variable.

2.2. Efficiency Measurement and Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is an application of linear programming methods, used to measure the relative efficiency of organizational units that have the same goals and objectives. This technique was initially developed by Charnes, Coopers and Rhodes [16], who based it on a preliminary work by Farrell (1957) [17]. The units of analysis in the DEA are called decision making units (DMU) and, for the purposes of this paper, each country represents a single DMU.

The application of DEA requires the selection of input and output variables. Indicators were selected from each country on the percentage contribution of GDP in Education and Research and Development (see Table 1). As output variables, indicators on ICT exports and High Tech were collected, in addition to the Global Innovation Indicator (see Table 2). The rule [18][19] was applied to ensure that the total number of variables (n) and units (DMU) were appropriate, with p being the number of input variables and q the number of output variables.

Table 1. Input Variables for Efficiency Analysis.

Tag	Variable	Description	Source	Year
IPIBEDU	Public spending on education as % of GDP	Current and capital expenses for education by local, regional and national government. The proportion of public spending devoted to education makes it possible to assess the emphasis of government policies on education in relation to the perceived value of other public investments. It also reflects a government's commitment to invest in human capital development.	ECLAC [11]	2003-2018
IPIBI&D	Spending on research and development (% of GDP)	Gross domestic expenditures on research and development (R&D), expressed as a percent of GDP. They include both capital and current expenditures in the four main sectors: Business enterprise, Government, Higher education and Private non-profit. R&D covers basic research, applied research, and experimental development. Research and development expenses are current and capital (public and private) expenditures on creative work undertaken systematically to increase knowledge, including knowledge about humanity, culture and society, and the use of knowledge for new applications.	World Bank [10] World Development Indicators database.	2013-2016
IUNIPOB	Indicator that relates the number of Higher Education Institutions (UNIV) to the country's population (POB).	Indicator obtained by dividing the number of Higher Education Institutions by the total population of the country, multiplied by 105. Number of Higher Education Institutions. Total population.	Webometrics World Ranking (Spanish National Research Council, Spain) [12]. World Bank [13].	2019 2017

Table 2. Output variables for efficiency analysis.

Tag	Variable	Description	Source	Year
OHTEXP	High-technology exports (% of manufactured exports)	High-technology exports are products with high R&D intensity, such as in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery.	World Bank [14].	2018
OTICEXP	ICT services exports (% of services exports, balance of payments)	Exports of information and communication technology services include communications and computer services (telecommunications and postal and courier services) and information services (electronic data and service operations relating to the transmission of news).	World Bank [15].	2017
OGIIRAN	Global Innovation Index rankings	The Global Innovation Index provides detailed indicators of innovation performance in 127 countries and economies worldwide using 81 indicators grouped into the dimensions: Institutions, Human capital & research, Infrastructure, Market sophistication, Business sophistication, Knowledge & technology outputs and Creative outputs.	World Intellectual Property Organization (WIPO) [9].	2017

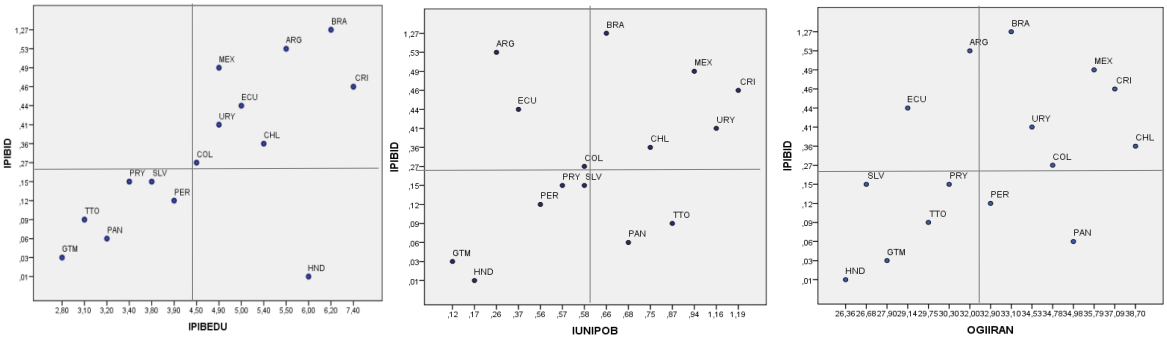
Table 3. Selected countries and formation of the two analysis clusters.

		Inputs			Outputs		
	Country	IUNIPOB	IPIBEDU	IPIBI&D	OTICEXP	OHTEXP	OGIIRAN
Cluster 1 PIB I&D >= 0,2%	BRA	0,66	6,2	1,27	6,34	13	33,1
	ARG	0,26	5,5	0,53	13,23	5,3	32
	MEX	0,94	4,9	0,49	0,29	21	35,79
	CRI	1,19	7,4	0,46	14,64	18,5	37,09
	ECU	0,37	5	0,44	1,93	5,3	29,14
	URY	1,16	4,9	0,41	7,55	7,2	34,53
	CHL	0,75	5,4	0,36	3,45	6,4	38,7
	COL	0,58	4,5	0,27	4,07	7,3	34,78
Cluster 2 PIB I&D < 0,2%	PRY	0,57	3,4	0,15	1,38	9,7	30,3
	SLV	0,58	3,8	0,15	8,00	6,1	26,68
	PER	0,56	3,9	0,12	2,11	4,6	32,9
	TTO	0,87	3,1	0,09	1,47	0,1	29,75
	PAN	0,68	3,2	0,06	2,21	9,2	34,98
	GTM	0,12	2,8	0,03	8,85	5,3	27,9
	HND	0,17	6	0,01	9,54	3,1	26,36

The BCC optimization mode (Banker, Charnes and Cooper, 1984) [20] with variable returns was applied to the efficiency analysis, aimed at maximizing output, that is, maximizing exports of technological services and positioning in the innovation index given the inputs. This optimization mode is flexible, imposing minimum conditions to the production function, assuming the hypothesis of variable returns to scale, with which a measure of Pure Technical Efficiency will be obtained. For the efficiency analysis the Analyst Frontier® by Banxia software was used.

2.3. Results

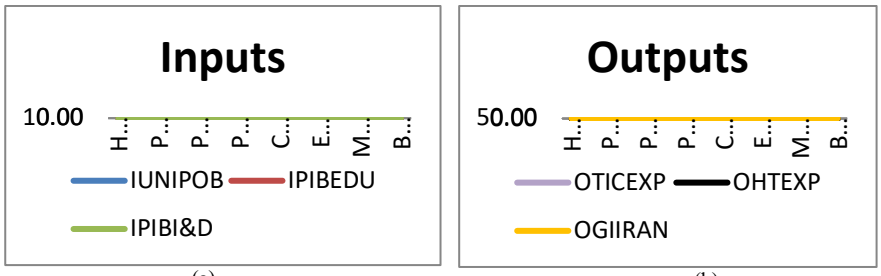
First, prior to the efficiency analysis, the countries under study are characterized. Fig. 1 shows groups that can be differentiated according to the investment they make in research and development, giving rise to the two clusters analyzed in this paper, in order to apply the efficiency analysis with groups of units (countries) that are homogeneous among themselves. On the other hand, a significant correlation (0.605 Pearson) is observed between contributions to R&D (IPIBID) and to education (IPIBEDU) (Fig.1.a). Additionally, Brazil, Mexico, Costa Rica, Chile, Uruguay and Colombia stand out in the upper right quadrant, showing a relationship between R&D contributions and the proportion of universities/population, as well as with the Global Innovation Index.



(a) (b) (c)

Fig.1. Representation in quadrants of the percentage contribution to R&D of Latin American countries with respect to (a) %GDP contribution to Education, (b) Universities according to the population of the country, and (c) Global Innovation Index.

Regarding the variables Inputs and Outputs by country (see Fig.2), Brazil is the only Latin American country with a %GDP for R&D higher than 1%, however, exports in ICT and HT are not the highest in the region. Costa Rica, Brazil, Chile, Argentina, and Honduras stand out for their contributions to Education above 5% of GDP. With respect to the Global Innovation Index, Chile and Costa Rica lead this Latin American ranking.



(a) (b)

Fig.2. **Input and Outputs** of the Latin American countries analyzed**.**

Regarding Pearson's correlations, within each cluster (see Table 5), significant differences are observed in the behavior of the variables in both groups of countries. In cluster 1, there are significant positive correlations between IPIBEDU and OTICEXP (0.695), IUNIPOB and OHTEXP (0.603), IUNIPOB and OGIIRAN (0.659). In the second cluster, there are important negative correlations between OTICEXP and OGIIRAN (-0.786), OTICEXP and IUNIPOB (-0.807), and a positive correlation between IUNIPOB and IPIBID (0.602).

Table 4. Pearson's Correlation of Inputs and Outputs.

Cluster		IPIBEDU	IPIBID	OTICEXP	OHTEXP	OGIIRAN	IUNIPOB
1	IPIBEDU	1	,397	,695	,463	,261	,346
	IPIBID	,397	1	,089	,241	-,242	-,102
	OTICEXP	,695	,089	1	,023	,069	,137
	OHTEXP	,463	,241	,023	1	,408	,603
	OGIIRAN	,261	-,242	,069	,408	1	,659
	IUNIPOB	,346	-,102	,137	,603	,659	1
2	IPIBEDU	1	-,334	,469	-,247	-,419	-,423
	IPIBID	-,334	1	-,501	,312	,157	,602
	OTICEXP	,469	-,501	1	-,182	-,786*	-,807*
	OHTEXP	-,247	,312	-,182	1	,395	-,032
	OGIIRAN	-,419	,157	-,786*	,395	1	,527
	IUNIPOB	-,423	,602	-,807*	-,032	,527	1

* Correlation is significant at the 0.05 level (2-tailed).

Second, the results of the efficiency analysis of the countries within each cluster, in addition to the contributions of the efficiency inputs, are reported below. Table 6 shows that Argentina, Ecuador, Colombia, Honduras and Guatemala are the countries that were one hundred percent efficient in the three analyses carried out in each cluster. In addition, in Cluster 1, Mexico showed efficiency in HT exports and Costa Rica in ICT services exports, which coincides with the WTO's 2016 report [4]. Chile also corroborates its efficiency and leadership in innovation. With respect to Cluster 2, Panama is efficient in HT exports and confirms its high performance in innovation. Paraguay is efficient in HT exports.

Table 5. Efficiency of the countries in each cluster, with respect to the use of inputs in each output variable *.

Country	OTICEXP	OHTEXP	OGIIRAN
BRA	46%	90%	89%
ARG	100%	100%	100%
MEX	4%	100%	98%
CRI	100%	96%	96%
ECU	100%	100%	100%
URY	98%	45%	95%
CHL	42%	49%	100%
COL	100%	100%	100%
average efficiency	74%	85%	97%

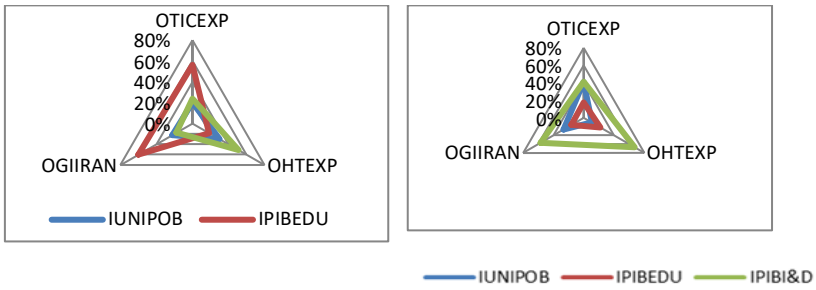
(a) Cluster 1

Country	OTICEXP	OHTEXP	OGIIRAN
HND	100%	100%	100%
GTM	100%	100%	100%
PAN	25%	100%	100%
TTO	17%	1%	90%
PER	23%	50%	99%
SLV	88%	63%	79%
PRY	15%	100%	90%
average efficiency	53%	73%	94%

(b) Cluster 2

* Those countries whose results indicate that they are 100% efficient have been highlighted in all three analyses.

Finally, Figure 3 presents the contributions of the resulting inputs from 100% efficient countries, with respect to each of the output variables.



(a) Cluster 1 (b) Cluster 2

Fig. 3. Contribution of 100% efficient country inputs in each cluster, with respect to exports and the innovation index.

In both clusters, it can be seen that the %GDP for research and development is the main input that contributes to high-technology exports. With respect to ICT exports and positioning in Innovation, differences in the contributions of the inputs can be seen.

3. Conclusions

Technical efficiency was analyzed using the DEA method in fifteen Latin American countries for six indicators on research and development, education, science and technology, and innovation. As inputs, the percentage of GDP contributed to education and research and development expenditure was considered, as well as an indicator on the number of universities in relation to the country's population. High-technology exports, ICT services exports and the Global Innovation Index were considered as outputs. Latin American countries present different performances in the two clusters designed for the analysis, based on the contribution of the GDP for research and development expenses, being this the main input that contributes with the High-technology exports in the studied Latin American countries. However, divergences were found regarding the efficiencies for ICT exports and the positioning in Innovation. With respect to the efficiency of the countries, Argentina, Ecuador, Colombia, Honduras and Guatemala were one hundred percent efficient in the three analyses conducted in each cluster.

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