Challenges in innovation management for Latin America and the Caribbean: an efficiency analysis

José G. Aguilar-Barceló and Fernanda Higuera-Cota

Abstract

Applying data envelopment analysis (DEA) to data from the 2016 Global Innovation Index (GII) (Cornell University/INSEAD/WIPO, 2016), the paper evaluates the efficiency of 19 Latin American and Caribbean economies in creating innovation-friendly environments. Where the region performs best is on infrastructure and adaptation of information and communication technologies (ICTs), but there are problems with human capital formation, the conduct and impact of research, and institutional aspects. The output of countries such as Chile and Colombia proved lower than expected given their factors, meaning that their strong innovation results are not matched by their efficiency management. Enhancing market functioning (competition, credit and investment) and knowledge absorption capacities is among the main challenges for the region.

Keywords

Innovations, evaluation, statistical data, human resources, technological change, competitiveness, statistical methodology, Latin America and the Caribbean

JEL classification

O32, D24, F63

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I. Introduction

In the past, countries' socioeconomic development and growth were considered to depend mainly on their capital and labour endowments, while other less tangible resources, such as levels of information and training, were treated as external factors influencing market behaviour only indirectly. Over time, however, the idea that knowledge management is a determinant of productivity in both modern and traditional economies has increasingly taken hold (Cañibano, 2005). According to this new holistic conception, more and more jobs need to centre on the development of innovative ideas that can be applied to products, services and processes.

Support for innovation, understood as the ability to generate, obtain, adapt and use new knowledge to achieve sustainable competitive advantages that accumulate over time (OECD/Eurostat, 2005), is provided for in the development plans of all first world countries where innovation policy has been strengthened as a key element in industrial policy.[1] Although Latin America and the Caribbean has a long tradition of science and technology development policies and has increasingly invested in innovation (Bárcena, 2008), the region is not finding it easy to reverse its deficit in this area by strengthening innovation policy.[2] Among other explanations, this is because the countries making up the region face challenges typical of emerging economies, such as failures of coordination between firms, high levels of corruption and informality, a shortage of skilled human capital and the limited ability of governments to act (Navarro and Olivari, 2016), which reduces the effectiveness of public policy implementation.

According to the Inter-American Development Bank (IDB), in 2016 the economies of Latin America and the Caribbean presented a large deficit in the incorporation of knowledge and technology into their production processes. This is why it is so important to analyse and understand the market failures that have resulted in investment in innovation being inadequate and its implementation unsystematic and intermittent, leaving it well below socially desirable levels. An added challenge is to find ways of measuring the efficiency of policies aimed at generating innovative environments and quantifying them in terms of economic returns.

The Organization for Economic Cooperation and Development (OECD) points out that reliably estimating innovation capacity is essential for the proper design of public policies and stresses that current measurements do not fully reflect the role it plays in today's economy (OECD, 2012). Against this backdrop, the present study focuses on analysing the way input endowments are used to create innovation-friendly environments in the countries of Latin America and the Caribbean, by measuring returns. It presents an alternative view of innovation management in the context of its most important aggregate indicators, as the individual results are linked to create regional benchmarks. The hypothesis to be contrasted is that in the countries of Latin America and the Caribbean it is not always true that a higher level of innovation inputs denotes a sounder economy with greater development potential, translating into more and better innovation outputs, with the result that an invaluable opportunity to reduce the gap with developed countries is being missed.

The aim here is to measure efficiency in innovation management through the statistical analysis of a number of observable variables obtained from the 2016 Global Innovation Index. This index provides an annual ranking of the world's major economies in terms of innovation performance and its impact on development. The economies included in the index represent 92.8% of the world population and 97.9% of world GDP.

The article is organized into six sections, including this introduction. Section II describes the theoretical framework used to outline the international innovation and efficiency landscape and presents

[1] Innovation policy can be understood as an amalgam of science and technology policy and industrial policy (OECD/Eurostat, 2005).

[2] According to Bárcena (2008), public spending on research and development (R&D) grew by about 40% in the region between 1990 and 2003.

the main challenges for developing countries in creating and capitalizing on innovation environments. Section III explains the variables and how they work, while section IV describes the methodology used. Section V interprets and discusses the results from the statistical analysis. Lastly, section VI sets out the main conclusions and future lines of work.

II. The theoretical framework

1. Clarification of some basic innovation and efficiency concepts

According to the European Commission (1995), innovation is the use of knowledge to turn an idea into a new or improved product, service or manufacturing or distribution procedure. It is therefore clear that innovation is particularly relevant to the development and competitiveness of emerging economies. OECD (2012) describes how innovation can make the difference in addressing the challenges faced by these economies, such as disease eradication, poverty alleviation and public insecurity, or technology transfer and adaptation to modernize production.

Different explanations have been proposed over the last century with a view to better understanding innovation, especially when conceived as a process. The main ones include the technology-push model, which encompasses the innovation process, originating in science and technology, right through to the commercialization of an economically viable good or process (Rothwell, 1994). Emphasis on the role of the market as a source of innovative ideas and a determinant of the course of R&D led later to the design of the demand-pull model. For Saren (1984), who adopts another perspective, the innovation process, from the time an idea becomes an innovation input until this input becomes a product, occurs in stages in terms of the functioning of the departments of a firm.

Another way of explaining innovation is the chain-linked model, in which different paths, based on information and knowledge, connect the three major areas in the technological innovation process (research, knowledge and the central chain of the technological innovation process), with success requiring interaction between technological capabilities and market needs (Kline and Rosenberg, 1986). Lastly, the triple helix model of Etzkowitz and Leydesdorff (2000) is the most complete of those described, as it deals with the role of the firm, the State-government and the academic sector as a whole.[3] The triple helix is considered to be a spiral model of innovation because it captures different relationships at multiple points in the knowledge capitalization process.

According to Restrepo and Villegas (2007), any production process involves the use of resources to turn inputs into outputs so as to meet certain needs. This results in a number of terms used in the resource management and administration debate that serve to establish parameters for the formulation and implementation of public policies, such as productivity, effectiveness and efficiency. Productivity can be defined as the relationship between the amount of goods produced and resources used (Carro and González, 2015). It is a tool for assessing the yield of the factors forming a society, country, organization or individual. Effectiveness is the virtue of achieving the expected results, which does not necessarily mean maximizing the productive capacity of inputs. In contrast to this concept, efficiency does imply the maximization of profit or the minimization of costs, which means obtaining more outputs with a minimum of inputs, or, in other words, ensuring that the means employed are correctly distributed in relation to the ends (Quindós, Rubiera and Vicente, 2003).[4]

[3] Quadruple helix innovation models, which add society to the triple helix components, have begun to be implemented.

[4] Restrepo and Villegas (2007) argue that the terms “productivity” and “efficiency” have traditionally been used interchangeably to measure the performance of production processes.

2. Creating innovation environments and assessing their economic returns

According to this resources and capabilities approach, an innovation system must be made up of the different public and private actors, bringing together the best technical, commercial and financial capabilities and inputs in order to foster a favourable environment. The government will always be one of these actors. Its role as implementer of a potentially efficient innovation policy goes beyond the design of regulations in this area and oversight of their implementation. It should also act as a facilitator in coordinating and operationalizing innovation initiatives and commit itself to building a receptive and creative population (World Bank, 2010).

For Guimón (2004), R&D plays a key role in the performance of a country's different industrial sectors, including the more traditional ones (such as agriculture). The author emphasizes that not only must new knowledge be pursued, but it is also necessary to create environments and develop capabilities that allow it to be absorbed. That is where the role of governments is crucial.

The World Intellectual Property Organization (WIPO) (Cornell University/INSEAD/WIPO, 2016) argues that a government can intervene in two ways to correct the problem of low private investment in R&D: explicitly, by investing in sectors considered crucial for economic development, or implicitly, by structuring policies that facilitate the creation of innovation-friendly environments. Likewise, OECD (2012) stresses that innovation is not only about generating high-technology products or increasing learning capabilities, but also involves seeking ways to maximize the use of technologies such as ICTs, as these are vital for disseminating knowledge and overcoming technological barriers.

Given limited resources, there is no single process for determining which elements to consider in order to correctly assess the economic returns on innovation. Use is generally made of output indicators, also known as "innovation outputs", and to a lesser extent of indicators associated with the factors conducive to innovation. For Atilano, Mercado and Casanova (2015), research outputs are the parameters that serve to establish a baseline for evaluating the process itself, via comparison with the expected results.

For the COTEC Foundation (2001), innovation requires investments in tangible and intangible assets that can increase economic growth in two ways: via a change in production structures (an increase in the innovation effort and recomposition of technology spending) and via an intensive multiplier effect in specific areas that may present a technological deficit or represent a strategic opportunity. From this it may be inferred that numerous indicators can be used to measure the economic returns on innovation, whose composition shows differences of degree and class.[5]

3. Innovation challenges for developing countries

Bogliacino and others (2009) argue that innovation is pushed by industrialization and pulled by growth of markets. For innovation to have its greatest social impact, however, research efforts must be directed towards finding solutions to the problems of the neediest populations and increasing their well-being, a task that must undoubtedly involve both private and public entities (World Bank, 2010).

Innovation involves different processes depending on whether a country is developed or developing (Bogliacino and others, 2009). Strategies to encourage innovation in high-income economies often include creating the conditions for factor mobility in markets, trade openness and investment.[6] This

[5] From the perspective of the Global Competitiveness Index, the measurement of innovation is related to the technological capabilities of firms, public investment in innovation, the quality of scientific research institutions and collaboration between firms and universities (Schwab, 2016).

[6] Factor mobility in markets means the adaptability of factors of production, especially labour.

could also apply to developing economies provided that procedures are adapted to local conditions and needs (Navarro and Olivari, 2016). However, emerging economies should emphasize knowledge management as a strategy for bridging the gap with the developed world.

In the case of developed countries, a strong R&D capacity and science and technology infrastructure are needed to acquire and, above all, develop the knowledge and skills required to operate at the technological frontier, while for developing countries technological change occurs through the acquisition of machinery and the imitation of products and processes previously developed in advanced economies.

III. Analysis of variables and indicators

1. The composition of the Global Innovation Index

The Global Innovation Index provides an annual ranking of 128 countries by their degree of innovation and the performance of their national innovation systems in the global economic context. The index aims to capture the multidimensional facets of innovation and to provide tools that can help adapt policies to promote productivity growth through the creation of an environment in which both the drivers of innovation and their outputs are constantly assessed.

This index comprises 21 indicators grouped into 7 pillars: 15 input indicators (conducive to innovation) and 6 output indicators (resulting from innovation) (see table 1).[7] It then presents four basic measures of innovation: (i) the input subindex, which averages out the scores of the five input pillars; (ii) the output subindex, which averages out the scores of the two output pillars; (iii) the overall index, which averages out the input and output subindices; and (iv) the efficiency ratio, which is the ratio between the output subindex and the input subindex.

Table 1
Composition of the Global Innovation Index (GII), 2016

Type of pillar	Pillar (identifier)	Pillar indicators
Input	Institutions (P1)	Political environment, regulatory environment and business environment.
	Human capital and research (P2)	Education, tertiary education and research and development (R&D).
	Infrastructure (P3)	Information and communication technologies (ICTs), general infrastructure and ecological sustainability.
	Market sophistication (P4)	Credit, investment, and trade, competition and market scale.
	Business sophistication (P5)	Knowledge workers, innovation linkages and knowledge absorption.
Output	Knowledge and technology (P6)	Knowledge creation, knowledge impact and knowledge diffusion.
	Creativity (P7)	Intangible assets, creative goods and services and online creativity.

Source: Prepared by the authors, on the basis of Cornell University/INSEAD/World Intellectual Property Organization (WIPO), *The Global Innovation Index 2016: Winning with Global Innovation*, Geneva, 2016.

The partial conception of the first two measures (the input and output subindices) clearly demonstrates their limitations in determining efficiency. For its part, the overall index treats input and output items in the same way (i.e., does not set them against each other), and although this means the level of the former is internalized, it does not contribute to an understanding of how they are used to obtain the latter, and thence of efficiency. Lastly, the efficiency ratio, while reflecting the differential between input and output items (treating the former as generating the latter), does not put this differential into perspective in terms of the performance of a group of similar countries.[8]

[7] The 21 indicators themselves are derived from 81 variables associated with innovation.

[8] In other words, it does not generate any information not arising from simple cross-sectional or temporal comparisons.

Because it is desirable for efficiency to be measured across similar units, this study is limited geographically to the Latin American and Caribbean countries. It is assumed, then, that the countries in this group share the economic and social problems associated with the development of innovation capacity, regardless of what are sometimes very substantial differences in income and human development levels, the type of political regime or patterns of innovation (Bogliacino and others, 2009).[9] The region is considered to have great unexplored potential for innovation, but also significant and latent short-term risks associated with inequality and social vulnerability.

A glance at the data from the 2016 Global Innovation Index shows that Chile topped Latin America and the Caribbean in the overall index and placed forty-fourth in the global ranking, followed by Costa Rica in both the regional and global tables.[10] Ranking sixty-first in the world, Mexico was the third best placed in the region. Table 2 shows the Latin America and Caribbean countries' scores and positions for the overall index, as well as the income categories, based on per capita GDP. The countries' efficiency ratios and rankings are also presented.

Table 2

Latin America and the Caribbean: innovation, income and efficiency indicators according to the Global Innovation Index (GII), 2016

Country (abbreviation)	Overall index (1)	Rank for overall index (1)	Income category (based on per capita GDP) (2)	Rank for income category (2)	Efficiency ratio (3)	Rank for efficiency ratio (3)
Argentina (AR)	30.24	81(10)	HI	48(2)	0.56	98(12)
Bolivia (Plurinational State of) (BO)	25.24	109(17)	LM	105(18)	0.59	89(9)
Brazil (BR)	33.19	69(7)	UM	66(9)	0.55	100(13)
Chile (CL)	58.41	44(1)	HI	40(4)	0.59	91(10)
Colombia (CO)	34.16	63(5)	UM	63(7)	0.56	96(11)
Costa Rica (CR)	38.40	45(2)	UM	54(5)	0.71	50(1)
Dominican Republic (DR)	30.55	76(9)	UM	70(11)	0.62	82(7)
Ecuador (EC)	27.11	100(14)	UM	82(14)	0.60	87(8)
El Salvador (ES)	26.56	104(16)	LM	101(17)	0.48	113(17)
Guatemala (GT)	27.30	97(13)	LM	97(15)	0.62	79(5)
Honduras (HN)	26.94	101(15)	LM	98(16)	0.53	105(15)
Jamaica (JM)	28.97	89(11)	UM	77(12)	0.53	104(14)
Mexico (MX)	34.56	61(3)	UM	63(6)	0.63	76(3)
Nicaragua (NI)	23.06	116(18)	LM	102(19)	0.41	120(19)
Panama (PA)	33.49	68(6)	UM	65(8)	0.66	61(2)
Paraguay (PY)	28.20	94(12)	UM	81(13)	0.62	77(4)
Peru (PE)	32.51	71(8)	UM	68(10)	0.51	109(16)
Uruguay (UR)	34.28	62(4)	HI	45(1)	0.62	81(6)
Venezuela (Bolivarian Republic of) (VE)	22.32	120(19)	-	49(3)	0.46	114(18)

Source: Prepared by the authors, on the basis of Cornell University/INSEAD/World Intellectual Property Organization (WIPO), *The Global Innovation Index 2016: Winning with Global Innovation*, Geneva, 2016.

Note: LM: lower-middle income; UM: upper-middle income; HI: high income. In columns 3, 5 and 7, the first value is the country's global ranking and the second (in brackets) its position relative to the other countries of Latin America and the Caribbean.

Overall, the correlation between the income classification and the efficiency ratio is 29.84%, while the correlation between income and the overall index is 68.81% (see table 2). This suggests that there is a very strong association between the population's income level and the level of inputs for innovation (which weigh heavily in the overall index). The relationship between the efficiency with which

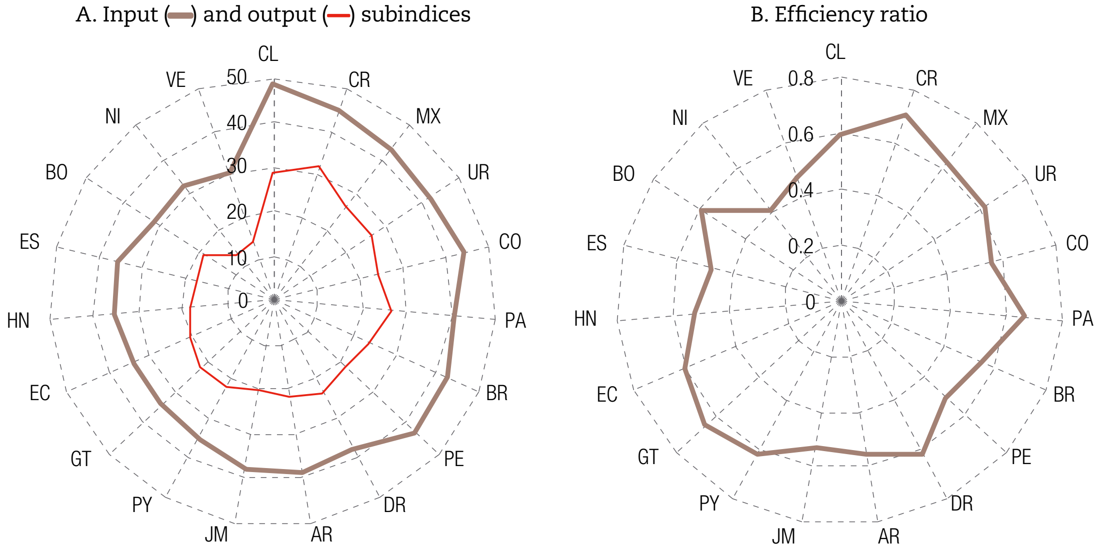
[9] This treatment of the information is justified at the end of section IV.

[10] Switzerland ranked first in the world, followed by Sweden and the United Kingdom.

these inputs are used and the level of wealth in the economy is not as strong, however. For example, economies such as the Bolivarian Republic of Venezuela, Ecuador, Guatemala, Panama, Paraguay and the Plurinational State of Bolivia ranked higher on input use (efficiency ratio) than in the overall index, both globally and regionally.

Figure 1 shows a set of radial shapes representing different measures of the Global Innovation Index associated with the creation of innovation-friendly environments. According to these data, not only is the average innovation output score much lower than the input score, but there is a notable lack of parallelism between the spirals forming the two scores in terms of countries.[11]

Figure 1
Latin America and the Caribbean: radial representations of different measures in the Global Innovation Index (GII)



Source: Prepared by the authors, on the basis of Cornell University/INSEAD/World Intellectual Property Organization (WIPO), *The Global Innovation Index 2016: Winning with Global Innovation*, Geneva, 2016.
Note: The countries are presented in descending order of their positions in the overall index, with Chile (CL) in first place. The nomenclature used in this chart is explained in table 2.

The Bolivarian Republic of Venezuela and the Plurinational State of Bolivia, even allowing for the fact that they are at the bottom of the overall index for Latin America and the Caribbean, have input subindex scores below what would be expected in a downward-trending spiral. In Brazil, Chile, Colombia, El Salvador and Peru, on the other hand, the level of outputs does not match the endowment of inputs (see figure 1.A), so that none of these countries manages better than tenth place in the efficiency ratio (see table 2).

In addition, a marked variability was found in the positions of the economies, measured as the difference between the position they occupy for an indicator and their position in the overall index. Notably, 22.44% of the positions of the Latin American and Caribbean countries for the different input indicators were worse than that of the hundredth-placed economy in the world and 17.21% were better than that of the fiftieth economy. When innovation outputs are reviewed, however, it is observed that 28.91% of the results were below the hundredth economy in the world and only 8.77% were in the top 50. This shows that the relative position of indicators worsens in Latin America and the Caribbean when outputs are looked at instead of inputs.

[11] It may be mentioned that the difference in scores is not as marked in some other regions of the world.

2. The relationship between inputs and outputs in the countries of Latin America and the Caribbean[12]

On the face of it, a positive relationship would be expected between the scores of the input and output indicators for the group of countries treated, and this is generally borne out.[13] The evidence shows a positive "one to one" correlation between the three indicators of the institutional pillar and the six output indicators.[14] The countries with the strongest presence at the efficient frontiers are Brazil (middle), Costa Rica (upper-middle) and Chile (high), all these being above the income average for Latin America and the Caribbean.[15]

There is also a positive (although in some cases incipient) correlation between the levels of human capital and research inputs and each of the outputs, except in the case of tertiary education and R&D and the generation of intangible assets, when it is negative. This is a cause for concern, as it shows that investment in higher education and research in Latin America and the Caribbean is not resulting in adequate development of the region's intellectual capital or in the creation of value from its trademarks, designs or patents.[16] The countries that usually form the frontier in these relationships are, once again, Brazil (lower-middle), Costa Rica (upper-middle) and Chile (high). Brazil is an outlier in that it has the worst tertiary education indicator in the region and one of the highest levels of knowledge creation and impact. By contrast with Latin America and the Caribbean, in Europe there is a positive relationship between tertiary education and intangible assets. The foregoing shows that high levels of inputs will not be sufficient to reduce the economic and social gaps between Latin America and the Caribbean and other regions of the world.

At the same time, there is a positive correlation between all elements of the infrastructure pillar and each of the outputs. The countries with the greatest presence at the efficient frontier are Guatemala (lower-middle), Costa Rica (upper-middle), Colombia (high) and Chile (high). In the area of ICTs, Costa Rica is a singular case, appearing below the trend line for four of the outputs, although for the rest it forms part of the efficient frontier. Also striking is the way Panama, with the best infrastructure indicator in Latin America and the Caribbean, performs only modestly because of its low output levels. Guatemala is in the opposite situation, since it has the worst infrastructure indicator but manages to position itself at the efficient frontiers, even without outstanding output levels.

The indicators of the market sophistication pillar are those that show the fewest positive relationships when transposed with outputs (55.56% positive correlations). Thus, investment is the input that has the least impact on the development of innovation in Latin America and the Caribbean, although the contribution of credit to knowledge creation and diffusion, and to online creativity, is also unclear.[17] The countries that usually form the frontier are Costa Rica (upper-middle), Chile (high) and Colombia (high). Mexico is below the trend line for three of the six outputs when it comes to trade, competition and market scale, an indicator for which it ranks first in Latin America and the Caribbean. Peru and the Plurinational State of Bolivia, meanwhile, have the highest levels for the credit factor, but are far below the levels of output needed to form part of the efficient frontier.

[12] It should be borne in mind that the output and input figures are for the same time period.

[13] There is actually a correlation of 40.92% between the level of inputs and the efficiency ratio, partially bearing out this conjecture.

[14] The construction of the efficient frontiers referred to in this subsection also needs to be understood in these terms.

[15] The lower part of the efficient frontier is excluded from the analysis because it is associated with incipient input values.

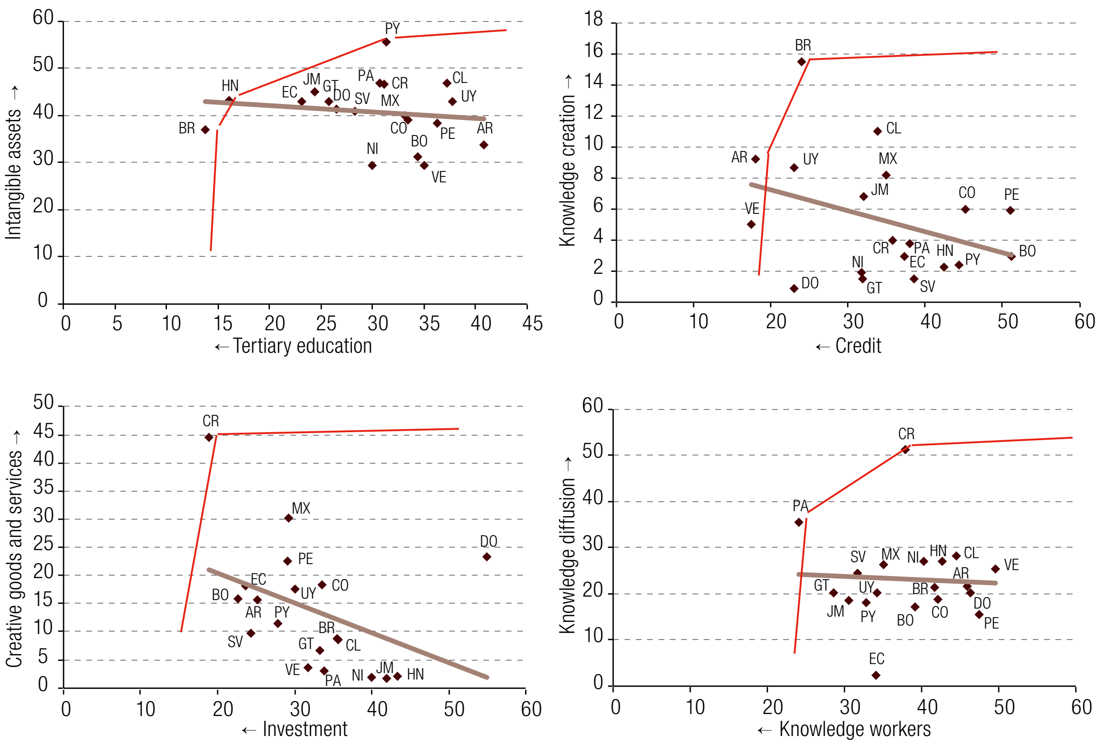
[16] In Europe, there is a positive relationship between these inputs and intangible assets. Even North Africa and Asia show a modestly positive correlation between these indicators (although in this case the relationships with most of the other outputs are not positive).

[17] In contrast to the situation in Latin America and the Caribbean, in Europe there is a positive relationship between the investment input and outputs, with the exception of knowledge impact.

As regards business sophistication, although knowledge absorption is positively associated with all outputs, in the case of knowledge workers and innovation links this sign is observed with only three of them. This behaviour could prove peculiar to Latin America and the Caribbean in relation to that pillar if it is shown that the absorption of knowledge (understood as an input) is being used as a development option because of the weakness of other inputs for this purpose. The countries that usually form the border are Chile (high), Costa Rica (high) and Uruguay (high).

Lastly, it is important to note that the negative relationships between the entry and exit indicators give rise to doubts as to whether the former really cause the latter. Around 25% of the individual relationships between these pillars showed a negative trend for Latin America and the Caribbean (see figure 2).

Figure 2
Some relationships between inputs and outputs with a negative trend



Source: Prepared by the authors, on the basis of Cornell University/INSEAD/World Intellectual Property Organization (WIPO), *The Global Innovation Index 2016: Winning with Global Innovation,* Geneva, 2016.

Note: The dashed lines represent a hypothetical efficient frontier between the variables depicted, premised on "more outputs with less inputs". The unbroken lines show the trend of the data.

IV. Methodology

Measuring efficiency means evaluating the performance of multiple indicators for an organization in search of an optimum (Álvarez, 2001). Setting out from this premise, one approach to ascertaining the level of efficiency would be to compare what the decision-making unit does with what it ought to have done to maximize its profit. However, it is unlikely that full information will be available on the context in which the decision-making units operate and, therefore, on what the maximum potential profit of each is. The best way of remedying this lack of information is to make a comparison between the decision-making unit concerned and the best-performing units with similar characteristics to the unit in question.

Setting out from the above definition of efficiency, it is important to look more closely at the distinction between technical and allocative efficiency. The former is achieved when it is technologically impossible to increase some output or reduce some input at the expense of another (Pareto optimality), while the latter (also called “price efficiency”) means minimizing the waste of resources (Navarro and Torres, 2006), which is equivalent to choosing the cheapest option among the efficient input-output combinations. Since this study assumes that agents have asymmetrical information and a degree of risk aversion, it will focus on the analysis of technical efficiency.

The data envelopment analysis method can be used to study the relative individual efficiency of a set of production units in relation to the behaviour of similar units, starting from the construction of an efficient frontier (real and not ideal, relative and not absolute). This is done through non-parametric approaches that accommodate assumptions about production technology priorities and achievable production plans (Martínez, de Miguel and Murias, 2005; Restrepo and Villegas, 2007). According to Quindós, Rubiera and Vicente (2003), the data envelopment analysis method has two strengths: its degree of standardization and the ability to work with multiple inputs and outputs.

This study will make use of elements of both the Banker-Charnes-Cooper (BCC) data envelopment analysis model, which is output-oriented, and the original input-oriented Charnes-Cooper-Rhodes (CCR) version (Banker and others, 1990). However, the second method will be given greater weight because it can be used to identify differences in the production scales of decision-making units, because its modelling presents fewer restrictions and because it is more helpful when the processes and mechanisms whereby inputs are transformed into outputs are not explicit, as in this case.

In a traditional efficiency estimation context, data envelopment analysis suggests that, setting out from a production process in which p inputs $(x_1, x_2, \ldots, x_p)$ are used to produce q outputs $(y_1, y_2, \ldots, y_q)$ and in which n production units participate, the technical efficiency of a given unit 0 can be estimated from the following expression:

$$max_{u_r, v_i} \frac{\hat{A}^{q}_{r=1} u_r y_{r0}}{\hat{A}^{p}_{i=1} v_i x_{i0}}$$

subject to

$$\frac{\sum_{r=1}^{q} u_r y_{rj}}{\sum_{i=1}^{p} v_i x_{ij}} \leq 1$$

where , j=1, …, n, r= 1, …, q and i=1, …, p. Furthermore, u_i, $v_i \geq e$, where e represents a value that is infinitesimally small but greater than zero. The underlying idea is to maximize a kind of total factor productivity index (units of output produced for each unit of input used) for each decision-making unit. The numerator of the index summarizes all the outputs in a single virtual output in the same way as in the denominator, where a single virtual input captures all the factors employed in the production process. What is used for these aggregates is not a conventional pricing system but a set of weights $(u_1, \ldots, u_q, v_1, \ldots, v_p)$, whose value is to be sought, such that they maximize the ratio for each decision-making unit while keeping the ratios of the others below 1.

In addition to this basic result, the data envelopment analysis provides additional information such as virtual inputs and outputs, i.e., the contribution of each factor to the efficiency index estimated, or the levels of inputs and outputs that would make an inefficient unit efficient. One of the main attractions of this technique is that it makes it possible to balance the objective and subjective elements of the aspect to be investigated, facilitating identification of the strengths and weaknesses of each of the decision-making units being compared.

Data envelopment analysis has been used to measure and compare efficiency in sectors considered critical to countries' development, such as education, banking, health and innovation. In recent decades, new applications of this analysis have emerged in contexts other than that of production as such, and these are particularly relevant to regional analysis of development. Examples are the estimation of the social welfare and quality of life index (Hashimoto and Kodama, 1997) and the province-level index of economic well-being (Martínez, de Miguel and Murias, 2005).

However, the method also presents limitations and risks. One of the main disadvantages of data envelopment analysis lies in the challenge of adequately defining inputs and outputs (in the present paper this definition is based on an external classification). It also tends to be difficult to meet the requirement of homogeneity between the units being analysed and the uses they make of their inputs and outputs. This article will assume a priori that outputs are associated with levels of inputs and that decisions by the decision-making units (countries) about the latter have a short-term impact on the levels of the former. It is also important to mention that the inputs considered are associated with tangible and intangible costs to national economies, the financing of which represents an opportunity cost that is not considered in the analysis.

At the same time, the scale and quality of innovation outputs are partially determined by the specific regional structure of the units of measurement and the differences between the sectors that compose them. While it is true that taking these differences into account makes the results scientifically more accurate (Broekel, Rogge and Brenner, 2018), it also requires a greater amount of data and knowledge about the relative performance of economies, with the risk of value judgements arising. Given the exploratory nature of this paper and the advantages the use of general measurements has in policy discussion, no weights are applied to differentiate sectors or units of measurement.

V. Results

1. Efficiency results

The aim, within an input-oriented framework involving calculation of how far inputs can be reduced while maintaining a given output level, is to find efficiency in the creation of an innovative environment in the countries of Latin America and the Caribbean. The difference between the greatest possible efficiency value (100%) and the value observed in a unit of measurement represents its degree of inefficiency (Coelli and others, 2003).[18] The closer the value is to its maximum, the closer the decision-making unit is to the efficient frontier. Table 3 presents the management efficiency results for the inputs of each pillar relative to the level of outputs they generate.

According to table 3, the pillars having the greatest number of countries with overall and scale inefficiencies are the institutional and market sophistication pillars. Although, as already noted, the latter exhibits a poor association with outputs, inefficiencies in institutional mechanisms, which are closely associated with them, do represent a wasted opportunity in the region's development.

In particular, the infrastructure pillar presents the highest average value in terms of overall technical efficiency and pure technical efficiency. Countries such as El Salvador, Honduras and Peru show inefficiencies in four pillars, while Chile and Nicaragua display inefficiencies in three pillars. Brazil, Costa Rica, Mexico and Panama are the only countries that do not present inefficiencies in any pillar. Meanwhile, Chile, Colombia and Honduras tend to show decreasing returns to scale, so their output

[18] Overall technical efficiency depends on the occurrence of pure technical efficiency (operational aspects) and scale technical efficiency (dimensional aspects). Scale technical efficiency is calculated from the ratio between overall technical efficiency and pure technical efficiency.

is lower than expected, while the Bolivarian Republic of Venezuela, El Salvador and Peru generally present above-optimum figures. Chile and Honduras are also the countries that most often show good operational performance, even with scale inefficiencies.[19]

Table 3
Efficiency results by pillar, 2016
(Percentages)

Pillar	Country[a]	Technical efficiency			Returns
		overall	pure	scale	
Institutional	Chile	95.05	100	95.05	Decreasing
	Dominican Republic	97.83	100	97.83	Decreasing
	El Salvador	68.02	71.13	95.63	Decreasing
	Honduras	97.50	100	97.50	Decreasing
	Jamaica	72.79	72.80	99.99	Increasing
	Nicaragua	65.40	67.76	96.52	Decreasing
	Peru	93.82	94.77	99.00	Increasing
	Uruguay	99.98	100	99.98	Decreasing
	Other countries	100	100	100	Constant
Human capital and research	Argentina	79.01	80.22	98.60	Increasing
	Bolivia (Plurinational State of)	72.02	73.58	97.88	Decreasing
	Honduras	68.49	100	68.49	Decreasing
	Paraguay	93.42	100	93.42	Decreasing
	Venezuela (Bolivarian Republic of)	53.97	55.66	96.96	Increasing
	Other countries	100	100	100	Constant
Infrastructure	Colombia	98.39	100	98.39	Decreasing
	Ecuador	99.81	100	99.81	Decreasing
	El Salvador	89.82	94.25	95.30	Increasing
	Peru	90.72	92.57	98.00	Increasing
	Venezuela (Bolivarian Republic of)	80.28	98.07	81.86	Increasing
	Other countries	100	100	100	Constant
Market sophistication	Chile	98.12	100	98.12	Decreasing
	Colombia	90.57	100	90.57	Decreasing
	El Salvador	80.16	95.82	83.66	Increasing
	Guatemala	82.21	84.44	97.36	Increasing
	Honduras	96.92	100	96.92	Increasing
	Nicaragua	68.08	93.87	72.53	Increasing
	Peru	77.44	81.63	94.87	Increasing
	Other countries	100	100	100	Constant
Business sophistication	Chile	96.70	100	96.70	Decreasing
	El Salvador	96.94	100	96.94	Increasing
	Honduras	86.20	88.09	97.85	Decreasing
	Nicaragua	81.82	88.35	92.60	Increasing
	Peru	89.74	92.59	96.93	Increasing
	Other countries	100	100	100	Constant

Source: Prepared by the authors.
[a] Only countries presenting some degree of overall technical inefficiency in each pillar are included.

Chile's good performance in pure efficiency terms clearly shows that its poor scores on some measures are due to its weight in the aspects of scale and returns. It is also for this reason that three of the four countries that do not display inefficiencies hold the top three positions in the region for the efficiency ratio (which is based on the type of returns), while those with inefficiencies in four pillars rank below fifteenth in the region for this indicator.

[19] Lastly, the economies with the worst overall efficiency levels were the Bolivarian Republic of Venezuela, El Salvador, Honduras and Nicaragua. This was primarily due to the weakness of their institutions and human capital formation.

2. Results for slack and relative contributions

Slack analysis shows the direction and magnitude of the adjustment required in the levels of the indicators in the decision-making units to turn a weakly efficient country into an efficient one. Output slack indicates a need for increased outputs, while input slack is a sign of excess inputs, to the extent suggested by the aggregate value of their indicators (Lo, Chien and Lin, 2001). Table 4 shows, for example, that Peru requires changes in its input and output indicators in four pillars to close up with the efficiency frontier.[20] Peru is followed by El Salvador and Nicaragua, which require changes in three pillars, and the Bolivarian Republic of Venezuela, which needs changes in two pillars.

Table 4
Slack results by pillar, 2016
(Percentages)

Pillar	Country	Input slack			Output slack					
		IP1	IP2	IP3	OP1	OP2	OP3	OP4	OP5	OP6
Institutional	El Salvador	3.30	17.63	-	2.42	3.00	0.14	-	-	2.01
	Jamaica	-	1.65	-	-	-	1.04	-	8.61	3.12
	Nicaragua	-	35.84	11.48	3.03	0.88	-	1.04	4.51	3.75
	Peru	-	15.49	-	1.07	2.23	8.95	-	-	-
Human capital and research	Argentina	-	-	1.75	-	11.16	-	7.95	-	-
	Bolivia (Plurinational State of)	1.90	-	-	-	-	-	11.39	0.50	2.02
	Venezuela (Bolivarian Republic of)	-	13.44	5.68	-	10.06	1.10	3.35	-	-
Infrastructure	El Salvador	15.86	-	-	0.46	21.50	-	1.92	-	0.44
	Peru	-	-	4.46	-	3.85	12.90	3.11	-	-
	Venezuela (Bolivarian Republic of)	11.49	-	-	-	17.86	-	13.67	-	-
Market sophistication	El Salvador	-	-	-	2.25	14.98	9.62	-	15.91	3.26
	Guatemala	-	-	-	5.88	-	3.92	-	13.75	13.65
	Nicaragua	-	0.87	-	1.80	5.43	-	7.05	2.61	1.72
	Peru	10.20	-	-	-	1.94	20.68	5.93	9.10	3.99
Business sophistication	Honduras	-	12.07	-	1.49	1.21	-	-	7.14	6.28
	Nicaragua	-	-	-	3.43	19.12	-	11.27	5.66	11.83
	Peru	5.71	-	-	1.12	3.55	3.70	-	-	0.30

Source: Prepared by the authors.
Note: The inputs represented by IP1, IP2 and IP3 differ depending on the pillar. For institutional, IP1: Political environment; IP2: Regulatory environment; IP3: Business environment. For human capital and research, IP1: Secondary education; IP2: Tertiary education; IP3: Research and development (R&D). For infrastructure, IP1: Information and communication technologies (ICTs); IP2: Infrastructure; IP3: Ecological sustainability. For market sophistication, IP1: Credit; IP2: Investment; IP3: Trade, competition and market scale. For business sophistication, IP1: Knowledge workers; IP2: Innovation links; IP3: Knowledge absorption. OP1: Knowledge creation; OP2: Knowledge impact; OP3: Knowledge diffusion; OP4: Intangible assets; OP5: Creative goods and services; OP6: Online creativity.

The output indicator that most often exhibits slack is knowledge impact, followed by online creativity (both of which had already been found to be somewhat decoupled from inputs such as credit). For the former, countries such as the Bolivarian Republic of Venezuela, El Salvador and Nicaragua need to achieve increases of about 20% in some cases. Peru has problems with knowledge diffusion. However, Nicaragua has the largest deficit in its output indicators, requiring adjustments in almost all of them.[21] These problems come on top of others already identified (e.g., with the generation of intangible assets) when the relationships between inputs and outputs were analysed, with some negative associations even being found. It should also be noted that levels of infrastructure, knowledge absorption and trade, competition and market scale are optimally employed to improve efficiency in the 19 countries of the region, which reinforces the conjecture that the region's main problems lie in the institutional and human capital and research aspects.

[20] The average results do not place Peru among the four worst-performing economies, however.

[21] It even presents a regulatory environment (institutional pillar) that is very unproductive for its level of output, as do El Salvador and Peru.

In contrast to the slack analysis, the relative contribution of the indicators points to a country's strengths and weaknesses in managing for certain objectives. A country that presents a relative advantage in an indicator will tend to get a greater contribution from it (Martínez and Murias, 2011). The business environment was found to be the indicator with the highest average contribution to innovation efficiency in Latin America and the Caribbean in the institutional area, while the regulatory environment was the input that contributed least to this objective within the institutional pillar.

Where human capital and research are concerned, secondary education was the indicator on which innovation efficiency primarily rested, while R&D was the input that contributed the least. In the case of the infrastructure pillar, ICTs were the indicator that made the greatest contribution, which is consistent with what Bárcena (2008) suggested, although Brazil and Colombia preferred to give more weight to infrastructure to make the most of their innovation potential, while the Bolivarian Republic of Venezuela, Costa Rica, Ecuador and El Salvador gave more weight to ecological sustainability.

The indicators of the market sophistication pillar contributed very equitably to the strengthening of innovation, averaging between 30% and 35% each in the countries of Latin America and the Caribbean. With regard to business sophistication, the knowledge workers indicator was the one on which the countries of the region relied most, while innovation links contributed least. This is evidence that the countries of the region are struggling to take advantage of the indicator with the greatest potential impact in the pillar (knowledge absorption) to increase the level of outputs.

3. International comparison

To situate Latin America and the Caribbean in the international context, table 5 shows the percentage differential between this region and the other regions of the world for each of the input and output pillars, in addition to the efficiency ratio. North America was found to have the largest positive differential with Latin America and the Caribbean for all pillars, which to some extent was predictable given that this region ranks first on 17 of the 21 indicators (Europe has the other top four positions).

Table 5
Differences in scores for the innovation pillars and efficiency ratio between the different world regions and Latin America and the Caribbean, 2016
(Percentages)

Region	P1	P2	P3	P4	P5	P6	P7	ER
North America	67.58	109.17	54.56	89.41	60.77	169.38	89.19	28.07
Europe	43.59	77.75	31.07	17.75	31.26	107.68	67.15	31.58
South-East Asia, East Asia and Oceania	31.68	63.52	26.76	34.59	34.87	99.34	43.66	24.56
North Africa and West Asia	14.21	21.80	10.61	-0.43	-12.54	33.89	10.08	10.53
Central Asia and South Asia	-6.54	-5.55	-12.76	-3.95	-16.22	10.12	-20.62	3.51
Sub-Saharan Africa	-0.96	-31.61	-29.72	-15.08	-10.43	1.77	-27.18	1.75

Source: Prepared by the authors, on the basis of Cornell University/INSEAD/World Intellectual Property Organization (WIPO), *The Global Innovation Index 2016: Winning with Global Innovation*, Geneva, 2016.
Note: The pillars are identified in table 1. ER: Efficiency ratio.

Table 5 is also very revealing because it shows that, according to the pillar scores, only the Central and South Asia and Sub-Saharan Africa regions have levels below those of Latin America and the Caribbean for most of the pillars and that no world region performs less well overall than Latin America and the Caribbean. Strikingly, no region scores as low as Latin America and the Caribbean for the knowledge and technology output pillar (P6), or even for the efficiency ratio.[22]

[22] The information in table 5 comes not from the efficiency analysis conducted in this study but from analysis of the data from the source cited using descriptive statistics.

VI. Conclusions

The countries of Latin America and the Caribbean are trying to adapt to the constant changes demanded by the world economy in quest of development, and innovation has become a key element in this. However, as Navarro and Olivari (2016) anticipated, many of these economies are lagging behind in the incorporation of knowledge and technology into their production processes because of impediments arising from the complexity of their social and economic contexts, which not only jeopardizes the attainment of development goals but increases the risk that the gap with the industrialized countries will be perpetuated and even widen over time.

Using data from the 2016 Global Innovation Index and applying the data envelopment analysis methodology, this paper assesses the efficiency of the 19 economies that make up the Latin American and Caribbean region when it comes to creating environments conducive to innovation. The intention is to identify the main challenges for these countries in the management and exploitation of what are usually understood as inputs available for this, irrespective of the income level of these economies. In fact, the countries with the highest income levels in Latin America and the Caribbean were not at the forefront of efficiency management, confirming that there is only a modest correlation between these variables.

Moreover, the countries that rank highest in the general efficiency index (Chile, Costa Rica and Mexico) or are at the regional efficiency frontiers (Brazil, Chile, Colombia, Costa Rica and Uruguay) do not always maintain this position when what is being evaluated is the use of inputs to achieve certain innovation outputs, especially given the presence of decreasing returns to scale for these economies, which prevents them from achieving better results as their inputs increase. This becomes evident when the leading positions of Chile and Colombia in the general index for Latin America and the Caribbean are contrasted with their positions in the bottom half of the table for the efficiency ratio.

The best performance in terms of overall technical efficiency and pure technical efficiency was in the infrastructure pillar. The worst average performance in overall technical efficiency was in the human capital and research pillar. The institutional pillar came out worst for pure technical efficiency and market sophistication for scale technical efficiency, which reveals difficulties with the development of financial markets and with trade and competition. At the same time, while most individual input-output ratios are positive in Latin America and the Caribbean (although less so than in other regions, such as North America and Europe), non-positive ratios tend to involve indicators such as tertiary education, R&D, credit and investment. This is worrying because these variables should be the basis for creating an environment conducive to innovative development. Nor do knowledge workers and innovation linkages appear to have a strong impact on innovation outputs, while skill constraints prevent knowledge absorption from being properly exploited to achieve efficiency outcomes.

The countries of Latin America and the Caribbean have a well-established tradition of scientific and technological development policies (OECD/Eurostat, 2005), and this has ultimately had an impact on the number of innovation support programmes implemented and the level of participation by the different actors. Nevertheless, the long-standing constraints on the region, which include weaknesses in institutions (regulatory aspects among them), economic instability, informal activities and corruption problems (Schwab, 2016), indicate that it will be a long haul to position its countries at the top of the Global Innovation Index through efficient input management that is also reflected in greater social welfare and economic growth.

Although most of the policies and actions carried out by the countries of the region to foster innovative environments are consistent with their capacities and relative advantages in a heterogeneous context (Bárcena, 2008), some challenges remain. One of them is to strengthen inputs that have traditionally performed poorly and, above all, to strategically exploit the input-output ratios that have the most solid track record so as to maximize their impact, first on productivity and then on development.

It should be noted that this study is a partial analysis of the efficiency of the countries of Latin America and the Caribbean, since, owing to technical limitations, it only takes into account the most representative relationships of the phenomenon as indicated by the literature. In addition, the results are obviously limited by the fact that there is no follow-up of public and private investments in innovation and development, their opportunity cost or the degree to which each country's specific targets in this area have been met. In other words, the relationship between innovation inputs and outputs has been evaluated, but not the processes and mechanisms connecting them. Possible national priorities in what is a heterogeneous region have likewise not been taken into account.

With regard to future lines of research, it is important to identify criteria that can be used to incorporate variables associated with the impact on productivity and human development. Above all, considering the role played by the public sector, the extent to which local goals have been achieved and their strategic consistency could make the conclusions more widely applicable.

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