Master’s Thesis

Measurement of Scientific and Technological Production: Innovation Trends in Latin America and the Caribbean

by

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Certification of Originality

I, **GARAY Vargas Victoria Andrea**, hereby declare that this research is my own work and has not been submitted in any form for the award of another degree at any university or institute of tertiary education. Any information derived from the published or unpublished work of others has been properly cited or acknowledged appropriately.

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Abstract

An important factor that contributes to the improvement of economies' standard of living and economic performance is progress of science and technology (Conceição, Heitor, Sirilli, & Wilson, 2004). According to the EU-Commission (2003), scientific production is composed of two main elements: scientific output (i.e. publications share index) and scientific impact (i.e. citations share index). On the other hand, technological production consists of the analysis of patents granted to a specific entity (country or region) during a specific period of time.

This study focuses on the analysis of scientific and technological production capabilities and innovation trends present in Latin America and the Caribbean. Results show an improvement of scientific output in relation to world average mainly in agricultural, natural and medical sciences, however, scientific impact shows serious deficiencies where only natural sciences fields reached same level as world average when considering the region as a whole. On the other hand, innovations trends are characterized by the existence of three groups: science-oriented, technology-to-science oriented and co-evolution oriented.

Keywords: Latin America and the Caribbean, Brazil, Mexico, Argentina, Chile, Colombia, Venezuela, Cuba, Puerto Rico, Peru, Uruguay, scientific and technological production, scientific output, scientific impact, innovation trends.

CHAPTER 1

1 Introduction

An important factor that contributes to the improvement of economies' standard of living and economic performance is progress of science and technology. In order to achieve competitiveness and sustainable growth in global markets, economies allocate efforts and resources towards generation of knowledge as it represents one of the sources of long-term productivity growth (National Bureau of Economic Research, 1998; Conceição, Heitor, Sirilli, & Wilson, 2004).

The main catalyst of a nation's knowledge creation is the so-called national innovation system (hereinafter referred to as "NIS"). A NIS can be defined as the macro element responsible for the innovative and technological performance of a country composed by three main actors: the private sector, educational institutions and public research institutes (OECD, 1997). Hence, strategies used by a NIS will shape the science and technological cycle of a country (Wong & Goh, 2015).

According to the EU-Commission (2003), scientific production is composed of two main elements: scientific output (i.e. publications share index) and scientific impact (i.e. citations share index). On the other hand, technological production consists of the analysis of patents granted to a specific entity (country or region) during a specific period of time. Consequently, scientific and technological competitiveness of a nation can be measured through the analysis of NIS output indicators such as publications and patents. Scientific publications represent the primarily outcome of basic research carried out predominantly by universities and public research institutions while patents represent a valuable indicator of technological performance. Therefore, output indicators, such as number of scientific publications, citations and patents granted, are key elements of a country's scientific position. Consequently, competition in science can be identified through the analysis of these elements (Hagstrom, 1965; Larsen, Maye, & von Ins, 2008)

1.1 Problem Statement

Latin America and the Caribbean (hereinafter referred to as "LAC") has received growing attention due to the region's rapid economic development indicating a paradigm shift from the traditional economic scenario composed by developed and developing countries dichotomy, suggesting an increasing interdependence between these two types of blocks (de la Torre, Didier, Ize, Lederman, & Schmukler, 2015). More specifically, LAC has been able to improve its world scientific production in a sustainable manner in terms of total publications worldwide from 2.2 percent in 1996 to 4.1 percent in 2014 (SCImago, 2016).

Figure 1 below, shows the evolution of output indicators (publications and citations) of LAC from 1996 to 2014. It can be observed that these elements have increased steadily over the years: from 22,511 publications in the first year considered to 103,498 in the last year, reaching a total of 22 percent of increment. On the other hand, citations increased a total of 33 percent during the same period.

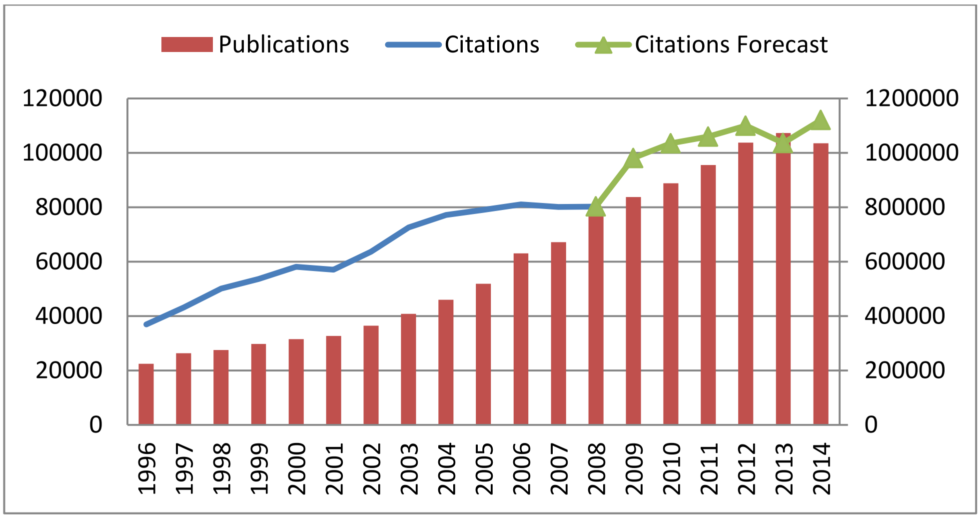
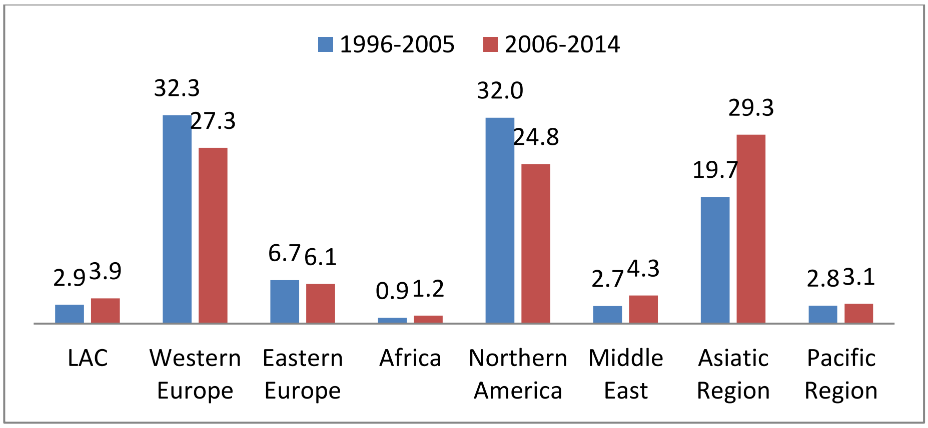


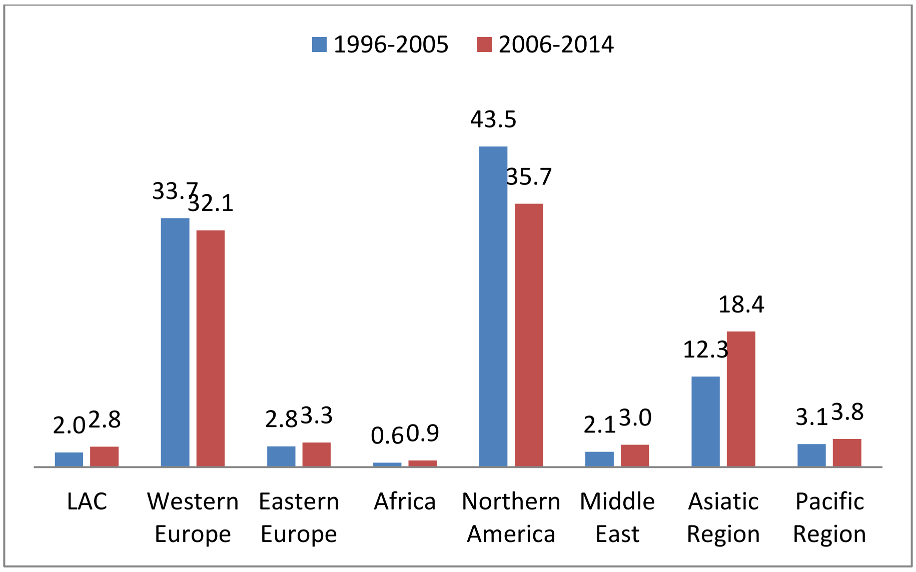
Figure 1. Integral Evolution of Publications and Citations

Additionally, LAC has been able to increase not only its quantity of scientific publications produced but also the quantity of citations received by those publications during the two periods considered in Figures 2 and 3 below. This is a considerable achievement when taking into account that traditional leaders of scientific competitiveness, such as North America or European regions, declined its share in either one or even in two of these elements.



Note. Adapted from SCImago Journal & Country Rank (2016).

Figure 2. Share of World Publications



Note. Adapted from SCImago Journal & Country Rank (2016).

Figure 3. Share of World Citations

On the other hand, the number of patents granted increased from 10,159 grants in 1996 to 18,500 in 2014, reaching a total of 45 percent growth (RICYT, 2016). Therefore, given the advancement in science and technology witnessed over the last decades and due to the lack of studies that currently assess scientific and technological production capabilities in LAC as a whole, it is relevant to analyze the evolution of scientific and technological production of the region in order to determine which countries are leading this path of growth, what scientific fields demonstrate competitiveness at international levels and what relationship exist between publications and patents in order to determine innovation trends present in the region.

1.2 Scope of Research

This study focuses on the analysis of science and technological production of top ten performing countries[1] from LAC, namely, Brazil, Mexico, Argentina, Chile, Colombia, Venezuela, Cuba, Puerto Rico, Peru and Uruguay (hereinafter this cluster of ten countries will be referred to as "LAC10").

The timeframe considered will consist of 18 years (from 1996 to 2014) and it will include eleven scientific fields:

1. Agriculture and Biological Sciences
2. Arts and Humanities
3. Business, Management and Accounting
4. Earth and Planetary Sciences
5. Energy
6. Engineering
7. Medicine
8. Pharmacology, Toxicology and Pharmaceutics
9. Physics and Astronomy
10. Social Sciences
11. Veterinary

[1] Top ten performing countries are those with the highest levels of GDP size and scientific production capabilities based on the information provided by the World Bank and SCImago Journal and Country Rank.

1.3 Research Objectives

This research aims to achieve the following:

1.3.1 To assess the scientific and technological production capabilities of LAC10.

1.3.2 To depict growth trajectories and characteristics of the eleven scientific fields considered.

1.3.3 To analyze the relationship between scientific publications and patents in order to determine innovations trends present in the region.

1.4 Research Questions

In order to achieve the aforementioned objectives, this research aims to answer the following questions:

1.4.1 Which countries lead scientific and technological production in LAC10?

1.4.2 Which scientific fields achieve or surpass world average in terms of quantity and quality?

1.4.3 Which scientific fields are being underdeveloped, thus not reaching world average neither in quantity nor in quality?

1.4.4 What phases of development characterize growth trajectories of the eleven scientific fields studied?

1.4.5 What patterns of growth can be found in growth trajectories of the eleven scientific fields studied?

1.4.6 Are innovation trends characterized towards scientific research development (publications) or technological development (patents)?

1.5 Significance of Study

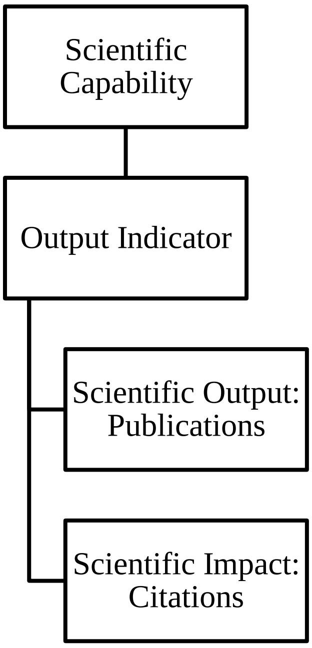
This research aims to be a contribution to current literature in regards of scientific and technological measurement, to provide insight on the current status of LAC scientific and technological production levels as well as a performance measurement framework capable of assessing countries' scientific and technological production capabilities and lastly, to be a source of reference for future research and related topics.

CHAPTER 2

2 Theoretical Framework

The main objective of this paper is to assess the scientific and technological production capabilities of LAC10; therefore, it is important to define these elements.

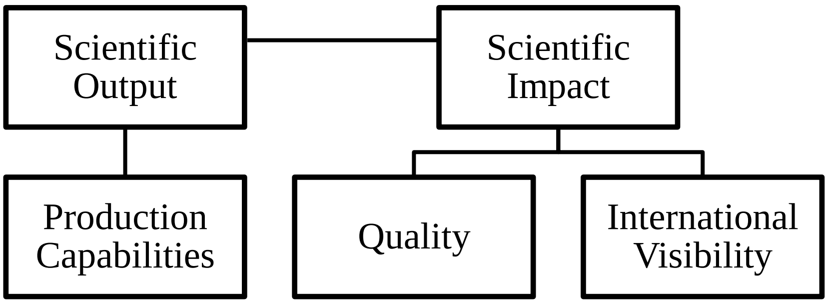
Larsen et al. (2008) stated that one of the primary elements to determine a country's scientific capability are output indicators. These indicators are comprised by two elements: the number of scientific publications and citations. When studying the relative position of China, Europe, India, Japan and USA, authors used the terminology "scientific output" to refer to the measurement of scientific publications and "scientific impact" when referring to citations, being the latter, the main focus of their research.



Note. Adapted from Larsen et al. (2008).

Figure 4. Scientific Capability

Moreover, Horta and Veloso (2007) analyzed the evolution of US and Europe in regards of scientific output and impact during the 1990s. Authors defined scientific output as the share of published research papers for each of the five fields proposed by the OECD (engineering, medical, agricultural, natural and social sciences) considering the world average as benchmark and scientific impact as the share of citations received by each paper against the world average in each particular scientific field found in ISI Thomson National Science Indicators. The scientific evolution analysis provided insight into the performance of the two aforementioned blocks in terms of scientific production capability (output) and quality and visibility (impact).



Note. Adapted from Horta and Veloso (2007).

Figure 5. Scientific Output and Scientific Impact

2.1 Scientific Production

Based on the considerations mentioned above, scientific production will be defined as the measurement of two main output indicators: scientific output and scientific impact.

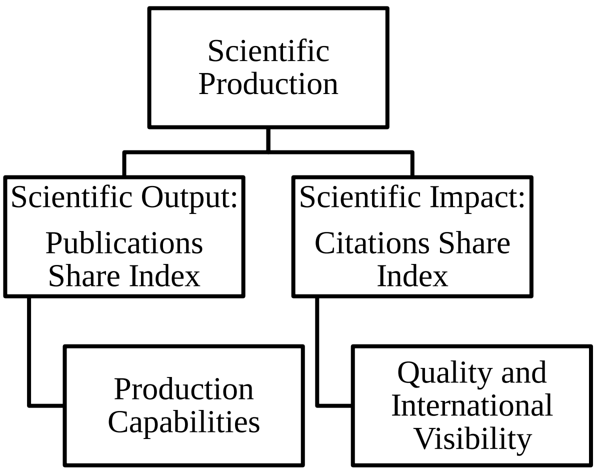
2.1.1 Scientific Output

Scientific output will correspond to the percentage share of publications of a country/region considering world average as benchmark. This measurement will provide insight of each country's production capabilities in the different fields analyzed.

2.1.2 Scientific Impact

Scientific impact will correspond to the percentage share of citations of a country/region considering world average as benchmark. This measurement will provide insight of each country's quality and international visibility of papers published in the different scientific fields considered.

For example, for both measurements world average is considered to be 1. If the measurement provides a result ≥ 1, it means the country is capable of producing same or higher level of publications and/or receiving citations. On the other hand, if the result is < 1, the country is lagging behind in either metric in comparison to world average. The definition provided can be illustrated as follows:



Note. Adapted from Larsen et al. (2008) and Horta and Veloso (2007).

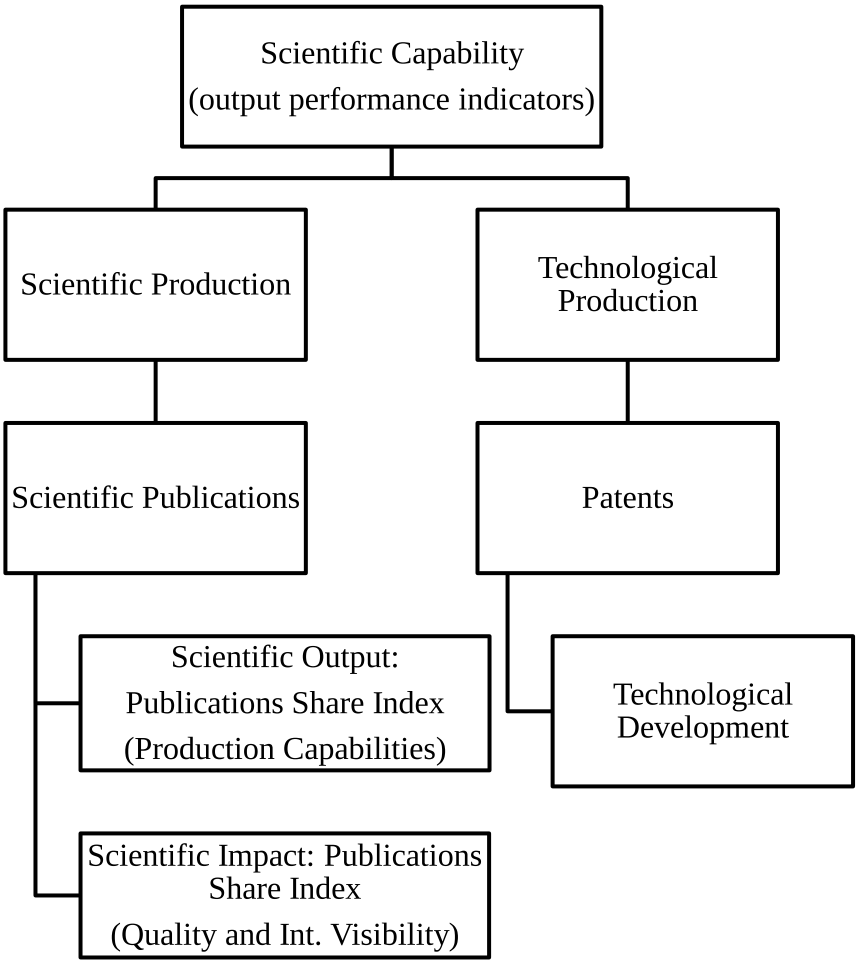
Figure 6. Scientific Production

As mentioned before, science and technology progress is a contributing factor towards economic performance. Since we have already defined scientific production, it is also relevant to define technological production as well.

2.2 Technological Production

According to Wong, Mohamad, Keng and Azizan (2014), technological production is the measurement of patents applications and grants made by a country or regional block on a certain period of time. Barroso, W, Quoniam and Pacheco (2009) stated that patents are an indicator of a country's level of technological development. Consequently, the concept of country's scientific capability, previously discussed by Larsen et al. (2008), is further expanded by including patents as a third measurement metric. From this definition we can observe that technological production is the next step towards measuring a country growth trajectory proxied by scientific publications and patents respectively. Hence, scientific production is the fundamental process that might evolve into technological production.

From the previous considerations the theoretical framework will be integrated as follows:



Note. Adapted from Horta and Veloso (2007), Larsen et al. (2008), Barroso (2009) and Wonget al. (2014).

Figure 7. Scientific Capability (output performance indicators)

CHAPTER 3

3 Literature Review

Various studies have been conducted in order to assess LAC scientific and technological production throughout the years. Nonetheless, these studies have represented fragmented attempts that put efforts on different areas. The first group focused mainly on determining the scientific output of the region, the second group emphasized the scientific impact of the block and the last group revised the different level of technology production through patents applications and/or grants in LAC as a measure of innovative capabilities within the region.

3.1 Studies on LAC Scientific Output

The studies made by Krauskopf, Pessot and Vicuña (1986), Lewison, Fawcett-Jones and Kessler (1993) and, de Moya-Anegón and Herrero-Solana (1999) concluded that Brazil, Argentina, Mexico, Chile and Venezuela are the top producers of scientific articles, even when controlling for GDP in milliard US$. These nations accounted for almost 85 percent of LAC´s total scientific output in 1981 when considering the first four nations and despite the increase observed between 1981 and 1997, LAC´s output still represented less than 2 percent of total publications worldwide (Krauskopf et al.,1986; de Moya-Anegón and Herrero-Solana, 1999).

Krauskopf et al. (1986) analyzed LAC scientific output from 1986 to 1991 considering twenty-one countries and thirteen scientific fields based on information indexed by the Institute for Scientific Information (ISI). Authors hightlighted that due to a lack of commitment towards science progress, the region did not show a meaningful performance of scientific achievement where efforts were largely concentrated in life sciences areas: mainly medicine and biology, for the period 1967-1976. However, thanks to the individual efforts of the aforementioned countries, LAC was able to sustain a minimum level of competitiveness in research activities. For example, Argentina was the only country capable of having a steady growth pattern for the number of publishing authors from 1978 to 1982, despite having an overall irregular pattern of growth rate when considering most productive countries, i.e., Brazil, Chile, Mexico and Venezuela, in this regard. Also, only seven nations were able to publish more than one hundred articles per year, representing one third of total countries analyzed.

Another approach was proposed by Lewison et al. (1993) by considering not only scientific ouput but also co-authorship levels present in LAC. Authors covered six years from 1986 to 1991 and included twenty countries in the analysis based on the information found in the CD room version of the Science Citation Index (SCI). In addition to determining that Brazil and Mexico were the two countries with remarkable steady increase in output, leading scientific centers in LAC where located in Brazil, Mexico, Argentina, Chile and, Venezuela. Another area considered was the analysis of regional cooperation and international co-authorship level. In spite of having a constant growth within the region, inter-LAC cooperation was low and international collaboration was almost equal for Europe and USA blocks, with 2.5 percent and 2.6

percent respectively. They concluded that international cooperation in LAC was at an introductory face and as such, the level was not highly significant.

Lastly, de Moya-Anegón et al. (1999) introduced a new measurement level by including five socio-economic indicators (or resources) such as Gross Domestic Product (GDP), percentage of GNP destined to R&D, scientific technological activities (STA), economically active population (EAP), and total numbers of researches dedicated to R&D, with the purpose of determining the degree of correlation between these factors and the production capability of each of the countries considered.

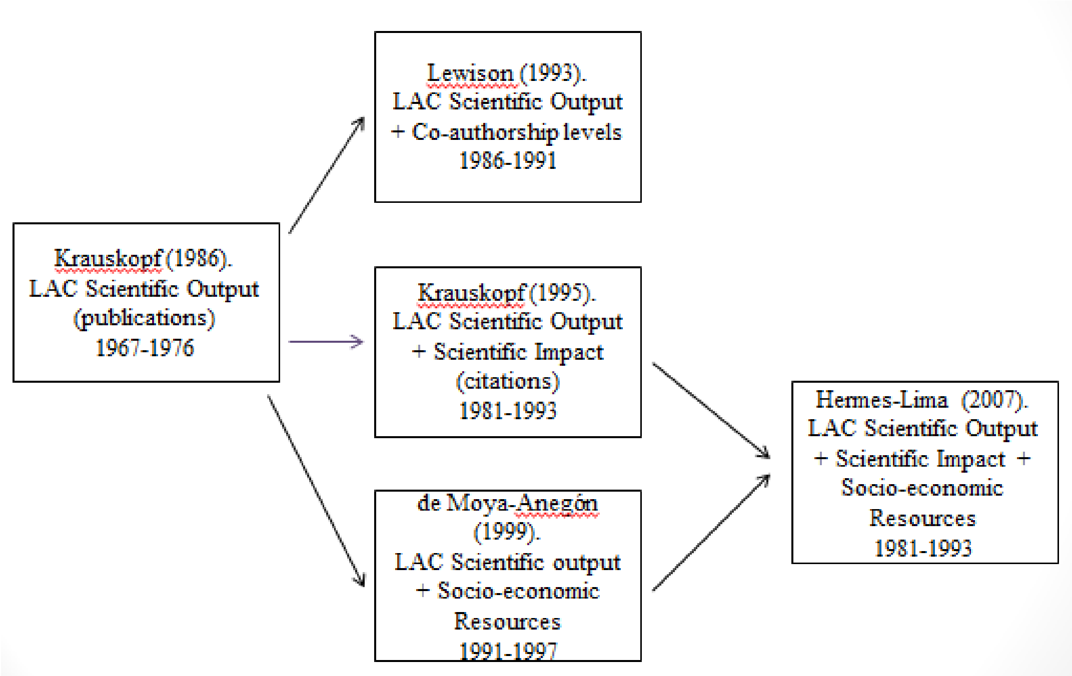
LAC scientific production was analyzed in terms of input (resources) and output (publications) through statistical analysis. Generally, input elements showed a positive correlation with the level of output studied. GDP versus articles indicated that there is a positive relationship between the economic potential of a country and their respective scientific output with an R^2 of 0.6877, expenditure in R&D had an R^2 of 0.865, STA obtained R^2 of 0.8784 and EAP, 0.5678. On the other hand, number of researchers versus publications showed a rather mix picture with Cuba suffering a considerable drop from the mean and Chile having the highest position level above the mean, demonstrating a more efficient production. Authors concluded that scientific output on LAC is directly proportional to its input indicators, being these human capital or budgetary resources, and relevant specific social and political contexts might present an important type of influencer towards output as well.

3.2 Studies on LAC Scientific Impact

The studies made by M. Krauskopf, Vera, V. Krauskopf and Welljams-Dorof (1995) and Hermes-Lima, Santos, Alencastro and Ferreira (2007) not only assessed LAC scientific output but also provided a second element of measurement within the region as given by scientific impact. Authors concluded that thanks to new policies implementations such as R&D expenditure, LAC was able to reinforce its scientific activity as witnessed by the increment of scientific output throughout the years. Nevertheless, despite this quantitative increment, international impact of research remained 40-60 percent below world average with the exception of few countries that excelled in particular fields.

Krauskopf et al. (1995) analyzed LAC´s scientific production in terms of scientific output and scientific impact from 1981 to 1993. After determining the patterns of publications growth and reconfirming that Brazil, Argentina, Mexico, Chile and Venezuela were the leading countries in this matter, output and impact trends by nation were identified. Peru was the only country with an impact relative to the world superior to 1, indicating an international visibility above world average. In order to obtain a more complete portrait of national research performance, a field-by-field bibliometric analysis was conducted including: agricultural sciences, astrophysics, biology and biochemistry, among others. This appraisal was further divided into three categories: number of articles cumulated for the aforementioned period, cumulative citation impact and Relative Citation Impact considering the last five years (1989-1993). Overall, LAC impact remained below world average for seven of the ten fields considered. However, remarkable countries were Chile by exceeding world average impact in astrophysics, Costa Rica and Peru in clinical medicine and Venezuela in engineering. Authors concluded that overall impact of LAC performed below world average; nonetheless, it is important to notice that LAC represents a dissimilar region where each country contributes differently to science given their unique profile and economic resources.

Hermes-Lima et al. (2007) analyzed scientific production considering scientific output, impact and socio-economic resources in thirty-four countries worldwide with a focus on LAC and biochemistry and molecular biology (BMB). Once more, top producers in terms of quantity were Brazil, Argentina, Mexico, Chile, among others that followed. By analyzing the different nations it was possible to determine that despite the rise in output, mainly attributable to the large increase in doctoral degrees awarded, international visibility or recognition of science for LAC remained low when compared to developed nations. Especially in terms of knowledge generation from the existing labor force in comparison with Spain. In contrast to previous research done by de Moya-Anegón et al. (1999), who studied the relationship between scientific output and socio-economic indicators (discussed in the previous subsection), Hermes-Lima et al. concluded that average citations received by published articles, or scientific impact, also correlates significantly with socioeconomic resources such as GDP per capita, number of researchers per million population and gross expenditure in research and development (GERD). Nonetheless, among the analyzed countries, LAC had some the lowest values for those elements with less than 1 percent of GDP expenditure, less than 2,000 researchers when controlled for population and less than 6 for GERD. When considering BMB citations scores, they seemed rather equitable to other research fields in LAC, however, when compared to world average or developed nations, relative impact was again low. Figure below shows the evolution of scientific production measurement in LAC when considering all studies:



Note. Adapted from Krauskopf et.al. (1986), Lewison et.al, (1993), Krauskopf et.al, (1995), de Moya-Anegón et.al, (1999) and Hermes-Lima (2007).

Figure 8. Evolution of Scientific Production Measurement in LAC

3.3 Studies on LAC Technological Production

According to the World Intellectual Property Organization (as cited in Cervantes et al., 2014, pp. 249,250), patents are an example of intellectual property safeguarded by law that allows the inventor to gain recognition and financial benefit by preventing others from commercially exploiting the patented invention without legal consent. Sáenz argued that (as cited in Barroso et al., 2009, p.207) patents are an important source of science and technology dissemination and, as mentioned before, Barroso et al. (2009) also stated that patents are an indicator of a country's level of technological development.

Studies regarding technological production in LAC through quantitative analyses of patenting application and/or grants have concluded that traditional leading countries within the region (with minor variations in order) are Brazil, Mexico, Argentina, Chile, Colombia and Venezuela,. These studies also indicate that patenting level is usually related with a country's innovative capabilities since it is considered as the traditional innovation output indicator of a national innovation system (Alcorta & Peres, 1998; Barroso, W, Quoniam, & Pacheco, 2009; Cervantes, King, Vázquez, Castello, López, & Díaz Moreno, 2014).

In this line of thought, Ketelhöhn and Ogliastri (2013) measured the level of patent production coming from native inventors residing in the region registered in the United States Patent and Trademark Office (USPTO) between 2008 and 2012. Authors focused on innovation produced within a business environment given the importance that company's innovation provides to Latin American nations in order to surpass the "small and medium family company" level and achieve an innovation-based economy. Consequently, there seems to be a bigger quantity of entrepreneurs motivated by necessity, e.g., unemployment, rather than opportunities, thus having no interest in pursuing high growth or adding little aggregate value to the company. When comparing to different periods (1976-1994 and 1995-2012), LAC increased 2.8 times its number of patents, however, this proved to be a negligible advancement when compared to others countries growth rates, e.g., South Korea with 28.4 and Taiwan 13. Authors concluded that LAC was a marginal contributor to the world innovative activity, generating 0.19 percent of total patents registered in USPTO for the aforementioned period. Furthermore, Alcorta (1998), who also concluded that LAC had a peripheral innovative performance when compared to developed and some other developing countries, determined that this situation was attributable to a weak NIS present throughout the region, where underperforming science and technology institutions had a loose link as witnessed by the fragile connection between government, business and academia and where public policies were also partially effective.

Barroso et al. (2009) studied twenty one LAC countries and its corresponding Industrial Property Offices websites to describe the type of information available to the public related with patent databases and/or patenting process. Authors considered the number of Latin American patents applications under the Patent Cooperation Treaty[2] (PCT) from 2000 to 2007 and determined that LAC had a small percentage around 0.4 of total applications, signaling that the quantity of patents applications is growing but a slow pace over the years. Additionally, Latin American Offices represented a mixed picture where further improvement of access to relevant patent information could leverage wealth creation and economic and technological development in the region. Despite this modest quantitative improvement during last decades, it is considered that LAC patent system is being reinforced because of the influence of various trade agreements and harmonization of several laws on trade and industrial property thanks to the accession to the World Trade Organization and its Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) in 1995 (Cervantes, King, Vázquez, Castello, López, & Díaz Moreno, 2014).

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[2] The Patent Cooperation Treaty (PCT) assists applicants in seeking patent protection internationally for their inventions. By filing one international patent application under the PCT, applicants can simultaneously seek protection for an invention in a very large number of countries (WIPO, 2016).

Despite the sustained increment in scientific and technological production over the last decades, LAC scientific contribution and innovative capabilities, as measured by the number of patent applications, is rather low when compared to developed countries as there seems to have small growth rates in USPTO and when controlled by PCT law.

From the previous review, it can be observed that previous studies did not link scientific and technological production when assessing LAC capabilities, there seems to be a lack of integral research with an inward focus to determine inner elements' condition. Therefore, since both scientific and technological production are considered to be the output of a NIS (EU-Commission, 2003), it is pertinent to connect these two elements and assess LAC scientific capability through the appraisal of quality and quantity of scientific production, forecast of growth trajectories when considering scientific output and analysis of the relationship between the quantity of publications and patents granted in LAC countries in order to determine the scientific and technological innovation trends present in the region.

CHAPTER 4

4 Research Methodology

This research uses a quantitative methodology with a descriptive approach. This type of approach focuses on determining properties, characteristics and important features of the phenomenon analyzed as well as describing trends of a group or population. Also, intends to collect and/or measure information about relevant concepts with the objective to accurately display the angles or dimensions of a phenomenon, event, community, context or situation. (Sampieri, Collado, & Lucio, 2010).

4.1 Research Design

In order to evaluate LAC scientific and technological capability, a non-experimental design is applied. As stated by Sampieri et al. (2010), this type of design refers to studies where variables are not deliberately manipulated. More specifically, non-experimental longitudinal design collects data over a period of time in order to extensively evaluate and make inferences about the evolution and possible causes of a phenomenon.

4.2 Data Collection

This study is based on secondary data collected from SCImago Journal & Country Rank (hereinafter referred as "SCImago"). SCImago is a publicly available portal that contains information about scientific indicators for journals and countries based on the bibliographic database called Scopus (owned by Elsevier), which contains over 21,500 peer-reviewed journals (Elsevier, 2016; SCImago, 2016). The information gathered corresponds to the number of publications (including articles, reviews and conference papers) and citations for the ten countries mentioned in Chapter 1, from the year 1996 until 2014.

Furthermore, socioeconomic indicators such as R&D expenditure on scientific fields, number of researchers and patents were obtained from the Network for Science and Technology Indicators database (RICYT)[3]. Lastly, information regarding population size and R&D expenditure as percentage of GDP were obtained from World Bank's World Development Indicators Database.

4.3 Model Construction

This study seeks to assess the scientific and technological capability of LAC10; therefore, quantitative analysis was conducted based on the methodology proposed by Horta and Veloso (2007) in their paper "Opening the box: Comparing EU and US scientific output by scientific field". Authors utilized six formulas[4] in order to assess the evolution of scientific output and impact between U.S. and Europe during the 1990s, based mainly on the taxonomy detailed below.

4.3.1 Horta Model - Measures of Comparative Advantage

This method introduces two formulas as a way to measure comparative advantage of countries in terms of scientific output (quantity of papers) and impact (citations) as follows:

---

[3] RICYT is a network that promotes the development of instruments for measuring and analyzing science and technology in Ibero-America (RICYT, 2016).

[4] Formulas were adapted from the originals found in Horta and Veloso. (2007).

Revealed Comparative Advantage (RCA): Measures the share of a country's papers in a given scientific field against the share of world papers in that field. Where *i* refers to a specific country, *j* to the specific scientific field, *Pij* to the number of papers published by a given country considering one scientific field, *Pwj* the total number of papers published by the world considering the same scientific field and *k*, the total number of scientific fields selected.

$$RCA_{i,j} = \frac{(P_{\mathrm{i,j}} / \sum P_{w,j})}{(\sum_{\mathrm{f=1}}^{\mathrm{k}} P_{i,j} \,/\, \sum_{\mathrm{f=1}}^{\mathrm{k}} P_{w,j})}$$

Relative Citation Impact (RCI): Is the ratio between citations and papers for a given field in a country in relation to the citations and papers of same field in the world. *C* refers to the number of citations received by a country (*i*) or by the world (*w*) in a specific scientific field (*j*) in a given period of time (*t*), P refers to the quantity of publications produced.

$$RCI_{i,j,t} = \frac{(C_{i,j,t} / P_{i,j,t})}{(\sum C_{w,j,t} / \sum P_{w,j,t})}$$

Formulas below were used in order to assess the structural change in quantity and quality of LAC10 science systems through two main periods: 1996-2005 and 2006-2014.

$$\triangle RCA_{i,j} = \log\left(\left(P_{i,j,2014}/\sum P_{w,j,2014}\right)/\left(\sum_{f=1}^{n} P_{i,f,2014}/\sum_{f=1}^{n} P_{w,f,2014}\right)\right) - log\left(\left(P_{i,j,2010}/\sum P_{w,j,2010}\right)/\left(\sum_{f=1}^{n} P_{i,f,2010}/\sum_{f=1}^{n} P_{w,f,2010}\right)\right)$$

$$\triangle RCI_{i,j} = \log\left(\left(C_{i,j,2014}/P_{i,j,2014}\right)/\left(\sum C_{w,f,2014}/\sum P_{w,f,2014}\right)\right) - log\left(\left(C_{i,j,2010}/P_{i,j,2010}\right)/\left(\sum C_{w,f,2010}/\sum P_{w,f,2010}\right)\right)$$

To determine the level of specialization and evenness of quality of LAC10 during 1996-2014, the following formulas were used:

$$RCA_{i,j} = \left(P_{i,j,96-14}/\sum_{c=1}^{LAC10} P_{c,j\,96-14}\right)/\left(\sum_{f=1}^{k} P_{i,j,96-14}/\sum_{c=1}^{LAC10}\sum_{f=1}^{k} P_{c,f,96-14}\right)$$

$$RCI_{i,j} = \left(C_{country,96-14\,/}\,P_{country,96-14}\right)/\left(\sum_{c=1}^{K} C_{LAC10,96-14}/\sum_{c=1}^{K} P_{LAC10,96-14}\right)$$

4.3.2 S-shaped Logistic Growth Model

A simple logistic function depicts an S-shaped curve with the equation below, where P_t refers the value of the unit of science at time t; K, is the potential limit growth or carrying capacity; α is the initial stage of growth and β refers to velocity (Chan-Yuan & Goh, 2015).

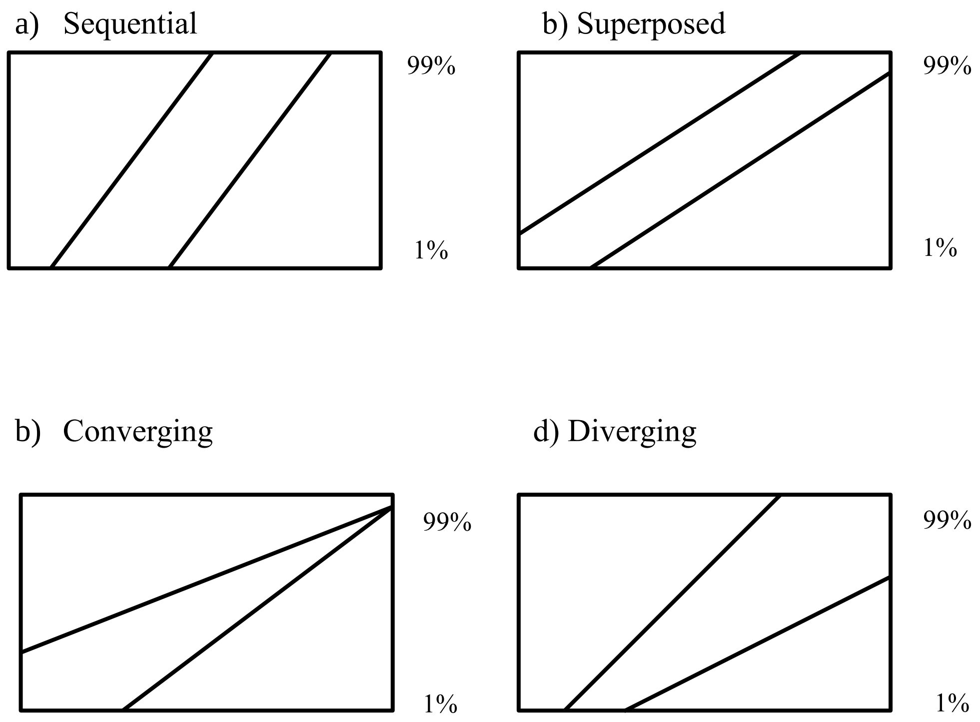
$$P_t = \frac{K}{1 + ae^{-bt}}$$

Despite being used originally in the biological realm, the logistic growth function is also used for socio-technical processes as a result of its effectiveness in mapping the changing nature of science and technology (Chan-Yuan & Goh, 2015). In this context, Loglet Lab program[5] was used in order to depict the growth of the different scientific fields analyzed. By adding the information obtained from SCImago database, the software will develop an S-shaped curve that will provide insight whether the discipline is at an introductory, growing or mature phase of development. Nonetheless, according to Chan-Yuan (2015) and Shehu (2015), it is also appropriate to use a bi-logistic growth function to map systems that experience two phases of logistic growth where a new institutional arrangement takes place and co-evolves or replaces the old one. Several authors (Meyer P. , 1994; Watanabe, Zhu, & Miyazawa, 2001; Watanabe, Hur, & Lei,

[5] Loglet Lab is a software package that analyzes logistic behavior in time-series data by decomposing growth and diffusion patterns into an S-shaped logistic growth (Shehu, 2015). The software was downloaded from https://phe.rockefeller.edu/LogletLab/2.0/ (The Rockefeller University, 2015).

2006; Schmoch, 2007; Chan-Yuan & Goh, 2015) have described the four basic pattern of growth in a bi-logistic function as shown in Figure 9 below:

a) Sequential Growth: It occurs when the system has a pause between phases represented by two non-overlapping logistic pulses, where the second logistic curve starts growing once the first one almost reaches its saturation point (K).
b) Superposed Growth: It occurs when the system contains two processes growing simultaneously. The second pulse (with faster pace of growth) emerges when the first one reaches around 50 percent of its saturation. This type of logistic growth could indicate that there is a co-evolution between science and technology development.
c) Converging Growth: It occurs when two curves emerge in different periods but culminate near the same saturation point. This type of logistic growth could indicate that an advancement in technology extended the life-cycles of a development process thus, incrementing its carrying capacity (K) and Δt.
d) Diverging Growth: It occurs when two logistic pulses that started at the same time, grow with different carrying capacities and rates. This could indicate that an economy succeeded in creating new growth avenues for science and technology, therefore, the second logistic curve has a longer pulse.



Source: (Meyer P. , 1994; Chan-Yuan & Goh, 2015).

Figure 9. Taxonomy of Bi-logistic Growth Model

CHAPTER 5

5 Analysis and Findings

5.1 Integral Analysis

Table 1 identifies the percentage of papers published and citations received by each scientific field in relation to the total scientific production of LAC10 for the period considered from 1996 until 2014.

Table 1. Weight of Scientific Fields

Scientific Fields	**Publications %** (percentage to total fields)	**Citations %** (percentage to total fields)
Agriculture and Biological Sciences	19.0	18.0
Arts and Humanities	2.0	2.3
Business, Management and Accounting	1.0	0.4
Earth and Planetary Sciences	6.4	8.7
Energy	2.6	1.7
Engineering	13.3	7.5
Medicine	28.2	34.2
Pharmacology, Toxicology and Pharmaceutics	4.2	5.5
Physics and Astronomy	15.8	18.2
Social Sciences	4.8	1.8
Veterinary	2.7	1.6
TOTAL	100	100

Note. Adapted from SCImago Journal and Country Rank (SCImago, 2016).

Fields with biggest shares when considering publications are medicine with 28.2 percent, agriculture with 19 percent, and physics and astronomy with 15.8 percent of total output. A similar situation is presented with regards to citations (with a small variation in order), where medicine obtains 34.2 percent; physics and astronomy, 18.2

percent and agriculture, 18 percent of total impact. In contrast, the field with the smallest share of publications (1 percent) and citations (0.4 percent) was business, management and accounting.

It is important to notice that results do not indicate a certain field is more important than other or that its quality is superior when compared to each other. This is due to the fact that the average citation per publication of each scientific field varies.

Figures 10 and 11 below show Revealed Comparative Advantage (RCA) and Relative Citation Impact (RCI) of selected economies considering two periods: 1996-2005 and 2006-2014, being world average equal to one.

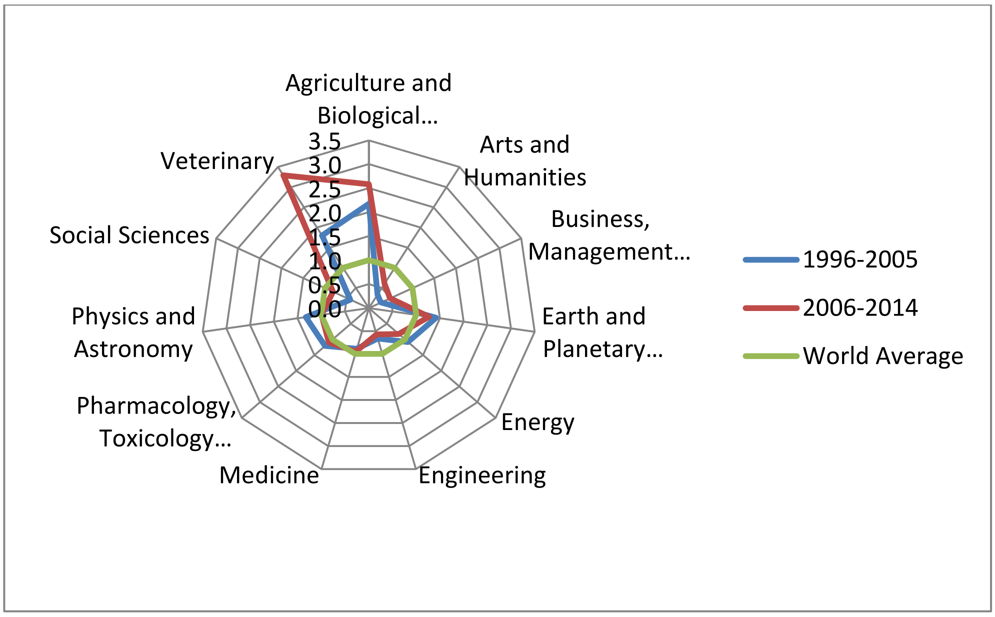


Figure 10. RCA of LAC10 compared to world average

As can be appreciated, LAC10 highly surpassed world average for Revealed Comparative Advantage (RCA) in the fields of agriculture and veterinary. Other fields that also reached a level of productivity above world average were earth and planetary sciences as well as physics and astronomy, however, most of the remaining scientific fields did not reach world base in any of the periods considered being business the lowest among all. When looking at the evolution over the two periods presented, it can be observed that LAC10 increased its RCA in five scientific fields (agriculture, arts, business, social sciences and veterinary), stabilized in one (medicine) and decreased in five (earth and planetary sciences, energy, engineering, pharmacology and physics). This scenario shows a rather stable position of the scientific fields considered when comparing them to the first period, where most of them did not witness a significant increase or decrease over time. The only exception corresponds to agriculture and veterinary fields which obtained the higher results.

However, it is important to consider not only the total share of scientific publications produced by a country or region but also the level of international visibility determined by the second measurement called Relative Citation Impact (RCI), as shown in figure below.

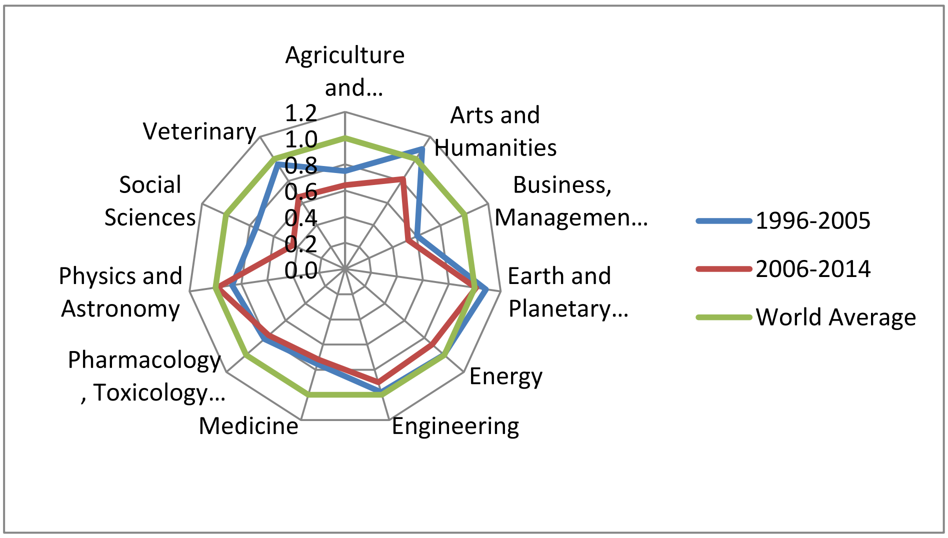


Figure 11. RCI of LAC10 compared to world average

Results show that most of the fields remained below world average during the two periods. Nonetheless, earth and planetary sciences together with physics and astronomy where the only fields that reached world average in the last period considered. In the case of agriculture, Brazil's research output accounts for more than 50 percent of LAC10 and according to Fink, Kwon, Rho, and So (2014), this area seems to be focused on specific domestic needs that are apparently irrelevant for the international scene, thus explaining the high quantity of publications produced but the lower citations received by the block.

Figure below shows the relation between cumulative RCA and RCI from 1996 to 2014:

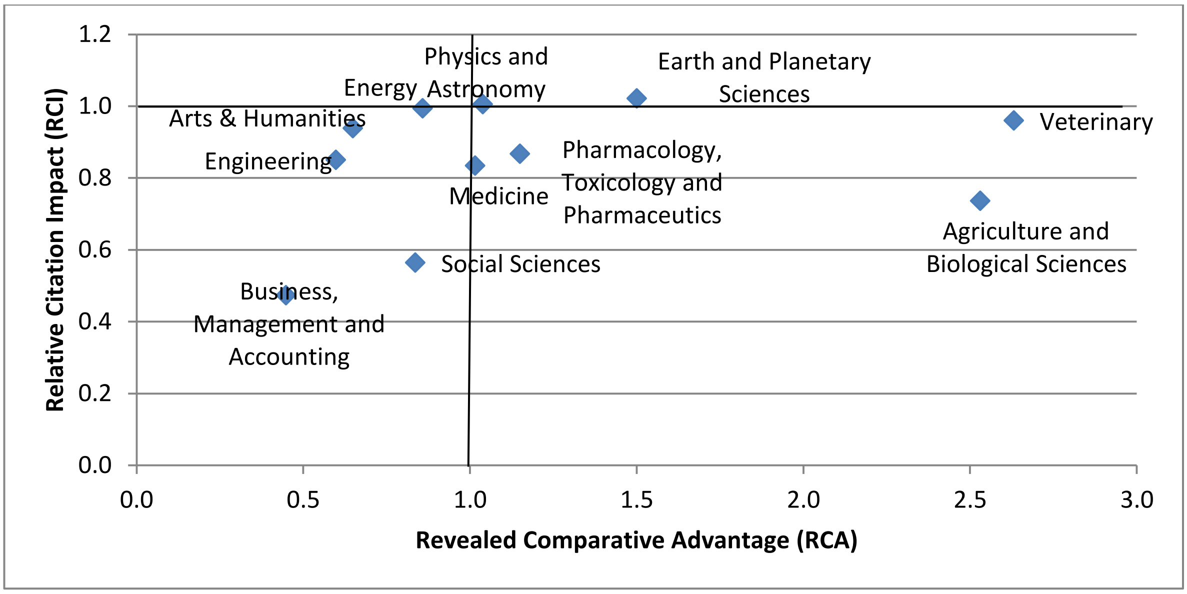


Figure 12. Relation between RCA & RCI, 1996-2014

First, in terms of quantity, measured by Revealed Comparative Advantage, we can observe that the fields of knowledge that were able to produce at the same level or higher than the world base (beginning with the highest values) were: veterinary, agriculture, earth and planetary sciences, pharmacology, physics and astronomy and medicine. On the other hand, in relation to quality and visibility as measured by Relative Citation Impact, three fields reached same level as world base: energy, physics and earth and planetary sciences.

This scenario follows the same trend as shown in Figures 10 and 11 above, with agriculture and veterinary being the most productive fields in terms of quantity and physics and earth sciences the fields with highest quality among best performers. Energy field showed an interesting case where its impact was slightly higher than its productivity. This could suggest that Latin American researchers publish more regularly in prime journals, thus receiving a higher number of citations. Although it is not possible to confirm this hypothesis by the data obtained, according to SCImago database (2016), countries with the highest H index[6] in this field were Brazil and Mexico, which are the two main producers of scientific papers from LAC10 in energy with a total output of 47.5 percent and 23.5 percent respectively.

Nonetheless, in order to obtain a more detailed understanding about comparative RCA and RCI measurements, it is pertinent to assess the evolution of both metrics between the two periods considered initially: 1996-2005 and 2006-2014. The first measure, ∆Revealed Comparative Advantage, assesses the change in production capabilities in relation to the world base and the second one, △Relative Quality, estimates the change in relative quality of scientific publications in relation to the world average.

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[6] The h-index, or Hirsch index, measures the impact of a particular scientist; it expresses the number of articles (*h*) that have received at least *h* citations. (Schreiber, 2008; SCImago, 2016).

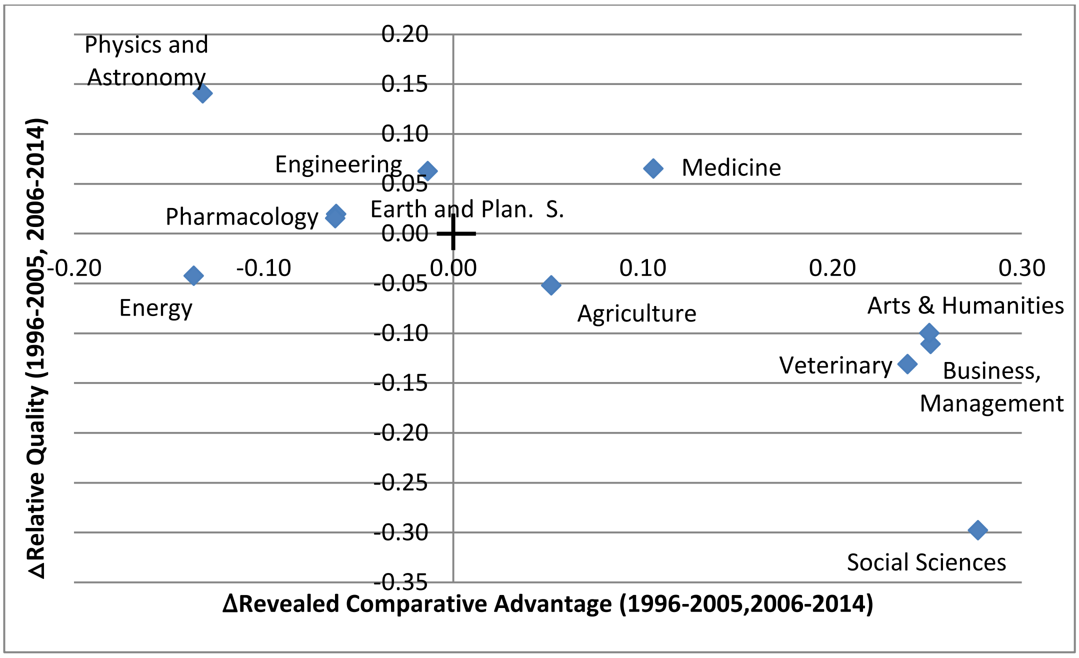


Figure 13. Structural change in quantity and quality in LAC10

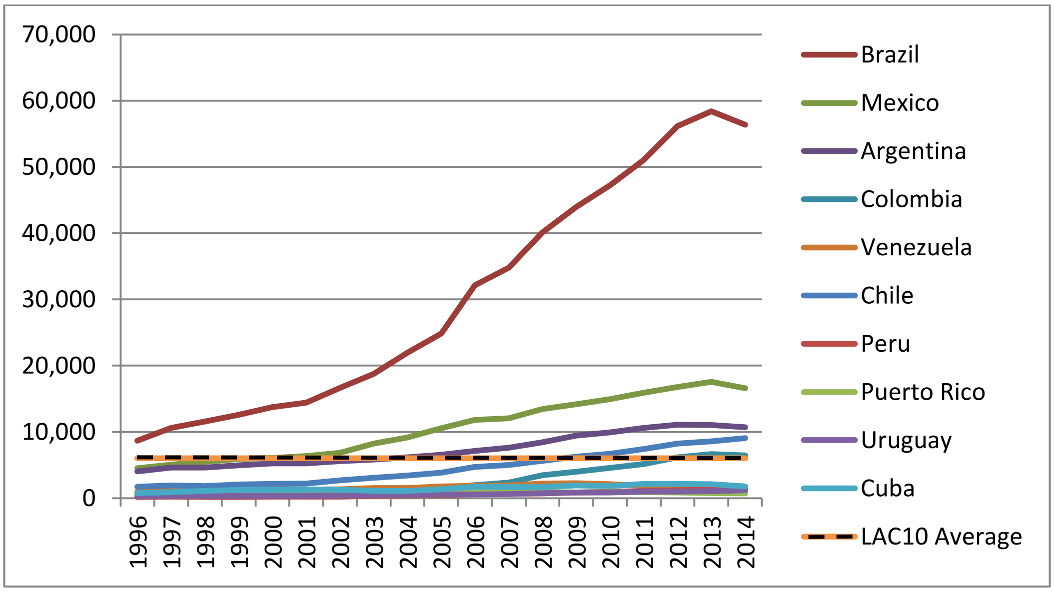
Figure above demonstrates that medicine was the only field capable of improving its international visibility (+7 percent) and its paper output (+11 percent). From the Cartesian plane it can be appreciated that there are gains in visibility in relation to the world since medicine and physics, which together account for 52.4 percent of the total number of citations (see Table 1 on page 29), increased their RCI. Similarly, the relative contribution of LAC10 in terms of paper output also increased as result of the increment witnessed by agriculture and medicine which represent 47.2 percent of total publications.

The overall development of LAC10 with regards to RCA during the two periods considered showed a rather mixed picture with six out of eleven fields either improving or maintaining its scientific production capabilities, while the remaining five decreasing its RCA result. When considering RCI, the overall result was negative; nine out of eleven scientific fields decreased its quality, pharmacology was the only field of knowledge that maintained the same level of impact (0.8) and, earth and physics fields reached world base during the second period considered.

5.2 Individual Contribution from LAC10 to Scientific Production

The increment presented by LAC10 in regards of quantity and quality on certain fields during the two aforementioned periods, calls for further analysis of production capabilities and international visibility within LAC. The figure below presents the evolution of publications (a) and citations (b) for each Latin American country in relation to each other from 1996 to 2014.

a)



b)

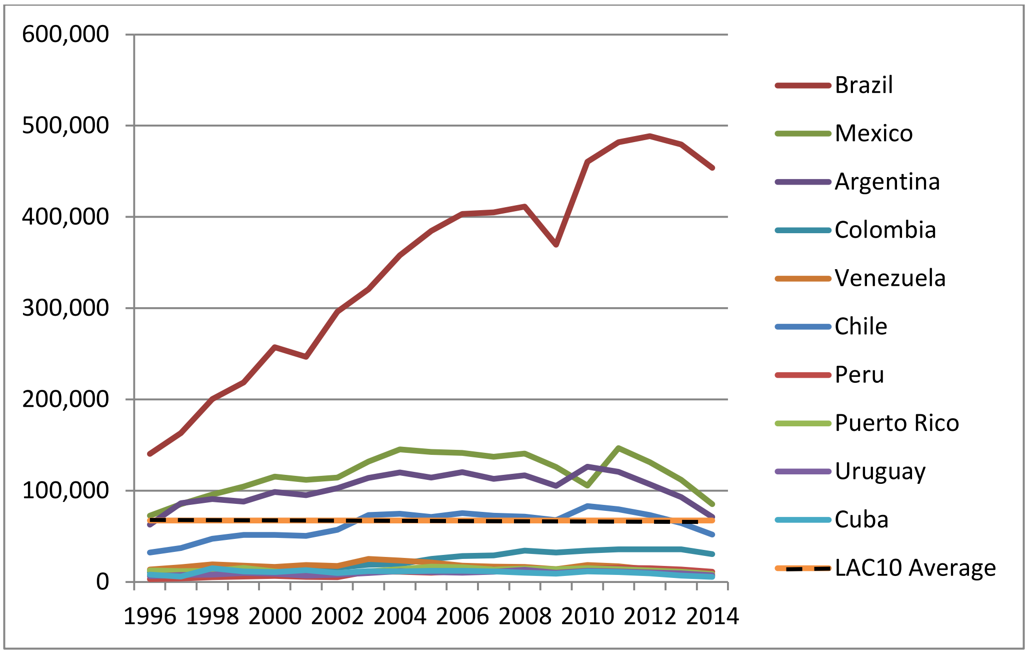


Figure 14. Individual Evolution Publications and Citations

Overall, there seems to be a clear differentiation between high-producers and low-producers depending on the capacity of each country to surpass (or not) LAC10 average for number of publications produced and citations received. Brazil, Mexico, Argentina, Chile and Colombia [7] pertain to the group of high-producers while, in contrast, Venezuela, Peru, Puerto Rico, Uruguay and Cuba pertain to the low-producers group. It can be observed that in both figures Brazil has consistently maintained a level above world average throughout the period. This concurs with a positive compound annual growth rate (CAGR) of 11 percent for publications and 7 percent for citations. According to (Velho, 2004), Brazil has been traditionally considered as the frontrunner

[7] Please note that Colombia does not reach LAC10 average for citations but due to the considerable gap between this country and the following ones, with more than 19,339 citations of difference with Peru, Colombia is considered as part of the high-producers group.

country by having the biggest volume of R&D expenditures among LAC nations, e.g., accounting with 42 percent of total expenditure in the year 2000. Additionally, Brazil has been the only nation capable of having investment rates consistently higher than the regional R&D/GDP average since 1990 (from 0.76 percent in 1990 to 1.05 percent in 2000, which was at the same level as European nations such as Italy). These elements show the commitment of the country towards development of national science and technology.

Colombia, Peru and Brazil were the countries that obtained the highest CAGR concerning publications with 15 percent, 12 percent and 11 percent respectively. Furthermore, countries with higher CAGR for citations were Peru with 8 percent and Brazil with 7 percent. This prompts us to highlight the Peruvian case. Peru's increment of quantity and quality of publications could be partly explained by the fact that the country has a scientific workforce that commensurate with the size of its economy, which indicates the government's efforts to the training of researchers (Velho, 2004).

On the other hand, Venezuela was the country were relative publication had the lowest increment (with a CAGR of 2 percent) and relative citation declined at the fastest rate (with a CAGR of -4 percent) among all countries. This suggests that the country experienced a slight shrinkage of overall scientific production during the period. This is in line with Raquena findings (2005) indicating that Venezuela had a reduction of scientific output during the last decade of the century due to public sector preference towards hydrocarbon related technological/service industry at the expense of academic research. Table below shows LAC10 integral analysis from 1996 to 2014:

Table 2. Cumulative Capabilities RCA and RCI, 1996-2014

	Brazil	Mexico	Argentina	Chile	Colombia	Venezuela	Cuba	Puerto Rico	Peru	Uruguay
Agriculture	X	X	X	X	X	X	X	△	X	X
Arts		O		X				O	O	
Business										
Earth Sciences		△	X	△		X		△	△	△
Energy	O	X	O	O	X	X		O		O
Engineering			O	O						
Medicine	X				X		X	O	△	O
Pharmacology	X	X	X				X	△	O	△
Physics and Astronomy	X	X	△	△	X	O		△	O	
Social Sciences				X	X		X	O	X	
Veterinary	X	X	△	X	X	X	X	O	X	△

Note: Symbols refers to countries that reached or surpassed world average either for RCA (x), RCI (○) or, both measurements (△).

Results show that all Latin American countries achieve RCA ("X") in agriculture and veterinary, indicating that they are able to produce publications at the same or higher level than world average. Earth and planetary sciences shows a clear competitive advantage for both RCA and RCI (as noted by "△"), this could be explained by the fact that LAC region is one of the most disaster prone areas in the world, therefore is it no unusual for Latin American countries to experience natural disasters such as earthquakes and tsunamis throughout its extension (Fagen, 2008). Physics and astronomy is also a field of knowledge well developed by LAC10 given the quantity of astronomical observatories located throughout the region. On the other hand, business field did not reach world base in any of the measurements considered and despite achieving or surpassing world RCA average on certain fields, Colombia and Cuba did not obtained international visibility comparable to world base (as noted by "O").

In addition to overall scientific production contribution, measured by publications and citations, it is important to analyze the scientific structure across fields in order to understand patterns of scientific specialization and (un)evenness of quality. The more the result approaches to zero when considering specialization, the broader the system is, meaning that the country's scientific fields share a similar level of quantity to those of LAC10 average in terms of number of publications. On the other hand, if the result moves away from zero, it signals a high level of specialization of certain scientific fields over others. This could provide relevant insight regarding the establishment of scientific priorities and its consequent use of resources for relevant fields (Horta & Veloso, 2007). For (un)evenness, if the result approaches to zero, it is an indicator that the country has a similar quality and international visibility for all of the scientific fields considered but if the result moves away from zero, it signals a different level of quality among its fields. Figures 15-16 below show specialization levels and evenness of quality for LAC10 from 1996 to 2014:

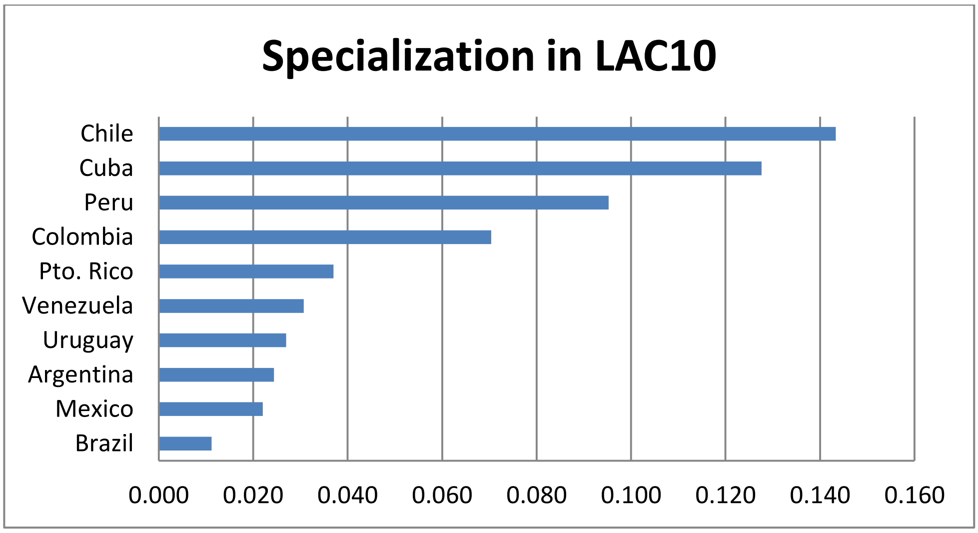


Figure 15. Specialization levels in LAC10, 1996-2014

In figure above it is not surprising that countries with higher R&D expenditure as percentage of GDP within LAC10, such as Brazil, Mexico, Argentina, and Puerto Rico, possess a broader system since these type of countries are capable of investing in a wider range of scientific fields and devote more financial resources in favor of a wider scientific structure (Horta & Veloso, 2007) in relation to LAC10. Results are in line with Fink et al. (2014) findings that portray Brazil as one of countries with the most even scientific capability across scentific fields. Regarding countries that are still developing its scientific base and therefore possess a narrower scientific structure, Colombia and Peru are clear examples of countries that devote fewer resources to science and technology development with the two having the lowest percentage of R&D expenditure as percentage of GDP in LAC10 with 0.19 percent and 0.15 percent respectively and showing specialization towards agriculture and veterinary fields (see Appendices E-J).

In this line of thought, Chile and Cuba are the exceptions. Both countries allocate a level of R&D expenditure as percentage of GDP towards science and technology development similar to LAC10 average (0.47 percent), with 0.40 percent and 0.38 percent respectively; however, there is a clear specialization within them: Chile mainly focuses on earth and planetary sciences and Cuba, on pharmacology (see Appendices D-G). This could be partly explained due to the fact that Chile is one of the most earthquake prone countries in the world and national objectives align towards the studies of natural processes of the earth such as earthquakes and tsunamis (Chilean National Seismological Center, 2016) . On the other hand, Cuba allocates a great part of its resources to medical-related fields since the health care system is a nationalized public program where government has the responsibility of providing free universal access, care and treatment to population (Hauge, 2007). In addition, the Cuban Ministry of Health produces a number of medical journals such as the Cuban Journal of Tropical Medicine focused on medical and pharmaceutical areas (Infomed, 2016).

Evenness of quality is a second element that also provides insight about the development of scientific structure within a nation, which is represented in figure below. This element represents the evenness or unevenness of quality across scientific fields for each country pertaining to LAC10. Moreover, it is important to clarify that this result only indicates that there are differences in the quality of the eleven scientific fields in a given country and it does not imply that a specific country has better quality and/or international visibility when compared to another.

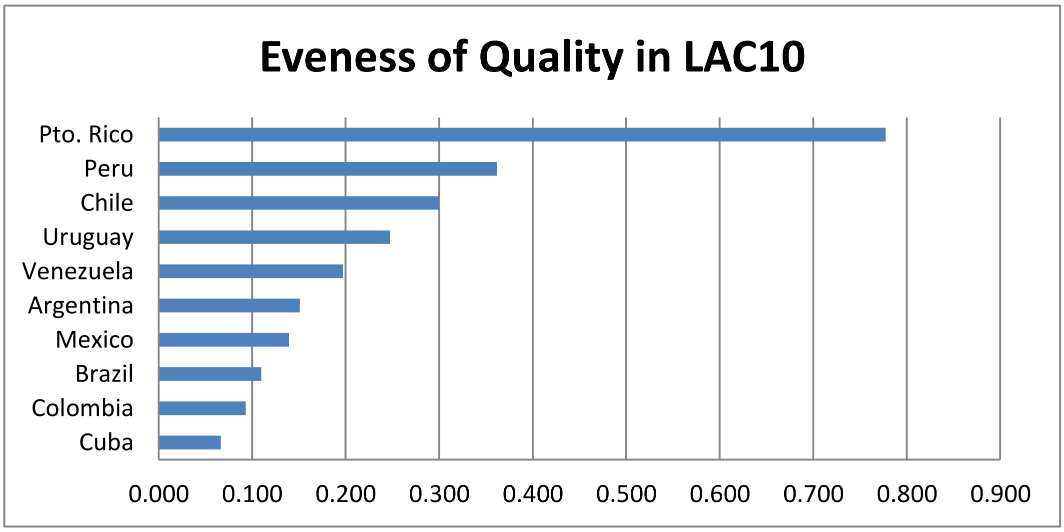


Figure 16. Evenness of Quality in LAC10, 1996-2014

Results indicate that Puerto Rico displays a disproportionate unevenness across scientific fields; much of this is due to its strong Relative Citation Impact in fields such as arts and veterinary along with weak Relative Citation Impact with regards of business and engineering fields (see Appendix H). The other two countries that attract attention due to its scientific unevenness are Chile and Peru; as can be observed, both countries had a variance equal to or higher than 0.3 for the 1996-2014 period. This result is also explained by the strong Relative Citation Impact for arts and humanities for the Peruvian case and, earth and planetary sciences and physics and astronomy for the Chilean case (see Appendices D-J).

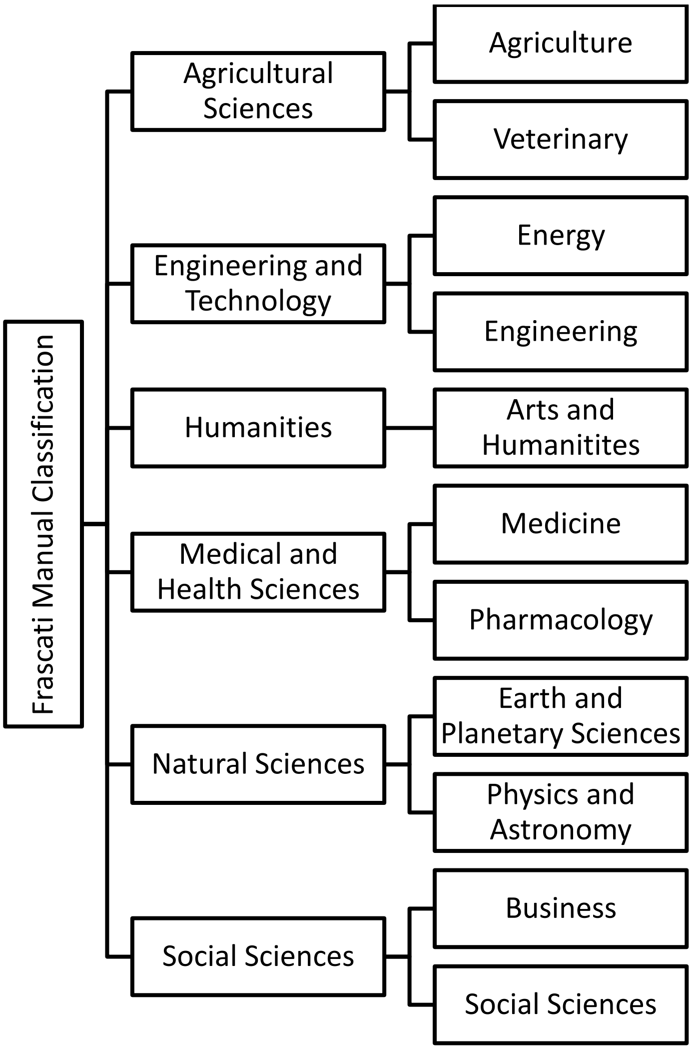
Countries with a lower level of unevenness are Uruguay, Venezuela, Argentina, Mexico and Brazil. Cuba and Colombia represent an unusual situation where in spite of having the second and fourth highest levels of specialization from LAC10 nations (Figure 15 page 40); they present the fairest levels on evenness. This signifies that a similar quality and visibility for papers is shared within its different scientific fields;

however, it is important to notice that these are the only countries from LAC10 that did not reach world average on any of the fields considered for RCI (see Appendices E-G).

When analyzing Figures 15-16 as a whole, the most visible fact is that this scenario shows a trend: there seems to be a positive correlation between the level of specialization and the level of unevenness of quality, as exemplified by Chile and Peru, which have the biggest degree of specialization and at the same time, one of the highest levels of unevenness across fields. Additionally, countries that do not seem to have a strong specialization on certain fields such as Brazil, Mexico and Argentina, neither have a significant difference on unevenness of quality. It is important to note that Cuba and Colombia had a high level of specialization but its overall quality, or RCI, remains below world average for all its scientific fields, therefore obtaining a fair level of evenness of quality.

Notwithstanding the degree of specialization in output and the degree of evenness in impact, it is equally relevant to identify the international quality of LAC10. Therefore, the eleven fields of knowledge studied were integrated into the six fields proposed by the Frascati Manual[8] (OECD, 2007) as shown in figure below:

[8] The OECD's Frascati Manual is an internationally recognized methodology for collecting and using R&D statistics related with science and innovation (OECD, 2007).

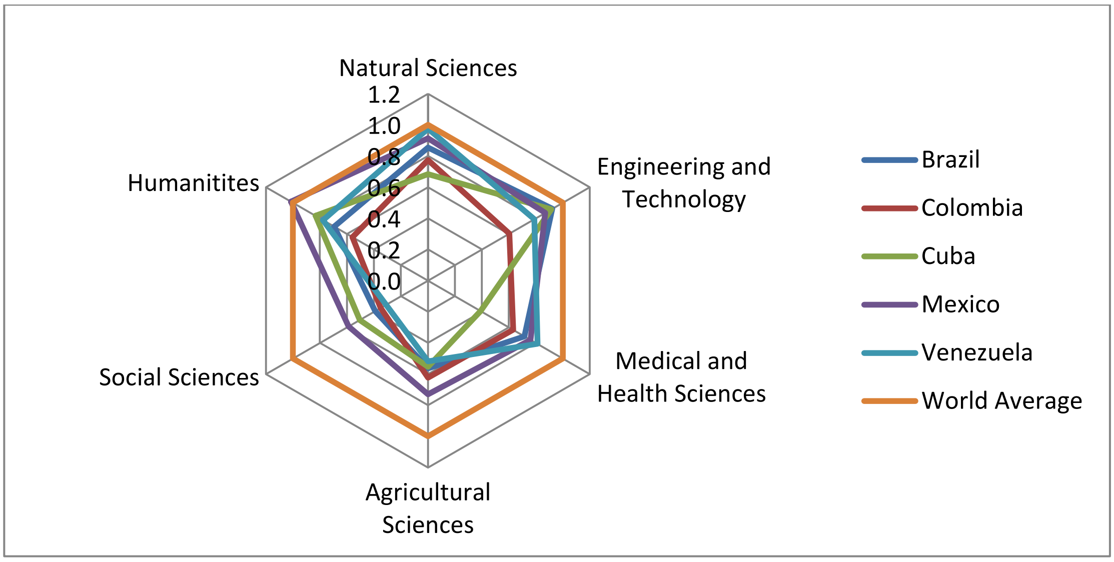


Based on Frascati Manual (2007) and SCImago (2016).

Figure 17. Scientific Fields Classification

Figure below considers the Relative Citation Impact of LAC10 in relation to the world. The first part (a) represents the cluster of countries that maintained a RCI equal to or below world average from the period considered between 1996-2014 whereas the second part (b) represents the cluster of countries that were able to surpass world average in at least two scientific fields for RCI during the same period.

a)



b)

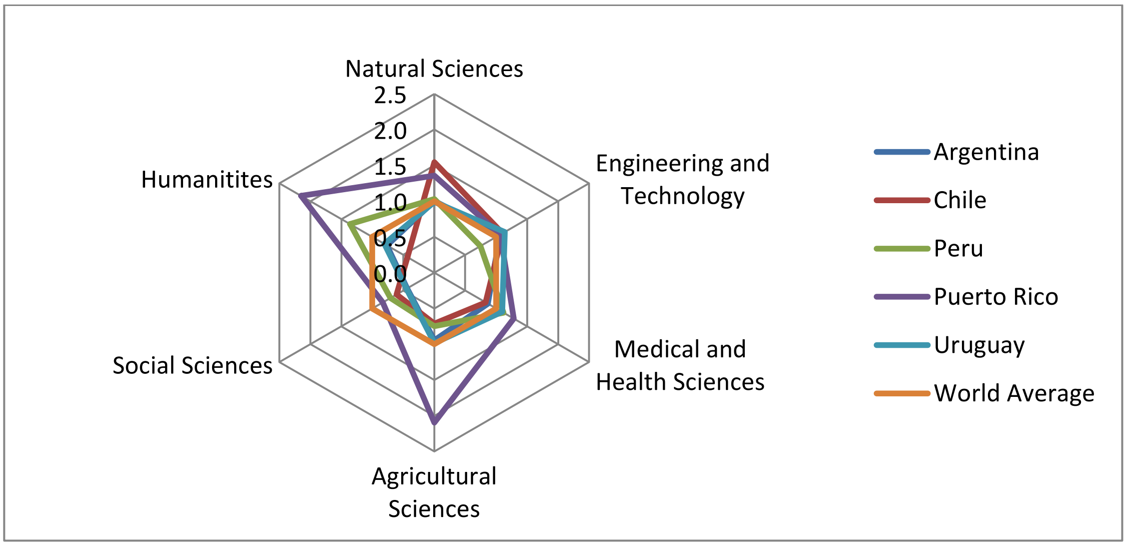


Figure 18. Cumulative RCI for LAC10, 1996-2014

In part a), the cluster of low performers is composed not only by nations considered as high-producers in terms of scientific output (scientific papers produced) such as Brazil, Colombia and Mexico but as well as by low-producers such as Cuba and Venezuela. The common element shared by these countries is that their level of evenness of quality is rather fair as shown in Figure 16 page 42. This signifies that a similar quality and visibility for papers is shared within all its scientific fields.

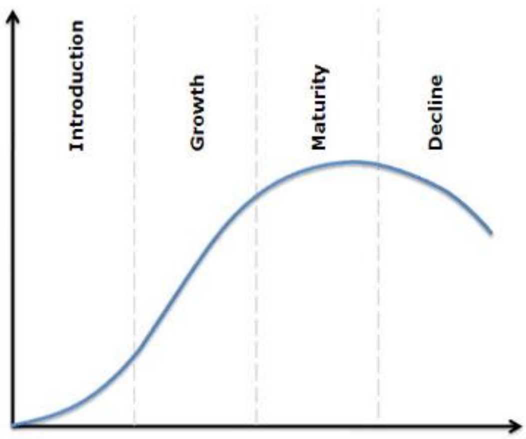
The cluster of high performers, part b), is mainly characterized by countries that reached or surpassed world impact average in at least two areas. This information seems to correlate with the countries that were found to have a high degree of unevenness of quality among its different scientific fields as shown in Figure 16 page 42. Examples of this are Chile, Peru, Puerto Rico Argentina, and Uruguay. This signals that high performers are such when having a high level of unevenness of quality among scientific fields, where prioritized areas allow them to surpass world impact average.

Summarizing, countries considered as low performers for international quality tend to be the ones that also possess a low or moderate level of evenness of quality in regards of Relative Citation Impact (Brazil, Colombia, Cuba, Mexico and Venezuela), meaning their quality across their different scientific fields are similar or do not present considerable gaps in terms of visibility between them. Nonetheless, these countries do not reach world impact average in most fields when analyzed. On the other hand, high performers (Argentina, Chile, Peru, Puerto Rico and Uruguay) are the ones that tend to have a broad unevenness of quality, meaning the quality across their different scientific fields is significantly dissimilar since there is a focus to develop specific scientific fields over others, consequently, this seems to be the reason why these nations are able to greatly surpass world impact average on specific areas while disregarding others.

5.3 S-shaped Curve Analysis

The following sub-section analyses the production trends of the scientific fields by aggregating them into the six fields proposed by the Frascati Manual as previously explained in order to illustrate the structure of science production in the selected emerging economies. As mentioned in Chapter 4, the logistic growth function will depict the "S" shaped or sigmoidal curve with its corresponding parameters: *K*, the maximum carrying capacity or limit of papers for each field; *tm*, the time in which the trajectory reaches half of its growth and *Δt*, the time required for the trajectory to grow from 10 to 90 percent of its saturation point (Meyer, Yung, & Ausub, 1999).

In addition, the shape of the S-curve will indicate if the scientific fields are at an introductory, growing or mature phase as exemplified below:



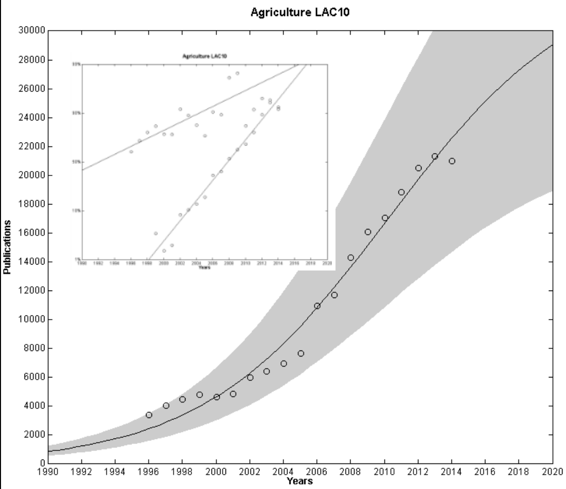
Source: (Notes Desk, 2009).

Figure 19. Phases of Development

Agricultural Sciences LAC10

Agriculture and Biological Sciences

K	34,093
tm	2010
Δt	25



Veterinary

K	3,891
Tm	2007
Δt	16

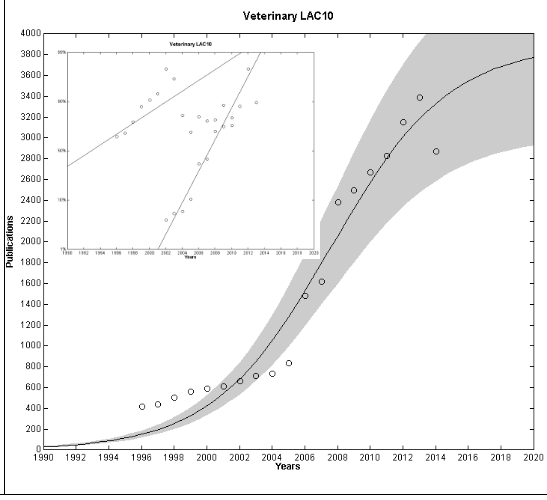


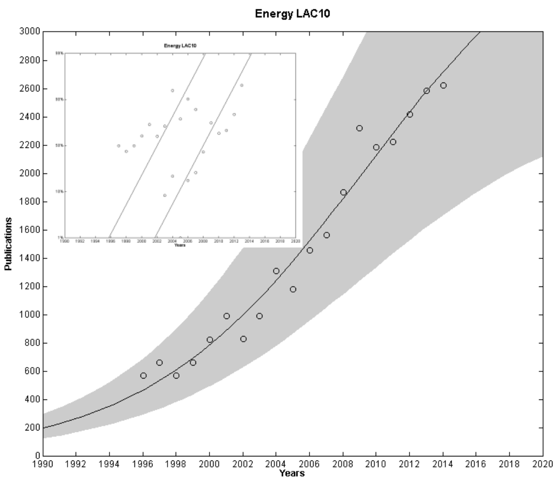
Figure 20. Growth Trajectory of Agricultural Sciences, 1996-2014

In terms of scientific output, the field of agriculture and veterinary were the ones that showed the biggest increment in the two periods addressed in Figure 10 on page 30. Agricultural Sciences in LAC10 are lead mainly by Brazil with more than 57 percent of total output, followed by Mexico with 13.3 percent and Argentina with 11.6 percent (SCImago, 2016). To a certain extent, this could be explained by Brazil's vast territory endowed with abundant natural resources and wildlife found in the amazon rainforest where the country strengthened its research capacity towards two core areas: agriculture, plant and animal science from the 2000s (Fink, Kwon, Rho, & So, 2014).

Therefore, both fields have a growing phase of development (main figures) and a converging pattern of growth (smaller figures at the upper left part), indicating that the improvement in the quantity of papers produced, more than 35 percent for agriculture and 27 percent for veterinary from 1996-2005 to 2006-2014 period, caused the second pulse to surge form the first allowing both, the growth rate (*Δt*) of the process and the carrying capacity (*k*) to increase by extending the life-cycle of the development process.

Engineering and Technology LAC10

Energy		**Engineering**	
K	4,034	K	15,712
Tm	2009	Tm	2005
Δt	29	Δt	22



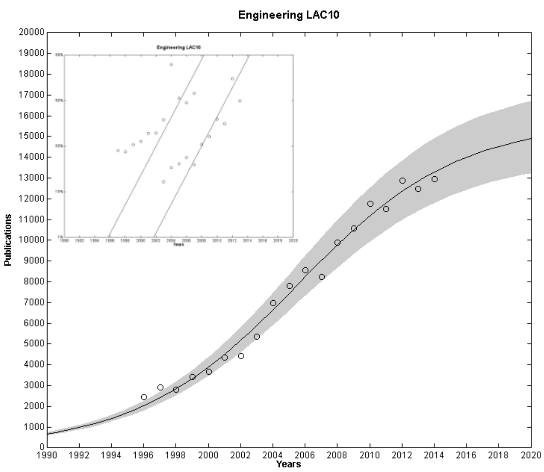


Figure 21. Growth Trajectory of Engineering and Technology, 1996-2014

According to Table 1 on page 29, Engineering and Technology field represents 15.9 percent of total scientific output of LAC10. Figure above shows two growing phases of development (main figures) and two superposed growth trajectories (smaller figures at the upper left part), indicating that the second pulse started growing when the first one reached 50 percent of its total capacity, i.e., around the year 2006. Therefore, there are two processes growing concurrently.

Engineering and technology output is lead mainly by Brazil, with more than 47 percent for each field, followed by Mexico with 23 percent, Argentina with 8 percent and Colombia with a share of 6.8 percent for energy (SCImago, 2016). The percentage of researchers that comprised the engineering community in LAC reached a level similar to the U.S. where leading countries in the field such as Argentina, had the second greatest percentage of researchers destined to this area with 18.7 percent in the year 2006 (Velho, 2004; RICYT, 2016). Additionally, total R&D investment for engineering and technology sector has represented a historical tendency to be a priority not only for Argentina, reaching the highest level of total investment with 38.55 percent in the year 2004, but also for Chile, another preeminent country, with a total investment of 43.26 percent for the year 2008 (RICYT, 2016).

On the other hand, Brazil accounts for 47.5 percent of total output in energy and it is said to be the leading country in clean energy innovation where researchers have focused on a vast portfolio of clean energy technologies, mainly in bioenergy as well as biogas production (Miller & Viscidi, 2016). As illustrated by Emodi, Bayaraa, and Yusuf (2015), the Brazilian government expenditure on energy research, development and deployment (RD&D) reached its peak in 2006 with a total investment of 424 USD millions which included renewable energy sources as well as fossil and nuclear energy. Additionally, Colombia has a rich endowment of energy resources such as hydro, coal, oil, gas and biofuels (Currie, 2016), where over the past decade the oil industry has been at the center of Colombia's economic growth (Oxford Business Group, 2016). However, non-conventional sources of energy such as biomass have captured the attention for further development. This results from the positive outlook that present the large waste volumes produced by forestry and agriculture (coffee, banana plantations, rice and livestock) within the country, with biomass projects being developed (Currie, 2016).

The previously described situation might explain the superposed growth trajectory for energy in LAC10 by having a co-development of traditional as well as non-conventional sources of energy within the region.

Humanities LAC10

Arts and Humanities	
K	5,062
tm	2011
Δt	16

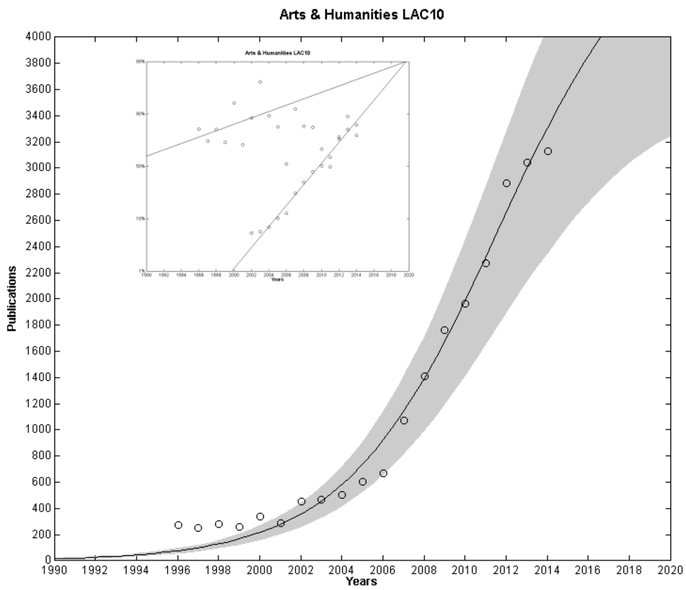


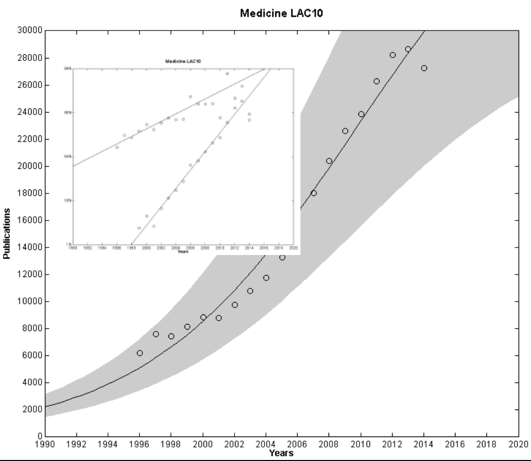
Figure 22. Growth Trajectory of Humanities, 1996-2014

Humanities also shows a growing phase of development and a converging pattern of growth (smaller figure in the upper left part) indicating that there was a revival of the development process of liberal arts around the year 2012. This area is lead mainly by high-producers: Brazil represents 38.4 percent of total output, followed by Argentina with 15.9 percent, Chile with 15.8 percent and finally Mexico with 15.3 percent (SCImago, 2016). In this context, there has been an increment in R&D expenditure regarding humanities with +2 percent for Argentina when comparing the years 2005 and 2014, +2.8 percent for Chile for the years 2009 and 2013 and finally, +3.67 percent for Uruguay when considering the years 2008 and 2014 (RICYT, 2016). Argentina, in particular, seems to place special attention towards the development on arts and humanities, having an increment from 12 percent of total output in 2007 to 18 percent in 2008 (Huggett, 2012). In this line of thought, in the year 2012, the country experienced an increment in the number of students enrolled in humanities at university level, representing 17 percent of total new students (Ministerio de Educación de la Nación , 2012).

Medical and Health Sciences LAC10

Medicine	
K	45,678
Tm	2009
Δt	29

Pharmacology, Toxicology and Pharmaceutics	
K	5,372
tm	2007
Δt	33



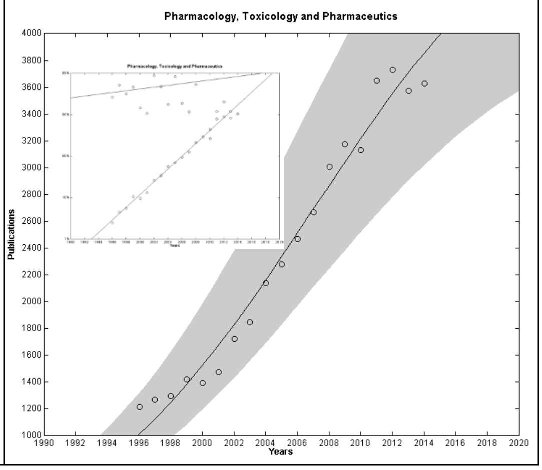
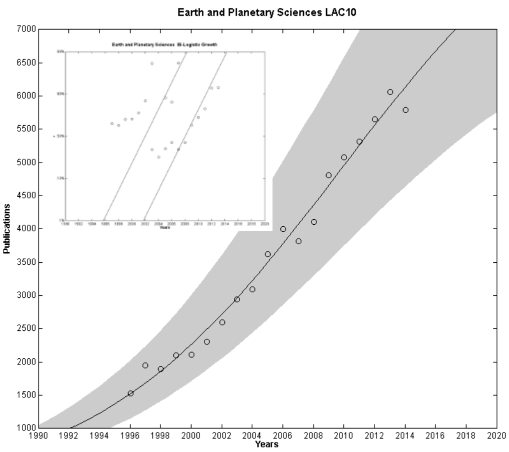


Figure 23. Growth Trajectory of Medical and Health Sciences, 1996-2014

Medical and health sciences represent the largest field in LAC10, accounting for a total of 32.4 percent of scientific output for the period 1996- 2014 (Table 1 on page 29). Figure above shows for both fields a growing phase of development and a converging growth trajectory where the second pulse, characterized by a faster Δt and higher carrying capacity, might be explained by the fact that some of the leaders in medical and health science output, i.e., Brazil, and Chile, increased their scientific production from 1996-2005 to the next period, 2006-2014. When assessing individual contribution to this area, Brazil emerged as the main leader by providing more than 52 percent of output for each area, followed by Mexico with more than 14 percent and Argentina, slightly above 11 percent. Additionally, Brazil, Argentina, and Peru have official health research priority agendas focused on specific research subfields and, since the year 2003, the Brazilian government has increased funds and grants for scientific research including public health (Martins Emmerick, Oliveira, Luiza, Azeredo, & Bigdeli, 2013).

On the other hand, it is important to highlight the Cuban case; despite pertaining to the low-producers group in terms of total scientific output from LAC10, medicine represents the main scientific field for the country, with a total share of 29.3 percent considering the 1996-2014 period. As mentioned before, the Cuban government devotes particular attention to the development of health care sector and because of integrated efforts, Cuba ranks fifth for medicine output and fourth for pharmacology scientific production among LAC10 countries despite having a lower level of labor force and economic resources, thus, surpassing high-producers such as Chile and Colombia. These results lead us to presume that the focus towards medicine and pharmacology or, in other words, the high degree of specialization, as shown in Figure 15 page 40, have contributed to the positive evolution of the medicine field for LAC10 as a whole.

Natural Sciences LAC10			
Earth and Planetary Sciences		**Physics and Astronomy**	
K	9,800	K	15,190
tm	2009	tm	2002
Δt	36	Δt	30



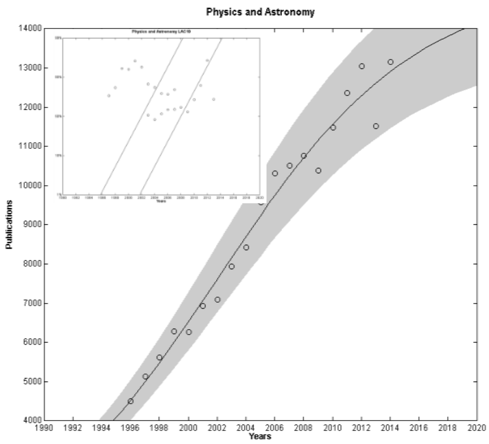


Figure 24. Growth Trajectory of Natural Sciences, 1996-2014

Natural sciences represent the second biggest field after medicine for LAC10 in terms of weight, as it has a total output of 22.2 percent including earth and physics fields combined (see Table 1 page 29). Once more, the main drivers of this area are Brazil, producing more than 32 percent of total output for each area; Mexico, with more than 21 percent; Argentina, with more than 13 percent and Chile with than 9.7 percent for physics and 17.8 percent for earth and planetary sciences. In figure above can be appreciated that there is a growing phase development and a superposed pattern of growth for both fields given the co-existence of both positive and negative, or even neutral growth from leading countries in natural sciences. In the case of earth and planetary sciences, this could be partly explained by the fact that even though Brazil incremented its share of scientific output by 6.1 percent from 1996-2005 to 2006-2014 period, Mexico declined by 5.2 percent and Argentina also declined around 3 percent. As recognized by OECD (2015) and as shown in Figure 16 page 42, Chile has a clear specialization, within its scientific output, towards earth and planetary sciences (see Appendix D) due to the fact that the country is one of the biggest earthquake-prone nations in the world (Chilean National Seismological Center, 2016). Therefore, despite the declining rate of others high-producers, the country was able to improve its total share of output in LAC10 by 2.8 percent.

On the other hand, physics and astronomy field decreased its Revealed Comparative Advantage from 1.3 to 1.0 in the last period considered. This may be explained due to the fact that Brazil (the main driver) did not increase its share of papers in relation to LAC10, maintaining it at 43 percent during the two periods analyzed. Therefore, it could be claimed that the country could not keep the production pace increments relative to other countries either (Fink, Kwon, Rho, & So, 2014). In contrast, Muriel (2012) stated that Argentina became the first non-European country to become a member of the Astronomy and Astrophysics (A&A) journal in 2004, which is considered as one of the principal journals for astronomy in the world, showing a clear preference from Argentinian astronomers for publishing in European journals since then (Muriel, 2012).

Additionally, over the last decades, Chile has become one of the world-leading countries in the field of astronomy, on accounts of the clear sky conditions, dryness and altitude characteristics offered by the Atacama Desert (ALMA Observatory, 2016). The country is an part of diverse international collaboration programs and hosts most of the most powerful astronomical ground-based observatories on Earth, e.g., Atacama Submillimeter Telescope Experiment (ASTE), European Extremely Large Telescope (E-ELT) and Atacama Cosmology Telescope (ACT), among others (Bronfma, 2002). In light of the proliferation of observatories since 2004, Chile was able to standout in physics activity in regards of quantity and quality (Soto, et al., 2008).

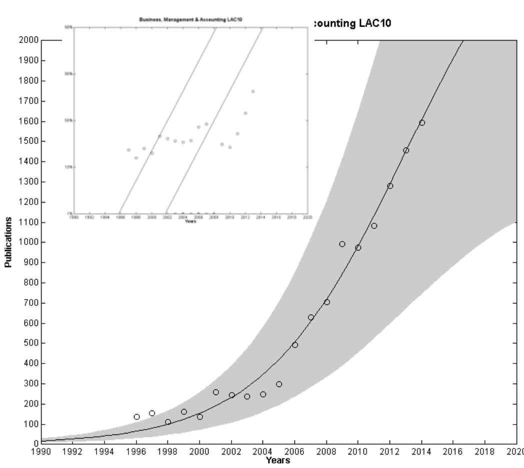
Social Sciences LAC10

Business, Management and Accounting

K	2,894
tm	2013
Δt	20

Social Sciences

K	9,402
tm	2009
Δt	13



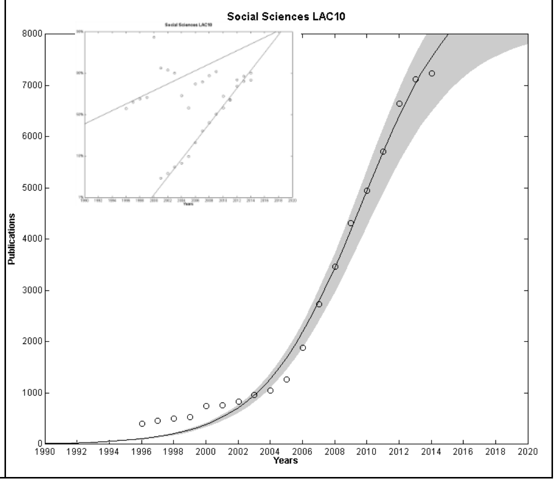


Figure 25. Growth Trajectory of Social Sciences, 1996-2014

Social sciences represent a total output of 5.8 percent for LAC10 including business and social sciences fields combined (see Table 1 page 29). Once again, the main drivers of this area are Brazil, producing more than 46 percent of total output for each area; Mexico, with more than 15 percent and lastly, Argentina and Chile with more than 9 percent each. In figure above we can observe that there is a growing phase development and a superposed growth trajectory for business and converging growth for social sciences. As discussed previously, business-related research increased its RCA during the last period analyzed. Several studies have stated that business and management research is growing at a considerable pace in Latin America and research institutions are experiencing a strong expansion with a huge increase in the number of publications in international journals (Rivera-Camino & Gómez-Mejía, 2006; Carneiro & Brenes, 2014; Coronado, F., Merigó, J. M., & Cancino, C., 2015). Additionally, the main leading institutions in business and management research in Latin America are found in Brazil, Chile and Mexico, with general management, finance and innovation and entrepreneurship as very relevant topics for the region. Specifically, the University of Sao Paulo ranks first in terms of number of articles published from the year 2010 (Coronado, Merigó, & Cancino, 2015). Lastly, Koljatic and Silva (2001) found that Argentina, Brazil, Chile, and Mexico were the only Latin American countries with significant research production in regards of business and management research.

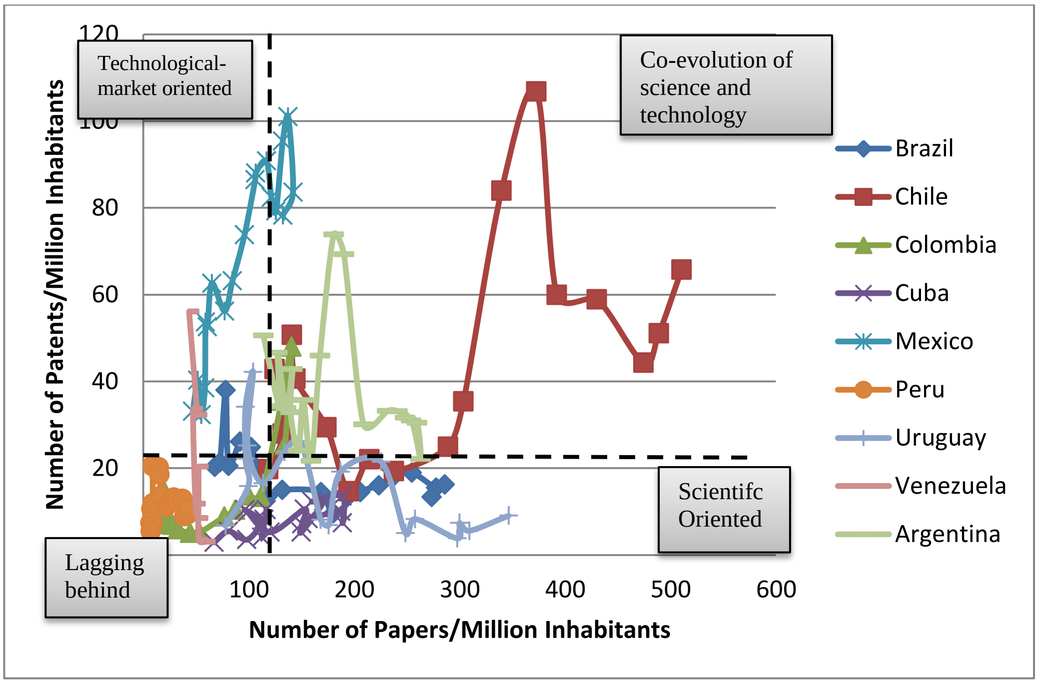
On the other hand, in the year 2010, Argentina reached the highest number of researchers dedicated to social science investigation with a total of 22.85 percent and also, began allocating resources above 9 percent of R&D expenditure to social structures and relationships when considering socio-economic objectives (RICYT, 2016). Furthermore and according to UNESCO (2010), the number of postgraduate programs in Latin America has risen sharply in recent years with a focus towards education and law. In Brazil, 58 percent of doctoral programs based on social sciences were evaluated as high level courses in 2008. Moreover, in terms of total publications, the country moved from twenty-third position in 1999 to fifteenth in 2008 according to the Thomson ISI database. All the aforementioned situations leads us to presume that the rise of the second pulse characterized with a faster Δt and higher carrying capacity ,k, for social sciences was influenced by the measures taken from the year 2008 by Brazil and Argentina in terms of human resource capital, R&D expenditure and increment of postgraduate programs.

5.4 Science and Technology Innovation Trends of LAC10

The following sub-section attempts to appraise the scientific and technological innovation trends of selected economies from LAC10 from 1996 to 2014. According to the methodology presented by Wong, Mohamad, Keng, and Azizan (2014, p. 796), it is possible to identify the innovation trends of countries in regards of science and technology levels by mapping the dynamics of publications and patents over time.

Figure 26 below depicts the different growth trajectories of selected countries[9] as measured by the quantity of published papers and granted patents per million inhabitants.

[9] Puerto Rico was not included in the analysis due to the lack of information of patents in RICYT.



Note: Dotted lines indicate sample average of 2005.

Figure 26. Patents versus publications per million inhabitants, 1996-2014

Overall, it can be observed that there is a distribution over the four quadrants including the nine countries considered but each of them with different trajectories. Countries such as Argentina, Chile, Mexico and, to a lesser extent, Colombia were able to be present in the upper right quadrant for a number of years, indicating the existence of a co-evolution between scientific research activities (publications) and industrial technological development (patenting). However, with the exception of Chile, countries seem to have lost interest in developing patenting activities in later years.

Countries that were clearly present in the upper left quadrant were Venezuela and Mexico, signaling a faster catching up rate for patenting than in publishing. On the other hand, countries that relied more on scientific production (lower right quadrant) were Brazil, Cuba, Peru and Uruguay. Finally, even though scientific output grew steadily over the years, Peru represents the only case that seems to have an unchanged position by remaining on the lower left quadrant during the whole period considered, in other words, lagging behind for publications and patents production in comparison to LAC10 average.

Evidence seems to demonstrate a mixed picture represented by three types of groups[10]: science-oriented, technology-to-science oriented and, co-evolution oriented. The first group, composed by Cuba and Peru (figures below), shows growing trajectories that remained in the lower quadrant with no significant development of technological or market oriented capabilities. Peru's low performance could be partly explained by the scarce allocation of resources towards R&D and science and technology (The World Bank, 2014) when compared to other countries within LAC10.

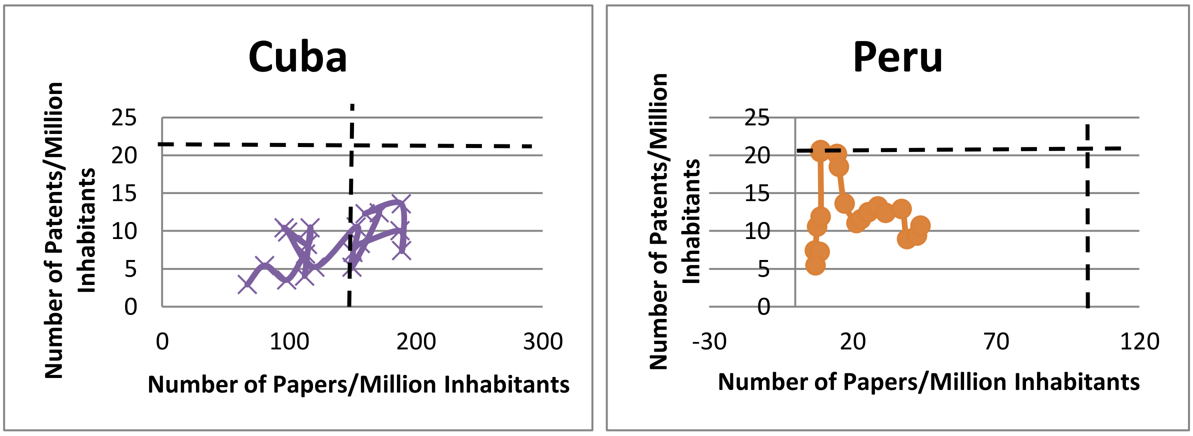


Figure 27. Science-Oriented Countries

Nonetheless, Cuba has had an inclination towards acquiring patents related with medical and health sciences given the commitment of the Cuban government towards

[10] Venezuela was not included in any group given the lack of information since the year 2000, which made infeasible to discern country's innovation trend.

the development of the health sector, consequently acquiring patents related with cancer, dengue fever and meningitis B and even leading the number of patent acquired per million population in 2003 in this area when compared to other developing countries (Quach, et al., 2006). Moreover, when considering USPTO database, the total number of patents granted are quite modest in comparison with the European Patent Office, this could be attributable to the longstanding US embargo, which had limited economic options and access for Cuba on different areas (Thorsteinsdóttir, Sáenz, Quach, Daar , & Singer, 2004). Furthermore, the capability to generate patents of this science-oriented group is relatively lower when compared to other countries, suggesting a gap to be narrowed. However, on account of recent efforts of the Peruvian government to improve innovation capacity as well as national research (The World Bank, 2014) and following the 2014 rapprochement of diplomatic relations between Cuba and the U.S., it is expected that both countries experience an increment of publishing and patenting share in the following years.

The second group, technology-to-science oriented, is composed by Brazil and Uruguay as follows:

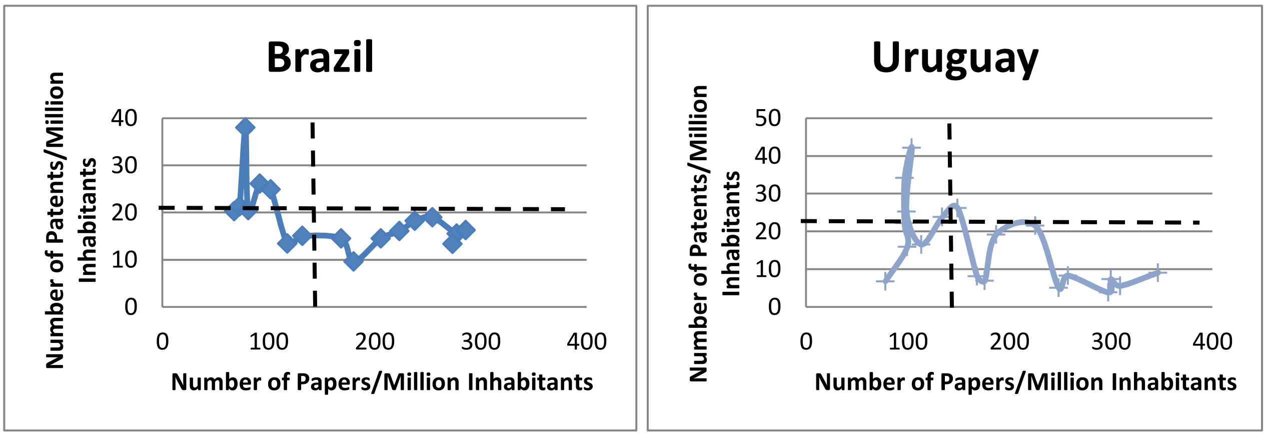


Figure 28. Technology-to-science oriented countries

As can be appreciated, this group is characterized by a change in its overall catching-up trend, shifting from technological-based to basic research activities since 2002, with a clear declining in patenting share followed by a surge in the number of publications per million inhabitants. According to the European Commission (2003), until 1999, Brazil was considered one of the fastest growing countries worldwide in terms of average annual growth rate in patent share, however, and as shown in this study, its patenting activities declined greatly in favor of scientific output. These findings are in line with Dias and Barbosa de Almeida study (2013), where author stated that Brazil suffers from a detachment between applied research and technological production. The declining share of patenting might be partly attributable to the fact that pharmaceutical field, for which Brazil accounts for 55.4 percent of total LAC10 output between 1994 and 2014, has had significant modifications regarding intellectual property management for drugs patenting (Shadlen, 2009). The 1996 Patent Law is considered to have on average a 10–year backlog and excessive bureaucracy which represents a patent system that is not aligned with international standards nor embodies a world-class patent system (Licks, 2013). Therefore, posing difficulties to obtain private ownership over knowledge.

In the case of Uruguay, according to Chinchilla-Rodríguez et al. (2015) for the period 2003-2011, the country had the highest number of researchers, a significant level of international collaboration and greater visibility for its scientific output in comparison with other Latin American countries regarding Public Health research area. In contrast, Velho (2004) stated that Uruguay was one of the countries with the most unfavorable position in terms of patent application; the nation experienced a notable reduction of 72 percent in the number of resident patent application from 1995 to the year 2000. These conclusions are in line with results where Uruguay experienced a reduction of patents creation but had the third highest rate for papers per million inhabitants from the cases studied.

The last group (and the predominant one) is called co-evolution oriented (figures below). Despite having different capabilities in their initial stages of catching-up development such as technological-market or scientific oriented, countries from this group (Argentina, Chile, Colombia and Argentina) grew towards the upper right quadrant indicating the birth of a co-evolution mechanism between industrial technological development and scientific research activities.

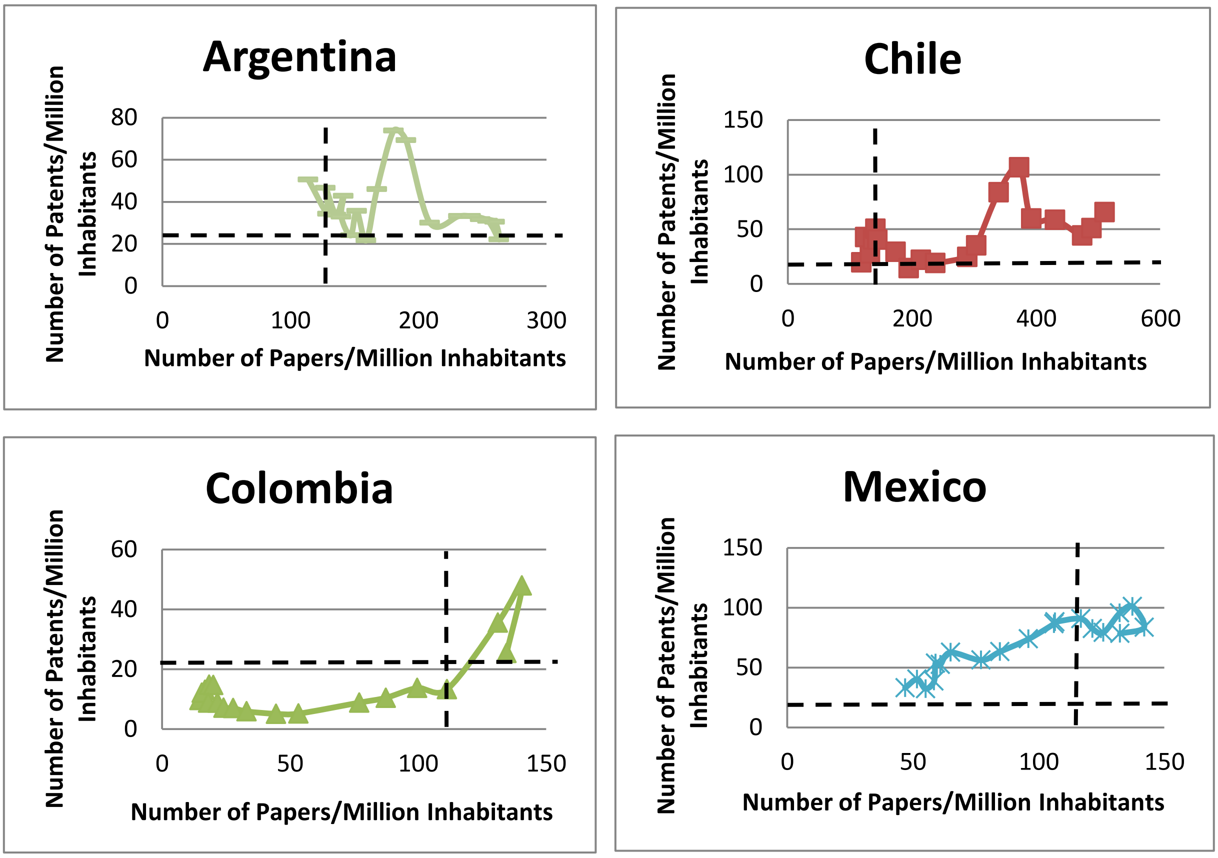


Figure 29. Technology-to-science oriented countries

According to Urquidi (2005), Argentina and Mexico possess official policy programs that promote technological information through the patent offices found in these countries: the National Institute of Industrial Property (INPI) in Argentina and the Mexican Institute of Industrial Property (IMPI). More specifically, since the year 2002, Argentina has focused on physics-related technology transfers processes (including patenting) through the Argentine Institute of Radio Astronomy (IAR) (Muriel, 2012). In the case of Mexico, since the incorporation of Mexico to the PCT in 1995, patents applications via this treaty increased 42 percent with 5,000 more applications annually, 40 percent of these related with chemistry and 25 percent with pharmaceutical areas (Urquidi, 2005). Moreover, Mexico's universities and research centers have incremented the number of patenting related with clean energy technologies (Miller & Viscidi, 2016).

Colombia witnessed a notable increment of national patent applications as reported by the Industry and Commerce Superintendence (SIC) (2016), being mechanical engineering the area with the highest number of applications (105 inventions), followed by chemical processes (59) and electricity, electronics and telecommunications (47).

In addition, given the importance of the mining industry in Chile, which provides approximately 20 percent of its GDP and represents 55 percent of its exports (Central Intelligence Agency, 2016), it is not unusual that universities associate with leading mining companies with the objective of developing renewable energy projects for mining operations. Additionally, researchers have patented and commercialized technology related with energy efficiency solutions and clean energy technology that utilizes renewable resources such as ocean, solar energy and biomass (Miller & Viscidi, 2016). Moreover, since the creation of the National Institute of Industrial Property (INAPI) in 2009, Chile has witnessed a significant increase in the registration of patents and inventions, with an average of 3,640 applications per year and more than 10,000 patent registrations over the last decade (Chilean Ministry of Economy, Development and Tourism, 2016). This seems to indicate a positive support to the development of technology.

Overall, when considering patents per million inhabitants, leading countries are Mexico, Chile, Argentina and Brazil. On the other hand, when considering publications, leaders are Chile, Argentina, Uruguay and Brazil.

CHAPTER 6

6 Conclusions and Policy Recommendations

This research aimed to assess scientific and technological production capabilities of LAC10 for the period 1996 to 2014. The countries of the region that lead scientific and technological production are Brazil, Mexico, Argentina, Chile and Colombia. Additionally, Cuba demonstrated significant competency in scientific output for Medical and Health Sciences given the role of the government in this area.

Overall, LAC10 scientific output during the aforementioned period achieved or surpassed world average in six out of eleven fields considered; aggregated in Agricultural Sciences (agriculture and veterinary fields), Natural Sciences (physics and earth sciences) and lastly, Medical and Health Sciences (medicine and pharmacology). These results are in line with national research objectives and governmental priorities present in the region. On the other hand, the least developed field was business where none of the countries demonstrated competency by reaching world average neither in output nor impact. Moreover, scientific impact as a whole showed serious deficiencies where only Natural Sciences fields (physics and earth sciences) reached same level as world average during the last period analyzed (2006-2014); consequently, none of the fields were able to surpass world base. This situation calls for further integration of LAC in the international science framework by improving its Relative Citation Impact (RCI) through the strengthening of international collaboration research focused on issues that are relevant for the global scene as well.

Depending on the capacity of each country to surpass (or not) LAC10 average for cumulative number of publications and citations received during 1996 and 2014, two groups were distinguished: high-producers composed by Brazil, Mexico, Argentina, Chile and Colombia and low-producers, conformed by Venezuela, Peru, Puerto Rico, Uruguay and Cuba. In terms of individual contribution, Brazil represents a great influence towards LAC10 average since the amazon country accounts for 48.7 percent of total publications and 40.8 percent of total citations received in LAC10. Therefore, Brazil has the potential to push the block's performance up or down when experiencing a significant change in its scientific output and/or impact.

When considering individual contributions, it is easy to discriminate between high and low producers through a simple quantitative analysis, nonetheless, when assessing international quality and visibility of each LAC country, nations with a low or moderate level of evenness of quality between its scientific fields, i.e., Brazil, Colombia, Cuba, Mexico and Venezuela form part of the low performers group, while nations with a broad unevenness of quality, i.e., Argentina, Chile, Peru, Puerto Rico and Uruguay, pertain to the high performers group. This situation signals that nations that tend to have a broad unevenness of quality, meaning the quality across their different scientific fields is essentially dissimilar since there is a focus to develop specific scientific fields over others, are capable of reaching or surpassing world average in those specific areas while disregarding others.

The progressive increment of total scientific output experienced by LAC is reinforced by the growth trajectories of eleven scientific fields, all of them characterized by having a growing phase of development. Furthermore, two patterns of growth were present in this process: converging in seven fields and superposed in four, indicating an extension of the life-cycle of the development process characterized by a higher carrying capacity (K) and Δt for the former, and the existence of two process growing simultaneously for the latter. The absence of a sequential growth trajectory also reinforces this idea since there was no pause between phases of developments. On the other hand, the nonexistence of a diverging growth signals that LA10 has not succeeded in creating new growth avenues for science and technology at a greater level.

Finally, three types of innovations trends exist in LAC. First, science-oriented countries (Cuba and Peru) that focused on catching up trends related with scientific research development. Second, technology-to-science oriented countries (Brazil and Uruguay) characterized by a change in its overall catching-up trend; shifting from technological-based to basic research activities and third, co-evolution oriented countries (Argentina, Chile, Colombia and Mexico). These nations have a co-evolution mechanism between industrial technological development and scientific research activities. This scenario signals that innovations trends are characterized towards scientific research development (publications) and technological development (patents) in a fair manner: four countries currently focus on scientific publications (Cuba, Peru, Brazil and Uruguay) and for countries focus on co-evolution mechanisms between science and technology (Argentina, Chile, Colombia and Mexico).

The main conclusion is that despite the fact that LAC10 has improved its scientific output in a number of scientific fields, its scientific impact still remains below world average. This suggests that a significant quantity of scientific documents lack of international visibility and quality. This situation reflects the need to establish effective policies that could support competitiveness at an international academic level.

Additionally, economic resources should be optimized in order to enhance LAC scientific impact within the academic community.

Given the fact that leading countries in all areas regarding scientific output are the same countries with biggest socio-economic resources, i.e., Brazil, Mexico, Argentina and Chile, additional measures should be taken in order further develop the science and technological systems of other LAC countries. Different approaches should be considered in order to foster networking with international research centers to finally improve international visibility of LAC scientific publications.

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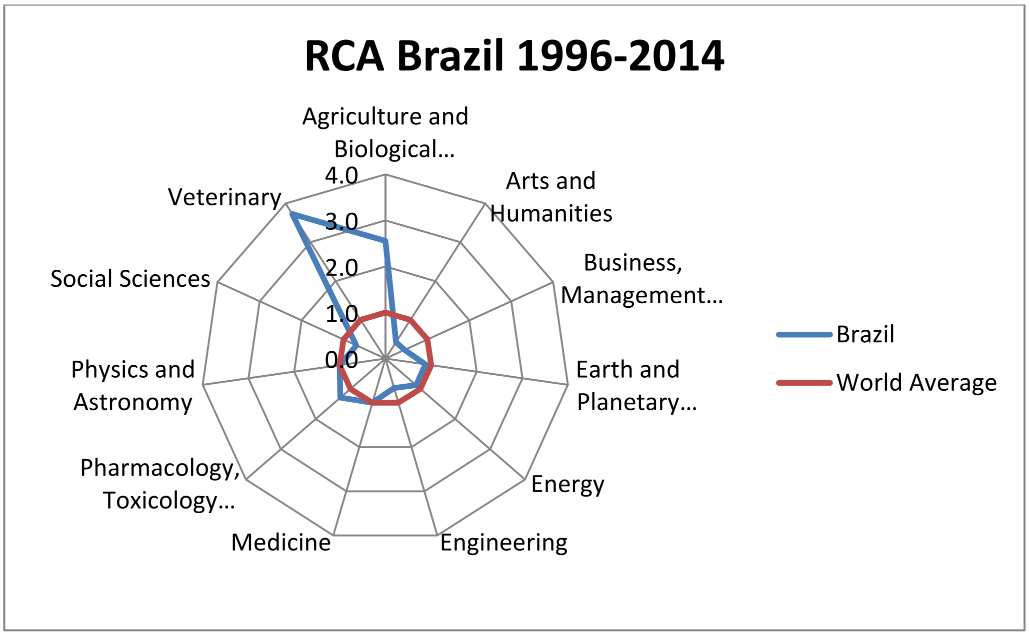
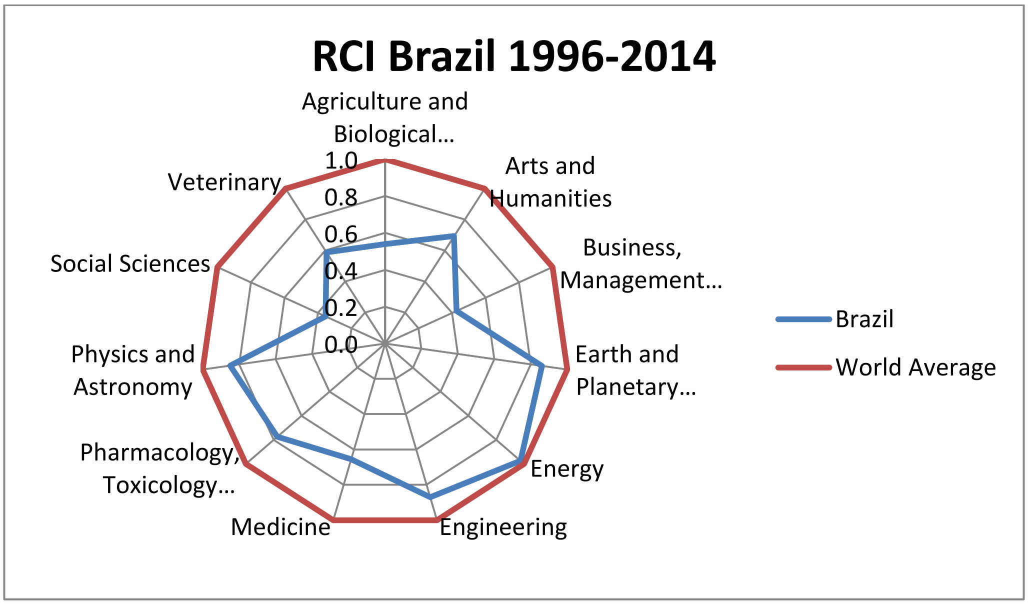
Appendices

Appendix A

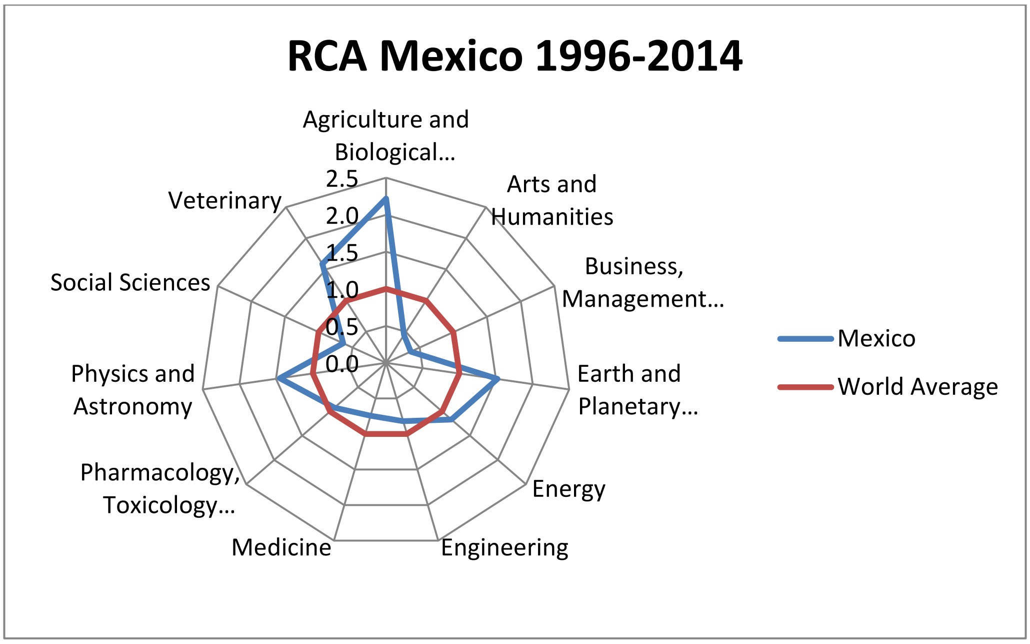
Brazil Individual Analysis of RCA and RCI.

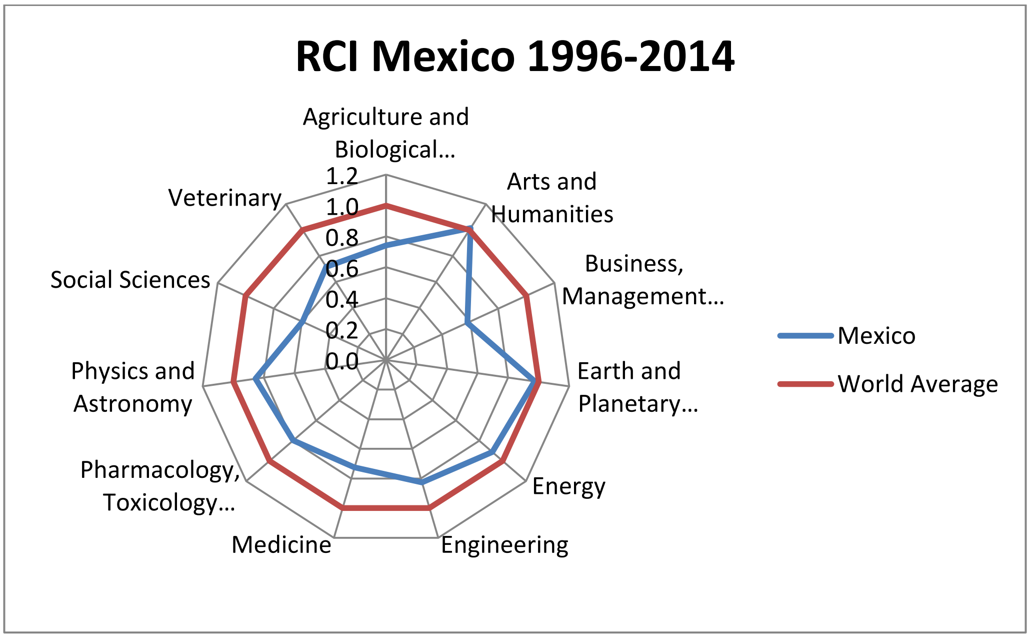




Appendix B

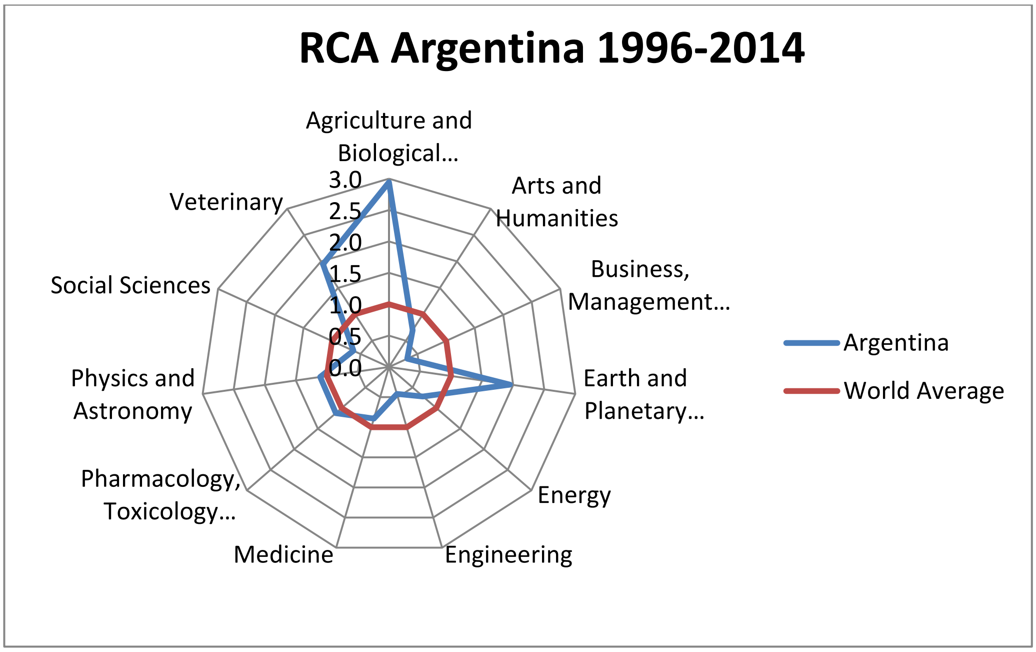
Mexico Individual Analysis of RCA and RCI.

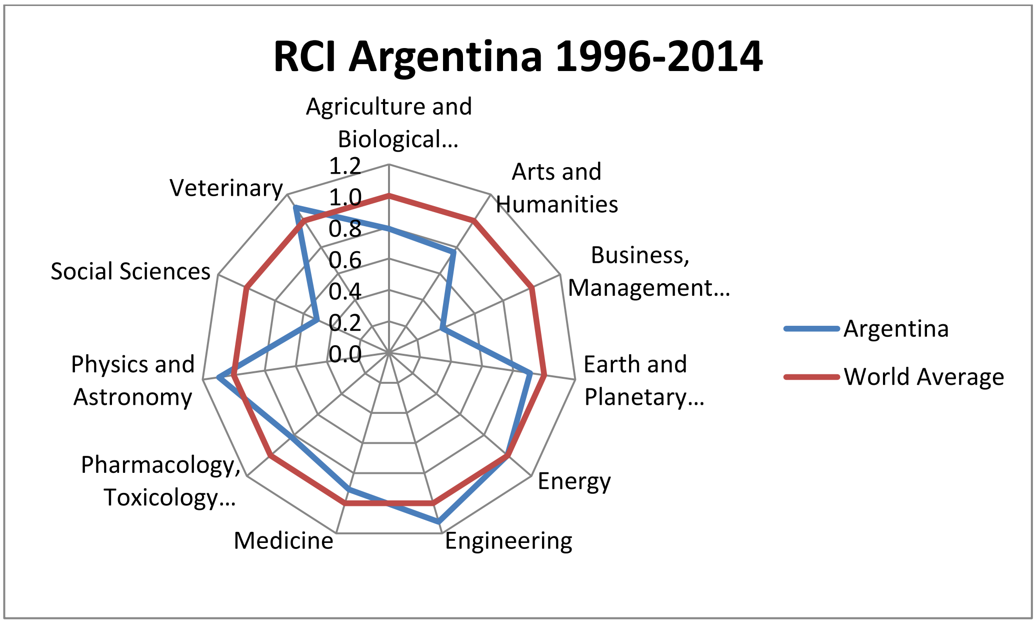




Appendix C

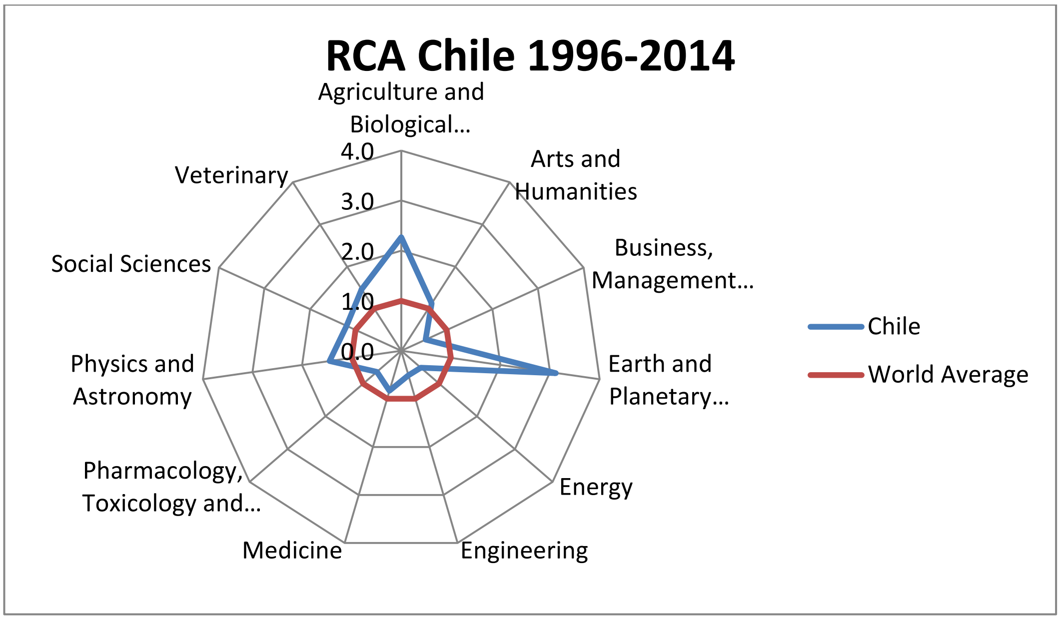
Argentina Individual Analysis of RCA and RCI.

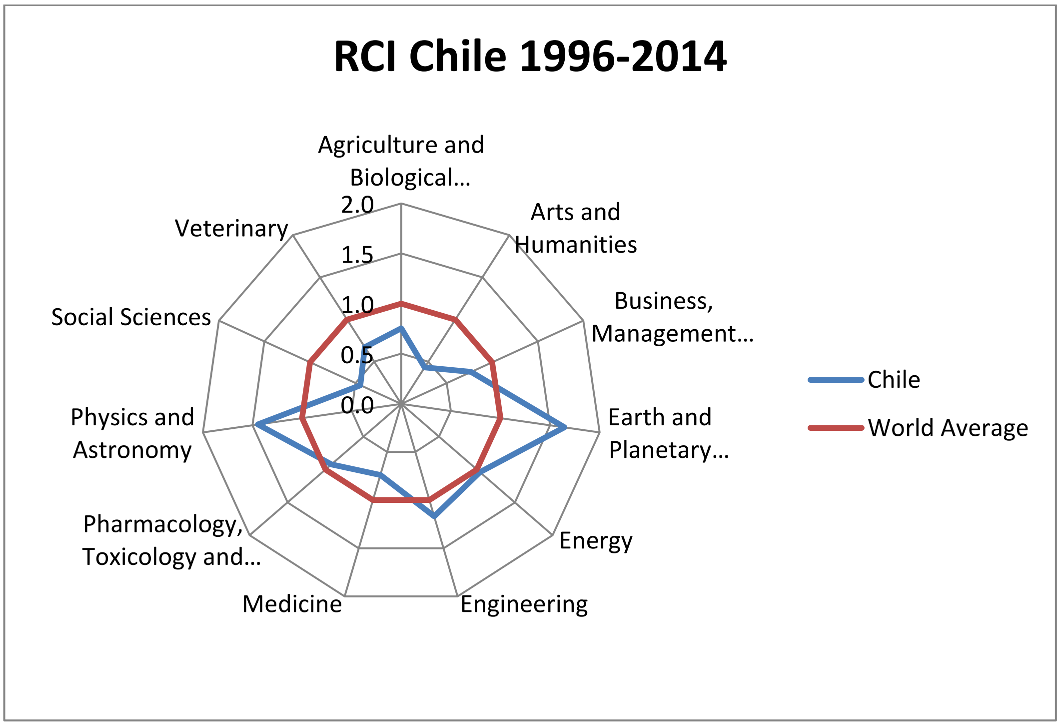




Appendix D

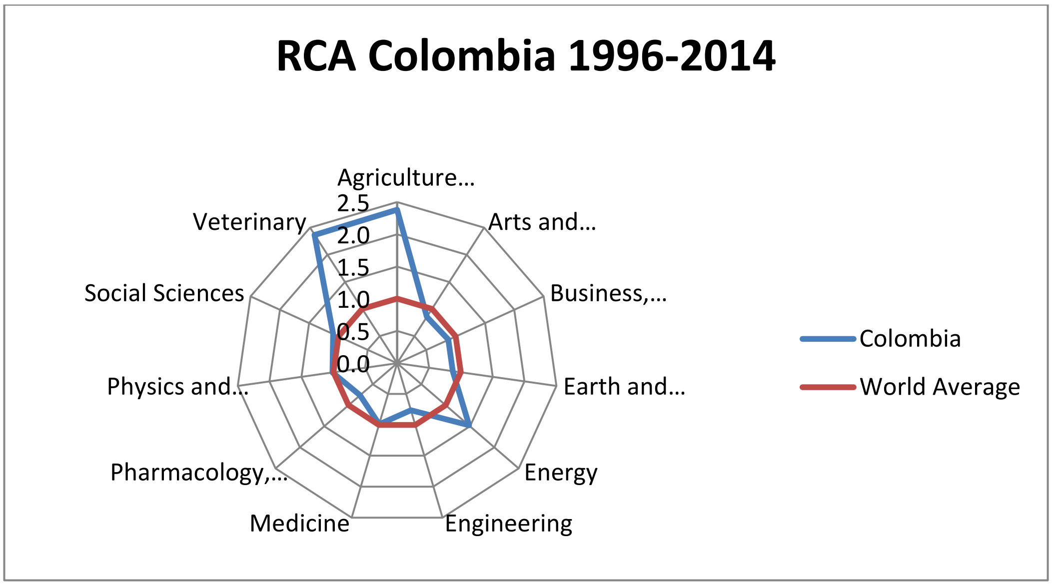
Chile Individual Analysis of RCA and RCI.

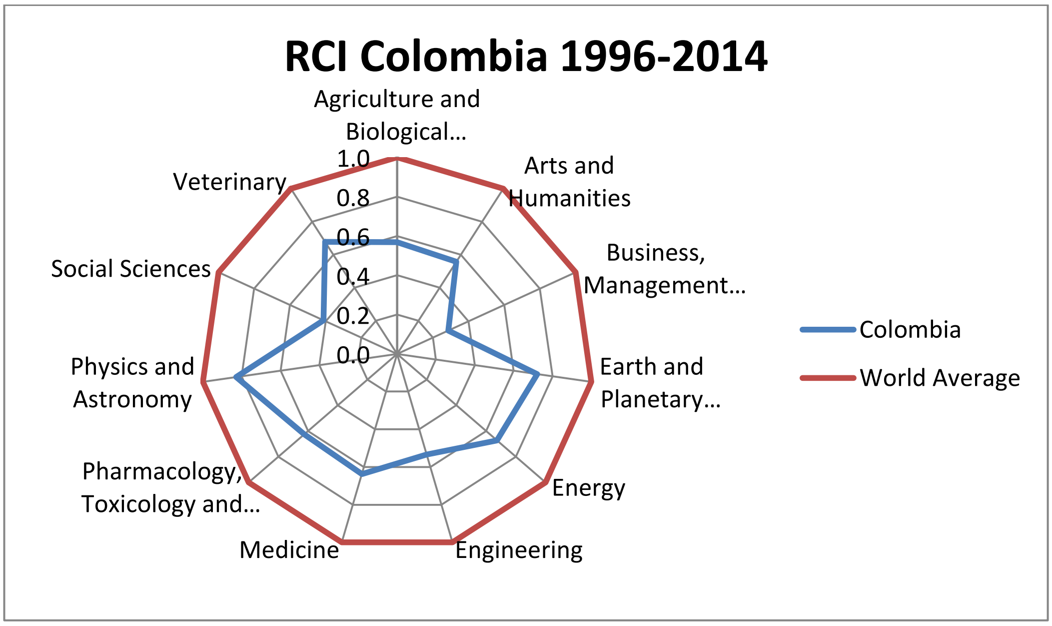




Appendix E

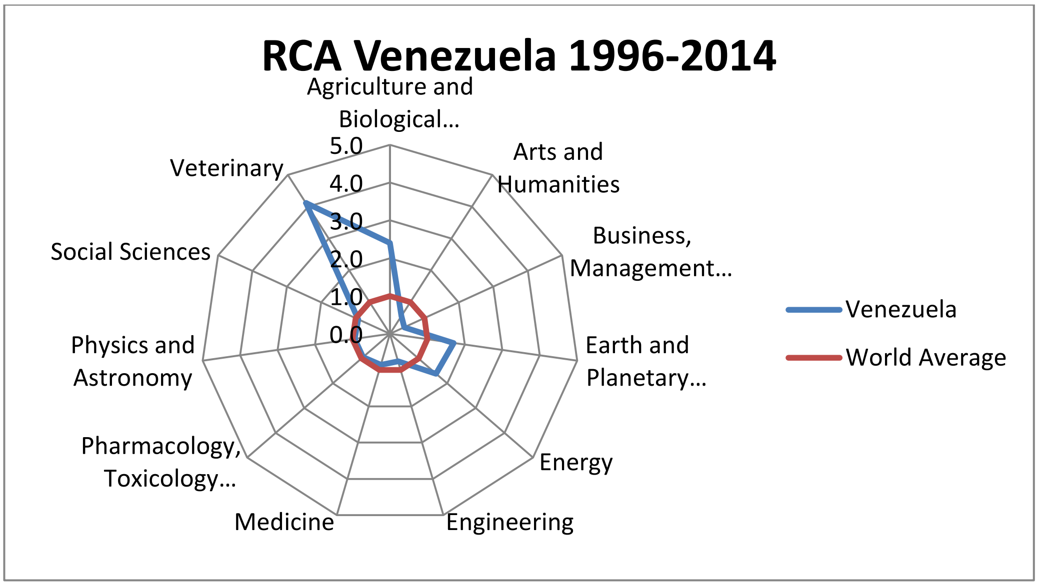
Colombia Individual Analysis of RCA and RCI.

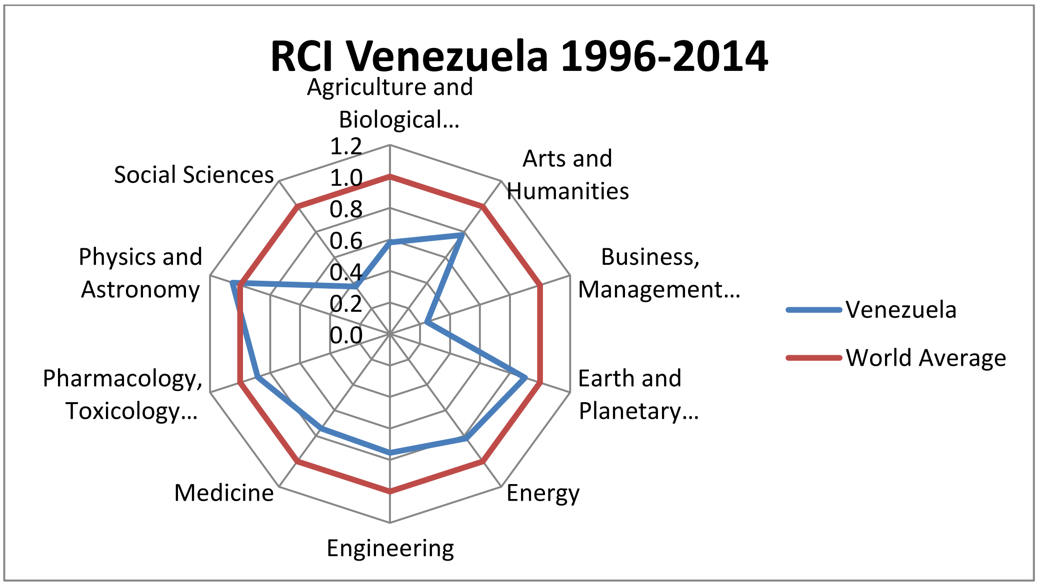




Appendix F

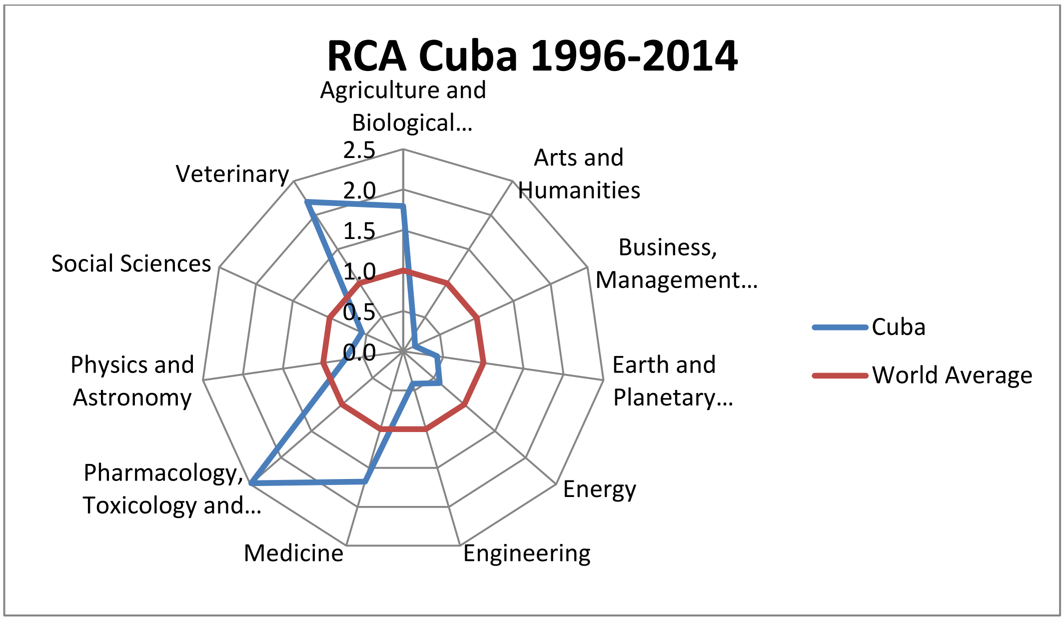
Venezuela Individual Analysis of RCA and RCI.

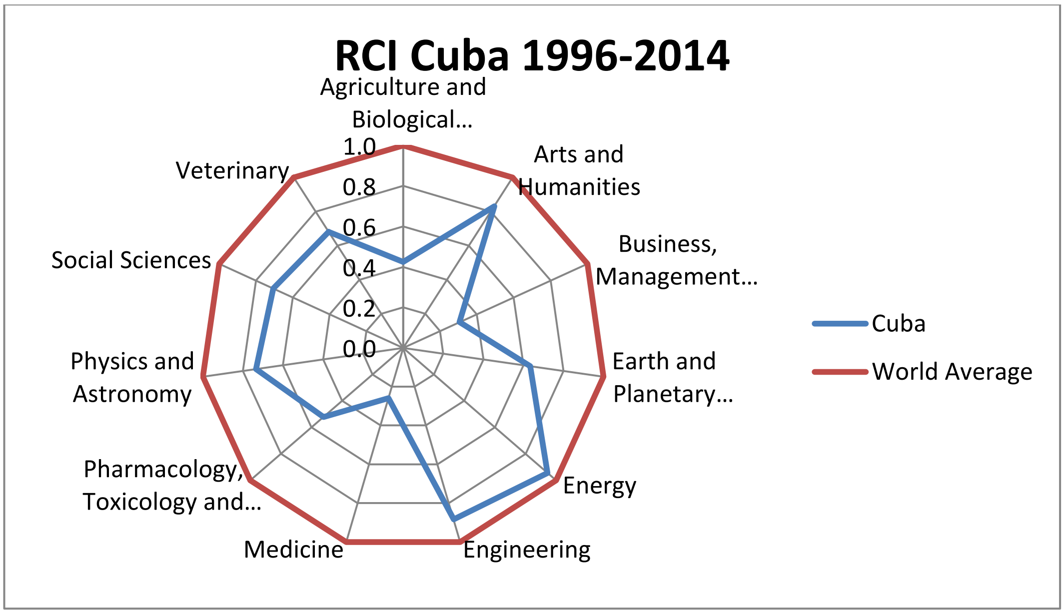




Appendix G

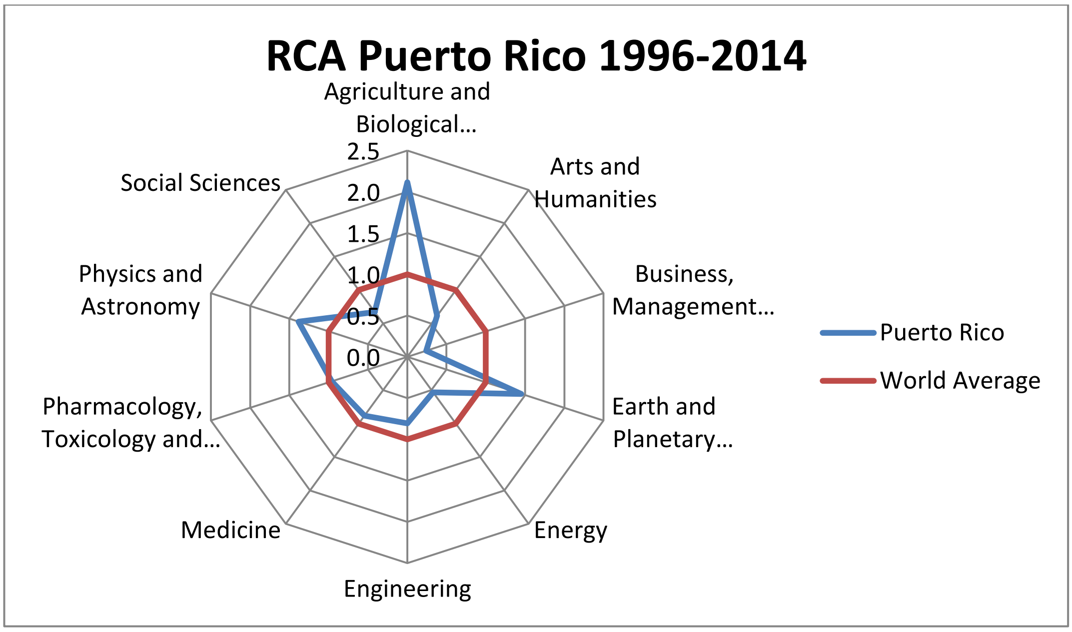
Cuba Individual Analysis of RCA and RCI.

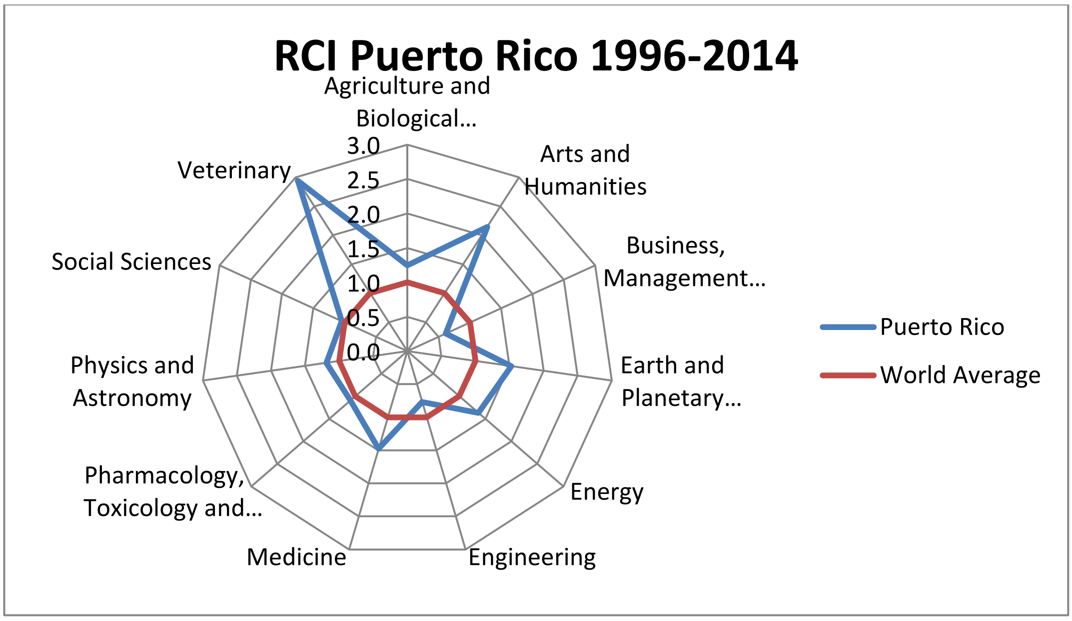




Appendix H

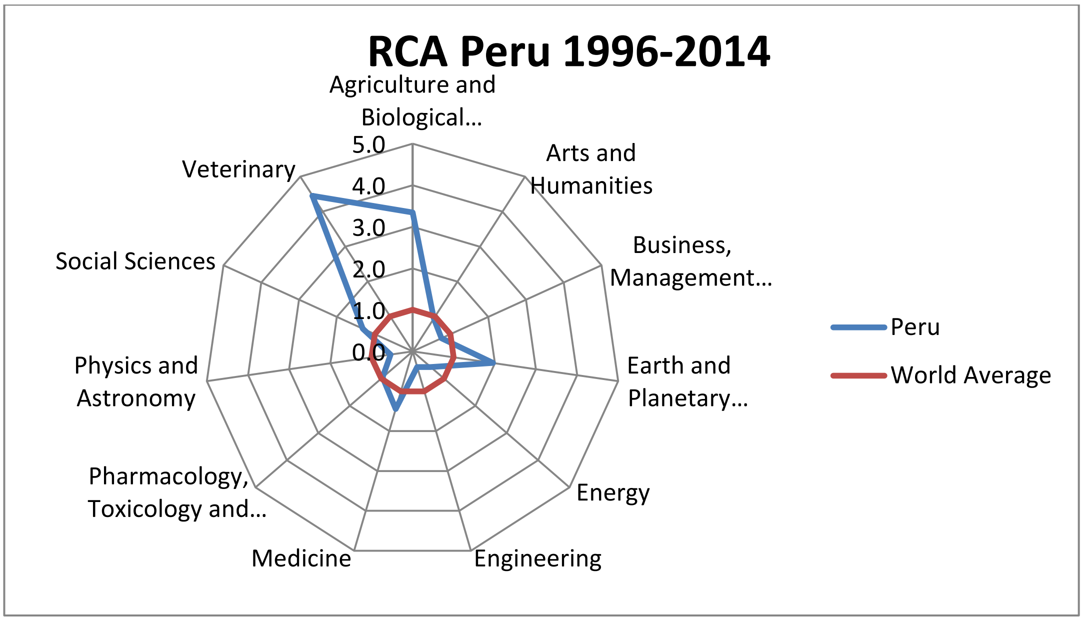
Puerto Rico Individual Analysis of RCA and RCI.

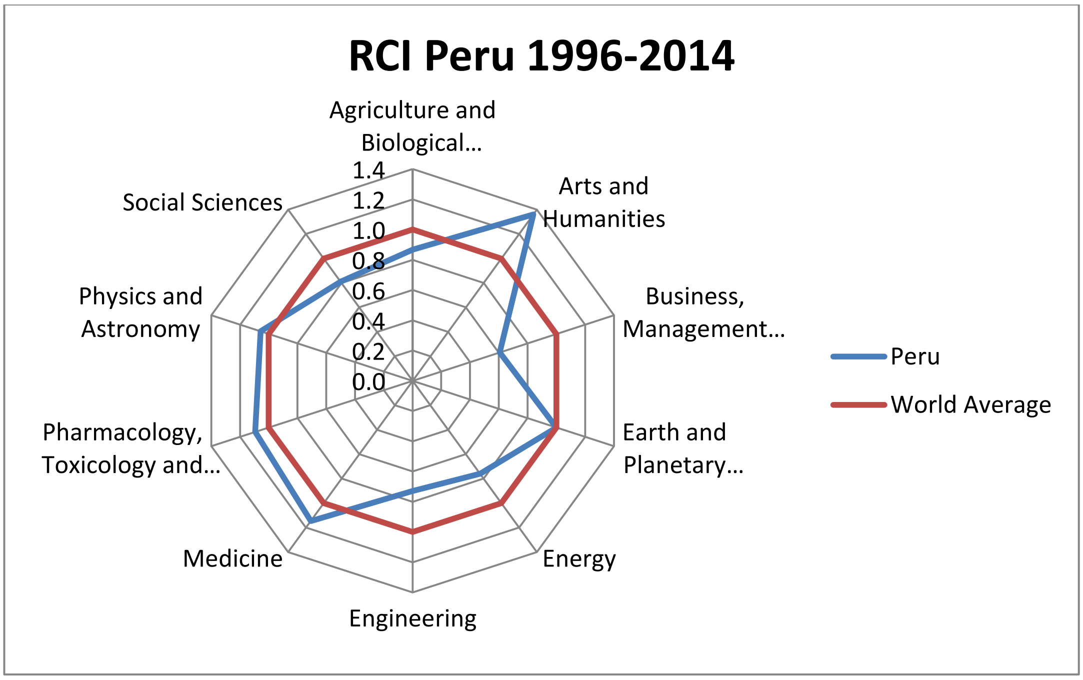




Appendix I

Peru Individual Analysis of RCA and RCI.





Appendix J

Uruguay Individual Analysis of RCA and RCI.