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Science, technology and innovation policies in Latin-America: fifteen years of scientific output, impact and international collaboration

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Introduction

During the 2000s, the election of progressive governments produced changes in the public policies guidelines of several Latin-American (LA) countries. For example, while Brazil and Argentina considered social development as a priority of scientific and technological activities, social issues remained absent in the science, technology and innovation (STI) policies of other countries such as Mexico, which mostly had conservative governments. Despite these differences, LA countries increasingly head to an alternative form of development focusing on social inclusion and sustainable development, in which science, technology and innovation play a key role. To this end, STI policies have identified key sectors that must be involved: health, nanotechnology, biotechnology, information and communication technology (ICT), clean energy, development of new materials, and cognitive sciences. Furthermore, several of these countries share common principles in their STI policies: Colombia and Mexico identify competitiveness and productivity as main goals of scientific and technological activity, while Argentina and Brazil precise that the competitiveness and productivity must respond to the social needs (Casas, Corona, & Rivera, 2014; Kreimer, Vessuri, Velho, Antonio, & Gutiérrez, 2015; Loray, 2017).

To analyse the effects of STI policies, scientific and technological indicators help to describe, assess and monitor the research and technology performance. Using three types of indicators: input (scientific workforce or funding), output (number publications or patents) and impact (citation rates), one can characterize the state of the research and the technology at the macro or micro level (Sugimoto & Larivière, 2018). Previous studies on the state of science and technology in LA in the 1980s and 1990s have explored the consequences of the STI policies on the increase of R&D expenditure, the growth of PhD graduation and the weight of scientific production in the international context (de Castro Moreira, 2003; De Moya-Anegón & Herrero-Solana, 1999; Leite, Mugnaini, & Leta, 2011). Other comparative studies have analyzed the development of scientific and technological capabilities after the stagnation period experienced in LA during the 1980s, the creation of infrastructure and the development of disciplines (Glanzel, Leta, & Thijs, 2006; Kostoff et al., 2005; Leta, Glanzel, & Thijs, 2006). Along these lines, recent studies have focused on the analysis of research evaluation policies and their impact on publication practices in regional and international levels (Chavarro, Tang, & Rafols, 2017; Vasen & Lujano Vilchis, 2017; Vessuri, Guedon, & Cetto, 2014).

This study aims at exploring the effects of STI policies on the state of research in LA since the 2000s. To do so, we analyze the scientific output and impact as well as the level of international collaboration of Argentina, Brazil, Colombia and Mexico. More specifically, we provide answers to the following research questions:

> RQ1. How did the scientific output of Argentina, Brazil, Colombia and Mexico evolve over the 2000-2015 period compared to the worldwide scientific output?
>
> RQ2. How did the scientific impact (citations) and visibility (Journal Impact Factor) of research performed in these countries evolve over the 2000-2015 period compared to the worldwide scientific output?
>
> RQ3. How did international collaboration evolve in these countries over the 2000-2015 period?
>
> RQ4. What disciplinary differences can be observed for RQ1, RQ2 and RQ3?

We also contextualize our results by analyzing socioeconomic data for each country, namely the population, the gross domestic product (GDP) and the research and development (R&D) expenditures and employment.

Material and Methods

We retrieved socioeconomic data from the World Bank databases that compile information for S&T activities from the UNESCO Institute for Statistics, the U.S. National Science Board, the UN Statistics Division, the International Monetary Fund, and the World Intellectual Property Organization (Bank, 2018). We obtained publication data from the *Observatoire des Sciences et des technologies* (OST) version of Web of Science (WoS) database. We retrieved all articles published between 2001 and 2015 for four disciplines (biomedical research, engineering, natural sciences, and social sciences). In total, we retrieved 99,177 articles for Argentina, 406,294 for Brazil, 30,793 for Colombia and 133,543 for Mexico. The average of relative citations and the impact factor over a five-year period were calculated. It is well known that the use of WoS entails certain linguistic and regional limitations in bibliometric analysis due to the very little non-English publications coverage. Although our study is framed within these limitations, the results presented consist in a reliable indicator of the state of international scientific literature produced in LA.

Results

Science and technology capacity

Although LA countries share a common historical past, their social, political, and economic characteristics lead to a different scientific and technological (S&T) capacity. **Table 1** summarizes socio-economic and S&T capacity of the four LA countries analyzed. Brazil and Mexico have the highest population. Between 2001 and 2015, the average of R&D expenditure in LA represented 0.66% of the GDP, with only Brazil reaching 1% in investment, followed by Argentina and Mexico with around 0.40%, and finally Colombia with less than 0.2%.

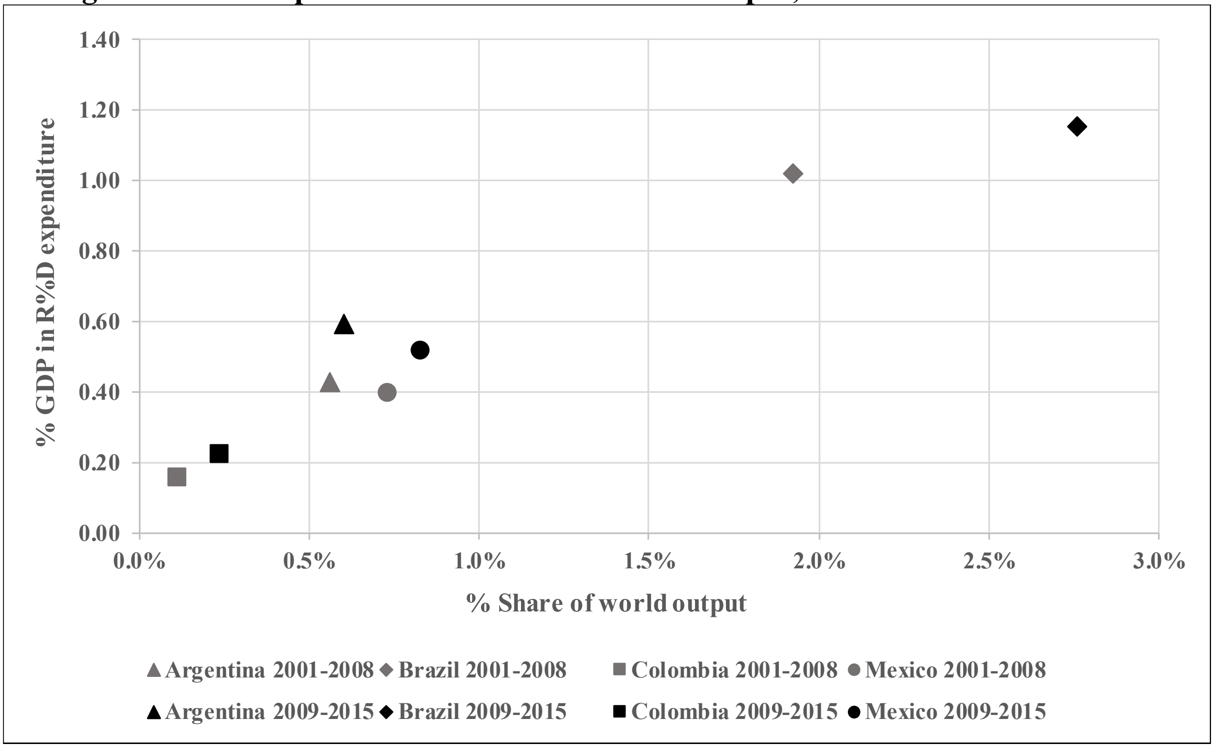
Table 1 Socio-economic and S&T capacity, 2001-2015

	Population for 2015*	R&D expenditure (%GDP) **	Researchers in R&D (average per 1000 of EAP)***
LA&C	631,058,524	0.66	1.4
Argentina	43,417,765	0.49	3.8
Brazil	205,962,108	1.07	2.1
Colombia	48,228,697	0.18	0.6
Mexico	125,890,949	0.44	1.0

* Source: The World Factbook
** Source: World Bank Open Data
*** Economically active population

Figure 1 presents the relationship between R&D expenditures and the share of output for all disciplines between 2001-2008 and 2009-2015 (except for Argentina whose data ends in 2013). Brazil maintains R&D investments that are slightly higher than 1% of the GDP, while its participation in world output went from almost 2.0% in 2001-2008 to 2.8% in 2009-2015. Argentina and Mexico make similar investments in this area, about 0.05% in both periods, which is lower than the 1% recommended by international organizations, and both participate similarly to world production slightly exceeding 0.5%. Colombia constantly increases the percentage of its R&D expenditure as well as its share of world output; however, its expenditure and output remain much more modest than those of Argentina, Mexico and Brazil.

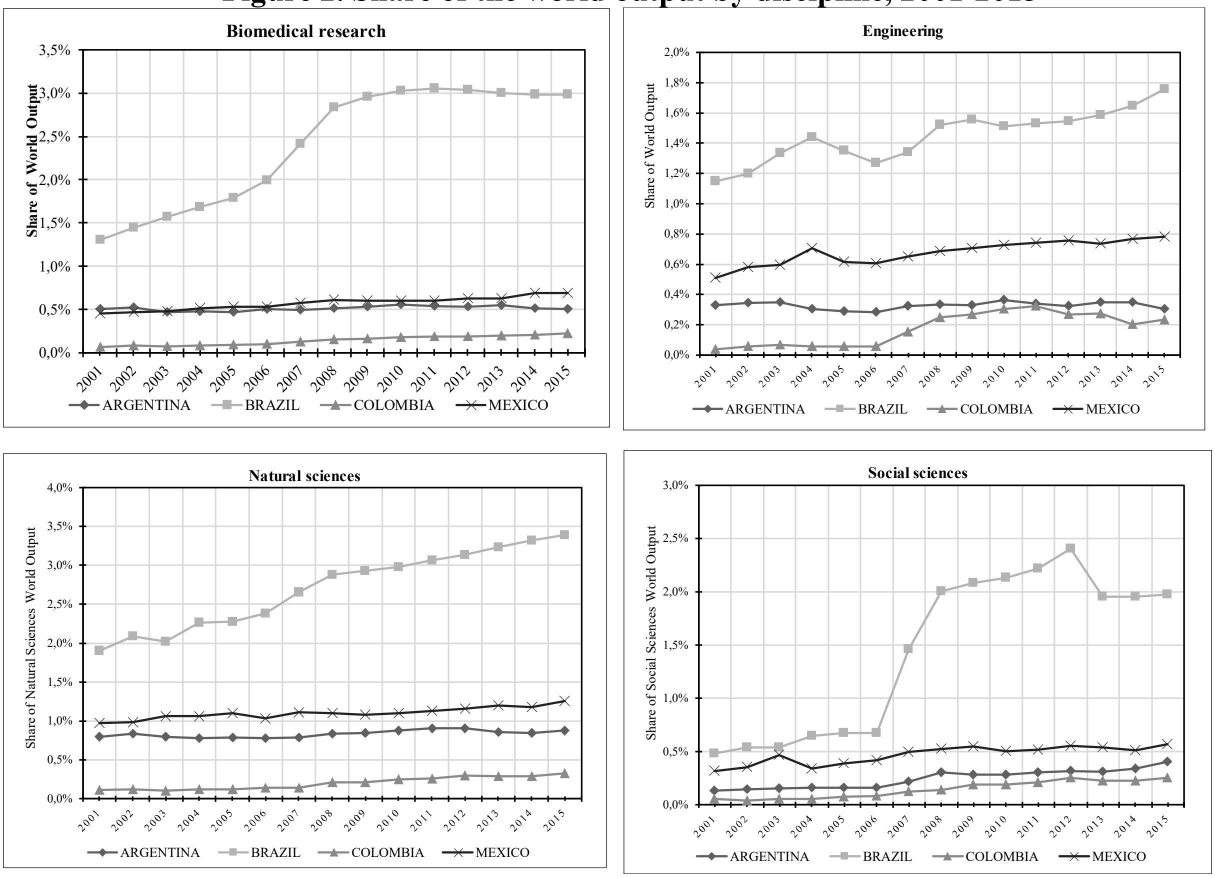
Figure 1 R&D Expenditure and share of world output, 2001-2008 and 2009-2015



Evolution of the share of world output

Figure 2 presents the share of the world scientific output by discipline for the four countries. All of them maintain modest growth until 2006, a breaking point from which important growth begins to be observed in almost all disciplines. In all disciplines, Brazil stands out as the country with the highest production, especially in Biomedical and Natural Sciences, in which it maintained consistent growth throughout the period, and even more so since 2007. Overall, it contributes to more than 3% of the total number of papers in those disciplines. For Mexico and Argentina, Natural Sciences constitutes the area with the most research activity, comprising 1% of the world's production. In the case of Engineering, Brazil maintains leadership within the region, contributing to more than 1% of the world's production during the entire period studied, followed by Mexico, which, likewise, has maintained steady growth since 2005. In Argentina, research in this area shows moments of decline and recovery between 2006 and 2015. Colombia experienced an important growth in production since 2007. In Social Sciences, Brazil again makes a considerable increase between 2006 and 2007, comprising 2% of the world's publications by the end of the period.

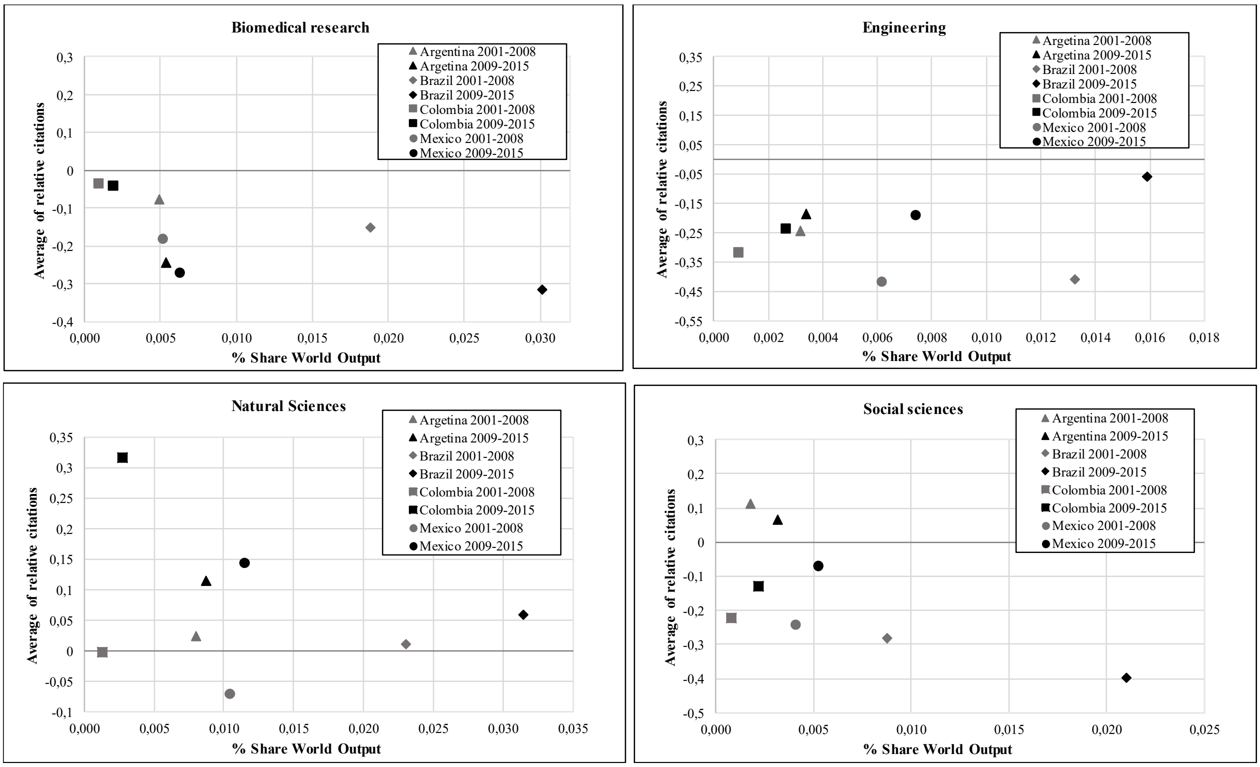
Figure 2. Share of the world output by discipline, 2001-2015



Scientific impact

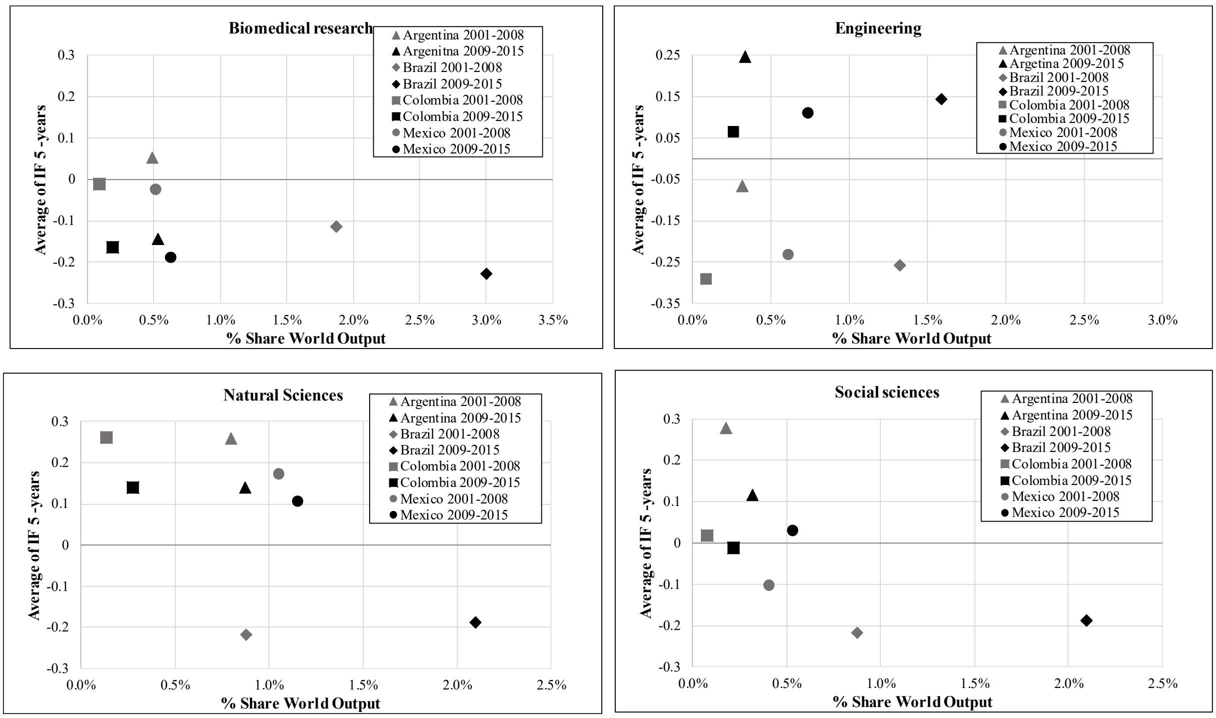
Figure 3 presents the scientific impact (average of relative citations) of the four LA countries as a function of their share of world output for 2001-2008 and 2009-2015. We subtracted 1 from ARC so that the value 0 represents the world average. In Biomedical Research, the four countries increased their output and scientific impact from the first period to the second. Colombia stands out for the highest ARC compared to its low percentage of production. Brazil, Mexico and Argentina, respectively, have published in greater proportion. In Engineering, the proportion of production and the average ARC increased from one period to another in all countries. During the second period, Brazil outpaces the other countries as it approaches the world's average ARC. The best performance of the four countries occurs in Natural Sciences where output and scientific impact remain above the world average of ARC. Colombia stands out with the highest ARC despite its comparatively smaller percentage of scientific production worldwide. In the case of Social Sciences, there are different combinations for each of the countries. Colombia and Mexico increase their production and their ARC, but remain below the world average. Brazil increases its production considerably and decreases in ARC. Finally, Argentina increases its production slightly, but decreases in ARC although it remains above the world's average in both periods.

Figure 3. Share of world output and average of relative citations 2001-2008 and 2009-2015



The visibility of the journal in which papers are published, as measured through the five-year journal impact factor, shows a trend similar to that observed for ARC (**Figure 4**). In Biomedical Research, the four countries tend to publish in journals with a lower impact factor (IF) over 5 years, which may explain the loss of scientific impact of these countries. In Engineering, those countries published articles in IF higher than the world's average during 2009-2015. The same occurred in Natural Sciences, except Brazil, in which production increased considerably in comparison with its regional neighbours. However, mean IF were considerably lower than the world average. Again, Social Sciences behave in a different manner, which is likely a consequence of the smaller number of papers. The production of Colombia slightly decreased, but remained close to the world average of IF. Argentina outdistances the group by publishing in journals with an IF above the world's average. However, a significant decrease occurs during 2009-2015. Mexico shows a higher publication in journals in which IF is slightly higher than the world's average, while Brazil maintains visibility below the world average.

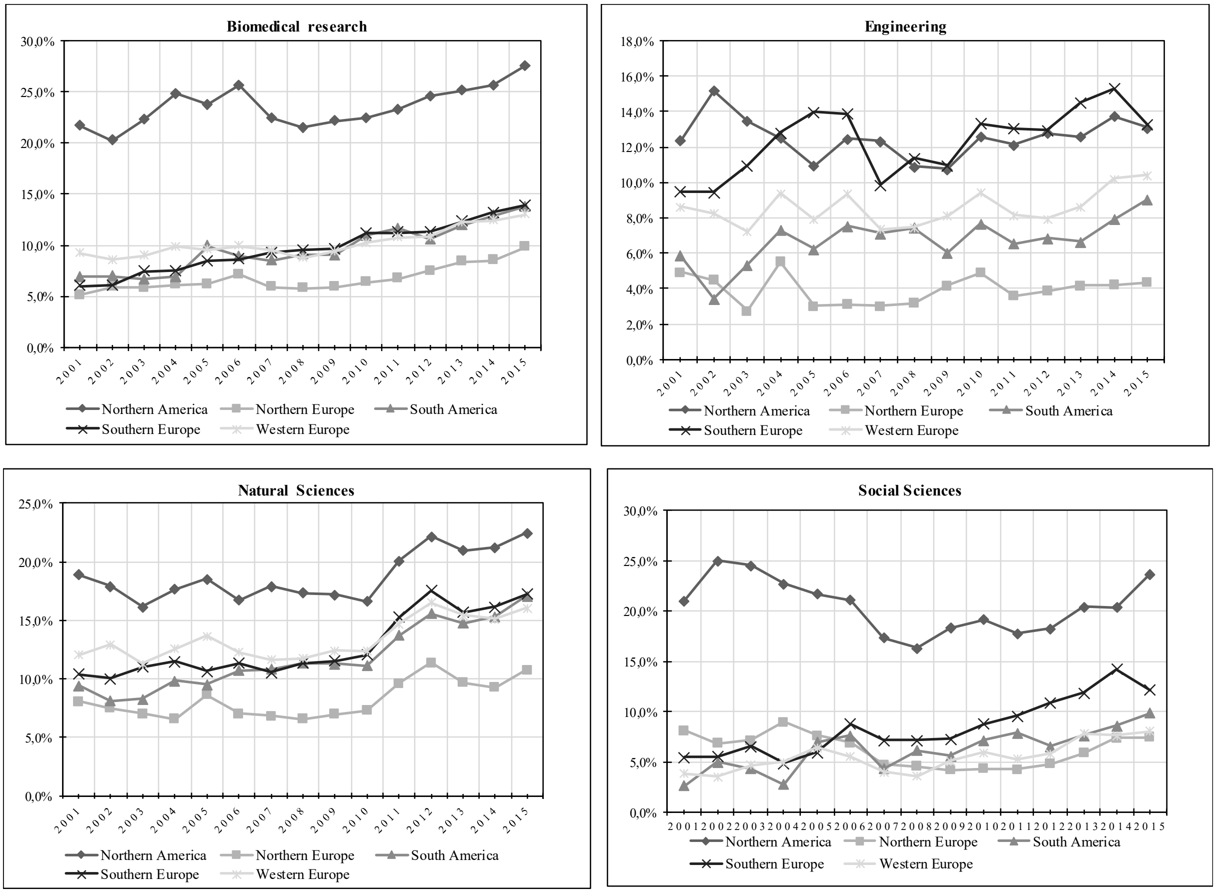
Figure 4 % Share of world output and 5-year IF, 2001-2008 and 2009-2015



International collaboration

Figure 5 shows the five regions with which our group of four countries collaborate in each discipline. North America stands out as the region with the highest percentage of collaborations for all disciplines, followed by Europe (South, West, and North respectively) and South America. In Biomedical Research, North America occupies a privileged place for publications, representing almost 30% by the end of the period studied, while collaboration with other regions has increased by a lower percentage during the period. In Natural Sciences and Social Sciences, North America remains the main international region of collaboration, although its importance oscillates throughout the period. Collaborations with Europe (South and West) and South America follow closely with similar percentages between 10 and 15%. For both disciplines, collaborations with Northern Europe are more stable than with other regions. As for Social Sciences, we found that despite a period of decline in collaborations between 2003 and 2008; there are greater collaborations with South America. Although the linguistic and country coverage of WoS may imply a bias in the analysis of these disciplines, collaboration with North America represents a significant aspect of publication practices in response to public policies that seek to increase visibility and volume (Mongeon & Paul-Hus, 2016).

Figure 5 Percentage of collaboration of the four LA countries, by region of collaboration, 2001-2015



Discussion

This paper analyzes the development of scientific output in LA within the framework of changes introduced since 1980 by the S&T policies in the region. These policies have aimed at increasing the enrolment in graduate studies, the number of full-time researchers, as well expenditures in scientific activities. Although national programs for training human resources and for research incentives have been the priority in LA (Glanzel et al., 2006), research activites conducted in those countries has had less social impact on those societies compared to the progress made by countries with similar economic development, such as those of Southeast Asia (Casas et al., 2014; de Castro Moreira, 2003).

As we showed, the four countries studied increased R&D expenditure, although not at the same pace as their publications in all areas of knowledge. The increase in international publications confirms the success of programs that created incentives to do research (Albornoz, 2017; De Moya-Anegón & Herrero-Solana, 1999; Jane M. Russell, Madera-Jaramillo, Hernández-García, & Ainsworth, 2008), which, rather, have become programs that incentivized publication in mainstream journals (Chavarro et al., 2017; Leite et al., 2011; Vasen & Lujano Vilchis, 2017; Vessuri et al., 2014). Although the purpose of these policies is to improve the quality of research, the research incentive programs (publication) have become the personal goal of researchers throughout their academic careers (Vessuri et al., 2014).

Our results showed that NS (biology, chemistry, engineering, materials, and physics) is the area of specialization for LA countries, where a major publication effort is underway, in addition to having a scientific impact and visibility above the world's average. In contrast, output in more applied disciplines (biomedical research and engineering) and social sciences is less important, and scientific impact and visibility remain under the world's average. The national or regional development of these disciplines (Glanzel et al., 2006; Kostoff et al., 2005; Leite et al., 2011; Russell et al., 2008) seems to explain why a lower number of papers from those countries is generally found in international databases.

Although it is expected that collaboration with the USA will result in higher scientific impact for collaborators, this rule applies only to Anglo-Saxon and European countries, but not for emerging countries that collaborate with the USA (Gingras & Khelfaoui, 2018). Some trends of international collaboration among developing countries can be explained by classifying researchers into two groups: those who publish in international journals and those who publish in national or local journals. However, a combination of both is possible when scientists choose a journal based on the audience and the research (basic or applied) (J. M. Russell & Galina, 1998; Jane M. Russell et al., 2008). The collaboration and selection of publication journals can shed light on the notorious gain in scientific impact of Colombia in NS as a strategy motivated by S&T policies, whose practice was used by Brazil in the 1980s to achieve this internationally recognized level and consolidate scientific processes (Glanzel et al., 2006).

Further research will analyse the development of the key sectors mentioned in the STI policies (health, nanotechnology, biotechnology, ICT, clean energy, development of new materials, and cognitive sciences) regarding the way LA countries build (if so) linkages between competitiveness, productivity and societal issues.

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