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Research Article

Transformations in the Ecuadorian Scientific Landscape: A Bibliometric Analysis of the Main Publications Trends and the Role of the Scientific Networks and the Public International Scholarship Program

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ABSTRACT
Like other Latin American countries, Ecuador has undergone major political and economic transformations in the last decade. Science, technology and innovation policies were at the core of some of these transformations. Despite the economic recession since 2015, the local techno-scientific landscape has experienced quantitative and qualitative transformations that need to be analyzed. This paper aims to shed light on these changes and on the Ecuadorian techno-scientific system, which so far remains under-researched. To do so, we first carry out a bibliometric analysis of more than 25,000 records with Ecuadorian affiliation from the Scopus database, published between 1920 and 2019. This allows us to reconstruct the growing complexity of local techno-scientific networks and their connections both inside and outside the country. This analysis shows a strong process of internationalization of local scientific production during the last decade, as well as a shift in research topics from publications focused mainly on health and environmental issues to research with a strong component on data and systems analysis. In a second level of analysis, we explore the relationship between these transformations in techno-scientific production and a postgraduate scholarship policy program which has sponsored Ecuadorians to study abroad over the past two decades. This analysis shows a significant correlation between the number of international scholarships granted and the number of indexed publications. The paper concludes that local transformations in techno-scientific networks are highly correlated with the internationalization process driven by this postgraduate scholarship program and in general by international scientific research training.

Keywords: Techno-scientific networks, Internationalization, Bibliometric analysis, Publications, Scholarships, Ecuador.

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INTRODUCTION

For several decades, Latin American countries have tried to implement different strategies of economic transformation based on local scientific and technological development. These strategies received new breath with the global geoeconomic reconfiguration that followed the 2008 crisis, which created conditions for unprecedented economic expansion in the whole region. For almost a decade, several of these countries took advantage of this economic boom to implement publicly-funded national modernization projects. Two elements were common to all these experiments: investment in infrastructure and the establishment of policies and programs to boost higher education (HE), science, technology and innovation (STI).

In the case of Ecuador, since the 1970s, different governments have tried to implement policies that promote such activities. Few of these policies have achieved their objectives.[1,2] After almost five decades of trial and error, the country has laid certain foundations for what has been called the National System of Science, Technology, Innovation and Ancestral Knowledge (NSSTI-AK).[3] This system has, however, an existence that is much broader than the public policies or the institutions that have tried to create, regulate or develop it.

From a systemic perspective,[4,5] NSSTI-AK cannot be created ex nihilo or located in some specific places or actors. Such a system exists in the relationships among its components; it is a phenomenon that emerges only from those interactions. In this sense, its development goes beyond the political and

institutional arrangements that have attempted to shape it in recent decades and is part of a long historical process whose trajectory has certain cyclical regularities. This observation is important because the process we analyze in this paper occurred in a context of transition not only in the local political cycle, but also in the global techno-economic transformation cycle.[6-8]

From the local perspective, the political stability and economic boom enjoyed by the Correa's government (2007-2017) gave a certain dynamic and direction to the STI policy. The transformation of the HE system at the beginning of the 2010s was at the core of this strategy. The HE Law in 2010 was reformed to merge the HE and the STI systems under the leadership of the National Secretary of HE and STI (SENESCYT). This institutional reconfiguration allowed to link the institutional reform of the HE with other investment policies such as the creation of four new universities, including Yachay,[9,10] the Prometheus program, which invited foreign researchers to Ecuador[11–13] and the Scholarship Program for Ecuadorians to study abroad.[14] These programs led to the development of connections with international techno-scientific networks. This articulation was based on the circulation of ideas, practices, information, instruments, but above all of students, professors, researchers and professionals among local and international centers.

However, these new collaborative networks seem to result more from global systemic dynamics, rather than from a strategic objective of the ruling national governments of this decade. Indeed, conceived and implemented from a linear and instrumental conception of education, science, technology and innovation,[15,16] these programs did not aim to create nor strengthen systemic relationships with global networks of techno-scientific production and innovation. Rather, they sought to import knowledge and train local experts to develop STI adapted to "national needs". Conceived on the basis of a "magic thinking" scheme, these programs were expected to automatically produce innovation and industrial development.

Thus, the lack of local capacities, the adherence to visions that do not reflect local realities, the authoritarianism and the lack of political management to integrate divergent opinions and criticism, led Correa's administration to implement policies and programs that were unviable in the long term.[17] This unfortunate gamble and the structural economic problems that followed this period contributed to the eventual defunding and delegitimizing of the national techno-scientific policy.

In 2017, Lenin Moreno was elected president. This new government gradually distanced itself from the policies of its predecessor due to the multiple problems and criticisms mentioned previously. During its first years, Moreno's administration dismantled a good part of the policies it had inherited. He focused mainly on higher education and technical training, leaving techno-scientific policy in the background. Thus, apart from the execution of some research projects that were already underway and some very specific initiatives, SENESCYT did not take any relevant action on STI during this period. This lack of policy characterized the trajectory of the NSSTI-AK during the last four years.[18–20]

Despite all the above mentioned limitations, the exponential growth of scientific publications with Ecuadorian affiliation in recent years suggest that the broadening and internationalization processes triggered by these policies and programs have transformed the local scientific sphere. In a way, these programs and their participants have very likely become one of the most important transmission chains that have brought this transformative process to Ecuador.

The evolution of the Ecuadorian NSSTI-AK took place in a context of a new global techno-economic revolution,[1,6,7,21] whose political and symbolic effects are just beginning to be seen. This transformation is characterized by the central role that information plays for the material and symbolic reproduction of contemporary societies. Under these new conditions, hierarchical and unidirectional forms of organization become obsolete. This allowed for new forms of networked organization to emerge, and a more systemic approach to problems such as economic development and innovation. These ideas and forms of organization originated in the epicenters of the technological revolution that produced the microchips and the Internet in the United States and Asia[22,23] have spread to the periphery. They have created new imaginaries and frameworks of interpretation on the challenges that affect these countries. In turn, this has produced new ideas on how to deal with these problems, but also new needs and desires for technological development. If, in the middle of the 20th century, we thought that the solution to underdevelopment was to produce cars locally, today it is probably thought that to do so we must produce nanotechnology or our own *Whatsapp*.[10]

This uncritical and decontextualized adoption of certain ideas was likely one of the causes that led to the failure of several techno-scientific policies implemented in the country. The shift from a linear and utilitarian vision of the relationship between STI to an ecosystemic and informational one, in which they are all interdependent, demands a long learning process and a change of mentality.[23-25]

To understand the evolution of the Ecuadorian NSSTI-AK and its scientific networks, it is fundamental to keep in mind these processes of techno-economic, organizational and symbolic change at the global level. These changes manifest in new forms of organization of local actors who seek to embed themselves into the new forms of economic or

symbolic reproduction that are emerging in this period of transformation. Therefore, through our analysis we aim to understand not only the concrete state of local scientific networks but also their projections at the global level.

CONTEXTUAL AND THEORETICAL BACKGROUND

Internationalization of science and the STI Policies in Latin America

According to Kreimer,[26] the development of the scientific fields in Latin America went through three stages. The first one (19th and early 20th centuries) is characterized by visits from European scientists. In the second stage (1920–1970), local researchers carried out doctoral studies in Europe and the United States and then founded their own laboratories back home. The third phase (since 1980) is driven by an accelerated process of internationalization of the higher education. This phase is characterized by the emergence of new strategies of training researchers through local PhD programs and scholarships for postgraduate studies abroad. These transformations supported the integration of local researchers into the large techno-scientific networks of what Kreimer calls "mega-science". The growth in the number of scientific publications and international collaborations has been one of the main features of the evolution of the techno-scientific field in the region since the 1980s.

According to Arellano, Arvanitis and Vinck,[27] the institutionalization of the techno-scientific field started in the 1930s with the emergence of several research groups financed by private foundations and international cooperation. Then, in the 1950s, organizations such as the United Nations Educational, Scientific and Cultural Organization (UNESCO), Organization of American States (OAS) and United Nations Economic Commission for Latin America and the Caribbean (ECLAC) started promoting STI policies throughout the region, which led to the creation of specialized public institutions in several countries and the emergence of a first generation of Latin American scholars interested in STS problems.[28–30] Finally, from the 1970s onwards, the global techno-economic transformations led to the multiplication of local actors and their integration into global techno-scientific research networks.

These three moments in the evolution and institutionalization of the techno-scientific field observed in the larger countries of the region are reflected with some nuances in smaller countries such as Ecuador.[2,8] Here we also observe the central role of several European and American scientists and researchers that came to the country as part of different scientific missions between the 18th and the 20th centuries and established the bases of different disciplines that later evolved into local scientific communities. These local communities emerged during the first half of the 20th century and their evolution has been intertwined with the trajectory of the HE system. The STI institutionalization process and the cooperation programs implemented since the 1950s were eventually consolidated. However, up until the beginning of the 21st century, their scale was very limited. This picture started to change during the last decade as a result of renewed interest into the development and consolidation of a STI policy. These processes were driven by: the availability of funding allowed by the economic boom, and the institutional reforms led by the internationalization process of HE and scientific production. At the crossroads of these two factors, the scholarship program for studies abroad seems to have played a central role.

The public scholarship program for studies abroad as a trigger for internationalization

As other Latin American countries, Ecuador faces a structural lack of scientists, technicians, managers and qualified professionals. This deficit is associated with the deficient university system, the country's low industrial and technological development, "brain drain" and, ultimately, the historical process of subordinate integration of peripheral countries into the world system.

Since the 19th century, Ecuador's elites ensured their reproduction by sending some of their members to study in Europe or in the United States. The individual relations of these elites with the metropolis have changed according to the local and global transformation cycles. In some contexts, this strategy has taken the form of public programs.[31] However, up until the mid-20th century, the scope and reach of these initiatives were reserved to the local elites, particularly those related to the Catholic church.

From the 1950s on, several international cooperation institutions such as UNESCO, ECLAC, Inter-American development bank (IDB) and OAS established a series of international programs to support the development of STI in peripheral countries.[32] Additionally, in the context of the Cold War, many Ecuadorians went to study in the United States under the Fulbright program.[33,34] Others went to the Soviet Union and other socialist countries that offered other scholarships to students from "Third World" countries.[35] At the same time, several Ecuadorians went also to Europe with the financial support of institutions such as the German agency DAAD, the Friederich-Ebert-Stiftung (FES-ILDIS), UNESCO, the French government, the Spanish government, and the Institute of Hispanic Culture.

At the end of the 1980s, other scholarship and training programs for Ecuadorians abroad were launched.[1] This was the case of the programs of the Belgian Technical Commission (BTC) and the Flemish Inter-University Council (VLIR) programs to study in Belgium. Moreover, other specific

programs for Ecuadorian students were created through bilateral cooperation agreements with countries such as Mexico, China, India, the Czech Republic, Israel, Venezuela, Cuba, Brazil, the Netherlands and Spain. Of these programs, the Cuban and Spanish programs were the most important in terms of number of scholarships. The Spanish scholarships, some of which were managed by the Spanish Agency for International Cooperation (AGECI) and others by the Carolina Foundation, became more prominent in the late 1990s and early 2000s. Finally, the European Union launched the ALFA program in 1999, which was replaced in 2004 by the Erasmus Mundus.[1]

Despite these efforts, the scope of these programs has not been sufficient to trigger a multiplier effect of scientific and technical training in the country. At most, they have contributed to the creation of an elite class of technicians, managers and intellectuals who have led several public and private organizations in the country. In a way, they have served to transmit the paradigms and imaginaries of the metropolis to the periphery.[36,37] Moreover, given the economic and political crisis of the country during the 1990s and 2000, it is very likely that these programs have somehow caused a "brain drain".[38-40] However, the lack of data on these programs makes it impossible to test this hypothesis.

As for the scholarship programs financed by the Ecuadorian state, although there is some evidence of the existence of this type of public aid since the 19th century,[31] most of these experiences were rather isolated cases. It was only in the 1990s that these programs became part of a more sustained public policy. The roots of this policy can be found in the 1950s, in the first international, regional and bilateral cooperation programs. Unlike the scholarship programs implemented since the 1990s, these early training programs were limited to training personnel already working in public institutions.[32]

The first large-scale scholarship program was launched in the 1990s as a part of the "First plan of scientific research and technological development", financed by the IDB. However, due to the acute economic and political crisis, the program was implemented partially and with several problems. This program financed only 148 scholarships.[41] The availability of new economic resources and the political transformation of the 2000s brought about several attempts to relaunch the program but all faced several administrative problems.

The HE Law reform of 2010 transformed the academic regime by requiring those pursuing academic careers to hold a PhD diploma and to have a number of indexed publications.[42,43] Such objectives needed strong support from the state to finance the training of researchers and professors. This need resulted in expanding the scholarship program that was sending about 100 students a year up to 2000 a year. The objective was that by 2017, at least 60% of the university staff would have a postgraduate diploma[1]. However, as we will show in the results section, by 2015 about 8,900 people benefited from these scholarships. 1,900 of these people were financed by international cooperation and 7,000 directly by the Ecuadorian government. These numbers, based on a verified database constructed by the authors, highlight the overestimation of the government Figures at that time: more than 11,500.[44,45] Funding for the program started to decline in 2017 due to the economic crisis and the ensuing austerity measures, but also as a form of criticism against the preceding administration. We estimate that from 1995 to 2019, there have been only about 8,000 beneficiaries from scholarships directly financed by the Ecuadorian government and at least 1,900 by other agencies. Nevertheless, as we explain below, this relatively small[1] contingent of researchers has qualitatively changed the national scientific landscape. Hence, the main hypothesis for this paper is that the number of Ecuadorian scientific publications are directly related to the number of scholars that benefited from the Ecuadorian scholarship program or more generally from international scientific research training.

METHODOLOGY

This paper is based on a twofold bibliometric analysis. For the first part, we used a database of scientific publications with Ecuadorian affiliation registered between 1920 and 2019. For the construction of this corpus, we used the Scopus database, which allows us to obtain publications by authors' country of affiliation. We used "Ecuador" as a search keyword. The search resulted in more than 25,000 items until December 2019. Each of these items contains bibliographic information by article (title, abstract, doi, publisher, keywords, date, etc.), authors, affiliations and sources of financing, number of authors, language, citations, and other information. We classified and debugged the database to individually identify the affiliation and location of every author of these publications. This process was carried out using several data processing routines developed in Python language. Using this data, we carried out classical bibliometric analysis on scientific productivity, collaboration networks and topic analysis. The network analysis and visualizations were produced by a combination of data processing routines developed in Python language and the software Gephi (0.9.2).

For the second part, we used a database of the scholarships allocated within this public program between 1995 and 2019. This database has been built over the past ten years from archival data and publicly available information on the results of each program call. Until 2015, the information that the SENESCYT published included names and identification

1 In 2009 only 1.2% of the 28,000 university professors had a PhD. The reform needed at least 16,000 postgraduates.

numbers. This allowed us to run verification routines also developed in Python language to verify their identity, their diplomas and other public information to confirm their academic records, affiliations and studies. This dataset counts about 7,000 scholars recipients of the public scholarship program and about 1,900 recipients of other international cooperation programs. We know from public information that another 1,000 scholarships were allocated between 2016 and 2019.[46-49] However, there is no public information on the identity of these scholars. Therefore, we have neither verified nor detailed information on this part of the data set. Nonetheless, for the global Figures we have used the whole data set of 9,900 registers. To analyze the relationship between these two variables during the whole decade, we matched the identity of those scholars whose name was in both datasets: authorships and scholarship until 2015. Additionally, we have run eight Simple Logistic Regressions to measure the statistical correlation between the number of publications per year, the number of scholarships allocated in different time spans and the type of study program.

RESULTS

The debugging process of the Scopus database resulted in a general database of more than 1.3 million lines detailing authors, articles and affiliations. These lines correspond to more than 85,000 unique authors, 25% of which have affiliations in Ecuador. These 85,000 authors are assigned to more than 4,000 research institutions around the world (universities, hospitals, research centers, foundations, etc.), 44% of which are based in Ecuador. Three main overarching themes stood out from this database:

The accelerated growth of the local scientific production and collaboration

Although Ecuador's scientific production is still limited, it has considerably increased in recent years. This evolution responds to: the development of greater local scientific capacities, the internationalization process of both universities and the NSSTIC-AK and the availability of greater resources for research in recent years. These factors have changed the local scientific culture. For instance, they gave greater relevance to publications, particularly of articles in scientific journals and conference's participation. In fact, until a few years ago, a large part of local scientific production was published (if at all) in the form of grey literature: books or reports with very little diffusion and outreach. The new culture of publication that is beginning to develop in the country, the greater local capacities for scientific production, and the formation of networks and research groups are all reflected in the explosion of the number of publications with Ecuadorian affiliation in scientific journals in the last 10 years (Figure 1).

Ecuadorian scientific production amounts to a little more than 25,000 articles and documents published in the last century (1920–2019). Most of these (83%) were published in the last decade. As can be seen in Figure 1, the number of publications with Ecuadorian affiliation in the last ten years grew exponentially, going from 462 in 2010, to 5,000 in 2019. This multiplied the share of Ecuadorian publications within the world scientific production by eight, going from 0.02% to 0.16%. Considering that local and regional journals and publishers are underrepresented in this database, it is very likely that the volume of production and the trend observed in recent years will be even more pronounced. In the absence of a better data source and considering that Scopus database demands certain quality standards from the publications and publishers it indexes, we will limit our analysis to this corpus of documents that very likely constitute the hard core of national scientific production.

Main characteristics

Most of this corpus corresponds to articles published in scientific journals (69%) and articles presented at conferences (21%). The remaining 10% are book reviews, chapters, editorials, books, letters, etc. (Figure 2).

Most of these publications came from collaborative processes of small research groups, but also of large transnational scientific networks. Figure 3 shows the different type of scientific teams that have produced this corpus of publications. The majority, 66%, were written with up to five authors, 23% with up to 10 authors, 6% between 11 and 50 authors and the remaining 4% with teams that range from 51 to more than 5,000 authors. The latter corresponds to publications of the ATLAS and CMS experiments of the Large Hadron Collider of CERN in Switzerland that were part of the discovery of the Higgs boson in 2012. These experiments were conducted by a collaborative network of several thousand scientists and engineers from different countries, including some researchers with Ecuadorian affiliation. Health is another area where

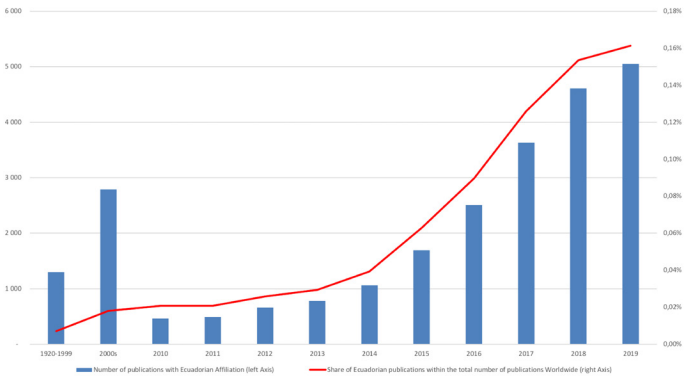

Figure 1: Publications with Ecuadorian affiliation in relation to the whole Scopus database.
Source: Scopus

collaborative scientific publication is very important. According to this database, about 100 scientists with Ecuadorian affiliation have participated in international collaborative networks of more than 1,000 members.

Only 25% of the 85,000 authors related to these articles register an affiliation in Ecuador. This means that local scientific production is highly dependent on international scientific production networks. These networks are mainly composed of scientists with North American (20%), Spanish (9%) and Brazilian (5%) affiliations (Figure 4).

Local networks of scientific production

About 32% of the more than 25,000 publications registered in this database were produced without external collaboration. Within these publications, 25% were produced by teams of more than 5 individuals and 36% by teams of 3 to 4. The remaining were individual products (20%) or publications written in pairs (17%). These data show that although the local networks of scientific collaboration are not as big as the international ones, they are the main source of national scientific production. These networks have evolved considerably in recent years. Figure 5 shows the status of local networks of scientific production in 2010, 2015 and 2019. Nodes in black represent the publications, those in orange the authors and those in blue their institutional affiliations. Authors are the source nodes. The size of the publication and institution nodes represents the number of authors linked to each one of them (in-degree). Publications include all types of scientific production (journal article, conference papers, books, etc.). Visualizations were produced through data processing routines developed in Python language and the software Gephi. These Figures clearly show the increase in the number

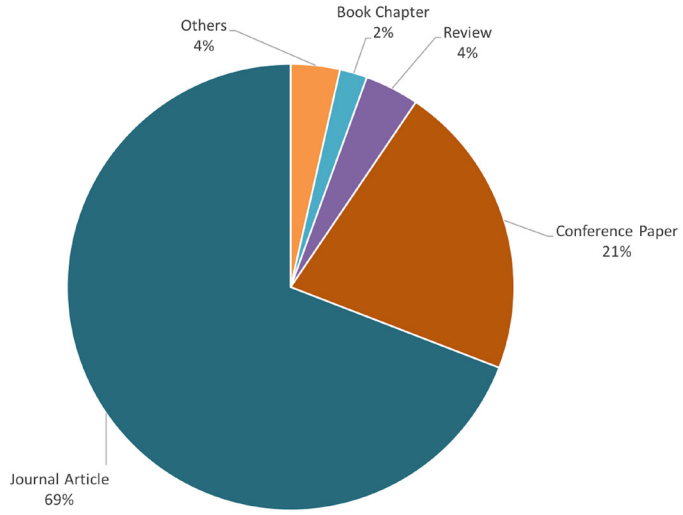

Figure 2: Scientific production with Ecuadorian affiliation by type of document, 1920-2019.
Source: Scopus

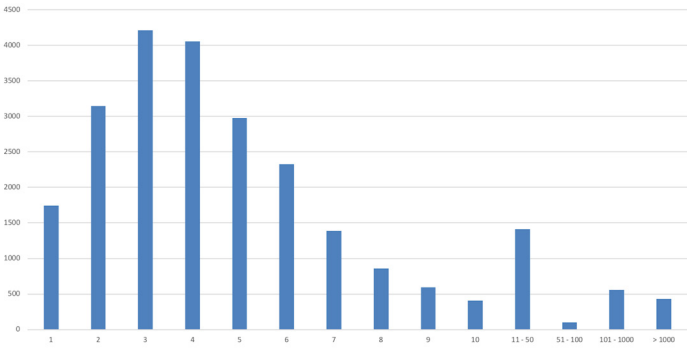

Figure 3: Number of authors per publication with Ecuadorian affiliation.
Source: Scopus

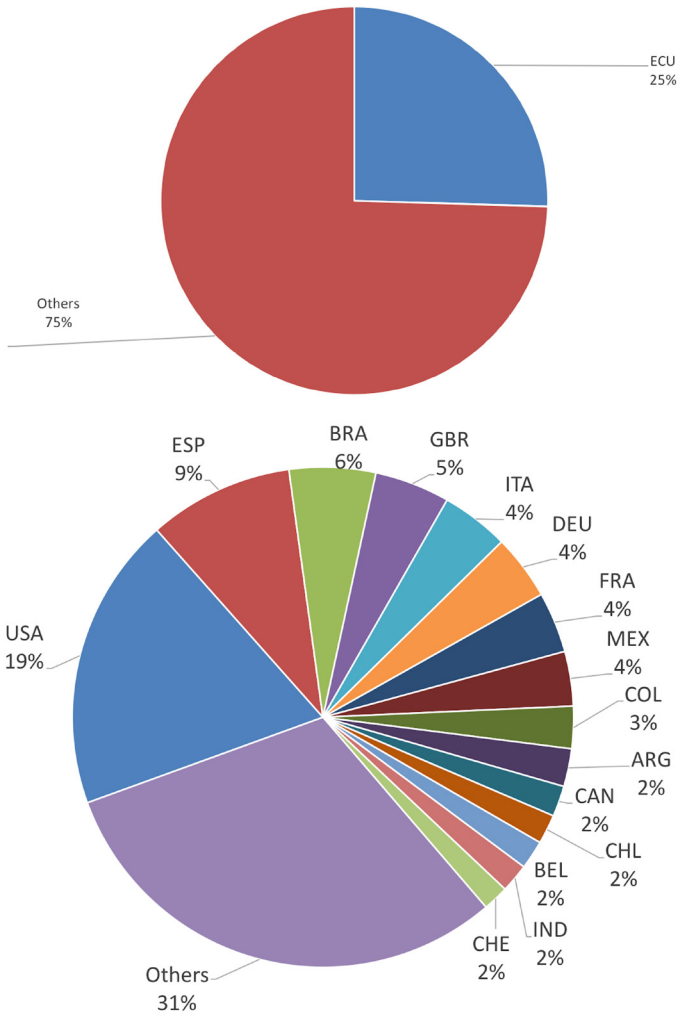

Figure 4: Publications in collaboration with scholars from other countries.
Source: Scopus

of networks, connections and complexity of the local scientific system.

It is important to clarify that the links between one network and another do not occur directly between and from the institutions, but through the researchers and their scientific production. The scientific production, the very object of the

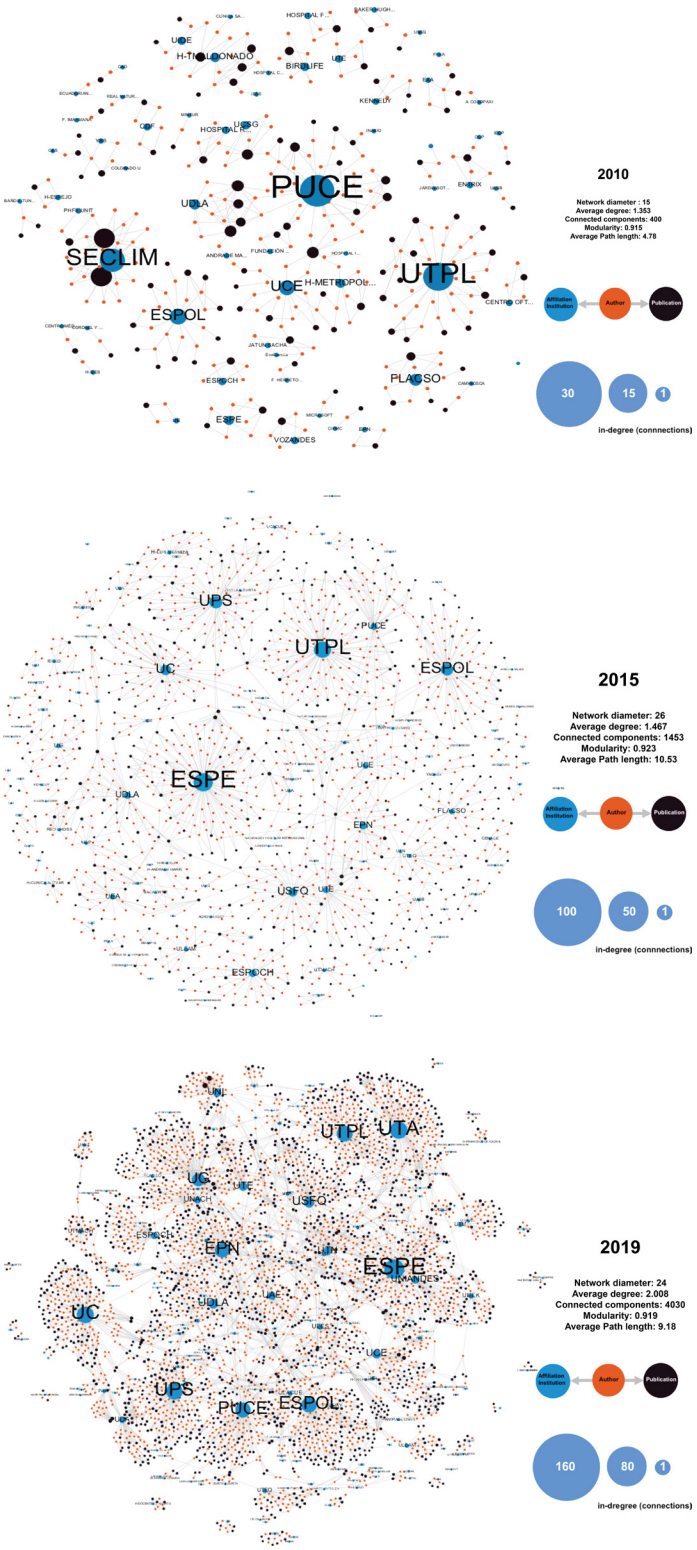

Figure 5: Local networks of scientific production in Ecuador.
Source: Scopus

network, is the node that links first the researchers among themselves, and then, through them, to their host, sponsorship or funding institutions. However, if we focus only on co-authorship, the resulting networks would appear more dispersed and less interconnected, whereas there are underlying institutional connections between these authors that are not necessarily reflected in the co-authorship of certain publications. Affiliation institutions are the nodes that allow us to identify certain structural clusters in the network and could explain in some extent their dynamics.

The centrality of universities within these networks is indisputable, but certain developments should be highlighted. For example, in 2010, the largest scientific production networks gravitated around five universities (Católica del Ecuador (PUCE), Técnica particular de Loja (UTPL), Politécnica del Litoral (ESPOL), Central (UCE), Facultad Latinoamericana de Ciencias Sociales (FLACSO)) and to a lesser extent around three universities (De las Américas (UDLA), Politécnica del Ejército (ESPE), Politécnica del Chimborazo (ESPOCH)). Moreover, the role of other non-university nodes such as hospitals and health research centers was more prominent. This was the case of the Metropolitan Hospital, Vozandes, Kennedy, Espejo, Teodoro Maldonado and above all the Ecuadorian Society for the Study of Climacteric and Menopause (SECLIM). Although these non-university networks continued to produce publications throughout the decade, their relative importance decreased in relation to the scientific production from academic centers. By 2015, some universities, such as ESPE, ESPOL, UTPL, Salesiana (UPS), De Cuenca (UC), San Francisco (USFQ) acquired greater centrality in the scientific production networks. Others, such as PUCE, UCE or FLACSO, diminished in relative importance. However, the system became more complex and diversified. Several collaborative groups emerged within certain universities (Politécnica de Manabí (ESPAM), Técnica de Machala (UTMACH), Católica de Cuenca (UCACUE), among others), but with few connections with other networks or organizations. Although their role was less prominent, new actors and networks appeared. These were integrated by companies, foundations, laboratories, public research institutes (IPIs) and the government. At the end of this decade, these networks of local scientific production have reached a greater complexity and interconnection, but as has already been pointed out, they remain isolated from international circuits of scientific production. The universities maintain their hegemony as central nodes of these networks but there are greater links between them. Universities such as ESPE, ESPOL, UPS, UTPL, UC continue to host the greatest number of connections, and others like PUCE, EPN, UDLA, De los Andes (UNIANDES), De Guayaquil (UG), Técnica de Ambato (UTA), Nacional de Loja (UNL), Técnica del Norte (UTN), UNACH, ESPOCH, have improved their positions. This shows the emergence of a more balanced scientific production with greater connections and collaborations among its members. The scientific production from hospitals, health research centers, private companies, foundations, laboratories, public research institutes and others, continues but loses

prominence against the dynamism of university production. Moreover, many of these production networks have little scope and connection with the rest of the system.

International networks of scientific production

Despite the remarkable development of the local scientific networks, it is worth noting that they are responsible for only 32% of scientific production with Ecuadorian affiliation. Most of these publications come from networks that have a strong link with international circuits of scientific production. Of the 460 documents with Ecuadorian affiliation published in 2010, 354 were produced by international collaborative networks in which 405 researchers from 104 institutions with registered addresses in Ecuador participated (Figure 6). In this case it is also the universities that have the greatest number of connections with these international networks: PUCE (60 researchers), USFQ (35 researchers), the EPN (25 researchers), the UTPL (23 researchers). The Charles Darwin Foundation (CDF) is also among the main nodes of these networks with 25 researchers. We also find other organizations with international connections: hospitals (e.g. Luis Vernaza, R. Gilbert, Metropolitano, Andrade Marin, Vozandes, Espejo); IPIs (e.g. Agriculture (INIAP), Health (INSPI), Biodiversity (INABIO), Oceanography (INOCAR), Weather (INAMHI), Heritage (INP)); and other foundations, government institutions and private research centers. Only 26 of these institutions were also part of the local scientific networks analyzed above. The other 78 were uniquely related to these international networks.

By 2019, these international networks were responsible for 3,500 out of the 5,000 scientific documents published that year. From 2010 to 2019, the number of Ecuadorian institutions linked to these networks has doubled (221) and the number of researchers has increased almost sixfold (2,323). The universities continue to be the main nodes of these networks with ESPOL (158 researchers), USFQ (136), UC (126), EPN (117), PUCE (105) and ESPE (103) at the head. Far behind are the IPIs (44); foundations and research centers such as CDF (10), Otonga (3), Azulado (3), Mashpi (2), Condesan (2), Cip (2); state institutions and ministries (39); hospitals such as Eugenio Espejo (4), de los Valles (3), Metropolitano (3), Solca (3); and companies such as Sicom (2), Petroamazonas (2), EMAP-Q (2), Respiralab (2), among others. Most of these institutions (63%) only interacted with international networks.

The evolution of the scientific production networks, both local and international, shows the process of developing and strengthening NSSTIC-AK in the last decade. This process has been marked, and in good part led, by the global process of the internationalization of universities and scientific production.[50,51,36,52,53] It is interesting to note that at the beginning of the decade, only a few universities were connected to international circuits of scientific publication. At

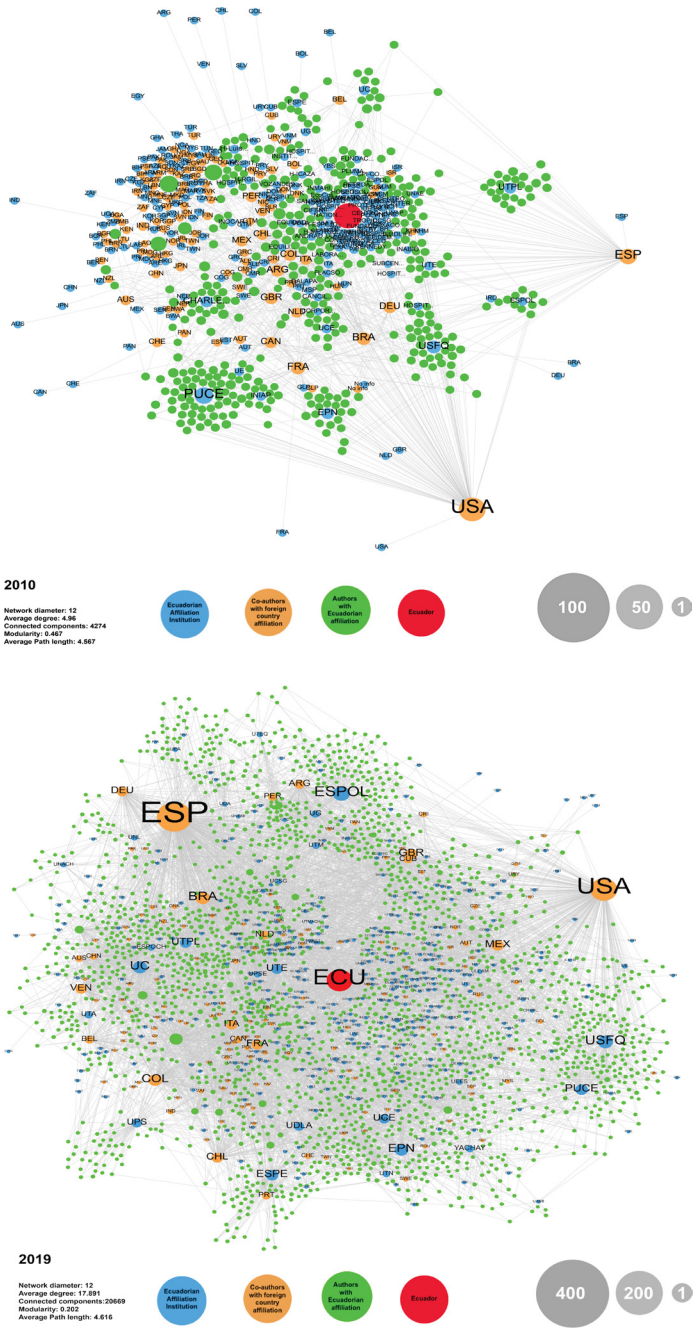

Figure 6: International networks of Ecuadorian scientific production. Source: Scopus

the end of the decade, most Ecuadorian universities have one or more researchers connected to these networks. These researchers are part of the process of strengthening NSSTIC-AK, promoted by the different scholarship and scientific cooperation programs supported by both the Ecuadorian State and by international institutions. The public scholarship program for postgraduate studies abroad that began in the 1990s was strengthened precisely during this decade. Likewise, it is important to consider the effects of the Prometheus program that brought several foreign researchers to the country, thereby generating new opportunities to

connect with these international knowledge networks. Finally, the university reform that introduced the demand for scientific publications when evaluating both universities and teachers undoubtedly served as a trigger for this process.

Shifts in main research topics

To complete this picture, we look at the main subjects of these productions. What kind of research is being produced by researchers with Ecuadorian affiliation? What are the main themes or objects of study in these publications?

We limit this analysis to some indicators that will let us see the main areas and topics on which the local and international networks of scientific production have been working in the last decade. For this, we used the keywords that define each of the articles contained in the database built for this study. Based on frequency tables that count the number of times these words are used, we have identified the top 20 topics of the research produced in 2010, 2015 and 2019 (Table 1). Based on the same principle, we have also generated clouds of keywords by year which give a synthetic visualization (Figure 7).

In 2010, local scientific production seems to have been focused on health issues (epidemiology, menopause, hot flushes, Chagas disease, climacteric, melanoma, Parkinson's). However, there is also some interest in issues related to sustainability (conservation, new species, climate change, Amazonia, forests, indigenous people). By 2015, the latter topics seem to have acquired a greater interest within these networks. Indeed, the first keywords include: climate change, taxonomy, Amazon, new species, biodiversity and conservation). Health issues, on the other hand, seem to have lost prominence. Only one health-related topic appears in the first 20 keywords: obesity. However, if we look at the word cloud, we also find words like "health" or "disease". In addition, there are topics such as "networks", "systems", "learning", "management", "data", "control" and "digital" that show the existence of another core of researchers more linked to ICT issues. This change in the orientation of scientific production is a reflection of the very evolution of the system. As mentioned before, in 2015, the scientific production of hospitals and health research centers lost prominence compared to the volume of research produced by researchers from universities and other actors in the system. Finally, in 2019, there is a new turn towards issues more related to ICT, data mining, machine learning, Internet, IoT, social networks, usability and also issues related to physics and ATLAS and CMS experiments. The topics of health and sustainability disappear from the list of main keywords, but in the cloud we can see that topics like "disease" and "health" persist, but above all "water", "urban", "energy", "forest", "soil", "environment". Once again, this change is explained by the development and increased complexity of NSSTIC-AK, which includes more local and external actors, whose productions acquire greater relative weight in scientific production as a whole. This is the case, for example, for the network related to ATLAS and CMS experiments. However, the greater interest in topics related to data mining, machine learning, IoT, systems and social networks is rather the reflection of global trends related to the ongoing techno-economic transformations.

Table 1: 20 most frequently used keywords per year, in order of importance.

2010	2015	2019
Epidemiology	Climate change	Hadron-Hadron scattering (experiments)
Menopause	Taxonomy	Machine learning
Conservation	Amazon	Data mining
Hot flushes	New species	Social networks
Morphology	South America	Physics
Component	Population-based study	Usability
Chagas disease	Biodiversity	CMS
Tevatron	Conservation	Segmentation
Electronic properties	Neotropics	Beyond Standard Model
Anura	Peru	Higher education
New species	Spain	Optimization
Climacteric	Tardigrada	Evaluation
Climate change	Shear	Fuzzy logic
Melanoma	Segmentation	ICT
Systematics	Tropics	Internet
Colombia	Invasive species	Agriculture
Structure	Twitter	Learning
Amazon	Diversity	Education
Parkinson's disease	Higher education	Android
Community structure	Obesity	IoT

This panoramic analysis of Ecuadorian scientific production in the last decade shows the relevance of scientific networks, particularly the international linkages. However, these networks are constantly changing and adapting to both local and international trends, which determine not only preferences for certain topics, but most likely access to funding and the very possibilities of publication.

The role of the public scholarship program on scientific production

The Ecuadorian public scholarship program that started in 1995, acquired a completely different dimension during the last decade to fulfill the objectives set by the university reform of 2010. Hence, between 2010 and 2012 the program went from sending about 100 students a year up to 2,000 a year.

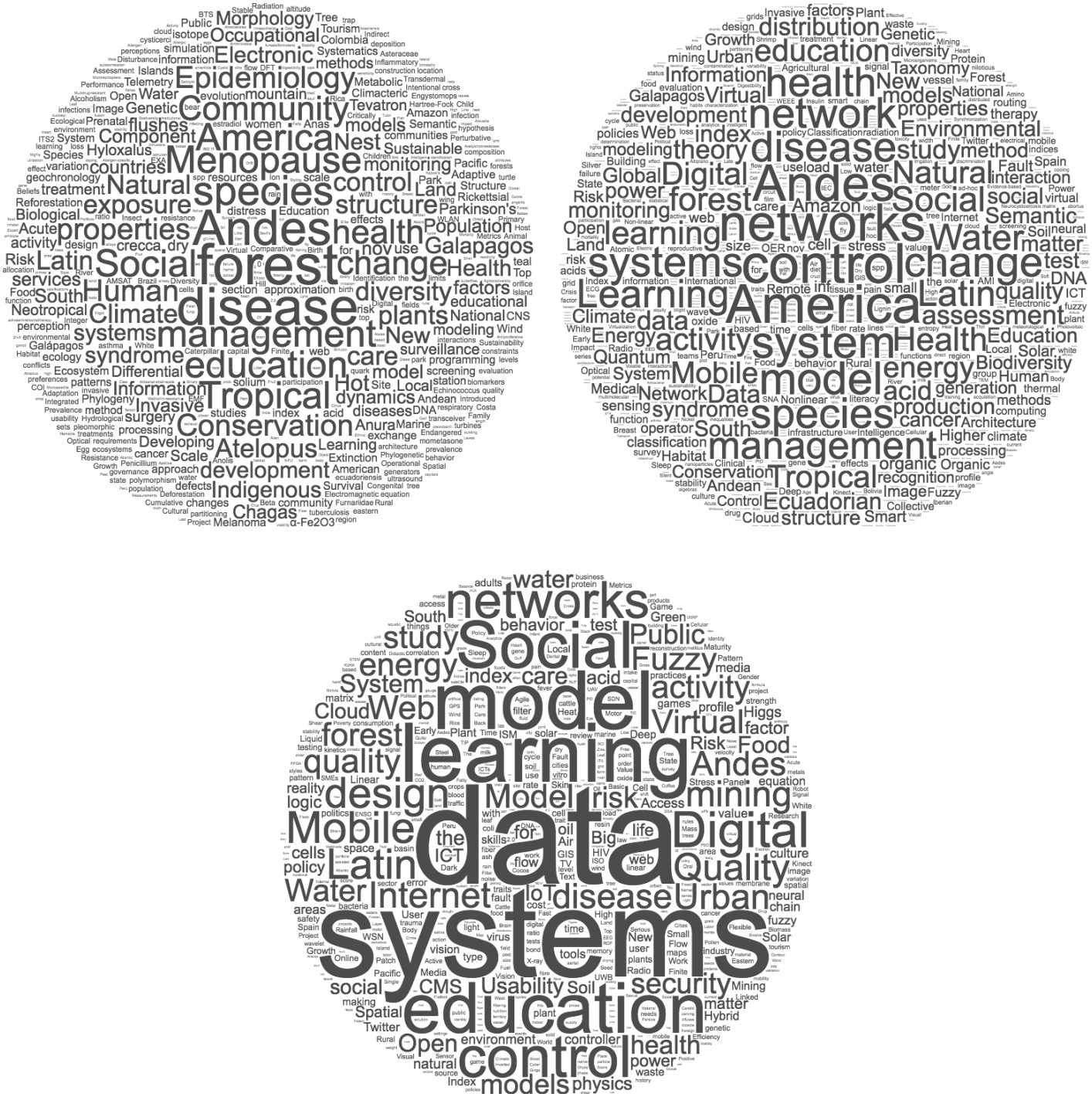

Figure 7: Cloud of keywords in publications with Ecuadorian affiliation
Source: Scopus

From the verified database constructed for this research, we know that by 2015 about 7,000 people benefited from these scholarships directly from the Ecuadorian government and that another 1,900 were financed by international funding agencies. Unfortunately, verified and detailed data for the 2016-2019 period is unavailable. However, aggregated numbers coming from public declarations and official documents show that 1,000 extra scholarships were allocated during these years. Therefore, we estimate that from 1995 to 2019, a total of about 8,000 scholarships were financed directly by the Ecuadorian government and at least 1,9000 by international cooperation agencies (Figure 8).

Based on the verified database, we estimate that about 12% of these scholarships were used to finance undergraduate programs, 66% master programs and 22% PhD programs. If those estimates are right, by 2025, national Ecuadorian

scholarships will account for about 2,000 PhDs graduated abroad, of which 1,300 should have already finished their studies by 2020. This number does not count the researchers that have done their scientific training abroad through self-funding or financed by other institutions. However, by 2020 the majority of Ecuadorian researchers with a PhD have been financed by the SENESCYT scholarship program.

By matching the identity of the recipients of scholarships and the authors in the Scopus database, we found that about 11% out of the 21,000 authors with Ecuadorian affiliations benefited from this program. These authors are directly responsible for 27% of all publications, which means that on average they produce 2,8 articles more than their non-recipients pairs. A third of these scholars have finished a PhD and produce 1,6 more articles than their colleagues. Table 2 shows that these ratios have increased over the last decade, most likely reflecting the effect of the scholarship program on the development of local research capabilities and scientific output. Based on data from the same Scopus database, we can extend this reasoning beyond the recipients of the public scholarship program to include all authors with a historical record of foreign affiliation. If we take these records as a proxy of research training abroad financed by other kinds of scholarships and institutions, we see that by 2019 authors with this background represent 29% of the Ecuadorian scientific community and they are responsible of 76% of all the publications which means they produce 7,5 more articles than their pairs with no record of foreign affiliation (Table 2).

Based on the previous observations, it is plausible to conclude that researchers who have benefited from the Ecuadorian public scholarship program and, more generally, those with scientific training abroad, are the main driving force of the explosion of Ecuadorian scientific production. Figure 9 shows a common patron between the publication trend line and

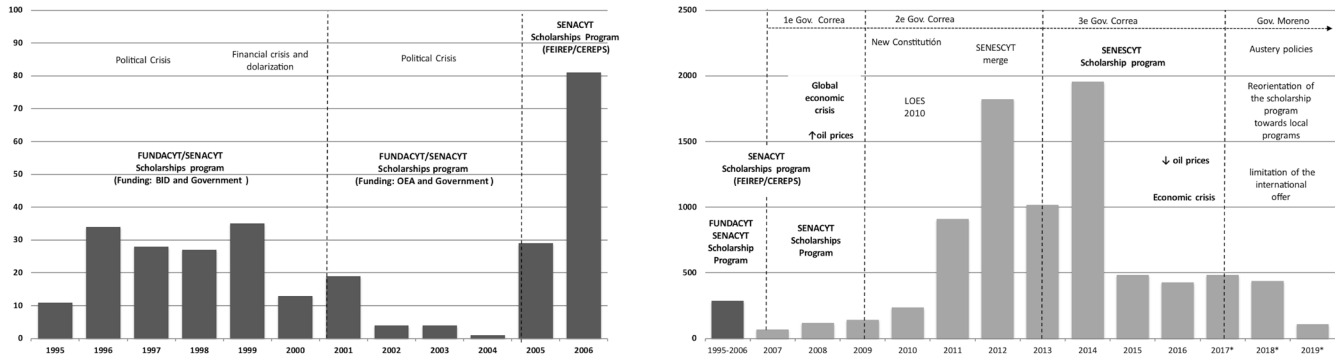

Figure 8: Number of scholarship recipients financed by the Ecuadorian government.
Source: SENESCYT/Red de becarios/IFTH

Table 2: Publications by authors benefited from Ecuadorian scholarships program and other foreign scientific training.

Year	Scholarship holder author (%)	Publications by scholarship holder author	Scholarship holder author output / non -scholarship holder author output	Author with foreign scientific record (%)	Publications by author with foreign scientific record (%)	Author with foreign scientific record / author with no foreign scientific record
2010	12,9	23,8	2,1	38,8	76,4	5,1
2011	14,4	21,6	1,6	42,7	76,7	4,4
2012	14,0	20,3	1,6	53,0	78,3	3,2
2013	11,7	24,7	2,5	27,2	77,3	9,1
2014	14,3	29,0	2,4	27,6	78,9	9,8
2015	12,0	25,8	2,5	28,9	79,1	9,3
2016	11,8	30,0	3,2	20,6	77,5	13,3
2017	10,4	29,1	3,5	22,3	75,7	10,8
2018	12,2	30,1	3,1	28,0	71,5	6,4
2019	13,1	32,8	3,2	29,8	76,0	7,5

Source: Scopus, SENESCYT

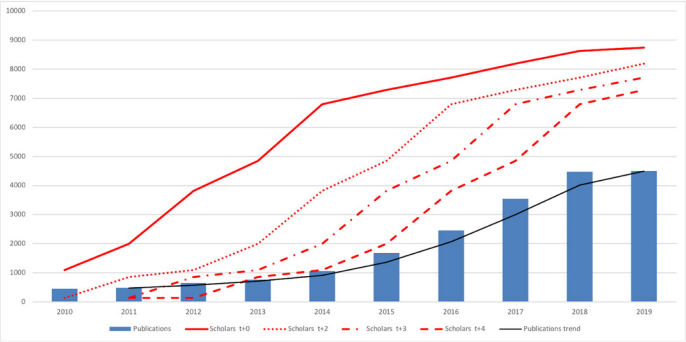

Figure 9: Publication vs. Number of Scholarships.

Table 3: Simple Linear Regressions between number of accumulated scholars and publications at year +0, +2, +3 and +4.

Model	R^2	B_0	p value for predictor B	B_1	p value for predictor S
$P_{t+0}=B_0+B_1S_{t+0}$	0.712	−1574.11	0.143	0.58	0.004
$P_{t+2}=B_0+B_1S_{t+0}$	0.885	−306.50	0.460	0.52	<0.001
$P_{t+3}=B_0+B_1S_{t+0}$	0.965	104.43	0.589	0.54	<0.001
$P_{t+4}=B_0+B_1S_{t+0}$	0.990	441.54	0.002	0.58	<0.001

P= Number of publications at year t+i

t= year

S= Number of accumulated scholarships at year t+i

accumulated number of scholarships. Although both lines seem to be offset in time, this corresponds with the average 2 to 4 years it takes to complete a postgraduate program (depending on if it is a master or a PhD program).

We have run four simple linear regressions to evaluate the correlation between the number of scholarships and the number of publications at year +0 (i.e. when the scholarship is granted), +2, +3 and +4 (i.e. at the end of their scholarship programs). This includes both master and PhD scholars. The results of these models, shown in Table 3, confirm that both variables are intertwined and that their correlation is higher if we consider their offset in time. Hence, the number of scholarships is a good predictor of the number of publications at time +4. Or in other words, the number of publications in a specific year is highly correlated to the number of scholarships awarded four years earlier.

Four additional regressions were run considering the type of program financed by the scholarship and a 4 year timespan (Table 4). Regressions for medical and PhD scholars show a statistical correlation at a higher average productivity: 2.7 publications per scholarship 4 years after the allocation for the former and 2.4 for the later. Even if equally correlated, Undergraduate's (1.58) and Master's (0.91) students seem to be less productive. This suggests that PhD students and medical

Table 4: Simple Linear Regressions between number of accumulated scholars by program and publications at year +0, +2, +3 and +4.

Model	R^2	B_0	p value for predictor B	B_1	*p* value for predictor S
$P_{t+0}=B_0+B_1UND_{t+4}$	0.951	955.59	<0.001	1.58	<0.001
$P_{t+2}=B_0+B_1MED_{t+4}$	0.949	978.28	<0.001	2.79	<0.001
$P_{t+3}=B_0+B_1MAS_{t+4}$	0.989	628.48	<0.001	0.91	<0.001
$P_{t+4}=B_0+B_1PHD_{t+4}$	0.984	430.23	0.006	2.44	<0.001

P= Number of publications at year t+i

t= year

UND (undergraduate), MED (medical specialisation), MAS (Master) and PHD = Number of accumulated scholarships by type of program at year t+4

doctors are the main driving force of Ecuadorian scientific production and the underlying networks.

CONCLUSION

We presented a general overview of the evolution of the techno-scientific field in Ecuador. Despite the political and economic upheavals of the last decade, the oversized objectives and the misguided scientific policy, the Ecuadorian techno-scientific landscape experienced an unprecedented quantitative and qualitative transformation. We highlighted the global context of techno-economic transformation within which this process took place and the central role of the internationalization process of both higher education and techno-scientific knowledge production. Within this context, we carried out a bibliometric analysis on Ecuadorian-affiliated scientific production to understand and characterize the publication boom of the last few years. This analysis allowed us to identify the underlying local and international collaboration networks behind this transformation, their characteristics, the main actors and the trending topics of their research. Additionally, we focused on the relationship between these transformations in local scientific production and a particular STI policy that we propose is one of its main triggers: the national public scholarship program for postgraduate studies abroad.

The results of the bibliometric analysis show that Ecuadorian scientific production is composed of about 25,000 records indexed in the Scopus database that have been published between 1920 and 2019 (83% in the last decade). These publications were produced by 85,000 scientists, 25% of which have affiliations in one of the 1,760 Ecuadorian research institutions indexed in this database. This includes universities, hospitals, research centers, foundations, enterprises and others.

The network analysis has revealed an accelerated evolution and increasing complexity of the local techno-scientific networks in the last decade. This process has generated a system with more collaboration networks both inside and outside the country. Only 32% of the publications were produced by

local networks. The remaining 68% comes from international networks. About 2,323 researchers affiliated to 221 Ecuadorian institutions are part of these networks. Most of them (63%) only interacted with international networks.

These results unveil a strong process of internationalization of local scientific production during the last decade, as well as a shift in research topics from publications focused mainly on health and environmental issues to research with a strong component on data and systems analysis. However, it is important to note that these analyses are based on relative measures. Therefore, this does not mean that these other topics have been neglected; rather, their volume in relation to other publications have decreased.

The analysis of the relationship between this boom of scientific production and collaboration and the postgraduate scholarship program sponsored by the government during the last two decades shows a statistical correlation between the number of international scholarships granted in a specific year and the number of indexed publications four years later (0.58 increase in publications for every scholarship allocated 4 years early). This correlation analysis also shows higher scientific productivity coefficients among PhD and Medical programs (>2.5 publications in 4 years). These statistical insights have been corroborated by matching scholarship and authorship databases. This match shows that by 2019, scientists with Ecuadorian affiliation who had benefited from a public scholarship represent 13% of the whole scientific community publishing in journals registered in the Scopus database and that they produce 3,2 more articles than their pairs. Assuming foreign affiliation records as a proxy of scientific training abroad financed not only by public scholarship programs but any other scientific funding scheme, we found that scholars with foreign training (29%) are the authors of 76% of the all publications in the Scopus database. This hard data insights support the hypothesis that the local publication boom is driven by the internationalization process triggered by these kind of international scientific training programs

All these Figures are based on limited but accurate and verified data. Given that verified data was unavailable for the 2016–2019 period, this four-year timespan has not been included in correlation analysis. Future research that runs similar tests on this topic should be careful to include accurate data for this period.

Further research is needed to test these findings and methodology in other countries and to carry out comparative analysis.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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