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Invention and Collaboration Networks in Latin America: Evidence from Patent Data

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Abstract

This research aims to analyze the collaboration networks associated with the processes of invention and patenting in Latin American countries between 1970 and 2017. To do so, we apply social network analysis techniques to a rich database containing information from patents developed by Latin American inventors and registered in the USPTO during such period. We build and analyze three types of collaboration networks: networks of inventors, networks of innovators (i.e. patent owners) and networks of countries in the region. The study of the structural properties and the evolution of such networks allow us to present unprecedented empirical evidence on the forms of interaction and collaboration to invent in Latin America. This evidence shows that collaboration networks in Latin America are highly fragmented and disconnected. Moreover, networks are notoriously foreign-oriented, i.e. the linkages with external nodes are critical compared to the low presence of local connections. Major differences among the countries of the region can be observed, which allow us to identify different behaviors according to how much they use the patent system and the relative development of the national networks. In a region which has been historically characterized by high heterogeneity, this research allows recognizing specific patterns of innovation at the national level. In sum, the contributions of the paper are three fold. First, it presents novel empirical findings with unique information on interaction patterns at the Latin American level. Second, it allows analyzing the whole region and the main trends in the light of the large research background on invention and development from this region. Finally, it discusses some stylized facts in national cases, with the aim of encouraging new research questions for further research agenda.

Keywords: patents, invention, social network analysis, collaboration networks, Latin America.

JEL Classification: O31, O54, P48.

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Resumen

Esta investigación tiene como objetivo analizar las redes de colaboración asociadas con los procesos de invención y patentamiento en los países latinoamericanos entre 1970 y 2017. Para ello, aplicamos técnicas de análisis de redes sociales a una base de datos que contiene información de patentes desarrolladas por inventores latinoamericanos, y registradas en la Oficina de Patentes y Marcas de Estados Unidos (USPTO) durante dicho período. A partir de estos datos, construimos y analizamos tres tipos de redes de colaboración: redes de inventores, redes de innovadores (es decir, de propietarios de patentes) y redes de países de la región. El estudio de las propiedades estructurales de las redes y su evolución, nos permite presentar evidencia empírica sin precedentes sobre las formas de interacción y colaboración para inventar en América Latina. Esta evidencia muestra que las redes de colaboración en América Latina están altamente fragmentadas y desconectadas. Además, encontramos que las redes están notoriamente orientadas al extranjero, es decir, los enlaces con nodos externos son críticos en comparación con la baja presencia de conexiones locales. Se pueden observar grandes diferencias entre los países de la región, lo que nos permite identificar diferentes comportamientos según la inserción en el sistema mundial de patentes y el desarrollo relativo de las redes nacionales. En una región que históricamente se ha caracterizado por una alta heterogeneidad, esta investigación permite reconocer patrones específicos de invención e innovación a escala nacional. En resumen, este trabajo realiza tres grandes contribuciones. Primero, presenta hallazgos empíricos novedosos con información única sobre patrones de interacción a escala latinoamericana. En segundo lugar, permite analizar a toda la región y sus principales tendencias a la luz de los antecedentes sobre innovación y desarrollo en América Latina. Finalmente, discute algunos hechos estilizados de los casos nacionales, con el objetivo de proponer nuevas preguntas de investigación para una agenda de investigación futura.

Palabras clave: patentes, invención, análisis de redes sociales, redes de colaboración, América Latina.

Código JEL: O31, O54, P48.

1. Introduction

Latin American studies on science, technology and innovation (STI) have a long tradition, which has been nurtured from different streams of research (Erber, 2009; Katz, 2000; Sábato, 1975; Sagasti, 2004; Thomas et al., 1996). These bodies of literature have made relevant contributions to understanding the specific features and main challenges of the relationship between STI and development in this region. While studying this relationship, previous research has addressed different key factors such as national development paths, sectoral and technological regimes or local development processes in Latin America. However, while data availability and information processing capacity have dramatically increased, several studies are claiming for the need of comprehensive research based on standardized data for the entire region (Dutrénit et al., 2019; Grazzi & Pietrobelli, 2016).

This working paper aims to address such need, presenting the first results of the project "Collaboration and invention networks in Latin America: empirical evidence from patent data". The main goal of this research project is to study collaboration networks derived from invention activities in Latin American countries. Therefore, we aim to contribute not only to the literature on STI and development in Latin America, but also to the growing literature on patent collaboration networks.

The relevance of collaboration networks in innovation has been widely analyzed by different streams of research. In recent decades, various studies on this subject have applied social network analysis to patent data, aiming to analyze collaboration networks (Fleming et al., 2007; Graf, 2017; see also Section 2.2). These works have made important empirical and theoretical advances; however, they have focused almost exclusively on analyzing cases in developed countries (mainly in Europe, North America and Asia). Meanwhile, underdeveloped regions, such as Latin America, have been neglected by this literature.

In this working paper we use data from the US Patent & Trademark Office (USPTO) retrieved from the PatentsView database. This database allows us to elaborate and analyze a wide range of collaboration networks associated with inventions that were developed by Latin American actors. Said networks also include direct links with actors collaborating from outside the region. In particular, we study networks of inventors and networks of innovators (i.e. patent owners) at different geographical levels.[1] First, at the regional level, we analyze interaction patterns among all actors located in Latin America, identifying intra and/or extra regional collaboration dynamics. Second, at the national level, we study networks for each Latin American country, searching for territorial differences and disparities in accumulated capabilities, which may be associated with their national innovation systems. In addition, we analyze collaboration networks at a macro scale, considering countries as nodes connected to each other through interactions among inventors and innovators located in different territories.

[1] Patent owners can be firms, research centers, universities, public sector agencies or individuals. These actors can search for a commercial application of inventions through the patent system (although most registered patents are never commercialized), therefore, the previous literature refers to them as innovators (Graf, 2017).

Applying social network analysis techniques, we study different topological properties that describe collaboration patterns in the region. We focus particularly on two network properties that have been extensively analyzed by the literature: internal connectivity (i.e. the extent to which nodes are connected to each other) and external openness (i.e. the extent to which local Latin American actors are linked to external nodes). We study and compare these properties in all the types of networks mentioned above and analyze how they evolve between 1970 and 2017.

Our findings reveal that almost all Latin American networks are highly fragmented and disconnected. However, in line with the abundant evidence of the high heterogeneity of this continent (Bértola & Ocampo, 2012; Castellacci & Natera, 2016; Dutrénit et al., 2019), we also find that internal connectivity in national networks evolved differently during the period under study. We managed to identify and analyze interesting cases (some of them unexpected) of network evolution. For example, while Brazil and Mexico present the largest networks, Cuba is the only country with a giant component, which emerged abruptly in the 2000s and remained connected until today. This implies that the Cuban network is the only case where most inventors are linked to each other, which has important implications in terms of the dissemination of knowledge and the capacity for collaboration at the national level. On the other hand, we find that other countries, such as Argentina and Chile, stand out mainly for the connectivity of their innovator networks, which seems to prove that these nations have a relatively cohesive system of innovative companies and organizations. We have also documented cases such as Venezuela, where a giant component emerged in the 1990s and subsequently disintegrated, resulting in a strongly fragmented and disconnected national network, possibly because of both internal and external institutional shocks experienced by the country in the last decades.

Previous research has widely shown that both research and innovation systems in Latin America are highly open systems (Cimoli et al., 2005; Cohen, 1995). Coherently, we find that Latin American networks are strongly outward oriented. National collaboration networks are highly connected to external actors. Yet, in certain countries, such as Peru or Venezuela, this orientation seems to indicate a strong dependence on international collaborations. Furthermore, we find a clear extra-regional orientation of links, which is consistent with the great fragmentation of the collaboration network at the Latin American level, evidencing the absence of a regionally-integrated innovation system. Macro-scale networks, in addition to confirming the external orientation of links, reveal the existence of a core-periphery structure, where a reduced group of highly-connected countries (the core) coexists with a disconnected periphery of nations that are only scarcely connected.

The results of this study make two relevant contributions to the previous literature. First, we obtain empirical evidence about a wide and very diverse range of countries during a long and relevant period of time. In this regard, our work provides a novel comparative analysis of network structures in multiple nations with different sizes, different levels of economic development and considerable heterogeneity of institutional frameworks. Furthermore, during the 48 years analyzed, Latin American countries experienced significant institutional shocks (e.g. signing of TRIPS, privatization of state-owned firms) as well as strong economic and political fluctuations (Forero-Pineda, 2006; Shadlen, 2009). This allows us to observe how collaboration networks evolve and may respond to such changes in the environment in which they are embedded. This empirical evidence is of great interest, not only for the literature on innovation and development, but also for the literature on collaboration networks.

Our second major contribution is related to the combination of networks analyzed here, where different types of nodes, links and geographical perspectives are considered. This variety of networks allows us to observe how collaboration patterns evolve at different levels: inter-personal, inter-organizational and inter-country. Such combination of perspectives, which has not yet been used in the literature on patent networks, provides a broad and exhaustive overview of collaboration patterns in Latin American countries.

It should be noted that the empirical evidence presented here is mainly descriptive. The document seeks to be comprehensive, giving a broad and general vision of what we can observe in the structure of networks. Although some interpretations of the results are also pointed out, it is left for the following phases of this research project to delve into the determinants and potential effects of the networks presented here.

The rest of the document is structured as follows. In section 2 we sketch our theoretical framework on innovation systems and collaboration networks. Moreover, we provide a brief overview of innovation activities in Latin America. The data collection and processing procedures are explained in detail in Section 3. Section 4 describes the methodologies used for the construction and analysis of collaboration networks. Section 5 presents descriptive statistics on the overall evolution of patents, inventors and innovators in the region. Networks are analyzed in the following three sections: in particular, Section 6 studies the networks on a Latin American scale, Section 7 analyzes and compares national networks in the different countries of the region, and Section 8 focuses on international connections in macro-scale networks. Finally, in Section 9 we conclude and present future lines of research.

2. Research Framework

2.1. Innovation Systems and Collaboration Networks

Innovation has been defined as an uncertain and cumulative problem-solving process which is interactive in nature (Dosi, 1988; Nelson & Winter, 1982). This definition relies on the distributed property of knowledge: solving complex problems requires a wide variety of knowledge that no single actor has, but rather it is distributed among a broad set of actors (Boschma, 2005; Foray, 2004; Hippel, 1988). Hence, innovation activities and outcomes may depend on the choices and actions of different actors who interact under uncertainty due to incomplete information and partial understanding of the complexity that each process involves (Graf, 2017; Lundvall, 1988; Sorenson, 2018).

Innovation studies have built different theoretical tools to explain the interactive nature of innovation. These tools have mostly been developed aiming to capture the systemic effects of interactions, i.e. the effects of the whole system, which is different from the sum of the effects of each action in an isolated manner (Dosi & Nelson, 2010).

In this sense, the approaches of innovation systems and network analysis are strongly intertwined and have been mutually influenced (Cimoli, 2007; Freeman, 1991; Lundvall, 1988; Maillat, 1998). On the one hand, the innovation system (IS) approach allows delimiting the system boundaries according to relevant attributes, e.g. national, regional, sectoral and technological. It mainly focuses on two aspects: the actions of different agents who –deliberately or not– build interactive linkages and the institutional and historical environment where such interactions occur (Freeman, 1991). On the other hand, the network analysis approach is particularly suitable to capture the effects of interactive behavior from a multilateral perspective, considering the role and position that each agent holds in the innovation processes (Graf, 2017).

The study of innovation through social network analysis can be carried out from two broad perspectives: node-level analysis and whole-network analysis. Node-level analysis focuses on the relative position of each agent in the network. It permits the identification of the key players (e.g. universities, research centers or firms), and it also facilitates the understanding of the effects that the network generates on each agent. The agents define and follow different strategies in order to obtain benefits from interaction. For example, holding a central or intermediary position in the network will imply more exposure to information flows and potential benefits to capture knowledge spillovers (Ahuja 2000; Borgatti 2005). However, such central positions will also imply transaction costs that are not only inherent to interaction and collective action (Olson, 1971), but also associated with the relative proximity among the agents connected to the network (Boschma, 2005; Graf, 2017).

On the other hand, the whole-network approach focuses on global patterns of collaborations among a set of actors that operate in a certain sector and/or territory. The unit of analysis in this second approach is not the agent but the collective of actors. Previous studies have found evidence that certain network structures facilitate innovation processes by improving cooperation mechanisms and information diffusion (see Galaso, 2018, for a review). Therefore, such network structures can be considered a collective capital that belongs to (and depends on) a set of agents who are simultaneously embedded in a certain network (ibid).

In line with this whole-network perspective, systemic theory has stressed that the outcomes of knowledge interaction depend on how different and complementary agents are connected. Interactions among agents that are too close will reduce the space of exploration, potentially causing a lock-in effect in an already well-known knowledge space. On the other hand, interactions among agents that are too distant may imply difficulties in building a shared language that allows knowledge flows (Boschma, 2005; Nooteboom et al., 2007). These authors identify different types of proximity (e.g. cognitive, institutional, geographic), stressing that the optimal distance will be determined by the characteristics of the agents and the relevance of the network.

In this sense, the agents' absorptive and connection capacities are two critical aspects of the IS. In particular, the agents' capacity to understand and use external knowledge as well as the density of connections among them have been considered key features that distinguish IS of developed countries from those of underdeveloped ones (Yoguel & Robert, 2010).

2.2. Patents and Collaboration Networks in Latin America

In order to study innovation processes, a growing literature uses patent data to elaborate and analyze collaboration networks. According to the nodes and links that are considered, this literature can be classified into three large groups. First, studies on networks of inventors connected via co-patents (Fleming et al., 2007; Lobo & Strumsky, 2008). Second, studies on networks of applicants (i.e. patent owners) linked via common inventors and/or co-patents (Cantner & Graf, 2006; Graf & Henning, 2009). Third, inter-territorial network studies, where the nodes are countries, regions or cities and the links are the collaborations between actors located in different territories (Ejermo & Karlsson, 2006; Guan et al., 2015; Prato & Nepelski, 2014). In this paper, we build and analyze the above three types of collaboration networks for all Latin American countries.

Although the literature on patents and collaboration networks is extensive, most studies have focused on developed countries and regions (North America, Europe and, more recently, Asia). Meanwhile, research on the subject for Latin America is scarce. A few recent studies have analyzed co-invention networks based on national-level patent data for cases such as Brazil (de Araújo et al., 2019; Reis et al., 2018) and Chile (Pinto et al., 2019). Other works in the region analyzed collaboration networks associated with innovation processes using primary data collected in surveys and following sectoral or territorial approaches (Arza et al., 2018; Galaso et al., 2019; Giuliani et al., 2019; Giuliani & Bell, 2005; Rodríguez Miranda et al., 2019). There are also some works that have studied Latin American networks from a macro perspective, analyzing international connections of knowledge (Arza et al., 2018) and investment flows (Galaso et al., 2018; Sánchez Díez et al., 2017). To the best of our knowledge, there are no previous studies of patent collaboration networks in Latin America combining these micro and macro perspectives.

In fact, we have not found previous research analyzing regional-scale networks in other parts of the world. Most studies of co-invention and co-patent networks analyze networks at sub-national scale, focusing on metropolitan areas (Fleming et al., 2007; Graf & Henning, 2009). Other works (more scarce) study collaboration networks on a national scale, analyzing nation-wide collaboration networks (Andersson et al., 2019; Galaso & Kovářík, 2018; Lim & Kidokoro, 2017). In this regard, our work makes a novel contribution to the literature by complementing national networks with international collaboration networks in Latin America. In particular, it allows unraveling the networks of inventors and other innovative actors located in the region as well as the connections they maintain with actors located in other parts of the world.

Yet, this study faces two major challenges. The first one is related to the delimitation of the IS under study. One of the pillars of the IS approach has been the widely diffused concept of National Innovation System (NIS). This approach set the boundaries of the IS according to the national state, which is considered an adequate delimitation to capture key political institutional and cultural features (Lundvall, 1992). NIS are usually open systems connected to international IS. In this regard, recent studies using patent data analyzed the process of knowledge internationalization (Bergquist et al., 2018; Danguy, 2017). They describe a sort of international division of labor driven by multinational companies (MNC) and associated with migration streams, mostly of highly qualified workers (Bergquist et al., 2018). These authors analyze the world knowledge network and, in line with previous research, they stress the importance for IS to maintain their openness in order to avoid lock-in situations.

In particular, for peripheral regions, opening their IS is essential to access and absorb new knowledge. Innovation networks operate as connection channels for both tacit and codified knowledge. As (Montobbio & Sterzi, 2011) pointed out, patent citations are an indicator of codified knowledge transfers, while co-inventor linkages seem to be a suitable indicator of tacit knowledge flows. Therefore, the study of networks using patent data allows describing national and regional features, as well as the insertion of territories in global knowledge production networks.

The second major challenge of our study is related to the specific cautions that the use of patent data requires, particularly in developing countries. Using patent data to conduct a longitudinal analysis of collaboration networks in Latin America requires considering economic and institutional features that may affect intellectual property regimes (IPR) during different periods and in different countries. Changes in the IPR can operate as external shocks to the IS, since they may affect the propensity to patent and, potentially, modify the benefits and costs of collaborating with other actors (Andersson et al., 2019). Indeed, during the period analyzed in this paper, Latin America experienced significant external shocks, such as changes in the national IPR regimes (Forero-Pineda, 2006; Shadlen, 2009) as well as strong economic and political fluctuations (Cimoli & Katz, 2003; Paus, 2014).

Considering the diversity between national IPR regimes and the subsequent potential biases for comparative analysis, we study an external patent system: the US patent regime. The use of a common IPR regime allows an adequate comparison of inventive activities between countries, avoiding problems associated with the institutional differences among national patent offices. Despite the general guidelines of the World Intellectual Property Organization, the patentable subject matter has significantly varied among certain countries during the last decades. Specifically, in fields related to health and pharmaceuticals, the main countries of the region have substantially changed their patenting policies during the years analyzed in this study (Shadlen, 2017). The US patent system has the advantage of being the world center of the market for technology during the period under study. This allow us to analyze inventive activities that fulfills the standards of USPTO and has been carried out from Latin America. As a counterpart, our analysis does not consider the inventive activity that is not patentable according to the US system.

Network connectivity and absorptive capacity are expected to be related with economic productivity and social welfare (Crespi & Dutrénit, 2014; Grazzi & Pietrobelli, 2016). Given that one of the most salient characteristics of Latin America is the high heterogeneity among and within countries (Bértola & Ocampo, 2012), this article aims to describe the main features of knowledge networks in the region, comparing the different national networks and their different levels of development.

Describing the role played by different types of actors in collaboration networks is critical to understand their contribution to the creation and dissemination of knowledge. Research centers and firms are usually seen as key actors in any IS. In this regard, previous literature has found that developing countries usually show an overrepresentation of public participation in funding for research and innovation activities. Particularly, in Latin American economies, the private expenditure is around 30% of the national investment in R&D (Crespi & Dutrénit, 2014; Grazzi & Pietrobelli, 2016; Velho, 2005). Furthermore, research and innovation activities are concentrated in public institutes and universities, which play a critical and singular role in the Latin American IS (Bianchi & Guarga, 2018; Dutrénit & Arza, 2015). Moreover, given the marginal role of Latin American countries in the world knowledge production, it is particularly worth distinguishing between national and foreign agents within the networks. This document aims to make initial contributions in these directions, describing the main trends and composition of collaboration networks and highlighting open research questions that will be addressed in future research outcomes.

In the same vein, it is expected to find knowledge networks territorially anchored around large cities, where the more dynamic universities and research centers are located. The literature on patent networks has widely inquired on the regional effects of networks, characterizing their dynamics as well as their interactions according to geographic proximity and knowledge spillovers (Boschma, 2005; Cantner & Graf, 2006; Strumsky & Thill, 2013). On the other hand, Latin American IS are characterized by a weak integration among agents and the absence of certain key actors and roles (Arocena & Sutz, 2000; Rapini et al., 2009; Yoguel & Robert, 2010). Such absences are usually filled by foreign actors. In addition, traditional knowledge centers, i.e. old universities or research centers (some of them specialized in a specific field of research, such as life sciences, geology and oil, among others), particularly those from the larger countries of the region, are expected to occupy central positions in the networks.

2.3. Innovation and intellectual property regimes in Latin America: stylized facts

Latin America has usually been characterized as one of the most unequal regions in the world, seriously affected by structural heterogeneity in its production systems (Bértola & Ocampo, 2012). Regarding research and innovation, heterogeneity is also the most salient feature. However, it is possible to describe some generalized patterns within the region.

Since the end of the 20th century, scientific production of Latin American countries has increased substantially, achieving just over 5% of worldwide scientific publications (Confraria & Vargas, 2019). However, the region continues to play a peripheral role in the global research system, registering structural delays with respect to more developed regions (Bianchi & Guarga, 2018; Lemarchand, 2010).

Investment in research and innovation in the region is critically low. As presented in Figure 1, average national expenditure in R&D for Latin American and Caribbean countries is well below that of most dynamic regions. After a slight increase, national expenditure in R&D seems to be stagnated, remaining below 1% of GDP, with the exception of Brazil and some observations from Cuba.

Moreover, as mentioned above, the public sector leads around 70% of the investment in Latin American STI activities. Meanwhile, in developed countries, most of these investments come from firms and other private organizations (Bianchi & Guarga, 2018). This fact reflects a significant structural constrain in the region, and it was already identified by the earlier Latin American literature on technical change and development (Sábato, 1975). Historically, research and innovation activities in the region have been carried out in universities and research centers, while firms have been mainly engaged in the production of traditional goods and services with a weak demand for knowledge-based productive solutions (Dutrénit & Arza, 2015).

The lack of innovation activities in private firms has been attributed to the productive specialization of the region, which is concentrated in traditional sectors and strongly based on natural resources extraction and transformation. In addition, recent works have shown that research systems related to key natural resources in Latin America have increased the quality and quantity of production. However, such scientific outcomes are mainly produced by research institutions, with relatively little collaboration linkages with the private productive system (Confraria & Vargas, 2019).

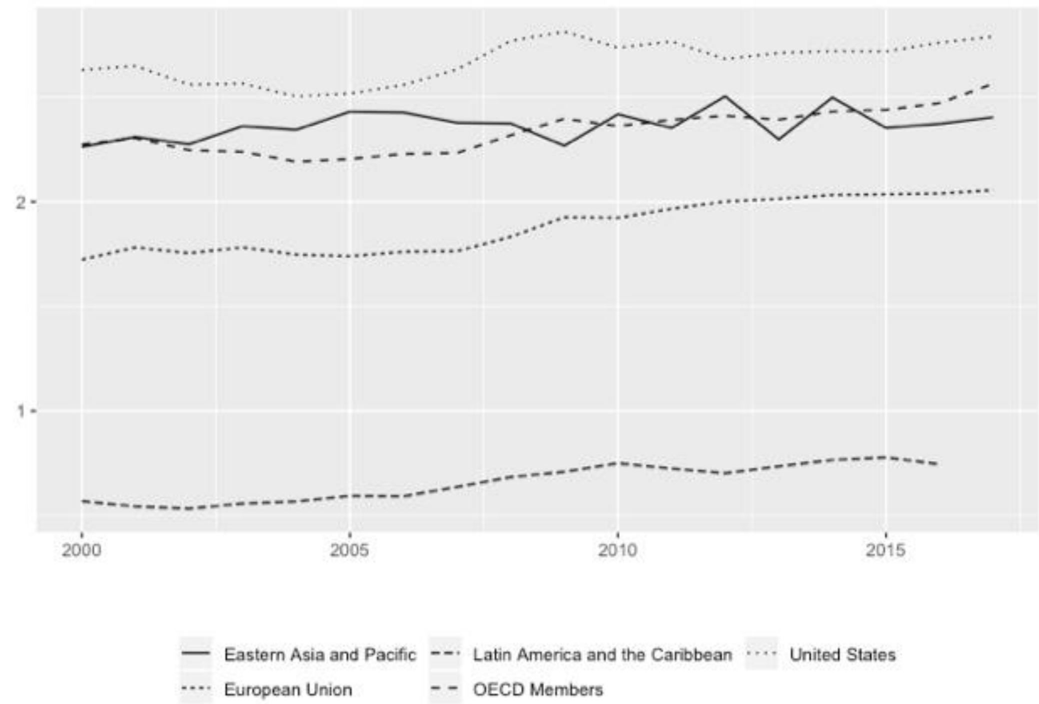


Figure 1. National expenditure in R&D as a % of GDP (regional averages)

Source. World Bank data. https://datos.bancomundial.org/indicador/GB.XPD.RSDV.GD.ZS?end=2017&locations=ZJ-EU-Z4-US-OE&most_recent_year_desc=false&start=1996&type=shaded&view=chart. Retrieved April 1 2020.

This overall picture may not obscure the recent progress achieved by the region in terms of technological accumulation. During the so-called state-led industrialization process, many Latin American countries developed an industrial base in a sheltered environment

(Bértola & Ocampo, 2012; Cimoli & Katz, 2003). Among a complex and extensive set of protection mechanisms, such industries (e.g. pharmaceutical) benefitted from the partial adoption of intellectual property rights (Shadlen, 2017). In this regard, due to the extension of the property rights agenda in the World Trade Organization (WTO) agreements, these industries have been critically affected since the liberalization process in the last decades of the twentieth century.

Our database covers two major phases of the international IPR regime. In the first phase, patenting activity was mostly related to national public policy and strategies from big actors. However, this situation changed after the introduction of the Trade-Related Aspects of IPR (TRIPS) in the WTO at the end of the twentieth century and the beginning of the twenty-first. In this new phase, Latin American countries progressively adopted the global IPR regime (Shadlen 2017) and this caused several effects on their economies that have been largely discussed in the literature (Correa, 2000; Shadlen, 2009). Since we study collaboration networks using patent data, it should be borne in mind that the global expansion of the IPR regimes during the period under study directly affects the phenomena that we aim to analyze. In particular, as (Hall, 2005) has pointed out, the measurement of innovation is challenged by feed-back effects from the countries' innovation performance and their institutional changes.

According to Figure 1, Latin American countries register a very low performance in research and innovation activities compared to other regions that have managed to catch up with central economies (i.e. Asian Tigers). Although in recent years there has been an effort to overcome this delay, the current world trade regulation involving IPR issues appears as a critical barrier for Latin American countries to climb the ladder followed by the Asian successful cases (Chang, 2010).

This last period matches the so-called patent boom at the global level (Hall, 2005). However, each national country in Latin America has followed different strategies to introduce world IPR trends (Díaz, 2008; German-Soto & Cantú, 2018). Thus, the adoption of the trade-related IPR in the region has been carried out under a pattern known as "diversity in the context of convergence" (Shadlen, 2017).

In sum, collaborative invention activities may be affected by several factors such as research and knowledge-related dimensions, economic and sectoral regimes, and the political economy of the national states. Countries with larger and more diversified economies have usually implemented more complex and diverse policy measures in this field (Hall, 2005; Shadlen, 2017). Therefore, understanding how the particularities of each Latin American country can be associated with their collaboration networks is another challenge that arises in this research. The data and methods we employ to meet these objectives are explained in the following sections.

3. Sources and Data Processing

The data used in this study are US patent records retrieved from the PatentsView platform. PatentsView collects and organizes data from the US Patent & Trademark

Office (USPTO), including patents granted since 1976 (as well as patents applied for before 1976). As explained above, the use of patent data from of a common IPR regime allows an adequate comparison of inventive activities between countries. In this regard, USPTO data has been widely used in the literature in order to compare inventive activities in different countries (CEPAL, 2016; Gao et al., 2017; Guan et al., 2015; Huang et al., 2004; Morales Valera & Sifontes, 2014).

Based on probabilistic methods, the PatentsView database incorporates disambiguated inventor and assignees identifiers. Disambiguation process is critical for analyzing collaboration networks with patent data because it allows determining whether or not inventors and assignees registered with the same name are indeed the same actor.

The database also considers inventors and assignees geolocation. This aspect is crucial to carry out a territorial analysis on collaboration networks. Another advantage of the database is that assignees (i.e. patent owners) are classified into different categories, distinguishing between private firms, government agencies and individuals.

To fulfill the objective of this research, we make a selection from the complete database that allows us to focus on patenting activity carried out in Latin American countries. The selection process resulted in a database that includes 17,942 Latin American patent registrations in the US, which cover the 1970 - 2017 period and account for 0.25% of the total USTPO database. Throughout such process, and despite the quality of the original database, we identified some inaccuracies on the data and proceeded to fix them. All the steps we followed in the data selection and processing are detailed below.

3.1. Primary sources of data

The original data sets used in this research are described in the following table. All of them can be downloaded from https://www.patentsview.org/download/.

Table 1. Primary data sets from PatentsView

Name	Description
inventor	Disambiguated inventor data set. It includes first and family name and id number for each inventor.
assignee	Disambiguated assignee data set. It includes id number and name. It also classifies each assignee according to a basic typology.
patent_inventor	It connects each patent with the id (s) of its inventor(s).
patent_assignee	It connects each patent with the id (s) of its assignee(s).
location_inventor	It assigns (at least) one location for each inventor.
location_assignee	It assigns (at least) one location for each assignee.
application	It indicates the date of application of each patent.
wipo	It indicates the technological sectors to which each patent is associated.[2]

[2] This document does not carry out a sectoral analysis, however, the data on technological sectors will be used in future investigations of this research project.

3.2. Selecting patents with Latin American inventors

This research aims to analyze collaboration networks associated with inventions that have been developed by Latin American actors. To identify such inventions, we select patents with, at least, one inventor located in a Latin American country. Although the precise delimitation of the Latin American region is variable, it basically groups American countries whose official language is Spanish or Portuguese. If we exclude the dependencies and constituent entities (such as Martinique or Puerto Rico), the list of countries comprises the following 19 nations: Mexico (in North America), Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama (in Central America), Cuba, Dominican Republic (in the Caribbean), Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay and Venezuela (in South America).

From the primary database, we identify those inventors who are located in at least one of any of the countries considered above. Using that list of Latin American-based inventors, we obtain the list of patents in which they intervene. That list of patents constitutes our reference database for this research.[3]

3.3. Locating the assignees

After defining the patents and inventors considered in our database, we will analyze the available information about the assignees. The assignees are the owners of the patents and, thus, may be companies, organizations, research centers, universities or even individuals.

We start from our database obtained following the process described above. In these 17,942 patents we find 4,735 different assignees and we observe that there are 4,104 patents without assignees. Our first step is to identify the country (or countries) where these assignees are located. It should be noted that, regardless of whether these assignees are located in Latin America or outside the region, they all have a patent with at least one inventor located in Latin America.

Assignees can have more than one location (e.g. firms with different headquarters), but some assignees with many locations outside the region can be problematic for our study. To deal with them, we have analyzed case by case to focus on the appropriate locations (see Annex A for more details on this process).

3.4. Setting the period under study

There are two key dates in patent records: the application date and the grant date. Between them, there is a time lapse during which the patent office examiners review the application. Since this time interval can last for several years, the application date represents the culmination of the invention process in a better way than the grant date.[4]

[3] In this list we identified some problematic cases. The procedures we followed to refine this list are detailed in Annex A.

[4] For patents filed at the USTPO, the average duration of this grant lag is 28 months with a standard deviation of 20 months (Popp et al., 2004).

Therefore, we use the application date of our patents in order to define the period of analysis.

In the selected patents (i.e. those with inventors in Latin America) the application dates cover the period between 1968 and 2019. Yet, very few observations were found in 1968 and none in 1969. From 1970, the data series remains continuous, with at least one observation per year until today. Therefore, we define the beginning of our analysis period in 1970.

Regarding the end of the period, we must remember that PatentsView database contains only granted patents. Thus, a large proportion of the patents that were applied for in more recent years do not appear in the database because they have not yet been granted by the USTPO. This leads to a significant decline in the data records of recent years and, for this reason, we decided not to include data from 2018 and 2019. In summary, our analysis covers a time period of 48 years: between 1970 and 2017.

After introducing all the adjustments described above, our database consists of the variables described in Table 2.

Table 2. Variables included in the database

Name	Description
assignee_id	Id code for each patent assignee.
patent_id	Id code for each patent.
application_year	Year of patent application.
inventor_id	Id code for each patent inventor.
is_latam	Indicates if the inventor is located in Latin America
application_id	Id code for each patent application.
application_date	Date of the application.
wipo_field_id	Technological field of the patent.
wipo_sequence_id	Second level of technological field classification.
n_loc	Number of locations assigned to each inventor.
country_of_LA	Latin American country with the highest number of occurrences in the inventor's records
inventor_name_first	First name of the inventor.
inventor_name_last	Surname of the inventor.
inventor_location_id	Id code for each inventor's location.
inventor_location_city	City of the inventor.
inventor_location_country	Country of the inventor.
inventor_location_latitude	Latitude of the inventor (for geolocation).
inventor_location_longitude	Longitude of the inventor (for geolocation).
assignee_location_id	Id code for each assignee's location.
assignee_type	Class of assignee, distinguishing between private company, government and individual.
assignee_name_first	First name of the assignee, in case it is an individual.
assignee_name_last	Surname of the assignee, in case it is an individual.
assignee_organization	Name of the firm or government organization, in case the assignee is not an individual.
assignee_city	City of the assignee.
assignee_state	State of the assignee.
assignee_country	Country of the assignee.
assignee_latitude	Latitude of the assignee (for geolocation)
assignee_longitude	Longitude of the assignee (for geolocation)
ass_country_name	Country name of the assignee according to the ISO2 international standard designation.
ass_is_latam	Binary variable indicating whether or not the assignee is located in a Latin American country.
ass_num_countries	Number of countries in which the assignee is located.
ass_num_latam	Number of Latin American countries in which the assignee is located.
colaboration_ass	Binary variable indicating whether or not the assignee shares any patent with other assignee.

4. Network Elaboration and Analysis

The two building blocks of networks are nodes or actors, and links or connections. In this research we elaborate two types of networks depending on the nodes and links that were considered: networks of inventors and networks of patent assignees or innovators.

Inventors are individuals who claim to have invented the patented technology. A link connecting two inventors is traced when they are registered in the same patent. Thus, co-invention links represent collaboration between at least two inventors that have patented the same product or process.

The second type of network is co-innovation networks. The nodes of such networks are the patent assignees, i.e. the owners. Most of them are firms, but research centers, universities, public sector agencies or even individuals can be owners as well. Following the previous literature, we refer to them as innovators, since they are usually firms that seek for a commercial application of an invention through the patent system. Links are traced considering that two or more innovators are connected if they have worked with the same inventor. Thus, inventors are used as links connecting innovators in this type of networks (Cantner & Graf, 2006; Graf & Henning, 2009).

Since inventors are individuals and patent owners are (mostly) organizations, these two types of networks allow us to analyze collaboration patterns at two different levels: inter-personal and inter-organizational. Figure 2 presents graphical examples of the elaboration of the networks using data from three patents.

Patent	Inventor	Innovator (assignee)
I	1, 2 & 3	A
II	3 & 4	B
III	5	C

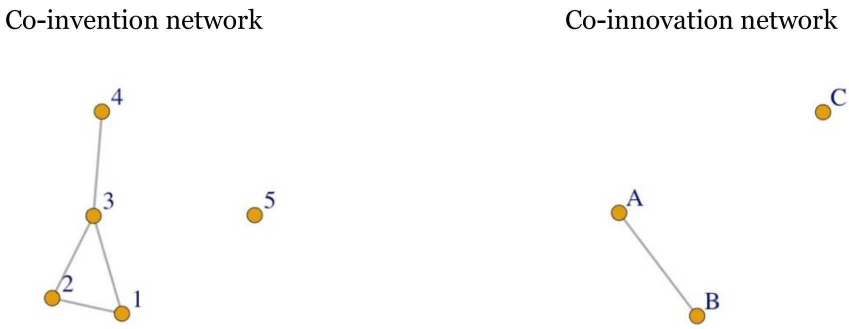


Figure 2. Example of co-invention and co-innovation networks based on patent data

Based on these two types of connections, we study collaboration networks at two different geographical levels:

- First, at the *regional level*: we build and analyze the networks that include all Latin American actors (inventors/innovators), and those external actors with whom they are directly linked. This allows us to study the overall patterns of interaction among inventors and innovators in Latin America, identifying intra and/or extra regional collaboration dynamics.
- Second, at the *national level*: for each country in Latin America, we trace collaboration networks of both inventors and innovators that are based in the country. We also include in the national networks those foreign actors who collaborate directly with local inventors or innovators. Such networks represent the collaboration patterns at the national level, including local links and connections between the country's actors and foreigners with whom they collaborate.

Regardless of the geographical boundaries of the above networks, both of them can be considered micro-scale networks. That is, networks that are composed of individuals (inventors) or organizations (innovators) interconnected by interpersonal or inter-organizational relationships. However, in this research we are also interested in building and analyzing macro-scale networks. In such networks, the nodes are countries and the links represent international collaborations carried out by inventors and innovators located in different nations (see Figure 3). As Latin American actors collaborate with inventors and innovators located in extra-regional countries, international macro-scale networks are made of both Latin American and non-Latin American Countries.

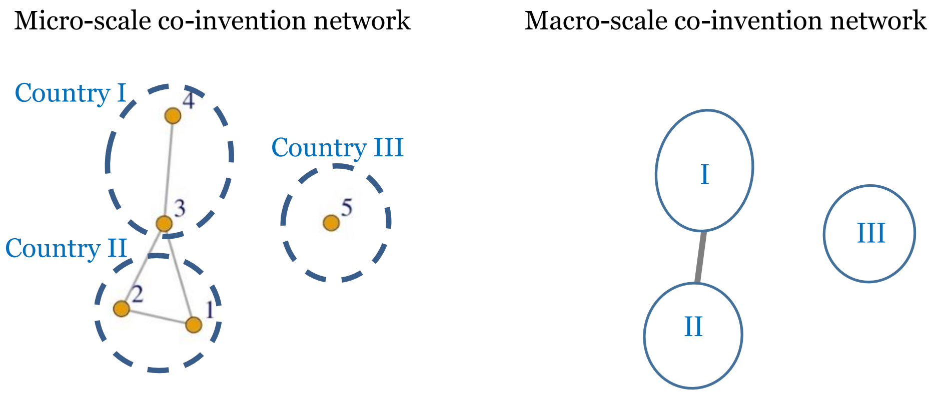


Figure 3. From micro to macro-scale networks

Note: suppose that the five inventors in our micro-scale network are located in three countries (left). With this information we can draw a macro-scale network (right), consisting of three nodes (one for each country) and one link connecting countries I and II.

Regarding the temporal evolution of networks, since inventors and innovators are supposed to collaborate before and after the patent application date, we must assume that each link exists previous to the date of the patent application and after such date. In accordance with this assumption, and in line with the literature on the subject, we consider time windows in order to study the evolution of the networks. In particular, we elaborate and analyze 8-year windows. For each temporal window, we trace the above types of networks, considering only nodes and links of the corresponding period.

After elaborating all the networks, we use social network analysis techniques to study their topological properties and evolution. We particularly focus on the following structural characteristics:

- *Size and evolution*: the number of nodes and links. This analysis shows the number of inventors and innovators as well as the number of collaboration links among them.
- *Connectivity*: the extent to which nodes are connected among them. This property shows whether the actors are well connected so that knowledge can flow among them or if, on the contrary, they work in separate groups or even isolated, conforming a fragmented and disconnected network.
- *Openness*: the extent to which local nodes are connected to foreign actors. In the national collaboration networks, this property reveals the degree of connection of the country with foreign inventors and/or innovators. This could reflect the internationalization of national invention activities with the consequent access to external knowledge and ideas.
- *Centralization*: the distribution of links among network nodes. This analysis is particularly interesting in the macro-scale international networks. It allows testing whether the network presents a core-periphery structure, i.e. if the network is made of a highly connected group of countries coexisting with a disconnected group of peripheral nations.
- *Identification of key actors and collaborations*: studying the relative position of each node, we can analyze which countries lead the international networks. We will also see which the strongest connections between each pair of countries are in order to identify the main axes of international collaboration.

In the corresponding sections below, we will explain the calculation and interpretation of the network statistics used for each of the above analysis. A detailed explanation of these indicators can be found in social network analysis manuals (Borgatti et al., 2013; Jackson, 2008; Wasserman & Faust, 1994).

5. Patents, Inventors and Innovators in Latin America

In this section we present descriptive statistics on the overall evolution of patents, inventors and innovators in Latin America. The results describe a predictable situation in terms of the concentration of inventive activities in larger countries of the region. Moreover, these results reveal that patenting abroad is a matter of countries with a relatively high tradition on science, technology and innovation (STI) activities. On the opposite side, researchers and innovators acting in the less developed STI systems in the region remain virtually apart of patenting activity. In this regard, our analysis on patents is coherent with previous research on STI indicators for the region (Lemarchand, 2010; Velho, 2005).

Figure 4 shows that the total number of patents developed in Latin America has grown during the period under study, especially since the 1990s. This result is consistent with the evolution of the number of patents worldwide, showing that Latin American countries, especially those with more advanced IS, have entered in the so called boom of patents (Hall, 2005) in a relatively encompassed time with developed countries. Although the region has managed to slightly improve its level of patenting in relation to the rest of the world, it still remains in a lagging position, far behind North America, Europe and Asia, and ranking only above the African continent (Miguelez et al., 2019; WIPO, 2019).

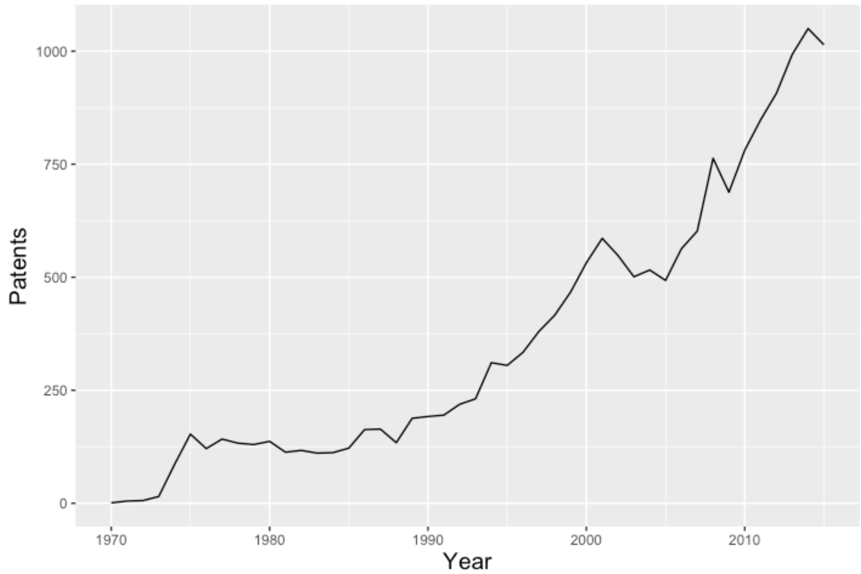


Figure 4. Evolution of US patents with Latin American inventors, 1970-2015

Source: authors based on PatentsView data.

The number of inventors involved per patent has also increased during the period (Figure 5). Furthermore, as presented in Figure 6, the proportion of individual patents has constantly decreased, while the share of patents developed by teams of inventors as well as the size of such teams have increased. All this evidence reveals a growing tendency towards collaboration for invention and patenting in the region. Such evolution is not exclusive to Latin America, but is consistent with a global trend in innovation activities (WIPO, 2019; Wuchty et al., 2007).

Regarding the average number of innovators participating in each patent, Figure 5 shows that it is much lower and has experienced a slower and more erratic growth than the number of inventors. In fact, as presented in Figure 6, the vast majority of patents are requested by a single innovator. Thus, as a general pattern, descriptive results confirm that invention in Latin America is a collective activity, while, innovation measured through patents, is mostly conducted by only one agent.

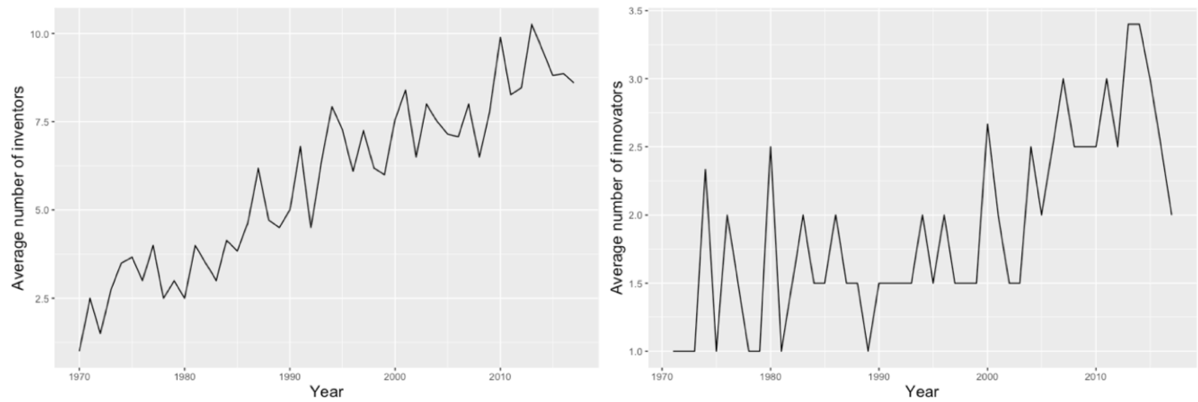


Figure 5. Average number of inventors and innovators per patent 1970-2017

Source: authors based on PatentsView data.

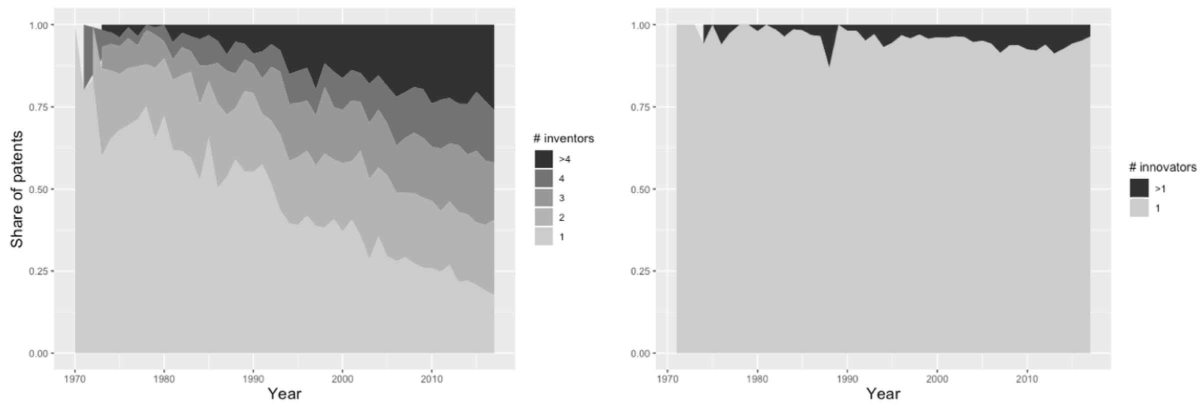


Figure 6. Evolution of team sizes (inventor and innovators)

Source: authors based on PatentsView data.

Patents developed from Latin American countries also register a high presence of non-Latin American actors. As shown in Figure 7, the percentage of external inventors has increased until the 2000s, when this tendency seems to slow down. Regarding innovators, we can observe a greater involvement of non-Latin American actors and, since 1990, there seems to be a slight but sustained increase in external participation. These findings do not imply that local inventors and innovators tend to be less active in generating US patents –the absolute number of local inventors and innovators has rather increased in absolute values–. What these figures do reflect is a growing tendency of local actors towards external collaborations in the development of patents.

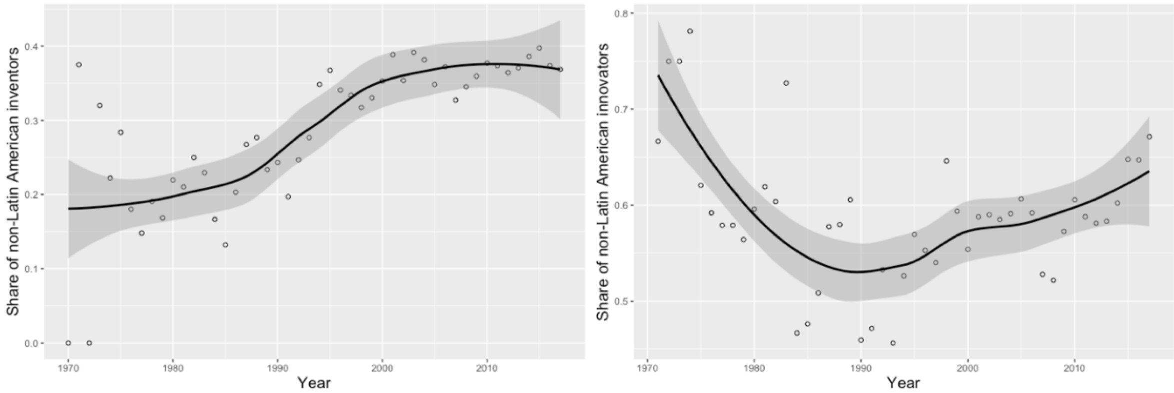


Figure 7. Proportion of non-Latin American inventors (left) and innovators (right)

Source: authors based on PatentsView data. Note: data points and locally estimated scatterplot smoothing (Cleveland et al., 2017).

Latin American patenting activities are highly concentrated in the two largest countries of the region: Brazil and Mexico (see Figure 8). By the end of the period, both countries account for almost three quarters of all patents and inventors. Regarding the number of innovators, Brazil progressively increased its weight while Mexico has been losing relative importance in recent years. Behind these two nations we find Argentina, followed by a group of three large countries: Venezuela, Chile and Colombia. Historically, Colombia and Venezuela have registered more patents than Chile. However, since the mid-2000s, Chile has outperformed these two countries.

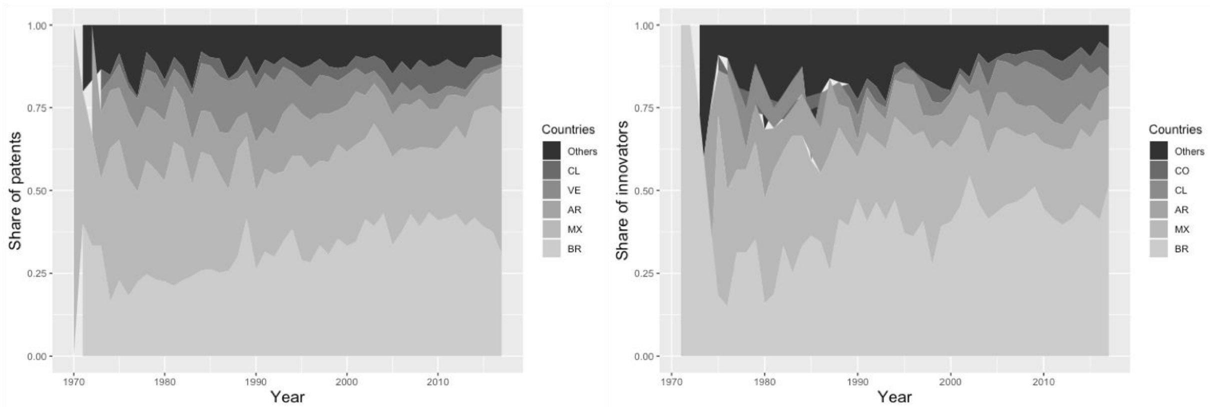


Figure 8. Evolution of patents and innovators share by top Latin American countries

Source: authors based on PatentsView data.

If we analyze the evolution of the number of patents, inventors and innovators during the period under study (Figures 9, 10 and 11), we find, behind Argentina, Venezuela, Colombia and Chile, another group of four countries with a certain critical mass in terms of their inventive activities: Costa Rica, Peru, Cuba and Uruguay. Within this group, Costa Rica has a greater number of patents, but Cuba stands out, above all, for its high number of local inventors. Behind these countries, Panama and Ecuador register a considerable number of patents but very low presence of local inventors. The remaining Latin American countries have very few patents, local inventors and innovators.

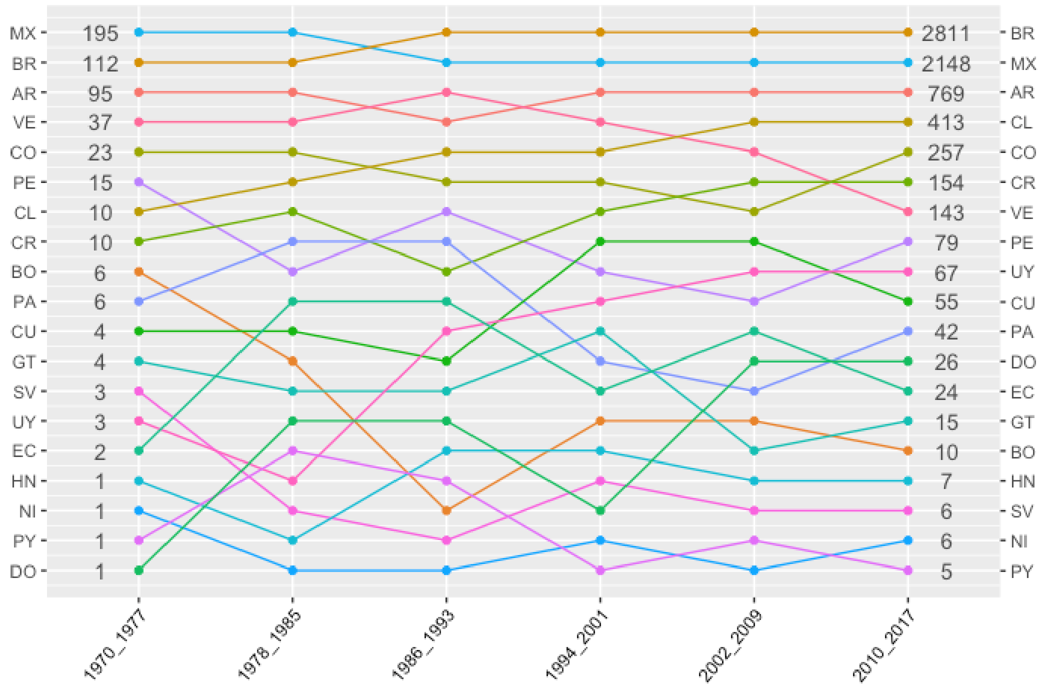


Figure 9. Number of Patents per country in Latin America

Source: authors based on PatentsView data.

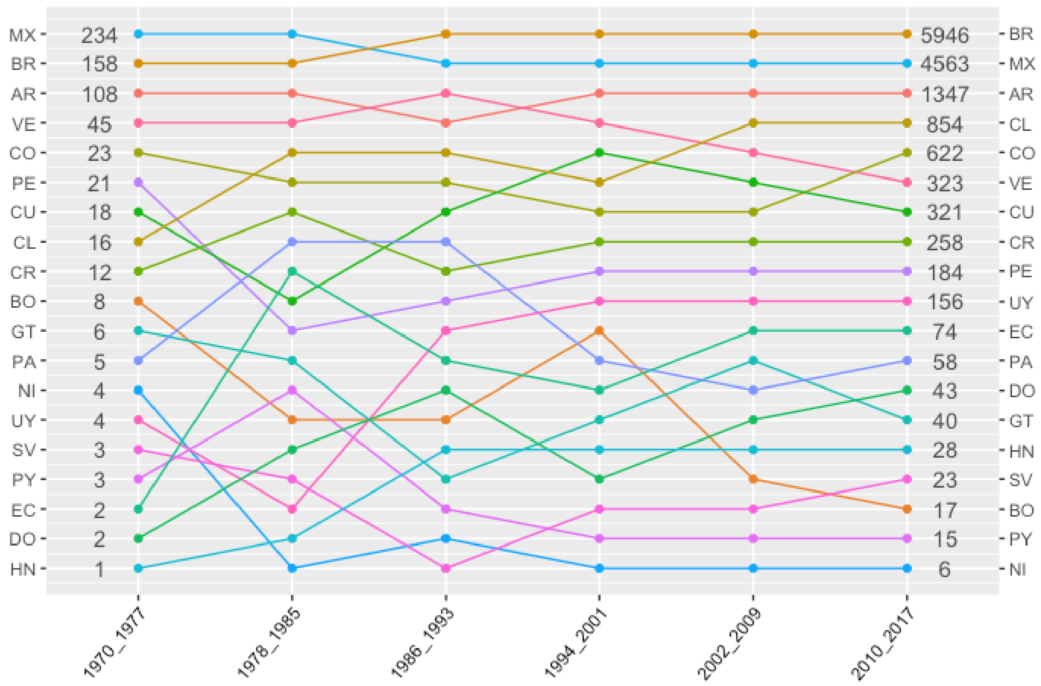


Figure 10. Number of Inventors per country in Latin America

Source: authors based on PatentsView data.

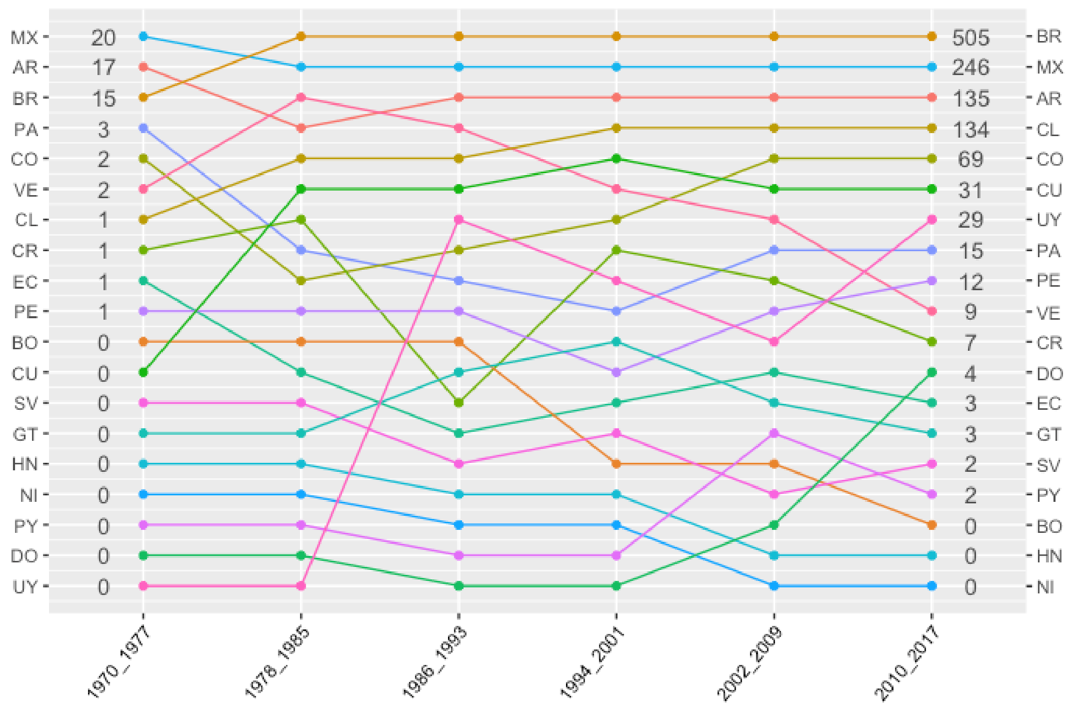
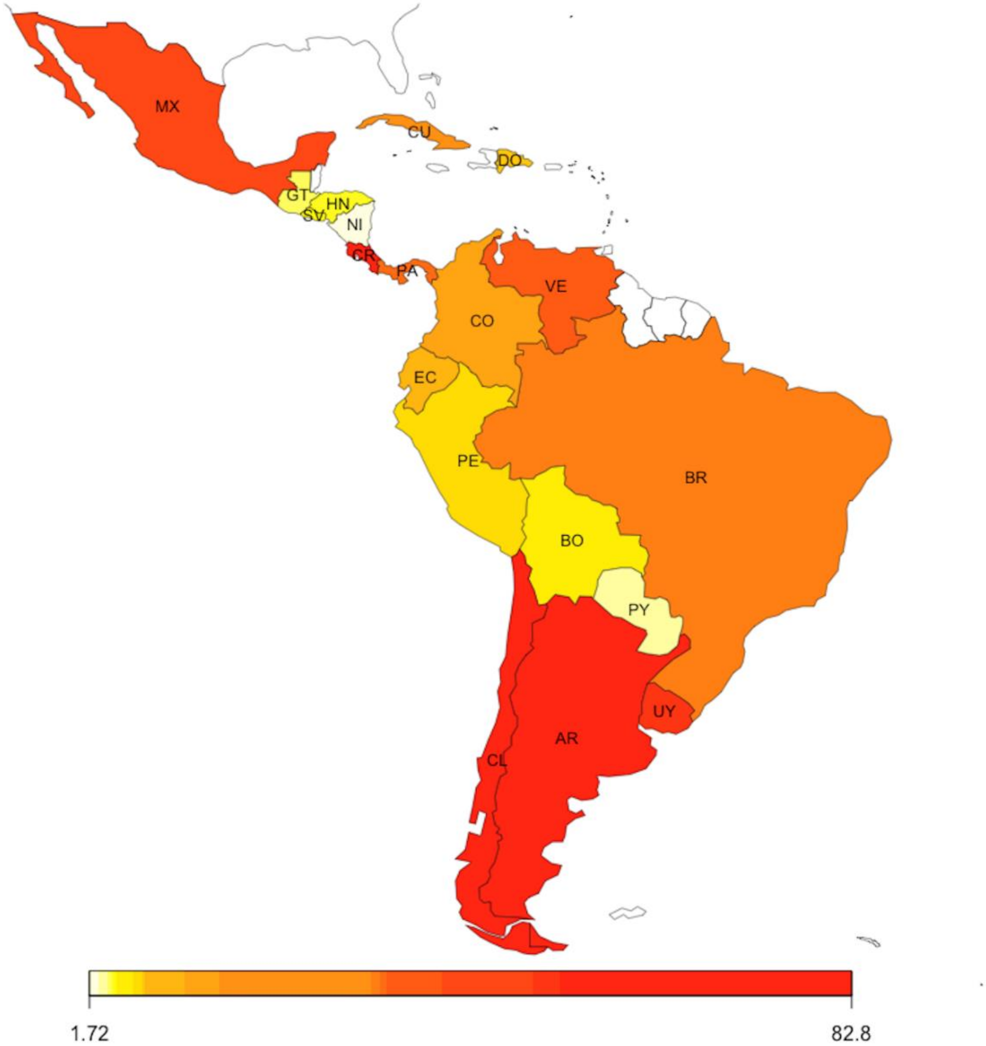


Figure 11. Number of Innovators per country in Latin America

Source: authors based on PatentsView data.

When analyzing the patent applications in relation to population, results show that Costa Rica leads the classification, followed by Chile and Argentina (see Map 1 and Table 3). Below these countries, we find a group of five nations with a medium level of patents per million inhabitants (between 30 and 50): Uruguay, Mexico, Venezuela, Panama and Brazil. On the lower side of the table, Bolivia, El Salvador, Honduras, Guatemala, Paraguay and Nicaragua, register less than 5 patents per million inhabitants.



Map 1. Patents per million inhabitants in Latin America

Source: authors based on PatentsView data.

Regarding the data on local inventors in relation to population (Table 3 and Annex B), Cuba is clearly above the rest of the countries in the region, with more than 70 inventors per million inhabitants. With much lower figures, we find Chile, followed by Costa Rica, Argentina, Mexico and Uruguay. On the other side of the table, countries like Bolivia, Guatemala, Paraguay, Honduras and Nicaragua present very low numbers of local inventors per population.

Finally, regarding the number of local innovators per million inhabitants, Chile leads the ranking, followed by Uruguay and Panama. Behind these three countries, we find Argentina, Cuba, Brazil, Costa Rica and Mexico. The rest of the countries in the region are far behind this group, with less than two innovators per million inhabitants.

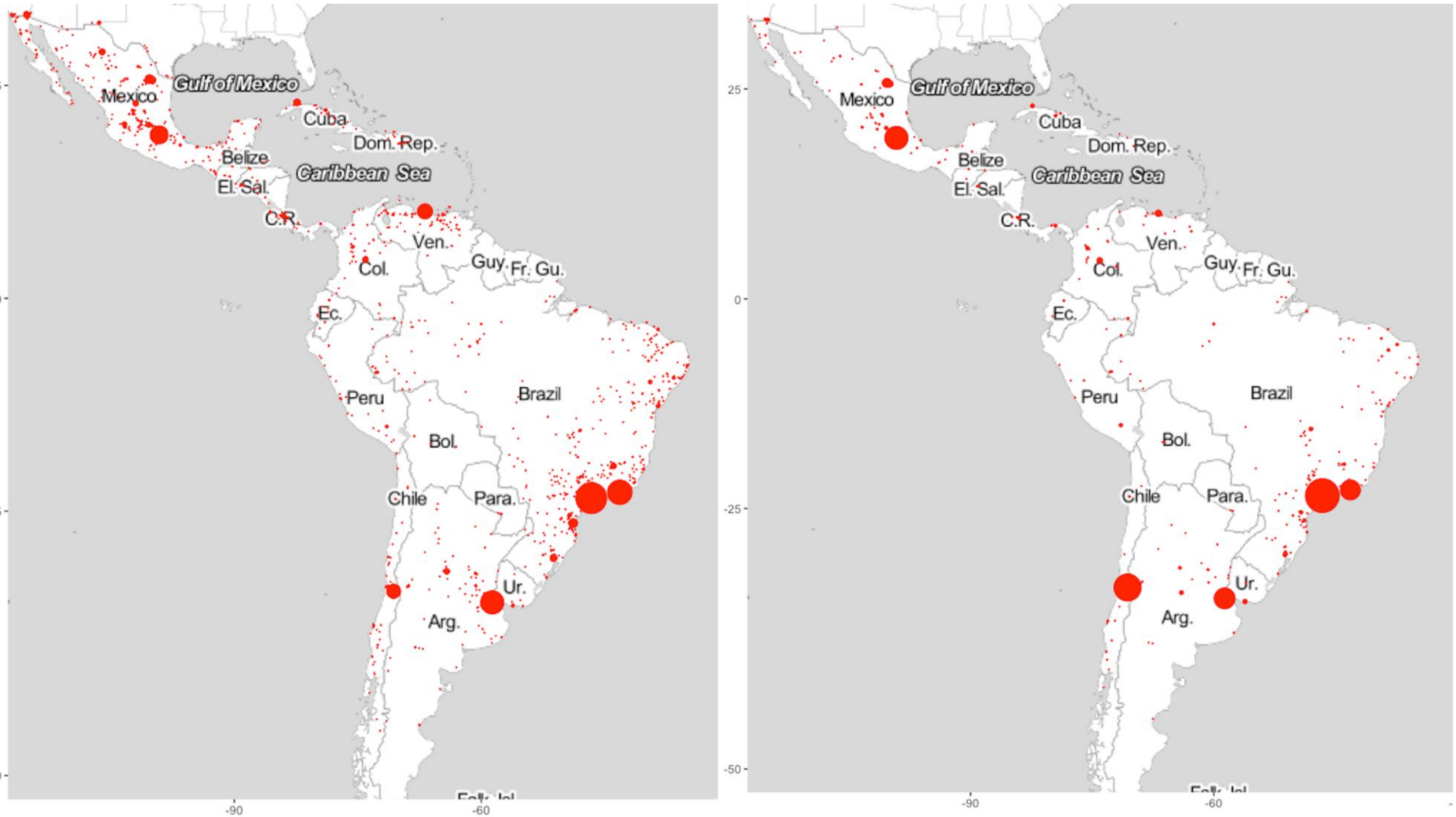
Table 3. Patents, Inventors and Innovators per Mill. Inhabitants in Latin America (1970-2017)

Country	Patents per Million Inhabitants	Local inventors per Million Inhabitants	Local innovators per Million Inhabitants
CR	82.8	44.6	4.2
CL	51.9	58.3	11.4
AR	51.8	43.1	5.5
UY	48.9	41.7	8.9
MX	39.2	42.3	3.6
VE	33.4	27.7	1.7
PA	32.6	16.7	7.1
BR	31.6	36.5	4.6
CU	15.6	71.2	4.7
CO	11.8	13.3	1.9
EC	7.5	4.8	0.5
DO	7.3	5.1	0.4
PE	6.4	5.0	0.7
BO	4.6	2.7	0.3
SV	4.4	4.1	0.6
HN	4.1	2.5	0.1
GT	3.7	2.6	0.3
PY	2.7	2.6	0.3
NI	1.7	1.4	0.0

Source: authors based on PatentsView data.

Another interesting aspect to analyze with our database is the geographical location of Latin American actors involved in patenting (see Map 2). Regarding inventors, the map shows that they are essentially concentrated in the large urban agglomerations of the region. Sao Paulo and Rio de Janeiro (in Brazil) and Buenos Aires (in Argentina) seem to be the leading Latin American hotspots, followed by Mexico City, Caracas (in Venezuela) and Santiago de Chile. Other relevant cities with high concentration of inventors are Curitiba, Porto Alegre and Belo Horizonte (in Brazil), Monterrey and Chihuahua (in Mexico), La Habana (in Cuba), Bogotá (in Colombia) and Cordoba (in Argentina).

On the other side, we observe that certain large metropolises of the region have a very low presence of inventors. In this regard, the case of Lima (in Peru) is especially striking, with more than 12 million inhabitants and a marginal number of inventors. Other large metropolitan areas like Brasilia, Recife and Fortaleza (in Brazil), Quito and Guayaquil (in Ecuador) and Asunción (in Paraguay) also register a scarce presence of local inventors compared to their large population sizes.



Map 2. Location of all Latin American inventors (left) and innovators (right)

Source: authors based on PatentsView data. Note: the red circles represent the location of inventors (left) and innovators (right) that appear in our database, considering all patents registered in the USTPO between 1970 and 2017. The size of the circles is proportional to the number of actors located in each geolocation.

Our map allows us to observe that the geographical concentration of innovators is much higher than that of inventors, who are more scattered throughout the territory. This finding was an expected result, because most innovators are firms that often patent using the address of the parent company headquarters, while inventors are people who, although they tend to agglomerate in cities (Balland et al., 2020), they are better distributed in the territory.

Another interesting finding obtained when comparing inventor and innovator maps is that certain Latin American cities, such as Buenos Aires and Caracas, are relatively less relevant in terms of innovators than of inventors. This may be revealing that a large number of inventors located in such cities tend to work for a proportionally smaller number of innovators. On the other hand, other locations, such as Santiago de Chile, are particularly relevant due to their higher concentration of innovators compared to that of inventors. The explanation could be the existence of a rich ecosystem of innovative firms in such territories along with institutional incentives that may encourage the registration of patents from these locations (Modrego et al., 2015).

As presented in Figure 12, there is a positive association between the number of local inventors and innovators among the different Latin American countries. Yet, certain countries stand out in the region, especially for their number of local inventors. The cases of Cuba and Venezuela are particularly clear in this respect. On the other hand, countries, like Chile, Colombia, Uruguay and Panama register comparatively more local innovators. These differences may reflect different patterns in the NIS within the region: countries with greater relative presence of local inventors could be indicating a particularly strong national scientific development, while countries with greater presence of local innovators could reflect a powerful system of innovative companies and national research centers, as well as a good incentive system for local businesses and organizations to patent inventions.

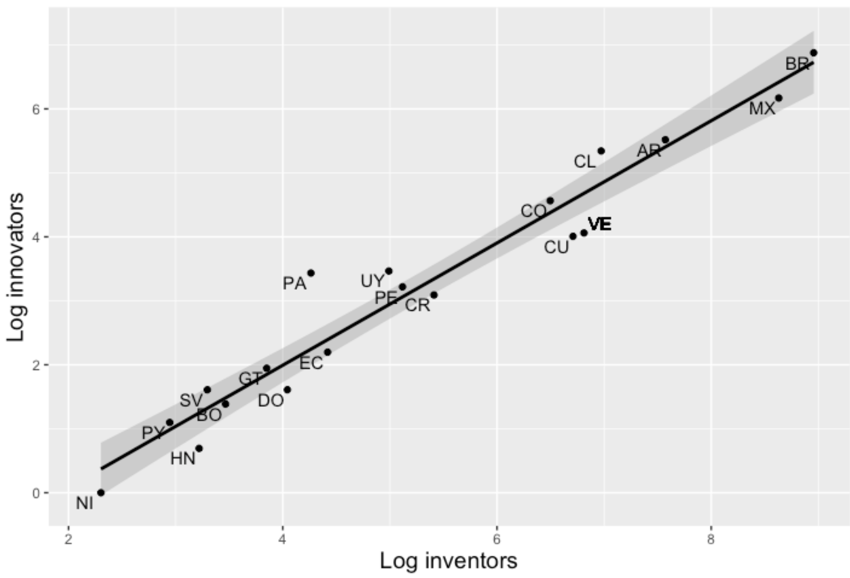


Figure 12. Local inventors and innovators by country in Latin America

Source: authors based on PatentsView data. Note: data points and locally estimated scatterplot smoothing.

Latin American countries also differ in the involvement levels of local vs. foreign actors in patenting activities. In order to obtain a first evidence on this aspect, we measure the proportion of US vs. non-US innovators in each country in the region (Figure 13). Results show that patents from countries like Nicaragua or Costa Rica have greater participation of innovators from the US. On the other hand, in patents from countries like Argentina, Brazil and Chile, there is a greater involvement of local innovators. As expected, the case of Cuba stands out for its very low proportion of US actors.

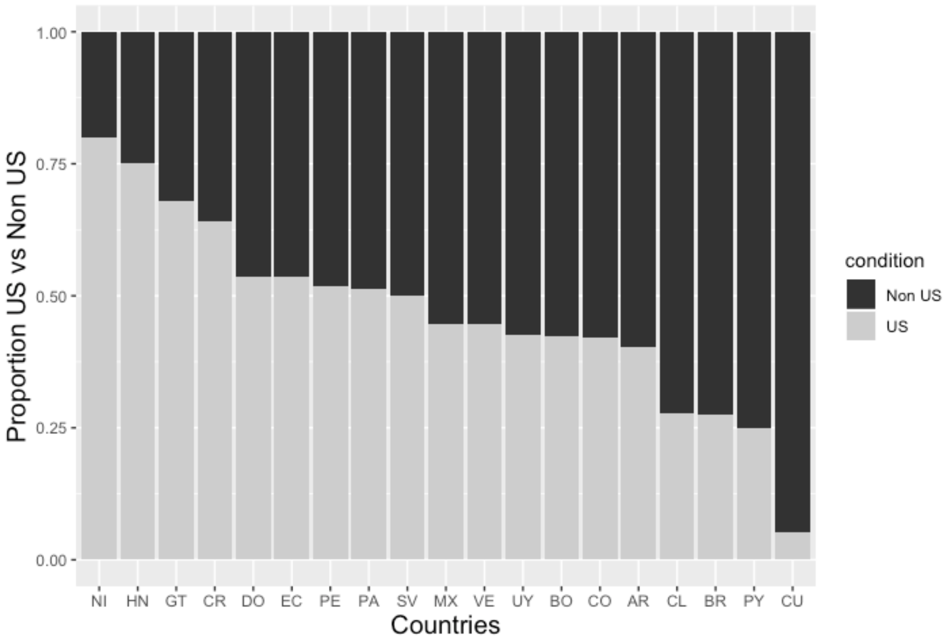


Figure 13. US and non-US innovators in Latin American countries

Source: authors based on PatentsView data.

As we mentioned above, patents are outcomes of the creative activity in research and innovation, which in turn, is a social interactive process. Hence, the number of patents registered by a country in our database can indicate its level of knowledge production. Furthermore, the interaction between local and external actors in patents can also reflect the effects of STI national policies aiming to connect the country in global innovation networks. In this sense, in the light of recent evidence (Danguy, 2017), the case of Cuba seems to reflect its relative isolation from the USA.

Regarding the leading countries in the region, Argentina and Mexico have been progressively reducing the proportion of local inventors, going from 75% (approximately) in the 1970s to less than 60% in the 2000s. On the other hand, Brazil systematically increased the proportion of local inventors, going from 54% in the 70s to 63% in the 2000s.

Our database also allows to categorize the innovators, distinguishing between corporations, individuals and government agencies, both from the US and from outside the US. Results presented in Figure 14 shows that almost all innovators, especially since 1990, are private firms, with a significant presence of US corporations. The preponderance of companies in the set of innovators is consistent with the evidence presented in previous studies with patent data for other countries (Fleming et al., 2007; Graf & Henning, 2009). With a much less relevant weight, we can observe the case of individuals, while government agencies have only a marginal presence in our data.

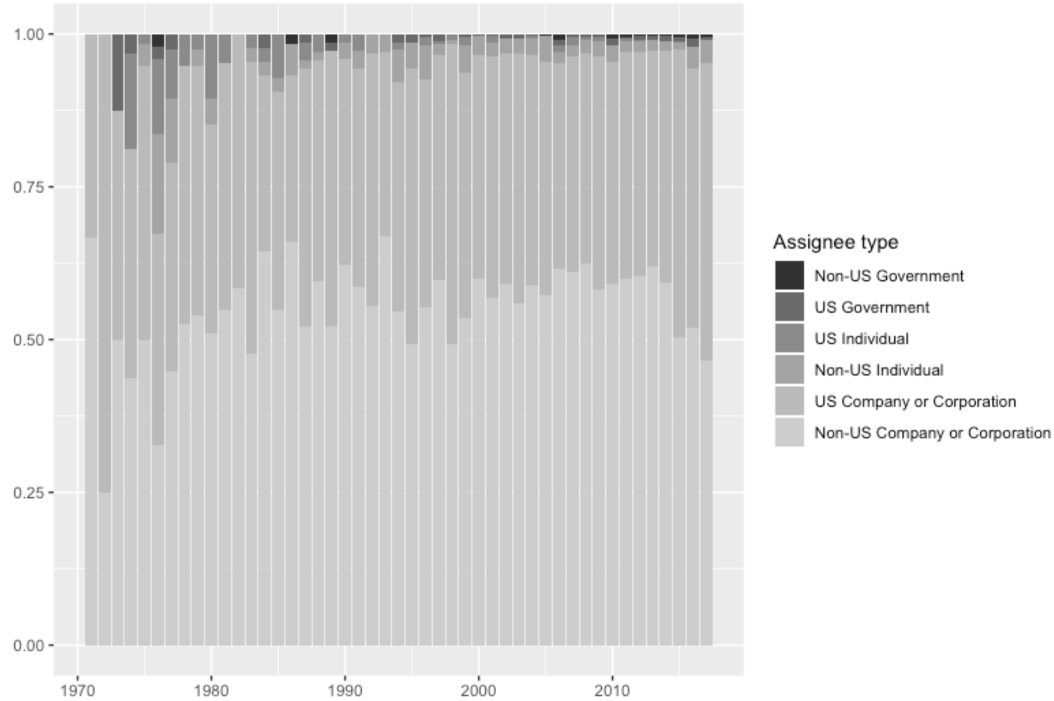


Figure 14. Types of innovators who hold US patents from Latin America (proportion of total number of innovators)

Source: authors based on PatentsView data.

6. Collaboration Networks at the Latin American Level

This section analyzes the structure and evolution of collaboration networks at Latin American scale between 1970 and 2017. As explained in the methodological section, we will distinguish two types of collaboration networks, according to their nodes: networks of inventors (or co-invention networks), and networks of innovators, i.e. patent owners (co-innovation networks). In both types of networks, we consider all actors located in Latin America as well the external actors located outside the region with whom local actors collaborate. As a general feature, it is possible to observe how both types of networks evolve in parallel with the growth in the number of patents registered on a global scale during these decades.

In particular, we observe how the networks increase their size, both in terms of the number of nodes and links (Figure 15). As expected, the network of inventors is much larger than that of innovators. Furthermore, while in the network of inventors, the number of links is always higher than the number of nodes, in the network of innovators the opposite is true. This implies that we can expect the network of inventors to be better connected.

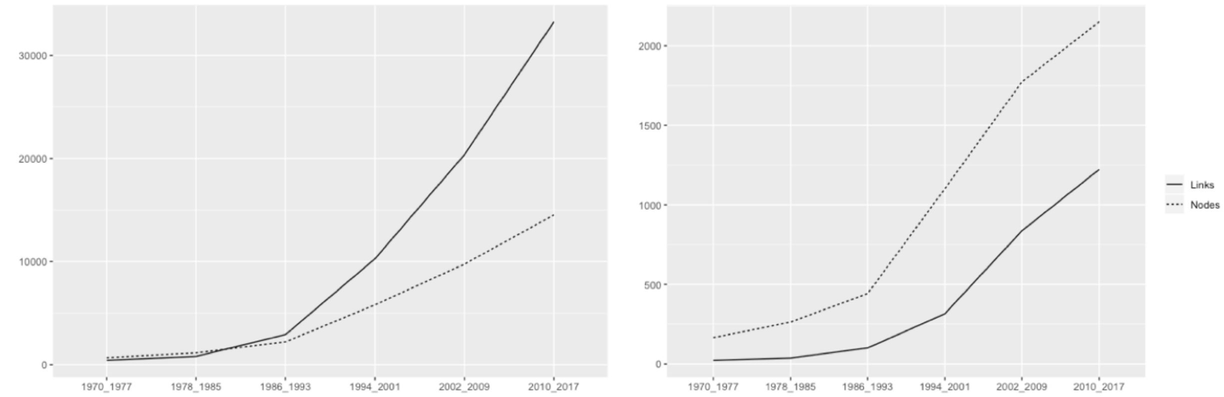


Figure 15. Size of co-invention (left) and co-innovation networks (right) at the Latin American level

Source: authors based on PatentsView data.

Network graphs provide us a first sight of the overall connectivity in co-invention (Figure 16) and co-innovation (Figure 17) networks. Both types of networks are very fragmented in separate components, especially in the case of innovation networks.[5] This finding implies that, at the Latin American level, there is no single and cohesive system of actors interacting and collaborating to produce patents. The Latin American reality seems to be made of, rather, a constellation of separate groups of inventors and innovators that, either form independent teams, or collaborate with absolutely no one.

Despite the fragmentation of both networks, the connectivity seems to improve throughout the period, particularly in co-invention networks. This evidence can be observed in the increasing size of the largest connected components. The graphs also allow to identify the existence of highly connected actors (hubs) that concentrate a great number of links. Furthermore, the significant presence of extra Latin American actors (i.e. black nodes in the graphs) connected to local nodes gives us a first idea of how these networks are oriented towards outside the region.

Using different SNA statistics, we now delve into the study of two basic network properties: connectivity and openness.

[5] A connected component of a network is a group of nodes in which each pair is directly or indirectly connected to each other but disconnected from the rest of the network.

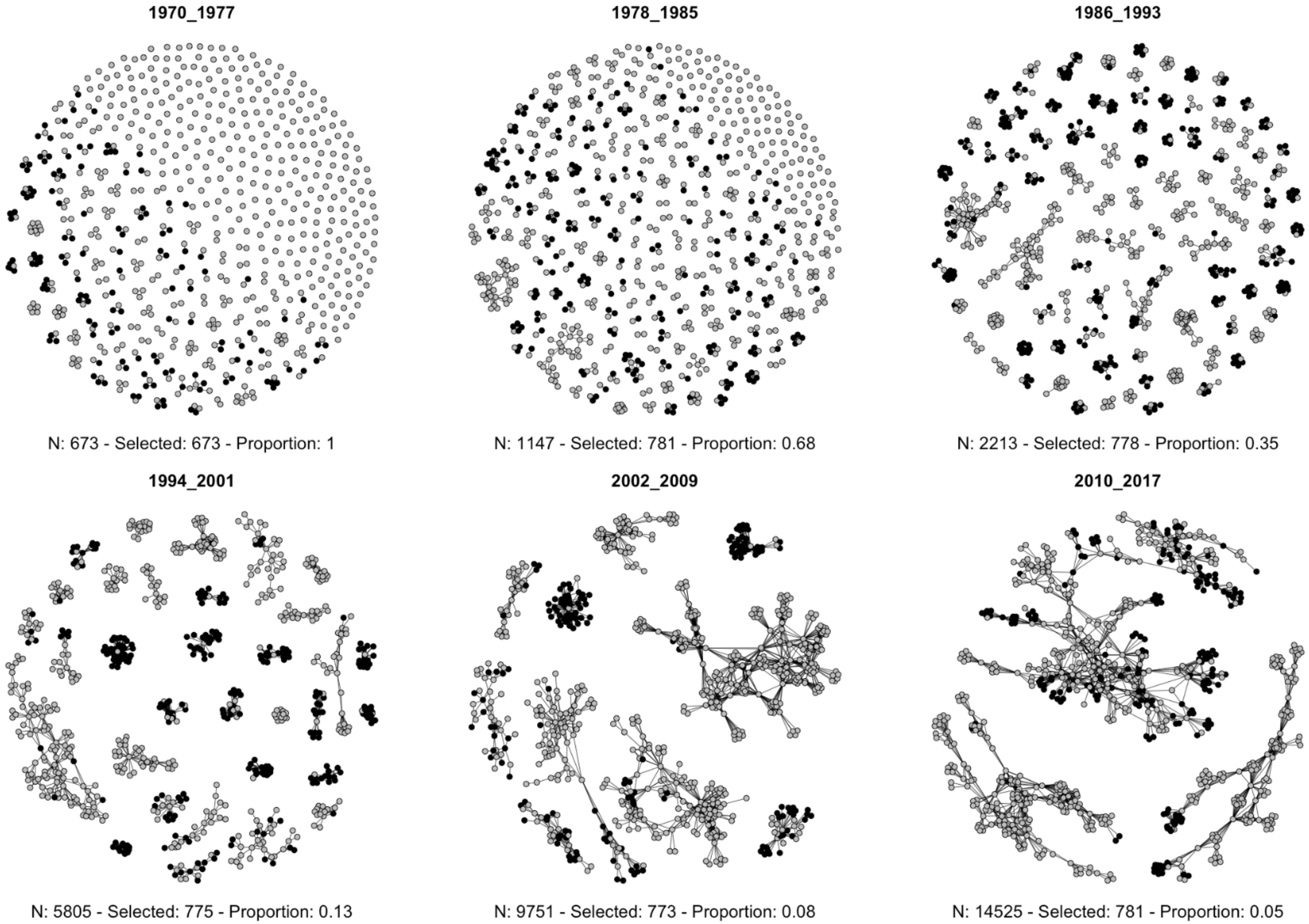


Figure 16. Co-invention networks at the Latin American level

Source: authors based on PatentsView data. Note: grey nodes are inventors located in Latin America, black nodes are inventors located outside Latin America. For the sake of clarity, we present only the best connected sections of the networks, where the largest components are located. Below each graph, the following data is presented: the total number of nodes in the network (N), the number of nodes represented in the graph (Selected) and the proportion represented by the nodes plotted against the total number of nodes of the network.

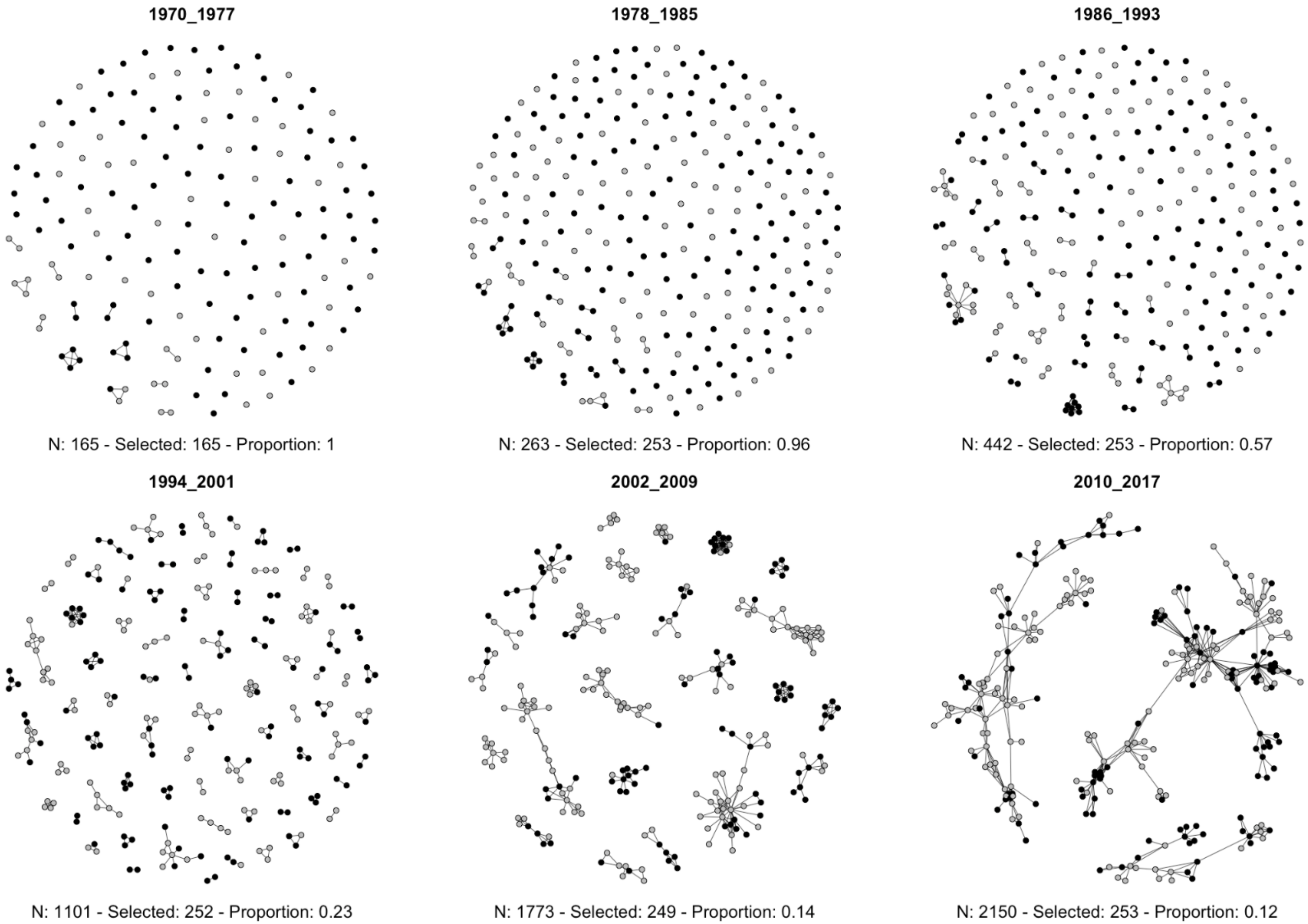


Figure 17. Co-innovation networks at the Latin American level

Source: authors based on PatentsView data. Note: grey nodes are innovators located in Latin America, black nodes are located outside Latin America. For the sake of clarity, we present only the best connected sections of the networks, where the largest components are located. Below each graph, the following data is presented: the total number of nodes in the network (N), the number of nodes represented in the graph (Selected) and the proportion represented by the nodes plotted against the total number of nodes of the network.

6.1. Network Connectivity

First, regarding connectivity, the proportion of connected nodes (i.e. nodes with at least one link) increases in both networks but is much higher in the network of inventors, where such nodes account for almost 100% of total actors in recent periods (Figure 18). On the other hand, in the network of innovators, most nodes are isolated. We believe that this finding is not exclusive to Latin America. Although, to the best of our knowledge, there is no previous literature comparing inventor and innovator networks for the same territory (except for the recent work by (Graf & Broekel, 2020)), the evidence collected from both types of networks suggests that inventor networks are larger and better connected than innovator networks.

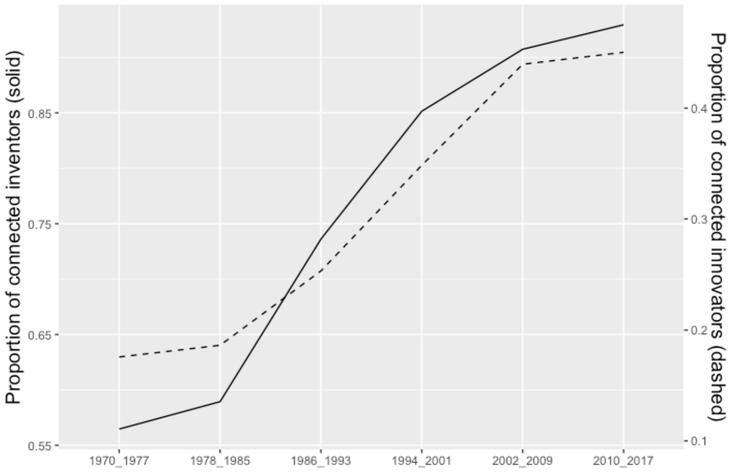


Figure 18. Proportion of connected nodes in networks at the Latin American level

Source: authors based on PatentsView data.

We now analyze the evolution of the largest connected component in both networks (Figure 19). Large components are crucial elements in innovation networks because they allow for the diffusion of information among a large set of –directly and indirectly– connected actors and the cross-fertilization of diverse ideas (Cantner & Graf, 2006; Fleming et al., 2007). We study the size of large components (measured with their number of nodes) and the proportion that they represent over the total network. We observe that, in absolute terms, the largest component (LC) is approximately 10 times higher in the inventor network. In relative terms, the LC represents a similar proportion in both networks (between approximately 0.5 and 1%). In neither of the two Latin American networks (inventors and innovators) can we conclude that a giant component has emerged.[6] We reach this conclusion for two reasons. First, because the ratio of the LC over the total number of nodes is very small. Second, because in absolute numbers the LC is not much higher than the second largest component. Thus, we can say that both

[6] A component of a network is considered to be the giant component if it connects a non-trivial share of nodes. Two giant components cannot coexist on the same network. Therefore, the largest component of a network can only be considered a giant component when its size is substantially greater than that of the second largest component. When a network increases its number of links connecting nodes with certain randomness, a giant component emerges abruptly after a tipping point (Jackson, 2008).

networks are below the threshold in which a giant component emerges (Erdős & Rényi, 1964).

In addition, the analysis of the largest components reveals that both inventor and innovator networks present a similar evolution: the absolute size of the LC increases especially during the last years. The weight of this component in the total network drops to the middle of the analyzed period and then increases in recent decades.

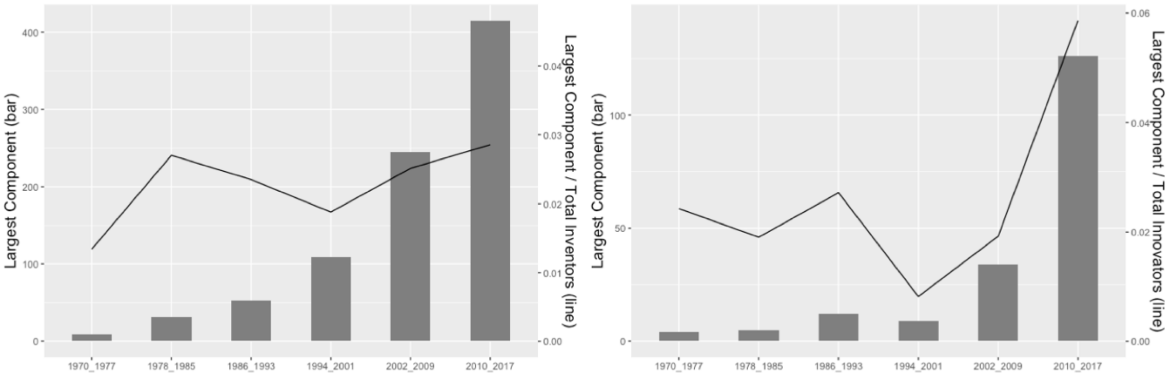


Figure 19. Size of the largest component in co-invention (left) and co-innovation (right) networks at the Latin American level

Source: authors based on PatentsView data.

We now study the distribution of links, focusing on the overall centralization of the networks, i.e. the extent to which links are concentrated in a few number of nodes. Results of the centralization indicator shows that the inventor network evolves towards an increasingly decentralized structure (see Figure 20). On the other hand, in the co-innovation networks there is a reduction during the initial years, with a clear change in trend since 2000, when the network started evolving towards greater centralization. This reveals that, while collaborations links among Latin American inventors tend to spread among more and more actors, links between innovators seem to be progressively concentrated in fewer agents since 2001.

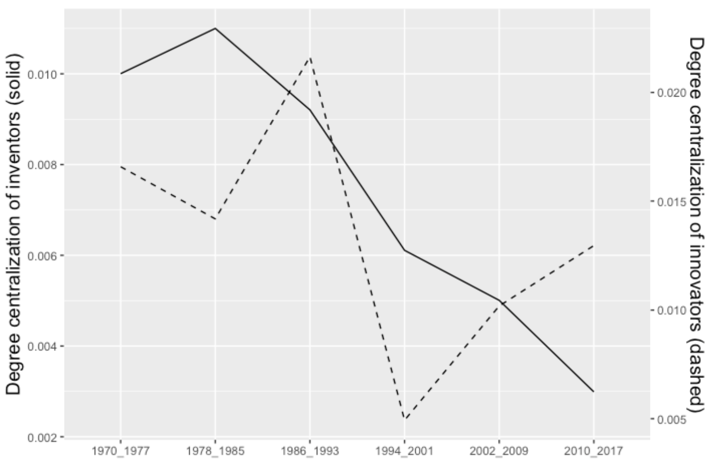


Figure 20. Centralization index in networks at the Latin American level

Source: authors based on PatentsView data.

6.2. Network Openness

In order to study network openness to external actors, we analyze the presence of non-Latin American inventors and innovators in the respective collaboration networks (Figure 21). The data shows that the relative weight of external actors is important in both cases. However, we can observe that both networks evolve differently: on the one hand, the network of innovators decreases the presence of foreigners in the first years and then maintains it approximately around 55% of nodes during the rest of the period. On the other hand, the network of inventors experiences a clear increase in the relative weight of external actors, revealing a stronger tendency towards extra-regional collaboration of Latin American inventors during the last decades.

Figure 21. Proportion of non-Latin American actors in the networks

Source: authors based on PatentsView data.

Next, we analyze the average number of links per node, distinguishing between Latin American and non-Latin American actors (Figure 22). This allows us to obtain evidence on the extent to which each group of inventors and innovators (i.e. local vs. external) are connected to the collaboration networks. Results show a clear difference between the network of inventors and that of innovators. In the first case, we find that non-Latin American inventors are, on average, better connected than their Latin American peers.[7] The opposite is true for the co-innovation networks, since Latin American actors have more connections than external nodes. These results seem to reveal a clearer tendency towards extra-regional openness in the network of inventors compared to that of the network of innovators.

[7] As explained in the methodology section, the way in which we have elaborated our inventor networks implies that non-Latin American actors maintain at least one link with local actors, thus, their average degree (i.e. average number of links per node) will always be greater than one. This is not the case for Latin American inventors, who can be isolated nodes. To achieve comparability between non-Latin American and Latin American inventors, we calculate the average degree of those local actors with at least one link, that is, we do not consider isolated nodes.

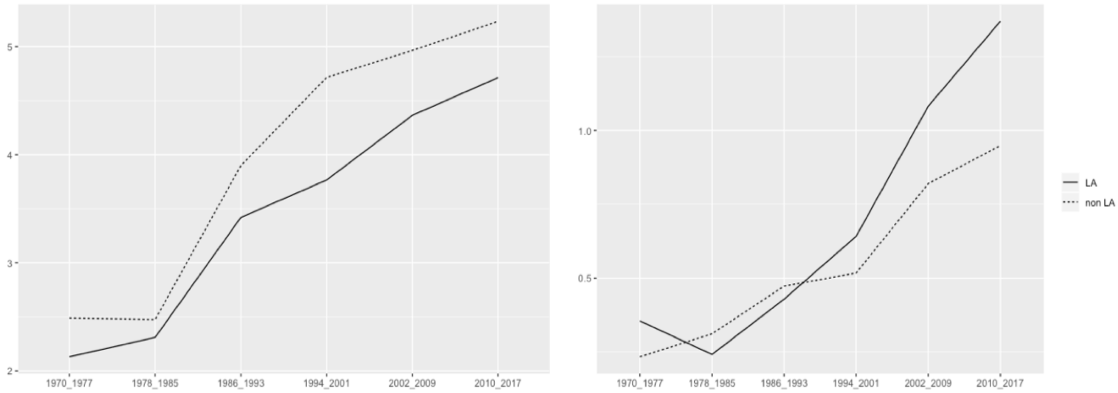


Figure 22. Average degree of local and external nodes in co-inventor (left) and co-innovator networks (right) at the Latin American level

Source: authors based on PatentsView data.

Other interesting way to study network openness to external nodes is using assortativity indexes, which allows us to measure the propensity of inventors and innovators to connect with actors located in their own country (or abroad). Previous evidence on collaboration networks with patent data proves that the links are strongly associated with geographical proximity between actors (Breschi & Lissoni, 2009; Singh, 2005). Therefore, this type of networks always shows positive assortativity (i.e. greater tendency to collaborate with actors from the same country than with actors from outside). Yet, the analysis of this indicator is interesting for our study because it allows us to observe to what extent this trend occurs in the two types of networks and how it evolves.

As expected, the assortativity index presents positive values in the two types of networks (see Figure 23). The figure shows similar levels of assortativity of inventors and innovators networks. Furthermore, since 1993, there has been a certain decrease in assortativity in the inventor network and a marked drop of this indicator in the case of the innovator network. This implies that Latin American networks, particularly co-innovation networks, experience a growing outward orientation, with an increasing presence of collaboration links connecting actors located in different countries.

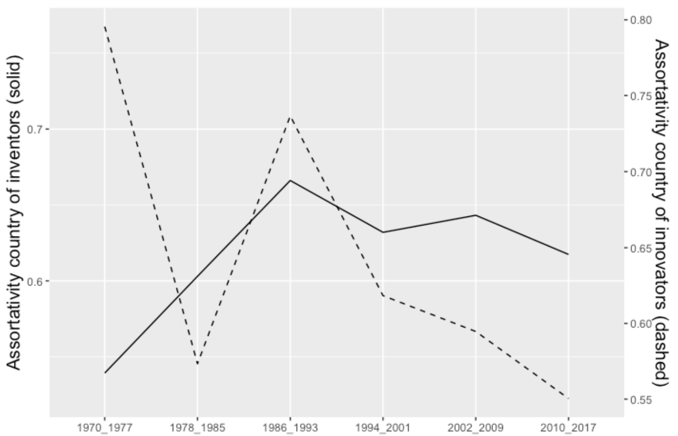


Figure 23. Assortativity in networks at the Latin American level

Source: authors based on PatentsView data.

7. Collaboration Networks at the National Level

Each of the national networks includes collaboration links among actors (i.e. inventors or innovators) located in the corresponding country as well as the external actors with which local actors are directly connected. This allow us to study and compare collaboration patterns for innovation in different Latin American countries.

As expected, the national networks increase their size in most of Latin American countries during the period under study. When we measure the network size with the number of nodes we observe a general growth trend in both co-invention and co-innovation networks, but with certain differences among countries (see Figure 24). For example, Mexico and, particularly, Brazil rapidly increased the size of their networks and forged ahead from the rest of the countries. Other nations, such as Argentina, Chile or Colombia also steadily increased the size of their networks. On the other hand, in cases like Cuba or Venezuela, the networks experienced a rapid growth in early periods and subsequently slowed or even decreased the size by the end of the period.

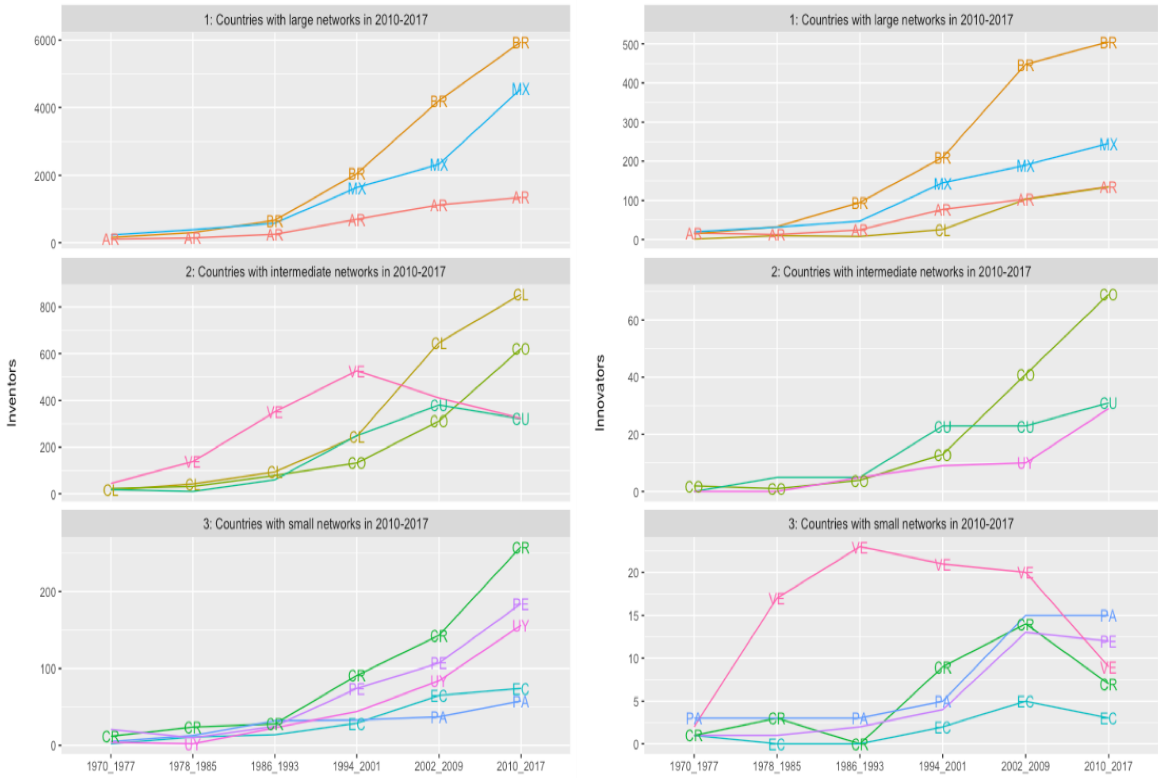


Figure 24. Number of nodes in co-invention (left) and co-innovation networks (right) of selected countries

Source: authors based on PatentsView data.

7.1. Connectivity of national networks

The most prominent aspect of national collaboration networks is not their size growth but their low density and great disconnection. In almost all Latin American countries, we observe that both co-invention and co-innovation networks are very fragmented in separated components. This is an expected result because, as mentioned above, innovation systems in Latin American countries have been characterized as "incomplete" systems, where the density of linkages is low (Arocena & Sutz, 2000; Rapini et al., 2009; Yoguel & Robert, 2010). Although research collaboration is growing in recent years, there are still very weak collaborative ties among innovators in the countries of the region.

Furthermore, the network fragmentation has an important particularity: most of connected components are made of teams of actors (inventors or innovators) where all of them are connected to each other but disconnected from the rest of the network (according to SNA terminology, we would say that most components in our networks are *cliques*). This feature is particularly clear in the co-invention networks and, thus, reflects that inventors cooperating in teams to produce one specific patent rarely collaborate also with other teams of inventors. The fragmentation of national networks into isolated teams of actors, represents an important barrier to the circulation of ideas and the flow of new knowledge. This, in turn, implies an important drawback in terms of the generation of new innovations in Latin American countries.

While national networks are highly disconnected, in general terms, connectivity levels improved during the period under study. This trend is more clearly observed in co-invention networks, where the average number of links per inventor steadily increased in all countries (see Figure 25). Regarding the co-innovation network, the evolution seems to be more diverse among countries, with some cases of strong improvement in connectivity (Cuba, Uruguay and Argentina) and others with more stability or even setback (Colombia and Venezuela).

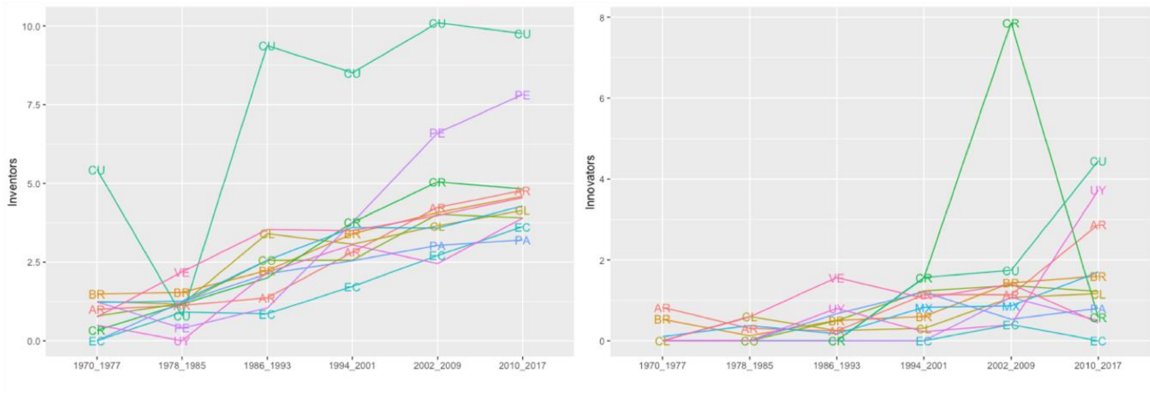


Figure 25. Average degree in co-invention (left) and co-innovation networks (right) of selected countries

Source: authors based on PatentsView data.

The study of connectivity in national co-invention networks allows us to identify Cuba as a clear outlier. The Cuban network has no isolated actors and their inventors have, on average, twice as many connections as those in the countries that follow it in the ranking. More importantly, in the rest of Latin American countries, the largest connected components of co-invention networks include only a low proportion of the nodes (Figure 26). On the other hand, the Cuban largest component connects to 160 actors that account for more than 50% of the nodes. Therefore, we can consider that Cuba is the only Latin

American country in which a giant component has emerged. We analyze the evolution of the Cuban network and observe that the giant component emerged abruptly during the penultimate period (see Annex C). This finding seems to fit the Erdős-Rényi model (Erdős & Rényi, 1964) on the sudden emergence of giant components in random networks.

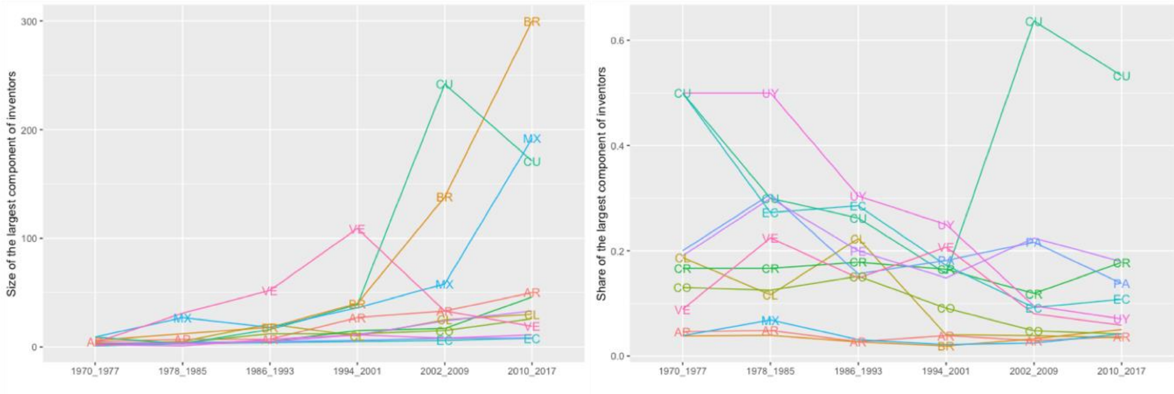


Figure 26. Size (left) and share (right) of the largest component in co-invention networks of selected countries

Source: authors based on PatentsView data.

Compared to its national co-invention network, the Cuban network of innovators is smaller and less well connected. The difference between the co-invention and the co-innovation networks could reflect a relevant feature of the Cuban national innovation system, where a strong scientific development coexists with a relatively weak and low diversified business and organizational ecosystem, being life sciences the most salient experience in this country (Brundenius et al., 2013; Mola et al., 2006; Thorsteinsdóttir et al., 2004).

Network connectivity in the leading Latin American countries evolves in a similar way. Both Brazil and Mexico improve their average degree and substantially increase the size of their largest components in both co-invention and co-innovation networks. In fact, several links between different teams of inventors can be observed in their co-invention network graphs. This causes the formation of large and complex components of actors that potentially facilitates the circulation of knowledge within the national network. Although these components are made up of a large number of nodes (300 nodes in Brazil and 192 in Mexico), they represent only a very small proportion of the total network (5% and 4.3% respectively). Therefore, they cannot be considered giant components.

Argentina also improved strongly the connectivity of its co-invention network, increasing the average number of links per inventor from one to 4.5. However, this country stands out mainly for the connectivity of its co-innovation network, which has experienced the emergence of a giant component in the last period. Such component is made of 47 innovators that account for 35% of the Argentinian nodes (Figure 27). In fact, the case of Argentina constitutes the only co-innovation network in Latin America that has experienced the emergence of a giant component during the period under study. This could reflect the existence of a healthy and interconnected system of firms, organizations and research centers that collaborate with each other to generate and register patents.

The evolution of the IS in the largest Latin American countries has been extensively studied. The general trends observed by previous research are in line with our results, revealing that IS in these countries are highly heterogeneous, showing a general landscape of immature development (Rapini et al., 2009; Ribeiro et al., 2009) coexisting with several high developed fields, such as biofuel system in Brazil (Andersen, 2015; Dantas & Figueiredo, 2009; Furtado et al., 2011) agriculture innovations in Argentina (Gutman & Lavarello, 2007; Marìn & Petralia, 2018) or the emergent biotechnology activities in Mexico (Flores-Amador, 2014; Stezano & Oliver Espinoza, 2019). However, it is quite clear that regarding the high complexity and long tradition of research and innovation in these countries, further research is necessary to understand and validate our results.

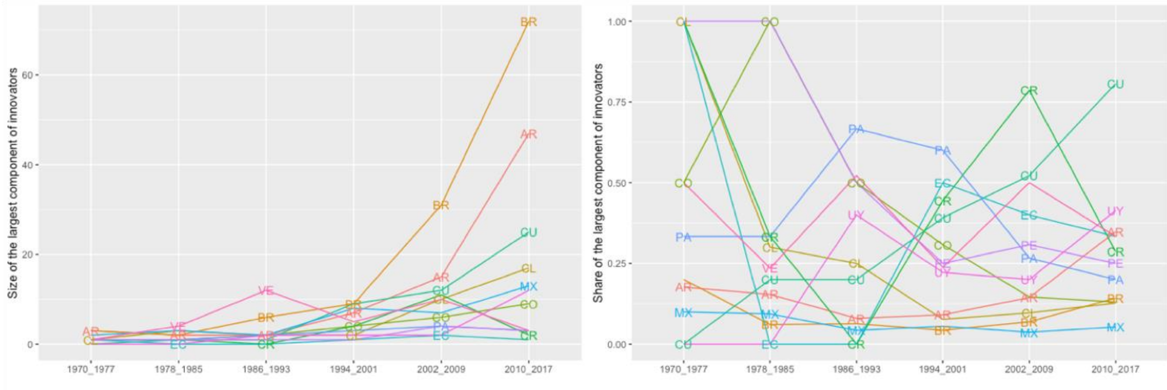


Figure 27. Size (left) and share (right) of the largest component in co-innovation networks of selected countries

Source: authors based on PatentsView data.

Colombia presents an evolution similar to Argentina, although with slightly smaller and less connected networks. In fact, its national collaboration networks (both co-invention and co-innovation) are small in relation to its population: although Colombia is the third most populous country in the region, its networks are relatively smaller and its connectivity levels are also low. This could be indicating a weakness of the NIS, which fails to generate and maintain an adequate critical mass of local inventors and innovators.

In the case of Chile, we observe that connectivity of co-invention networks has not improved since 1986, while the co-innovation network has strongly improved its size and connectivity. Compared to the rest of Latin American countries, the Chilean co-innovation network seems to be more relevant than its co-invention network, which may indicate that this country has a relatively strong system of innovative firms and organizations.

It is remarkable the recent evolution of co-invention network in Peru. Despite it is not one of the largest networks in the continent, it presents a very high average degree in the last periods, with values only below Cuba and much higher than the rest of the countries.

This is indicating an increasing collaborative tendency of inventors from Peru. Yet, the network graph (Figure 30) reveals that this increase in collaboration could be caused by the presence of large inventor teams. Within these teams, all inventors are connected to each other, but there are only a few links connecting inventors of different teams. As a consequence, the Peruvian network is still highly fragmented in separated components.

The case of Venezuela is particularly interesting because of the evolution of network connectivity. Both co-invention and co-innovation networks experience a clear positive evolution until about half of the period, followed by a strong reduction in size and disconnection in recent years. In the co-invention network, we find that a large component (more than 100 inventors representing 20% of nodes) emerged in 1994 and subsequently disintegrated until it reached to only 19 nodes during the last period (Figures 29 and Annex D). This finding seems to imply that Venezuelan network underwent the process of forming a giant component and that, after reaching a very advanced stage, this process was reversed. We hypothesize that the Venezuelan collaboration networks show the effects of qualified emigration that the country has experienced in the last decades. According to this evidence and considering previous studies on human capital and innovation processes in Venezuela (Clark, 2011; Freitez, 2011; Requena & Caputo, 2016) we conjecture that the Venezuelan network has been affected by institutional shocks, both internal (big strikes in the state owned petroleum firm) and external (international restrictions and blockage).

There seems to be a positive relationship between co-invention and co-innovation networks. Countries with large and dense co-invention networks also have large and dense co-innovation networks (e.g. Brazil, Mexico, Argentina). However, there seems to be some particularities in this relationship. The case of Chile stands out because its innovator networks are better connected than its co-invention networks. On the other hand, we find the cases of Cuba and Venezuela, where inventor networks are larger and better connected than those of innovators.

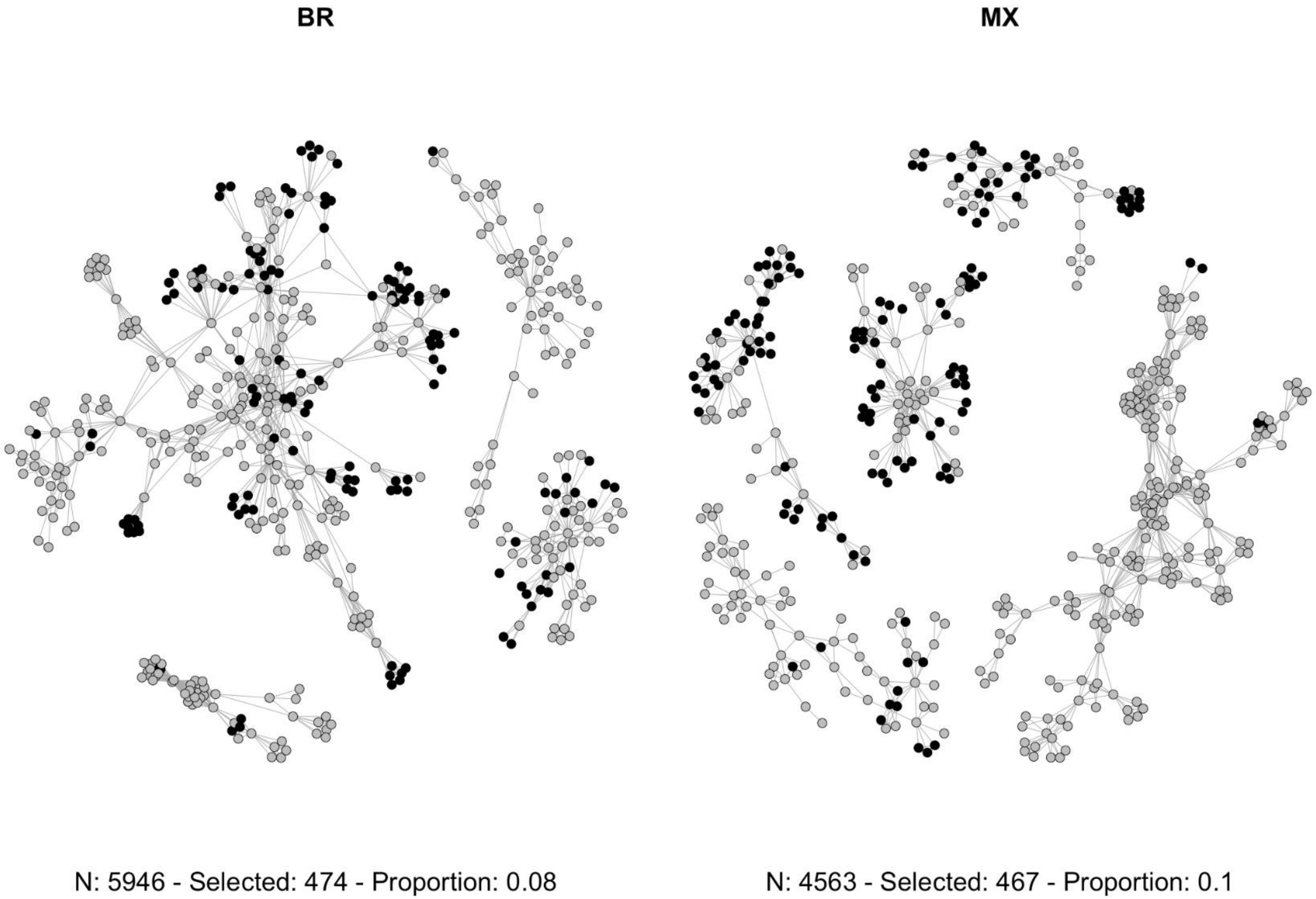


Figure 28. National co-invention networks in Brazil and Mexico (2010-2017)

Source: authors based on PatentsView data. Note: grey nodes are inventors located in the corresponding country, black nodes are located outside the country. For the sake of clarity, we present only the best connected sections of the networks, where the largest components are located. Below each graph, the following data is presented: the total number of nodes in the network (N), the number of nodes represented in the graph (Selected) and the proportion represented by the nodes plotted against the total number of nodes of the network.

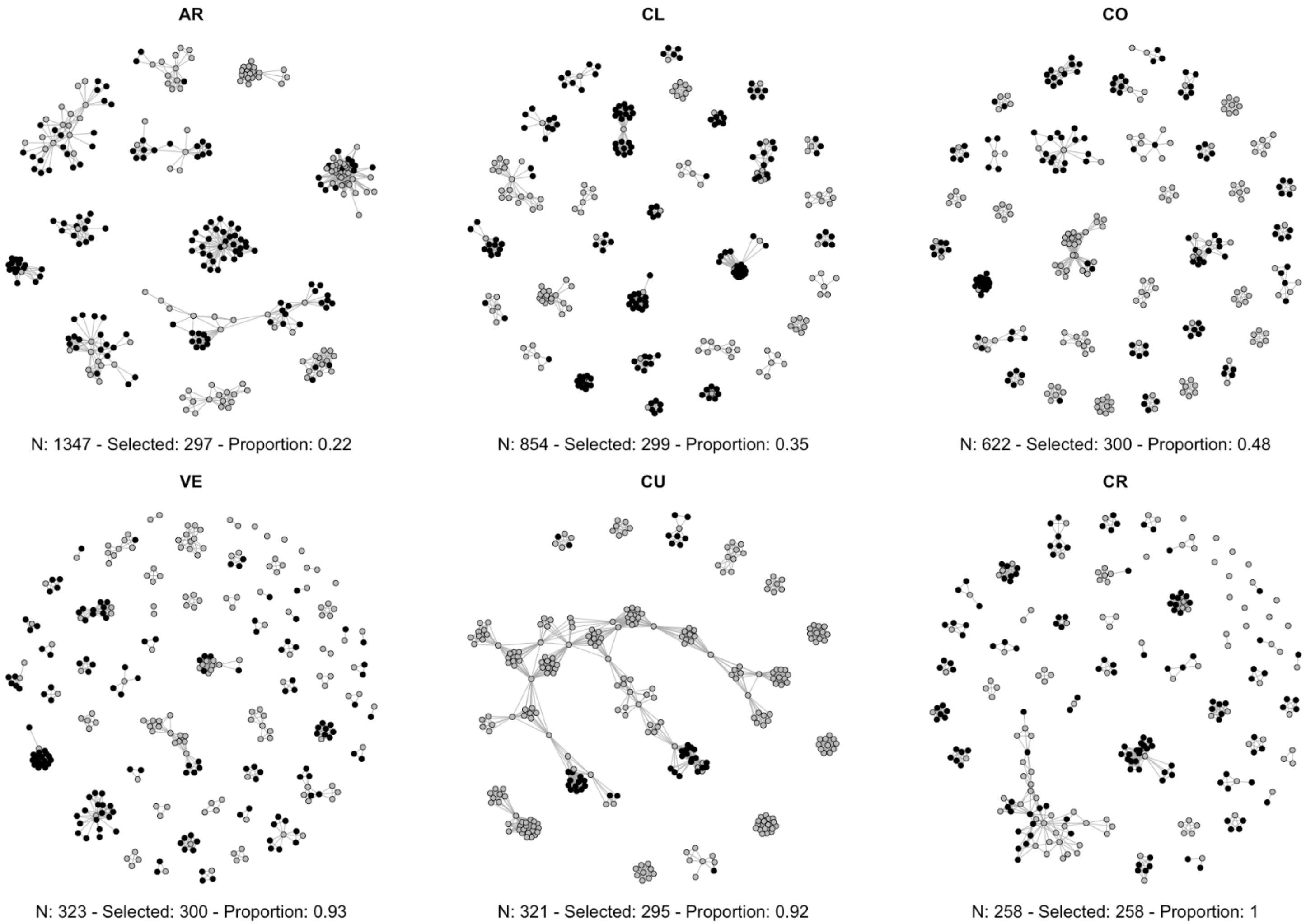


Figure 29. National co-invention networks of selected countries with large networks (2010-2017)

Source: authors based on PatentsView data. Note: grey nodes are inventors located in the corresponding country, black nodes are located outside the country. For the sake of clarity, we present only the best connected sections of the networks, where the largest components are located. Below each graph, the following data is presented: the total number of nodes in the network (N), the number of nodes represented in the graph (Selected) and the proportion represented by the nodes plotted against the total number of nodes of the network.

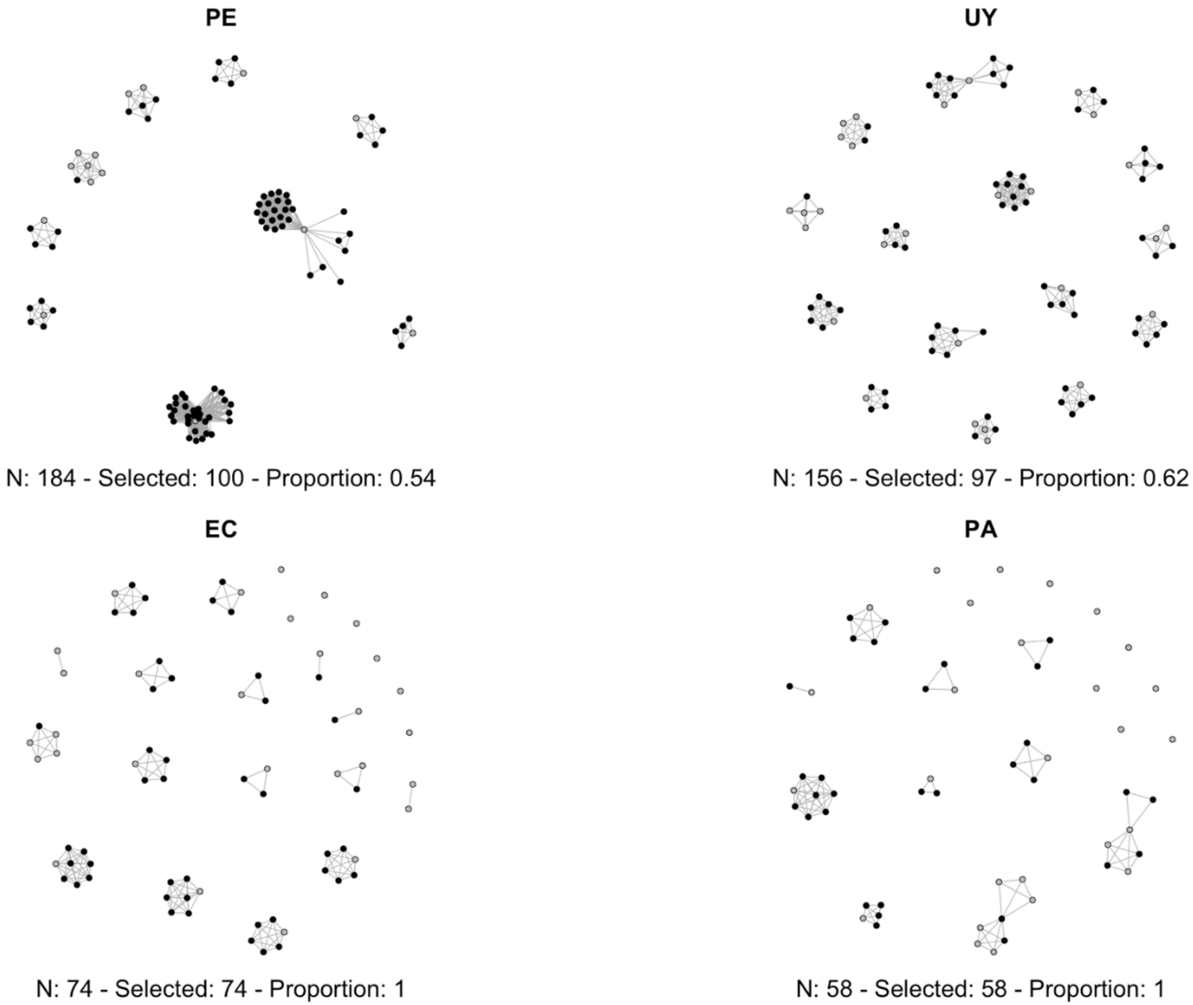


Figure 30. National co-invention networks of selected countries with intermediate size networks (2010-2017)

Source: authors based on PatentsView data. Note: grey nodes are inventors located in the corresponding country, black nodes are located outside the country. For the sake of clarity, we present only the best connected sections of the networks, where the largest components are located. Below each graph, the following data is presented: the total number of nodes in the network (N), the number of nodes represented in the graph (Selected) and the proportion represented by the nodes plotted against the total number of nodes of the network.

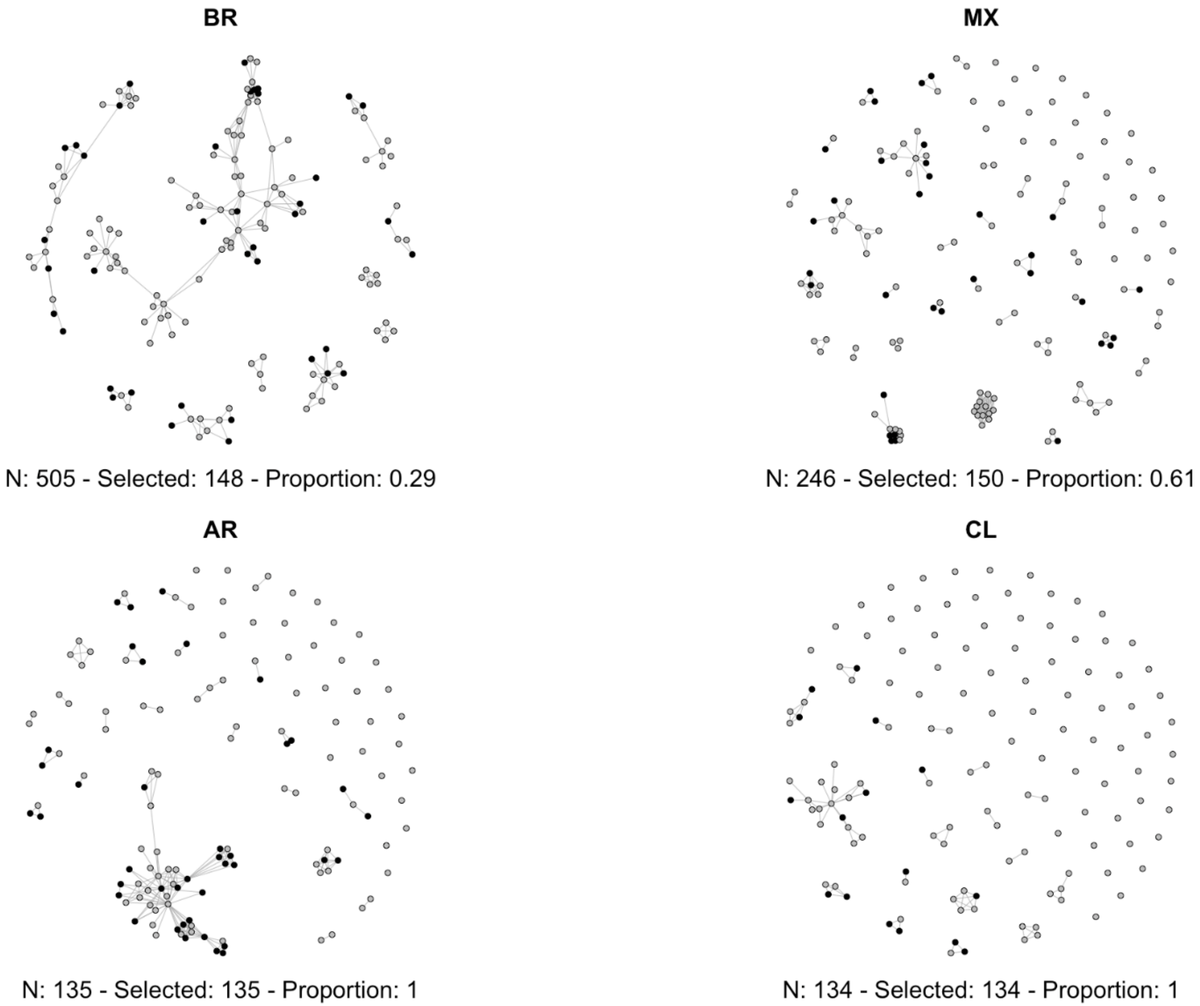


Figure 31. National co-innovation networks of selected countries with large networks (2010-2017)

Source: authors based on PatentsView data. Note: grey nodes are innovators located in the corresponding country, black nodes are located outside the country. For the sake of clarity, we present only the best connected sections of the networks, where the largest components are located. Below each graph, the following data is presented: the total number of nodes in the network (N), the number of nodes represented in the graph (Selected) and the proportion represented by the nodes plotted against the total number of nodes of the network.

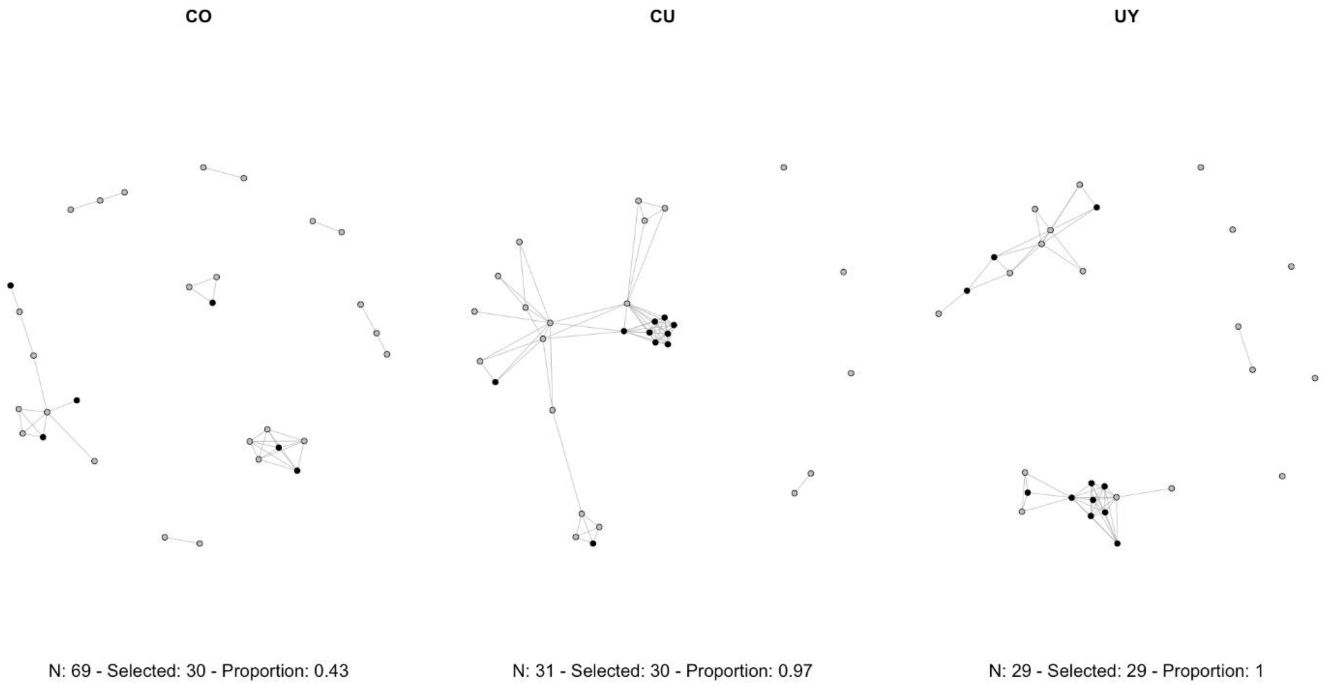


Figure 32. National co-innovation networks of selected countries with intermediate size networks (2010-2017)

Source: authors based on PatentsView data. Note: grey nodes are innovators located in the corresponding country, black nodes are located outside the country. For the sake of clarity, we present only the best connected sections of the networks, where the largest components are located. Below each graph, the following data is presented: the total number of nodes in the network (N), the number of nodes represented in the graph (Selected) and the proportion represented by the nodes plotted against the total number of nodes of the network.

7.2. Openness of National Networks

We now focus on studying network openness, i.e., the extent to which national networks are connected to external actors. To do so, we analyze the presence of local vs. non-local nodes in the national collaboration networks.[8] Figure 33 shows that almost all countries have highly outward-oriented networks. Regarding co-invention, we can observe that countries with larger networks seem to have a smaller proportion of foreign nodes. Brazil, Mexico, Chile and, to a lesser extent, Argentina, present lower levels of openness. On the other hand, nations with smaller networks such as Costa Rica, Panama, Uruguay and, particularly, Peru register the greatest presence of foreign actors.

Venezuela shows a strong tendency towards openness since 1986. However, the progressive decline of Venezuelan network size presented above, combined with this openness tendency may be revealing a weakening of the national collaboration networks and, therefore, a greater dependence on external actors. An interesting finding in this regard is that Cuba registers the least externally oriented network in the region. Considering the high internal connectivity explained above, the low external orientation of the Cuban network can be also an indication of the strong internal dynamism of its national co-invention network.

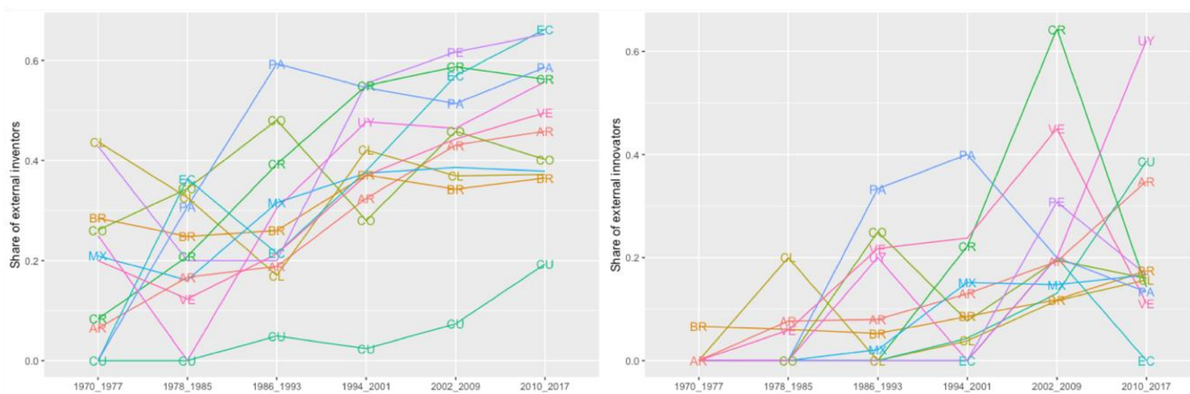


Figure 33. Share of external inventors (left) and innovators (right) in networks of selected countries

Source: authors based on PatentsView data.

Regarding co-innovation networks, the presence of foreign nodes seems to be lower than in co-invention networks. In this case, it is worth to mention the network openness of Uruguay, Argentina and Cuba. In the Cuban case, the local orientation of the co-invention network in relation to the external openness in the co-innovation network could be explained by the existence of a strong national system of scientists and researchers that operates within a framework that is highly dependent on foreign companies and research centers.

In order to study openness of national networks we analyze assortativity indexes that measure the extent to which local nodes collaborate with external actors. Figure 34 allows

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[8] It should be remembered here that the national networks were elaborated considering both local actors (inventors or innovators) and those foreign actors that are directly linked to the local ones.

to identify different behaviors of countries. For example, Panama presents negative assortativity, i.e. propensity of local nodes to collaborate with external nodes (and vice versa). Although other countries have registered negative assortativity in some years (e.g. Chile, Colombia, Peru or Uruguay), all of them present positive values in recent years.

In co-inventor networks, countries such as Brazil, Mexico and Argentina increased their assortativity to a certain point when this indicator seems to stagnate. This could reflect a process of developing intra-national collaboration systems that seems to give way to a progressive presence of international collaborations. On the contrary, in cases such as Chile, Colombia and Cuba, the index persistently growths, showing an increasing weight of local collaborations throughout the period.

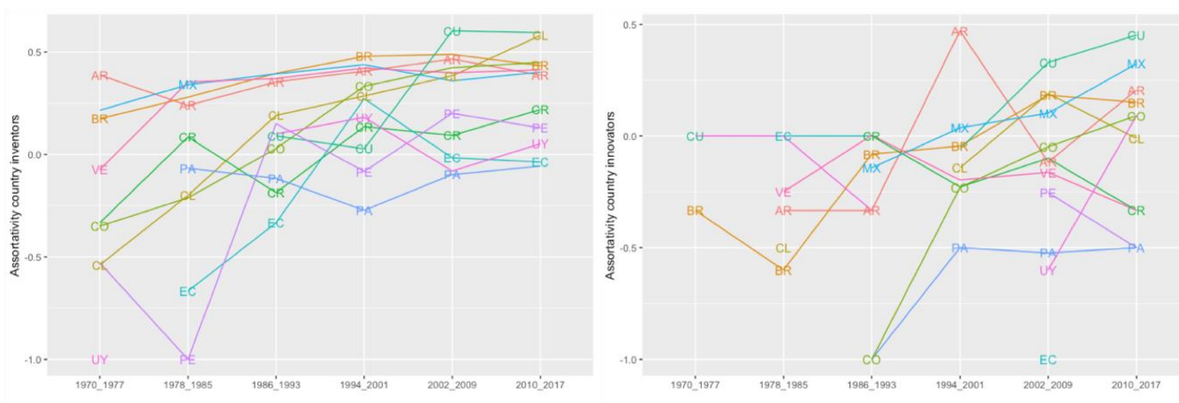

Figure 34. Assortativity indexes in co-invention (left) and co-innovation networks (right) of selected countries

Source: authors based on PatentsView data. Note: assortativity indexes were calculated based on nodes' country attribute. The discontinuities in the series are explained because in some periods the national networks of some countries do not have any foreign nodes, which prevents the calculation of the assortativity index.

Regarding co-innovation networks, we observe more erratic evolutions. Countries like Chile or Argentina alternate negative and positive values of the index. Other countries like Cuba, Mexico or Colombia steadily increased their assortativity throughout the period, revealing a propensity towards intra-national collaborations of innovators. In summary, and leaving aside the fluctuations of some cases, it can be affirmed that as the countries of the region were building and connecting their national networks, they progressively showed a tendency to generate more local collaborations and reduce their dependency on external connections.

8. International Collaboration Networks at the Macro Level

As explained in the methodological chapter, in this section we analyze international connections in macro-scale networks. In such networks, nodes are countries and links represent collaborations between inventors or innovators located in different countries. In order to compare interaction dynamics on a regional scale with extra-regional connections, we build international collaboration networks in two ways. First, considering both Latin American countries and external countries that are directly linked to the region (see Figures

35 and 37). Second, eliminating external countries and tracing the network made up only of Latin American nations (see Figures 36 and 38).

The main remarkable feature of networks revealed by this analysis is the extra-regional orientation of Latin American countries. When local inventors and innovators collaborate with actors located abroad, they do not link with actors from other countries of the region, but with extra-regional actors. The graphical representations allow us to observe that the networks are much worse connected if we eliminate non-Latin American nodes. Thus, the intra-regional networks (made only with LA countries) are poorly connected compared to the networks that include extra regional countries, especially in the first periods.

Assortativity indexes are always negative both in the co-invention (Table 4) and the co-innovation networks (Table 5), which also evidences the tendency of Latin American countries to interact with non-regional actors instead of cooperating with other Latin American nations. However, there is a persistent reduction in this indicator, which reveals a progressive trend towards greater interaction between countries in the region during the last periods. This result is also in accordance with the evolution of connectivity in the intra-regional networks. Indeed, although these networks, formed only by Latin American countries were disconnected during the initial periods, they progressively improve their connectivity (Tables 4 and 5): the share of isolated nodes decreases, the average degree per country increases and a giant component of connected Latin American nodes emerges in the networks.

The country to which most of the international collaborations are directed is the US. Two links connecting inventors are particularly strong and involve such country: US-Mexico and US-Brazil. Furthermore, while Mexico is clearly focused on collaboration with the US, Brazilian links are clearly more diversified, as their inventors also maintain strong links with Germany and France in some periods. Other Latin American countries also maintain strong links with the US: Argentina, Chile, Colombia and, before 2001, also Venezuela. If we focus on networks connecting innovators, we find that US-Mexico and US-Brazil connections are relatively less important. Instead, US-Panama (particularly before 2001) and Brazil-Belize are also strong extra-regional collaboration links.

Regarding intra-regional collaborations, we observe that the network made of only Latin American countries is much less connected. In fact, during the first two periods (before 1985), most countries were isolated and only a few links connect couples of Latin American countries. This finding is verified both for the network formed by links between inventors, and for the network between innovators. As of 1986 the international co-invention network experiences an important phenomenon: the emergence of a giant component. This component is a group of interconnected countries that remains grouped until the end of the period. Furthermore, it could be reflecting a certain –albeit weak– dynamic of interaction and collaboration at the regional level.

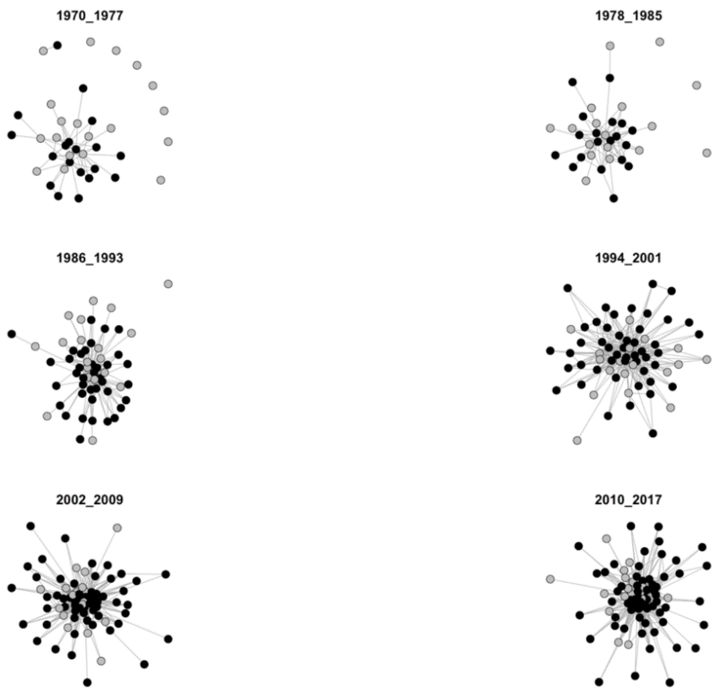

Figure 35. International co-invention networks of Latin American countries and other countries linked to the region

Source: authors based on PatentsView data. Note: grey nodes are Latin American countries; black nodes are non-Latin American countries.

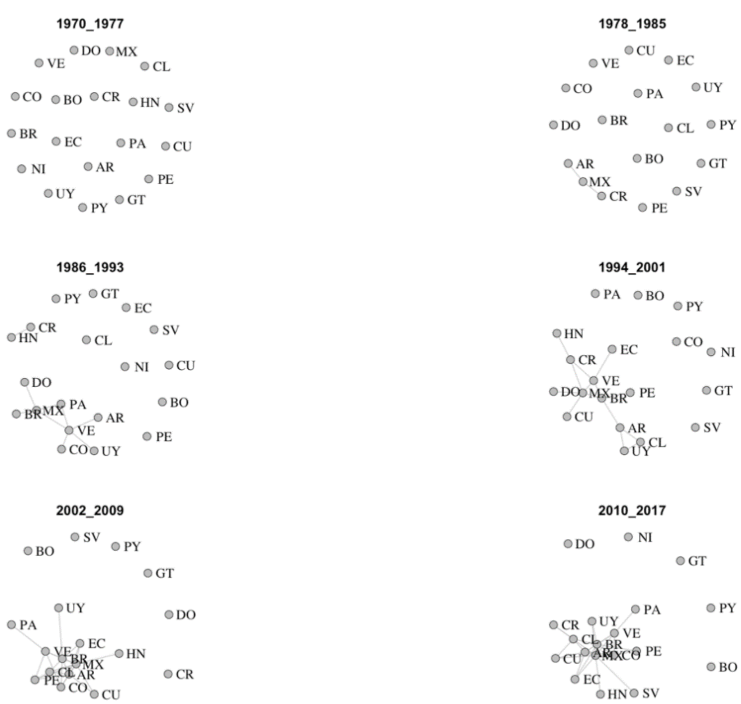

Figure 36. International co-invention networks of Latin American countries

Source: authors based on PatentsView data.

Table 4. Topology of international co-invention networks

	1970_1977	1978_1985	1986_1993	1994_2001	2002_2009	2010_2017
Nodes	38	36	57	67	78	85
% LA nodes	0.50	0.47	0.33	0.28	0.23	0.22
Links	65	89	202	356	597	712
Av. Degree	3.42	4.94	7.09	10.63	15.31	16.75
Av. Deg. LA	2.42	3.47	6.68	10.84	16.61	18.68
Av. Deg. nonLA	4.42	6.26	7.29	10.54	14.92	16.20
% Isolates	0.18	0.08	0.02	0.00	0.00	0.00
Centralization (x100)	0.31	0.54	0.55	0.73	0.68	0.72
Assortativity (LA - nonLA)	-0.55	-0.39	-0.25	-0.22	-0.12	-0.13
Networks with only LA countries						
Nodes	19	17	19	19	18	19
Links	0	2	9	14	24	27
Av. Degree	0.00	0.24	0.95	1.47	2.67	2.84
% Isolates	1.00	0.82	0.47	0.37	0.33	0.26
Centralization	0.00	0.11	0.23	0.20	0.37	0.40

Source: authors based on PatentsView data.

As per the strength of links, results show that intra-regional connections are much weaker than extra-regional collaborations (between 10 and 100 times weaker).[9] The connection between Mexican and Brazilian inventors conforms the strongest link (except in 2002-2009). These two leading countries are also responsible for other relevant regional links: Brazilian inventors collaborate especially with Argentina, Chile and Venezuela, while Mexico is particularly linked with Argentina and Venezuela. On the other hand, intra-regional collaboration links excluding Brazil and Mexico are much weaker. The only remarkable cases involve Argentina with Chile and Uruguay, and Venezuela collaborating with Ecuador.

[9] The strength of a link connecting two countries in the international collaboration network measures the number of collaborations between one actor in one country with another actor in the other.

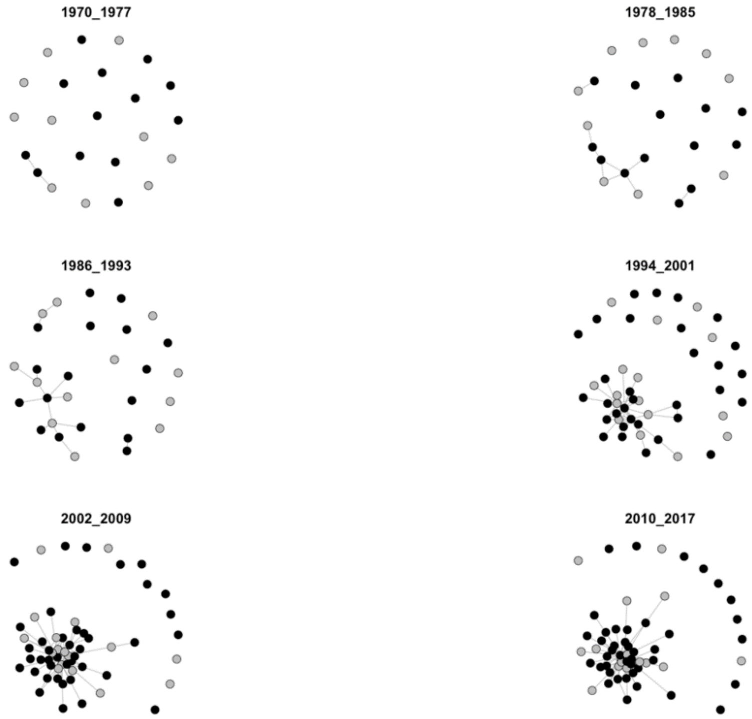

Figure 37. International co-innovation networks of Latin American countries and other countries linked to the region

Source: authors based on PatentsView data. Note: grey nodes are Latin American countries; black nodes are non-Latin American countries.

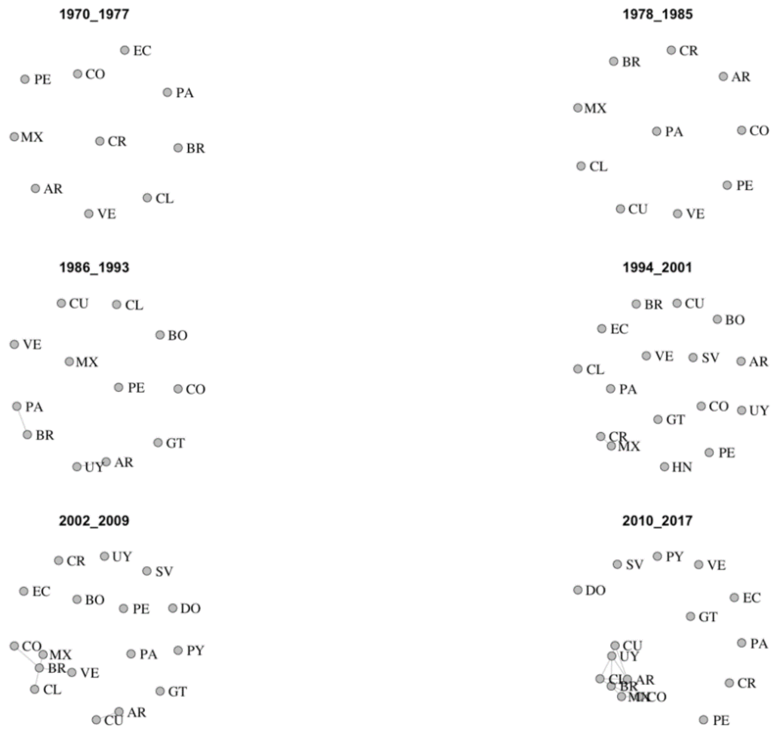

Figure 38. International co-innovation networks of Latin American countries

Source: authors based on PatentsView data.

Table 5. Topology of international co-innovation networks

	1970_1977	1978_1985	1986_1993	1994_2001	2002_2009	2010_2017
Nodes	24	29	48	58	59	24
% LA nodes	0.42	0.41	0.33	0.29	0.27	0.42
Links	9	14	44	89	118	9
Av. Degree	0.75	0.97	1.83	3.07	4.00	0.75
Av. Deg. LA	0.50	1.08	2.00	3.71	5.06	0.50
Av. Deg. nonLA	0.93	0.88	1.75	2.80	3.60	0.93
% Isolates	0.54	0.41	0.44	0.24	0.22	0.54
Centralization (x100)	0.14	0.14	0.28	0.45	0.48	0.14
Assortativity (LA - nonLA)	-0.38	-0.29	-0.47	-0.30	-0.03	-0.38
Network with only LA countries						
Nodes	10	12	16	17	16	10
Links	0	2	1	5	13	0
Av. Degree	0.00	0.33	0.12	0.59	1.62	0.00
% Isolates	1.00	0.67	0.88	0.59	0.56	1.00
Centralization	0.00	0.06	0.06	0.21	0.29	0.00

Source: authors based on PatentsView data.

Another relevant finding that we obtain when analyzing these networks is the unequal distribution of links per country, which is associated with a core-periphery structure. This structure implies that a small group of highly connected countries (the core) coexists with a disconnected periphery of nations that only maintains a few links with the core. The visualization of network graphs allows to obtain a first impression of this structure, which is maintained throughout the period and appears both when considering the links between inventors (Figure 35) and innovators (Figure 37).

The high levels of centralization indexes, especially in the co-invention networks, are consistent with the existence of a core-periphery structure (Tables 4 and 5). Network centralization persistently increases during the period (especially after 1985 and after 2009), revealing a tendency towards concentration of links in few countries. When considering the network composed only with Latin American Countries, centralization is much lower but also shows a general increasing tendency.

We test this structural property by estimating the existence of a power law degree distribution in both the international co-invention and co-innovation networks (Figure 39). If the network has a core-periphery structure, with great concentration of the links, then it will exhibit a power law degree distribution. Using the maximum likelihood method, we estimate the alpha parameter and the p-value of the Kolmogorov-Smirnov test (Clauset et al., 2009; Newman, 2005). The alpha parameter measures the degree of concentration of the links, and the p-value indicates whether we can reject or not the existence of a power law distribution.[10]

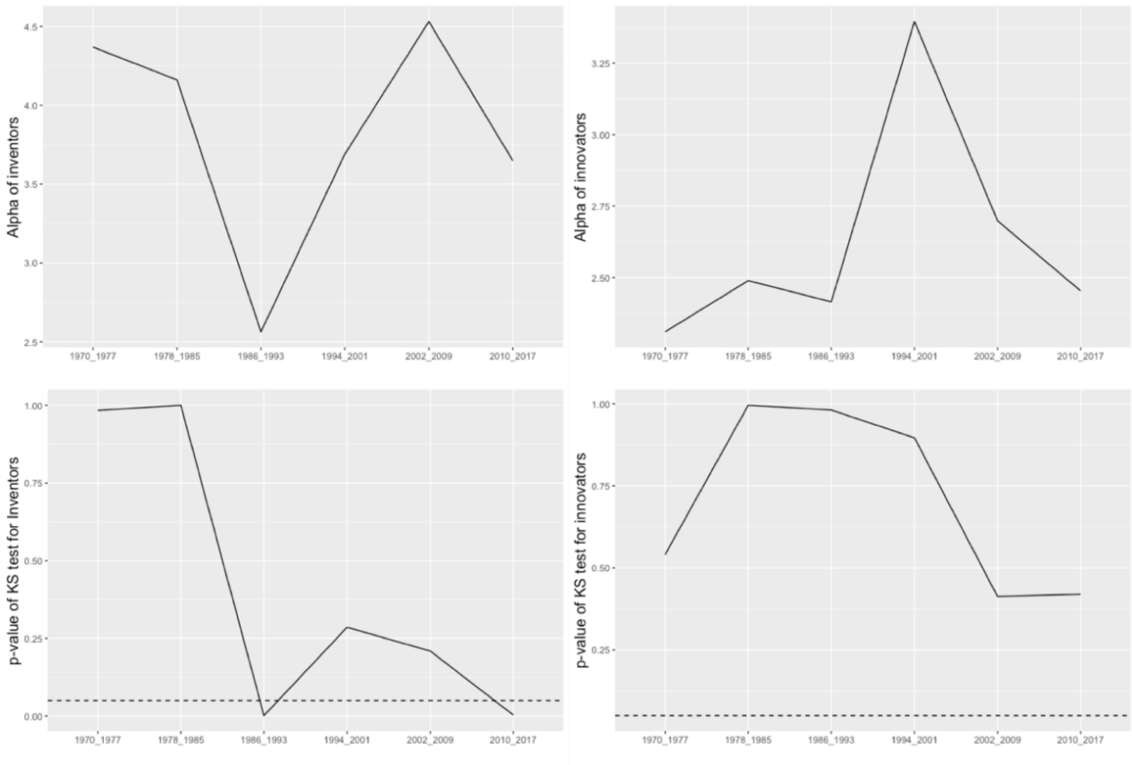

Figure 39. Results of the Kolmogorov-Smirnov test on power law distribution of international collaboration networks of Latin American networks

Source: authors based on PatentsView data.

The results presented in Figure 39 confirm that the networks have a highly centralized structure that can fit into a core-periphery model. Yet, certain differences between co-invention and co-innovation networks can be identified. Concentration of links, measured with the alpha parameter is higher in the co-invention network, indicating higher inequality in the distribution of links among countries in co-invention compared to co-innovation. However, p-values reveal that only the co-innovation network exhibit a power law distribution throughout the entire period while the co-invention network does not fit into this model during two of our six sub-periods (1986-1993 and 2010-2017).

At this point, the question that arises is which countries belong to the core and which ones are located on the periphery of the network. To do so, we analyze the k-cores and calculate the coreness levels of each country. The k-core of a network is the maximal subgraph in which every node has at least degree k, and the coreness of a node is k if it belongs to the k-core but not to the (k+1)-core (Seidman, 1983). Countries with high levels of coreness are embedded in highly connected clusters of countries. Therefore, by identifying the countries with the highest levels of coreness for each period, we can

[10] P-value values above 0.05 indicate that we cannot reject the null hypothesis and, therefore, that the network may exhibit a power law degree distribution.

identify the group of countries that make up the core of the network (the rest being the periphery).

As presented in Table 6, the core of the international collaboration network is made by both Latin American and non-Latin American Countries. Regarding Latin American nations, Brazil and Mexico are always in the core while Argentina, Chile and Venezuela become part of the core from 1978. It is also interesting to note that Colombia and Panama appear in the core of the co-innovation network but not in the co-invention network. Regarding non-Latin American Countries, the US and Germany have always been part of the core while the UK, France, Canada and China belong to the core since 1978. Spain and Belize join this core group of countries in the case of co-innovation networks.

Table 6. Core nodes in international networks

	Co-invention networks	
	Latin America	Non-Latin America
1970_1977	BR, MX	AU, CA, DE, DT, FR, GB, US, WI
1978_1985	AR, BR, CL, MX	CA, DE, EN, FR, GB, SE, US
1986_1993	AR, BR, CL, MX, VE	AT, CA, CH, DE, DT, FR, GB, IT, US, ZA
1994_2001	AR, BR, MX, VE	BE, CA, CH, DE, FR, GB, IT, JP, TW, US
2002_2009	AR, BR, CL, CO, MX, VE	AU, CA, CH, CN, DE, DT, ES, FR, GB, IN, IT, JP, MY, NL, SE, SG, TW, US, ZA
2010_2017	AR, BR, CL, CO, MX, PE, VE	AU, CA, CH, CN, DE, ES, FR, GB, HK, IN, IT, JP, KR, NL, SA, SE, SG, TW, US
	Co-innovation networks	
	Latin America	Non-Latin America
1970_1977	BR	GB, US
1978_1985	BR	DE, US
1986_1993	AR, BR, CO, MX, PA, UY, VE	AT, CH, DE, FR, GB, IT, NO, SE, US, VG
1994_2001	BR, MX	BE, CA, DE, FR, US
2002_2009	BR, MX, VE	CH, DE, ES, FR, US
2010_2017	AR, BR, CL, CO, MX, UY	CH, DE, ES, FR, JP, US

Source: authors based on PatentsView data.

We now analyze which are the most central Latin American countries in the international collaboration networks. To do so, we use two well-known indicators of network centrality: degree and strength centrality. Degree centrality measures the number of links adjacent to each node, that is, the number of countries with which it links directly. Strength, meanwhile, weights these links by the intensity of the collaborations.

Results presented in Figure 40 show that Brazil is the most prominent country both in the co-invention and the co-innovation networks. The leading position of Brazil is also consistent for the two centrality indicators. However, when analyzing the countries that follow Brazil in the ranking, certain differences can be observed according to the type of links considered and the centrality indicator used in the analysis. For example, in the co-invention networks, Mexico and Argentina are directly behind Brazil. But in co-innovation networks Chile grows rapidly in recent periods and manages to overcome Mexico and reach Argentina, according to its degree centrality. Furthermore, according to the strength centrality indicator, we find an important divergence starting in the 1990s, when the leading nations, especially Brazil, took off from the rest of the countries in the region.

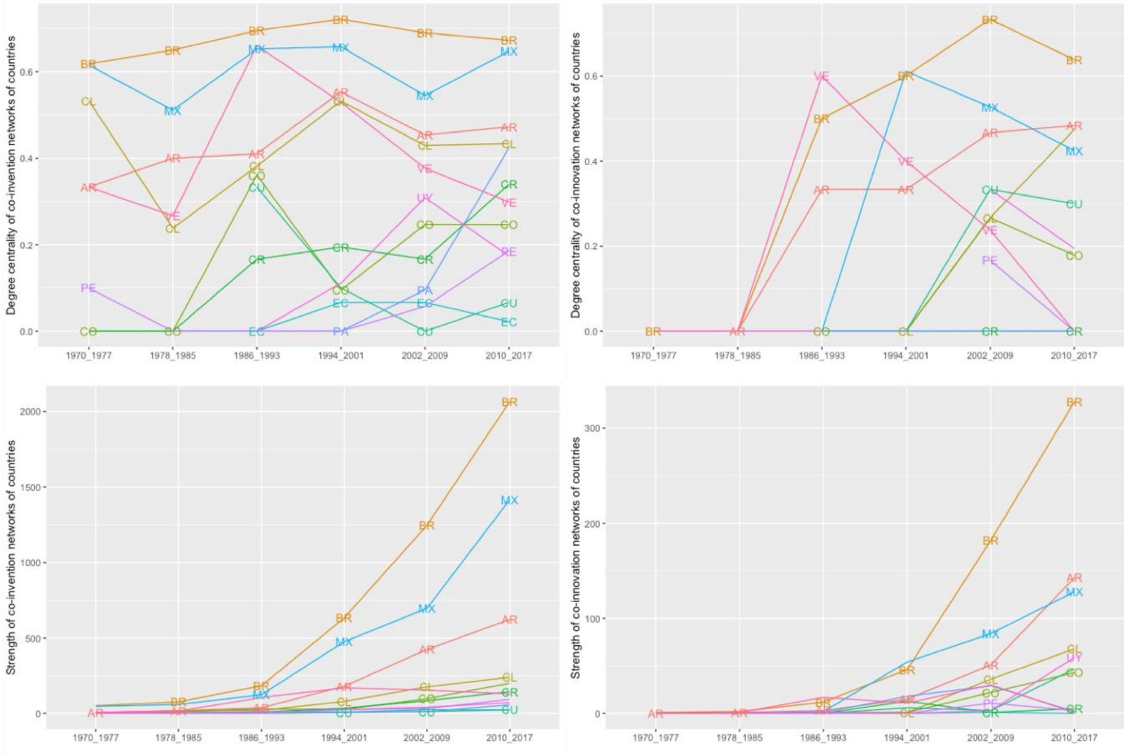

Figure 40. Evolution of network centrality indicators in international co-invention (left) and co-innovation networks (right) of selected countries

Source: authors based on PatentsView data.

Finally, we are interested in comparing the position that countries occupy in co-invention vs. co-innovation international networks. As presented in Figure 41, there is a positive relationship between the position that each country occupies in both networks.

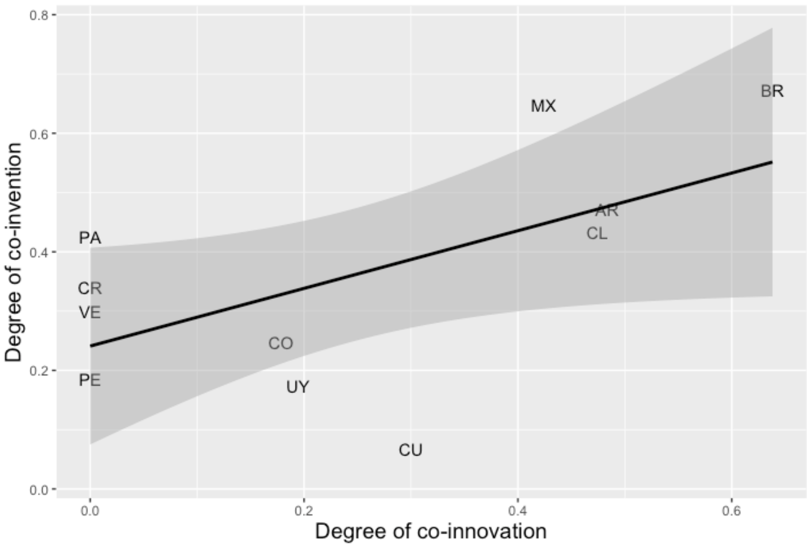

Figure 41. Degree centrality in international co-invention vs. co-innovation networks of Latin American countries

Source: authors based on PatentsView data.

However, some countries appear to be relatively more central in one network than in another. For example, the cases of Brazil, Mexico and Panama are relatively more central in the co-invention network. In these countries, local inventors seem to be relatively more active in establishing international collaborations than local innovators. On the other hand, countries such as Chile, Colombia, Uruguay and Cuba are relatively more prominent in the co-innovation network. Thus, such countries show a greater relevance of international collaborations carried out by their local innovators compared to those that were carried out by their inventors.

9. Conclusions

This document collects novel empirical evidence on patents and collaboration networks in Latin American countries between 1970 and 2017. Based on a rich data set of patents registered in USPTO and using social network analysis techniques, we not only corroborate some long-run stylized facts about innovation dynamics in the region, but also shed new light on intra/extra regional collaboration links. The empirical evidence provided here is particularly relevant due to the diversity of countries, the wide time interval and the combination of multiple types of networks that were analyzed.

Three major contributions of this document can be emphasized. First, collaboration networks in Latin America are highly disconnected. We find a constellation of separate groups of inventors and innovators that either form independent teams or collaborate with absolutely no one. This is observed not only at the regional level, where the absence of a well-connected Latin American system is corroborated, but also at the national level, where most of the nations present very low-density networks.

Second, despite this general disconnection, certain country exceptions can be found. For example, countries like Cuba show tightly connected networks of inventors, while cases such as Argentina and Chile register highly cohesive networks of innovators. The differences we found between co-invention and co-innovation networks can illustrate distinctive features of national innovation systems.

Third, networks show a great dependence on international collaborations as well as a clear extra-regional orientation of links. Macro-scale networks corroborate the absence of a regionally integrated innovation system and the existence of a core-periphery structure. In such structure, only the largest countries in the region make up the core that is mainly connected to Europe, Asia and the US, while the rest of Latin American nations remain almost disconnected from each other.

These findings open new avenues for further research. Regarding networks at the national level, it may be particularly interesting to delve into the specifics of institutional, political and economic frameworks of each country in which collaboration networks are embedded. Our results suggest that network topologies are associated with the size and relative diversification of national productive and scientific systems. Therefore, it might be interesting to study this association more systematically.

Furthermore, the evolution of networks suggests that collaboration dynamics may have been affected by some relevant events experienced by Latin American countries during said period. Between 1970 and 2017, several legal changes, institutional shocks, or political and economic crises occurred in the region. Testing the response of collaboration networks to these events can be another interesting line of research.

Finally, further research on this topic may consider also a sectoral approach. Given that not all industries have the same propensity to patent, nor the same dynamic of collaboration among actors, the differences among national networks reported in this document could be partly explained by the different productive specializations of countries. Thus, identifying and analyzing patent collaboration networks in different industries would help to better understand innovation processes in Latin American countries.

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Annexes

Annex A: Adjustments and debugging applied on the original database

From the original database, we identify those inventors who have at least one location in any of the countries considered above. Using that list of Latin American-based inventors, we obtain the list of patents in which they intervene. That list of patents constitutes our reference database for this research. However, when analyzing the selected database, we found some cases that do not adequately fit into our subject of enquiry. Facing such cases, we made several adjustments to the database:

First of all, we found several inventors with multiple locations. The original database assigns each inventor one or more locations, yet it does not take into account the time in which the inventor is linked to each location. Therefore, if an inventor has multiple patents and different locations, it is unknown what the location declared in each patent was. Analyzing the number of locations of each inventor, we find that some inventors have many locations, of which only a small proportion is in Latin America. These inventors can be problematic because they may not have a real and stable link with Latin America, which would leave them outside our research aim. In addition, some of these inventors present a very high number of registered patents with multiple locations, which leads us to suspect that there could be imputation errors in the location of the inventor of the original database. To address the problem of inventors with multiple locations, we selected only the inventors who have at least one third of their locations in Latin America. This adjustment to the database meant reducing the number of inventors by only 544 (2.5%), while the number of patents was reduced by 9215 (30.4%). This indicates that the inventors eliminated have a level of patenting well above the average.

Secondly, we found that certain patents were the result of very large teams of inventors in which the presence of Latin American actors is only marginal. These cases can be problematic since they may not really represent inventive activity carried out from Latin America. For example, we identified one patent involving nearly thirty inventors and only one of them is located in Latin America. To solve this problem, we remove from our database those patents with less than 10% of inventors located in Latin America. This criterion implies a small loss of information (Figure A1) but, on the other hand, it allows obtaining a database that more accurately represents inventions developed with the participation of Latin American actors.[11] This database adjustment also eliminates all patents with very large teams of inventors, which is an advantage in terms of social network analysis because some network measures are highly sensitive to these large-team patents (Graf & Broekel, 2019).

[11] We erased 349 patents (1.1% of all patents) involving 1302 non-Latin American inventors and only 21 Latin American inventors. Given the composition of these teams of inventors, we believe that the involvement of Latin American actors is negligible and, therefore, we cannot consider them as inventions developed with active participation of regional inventors.

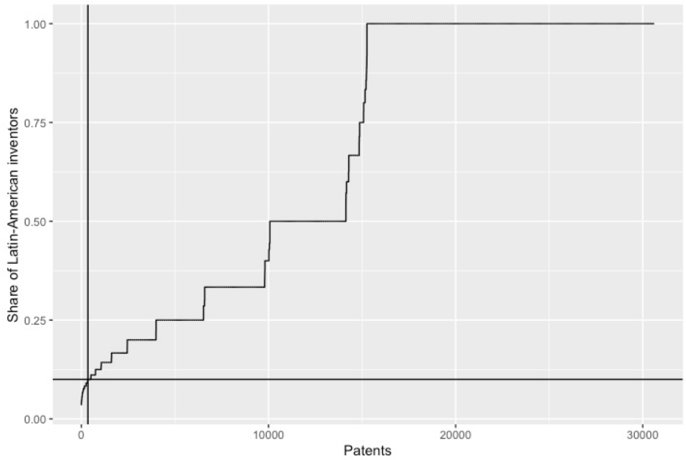


Figure A1. Share of Latin-American inventors per patent

Source: authors based on PatentsView data.

Regarding patent assignees, we found 530 cases with more than one location, some of which have even more than 10 locations. For the assignees with multiple locations in Latin America, we maintain all their locations. However, cases with multiple locations outside the region may be problematic, for example, by including them in our analysis they may generate several links connecting different countries outside the region that do not necessarily correspond to collaborations between different actors). Since our research object is delimited to Latin America, we decided to choose only one extra regional location in such cases. To do so, we analyzed case by case using the typology of assignees offered by PatentsView and looking for additional information when necessary. For example, assignees characterized as US Company (190 cases) and US Government (2 cases) were logically located in the US. For those actors categorized as Foreign Company or Corporation (266 cases) we chose their headquarters' location. Finally, we found one actor classified as Foreign Government, which we locate it in its country, and one Foreign individual, to whom we maintain its both locations because we do not have a criterion to assign one.

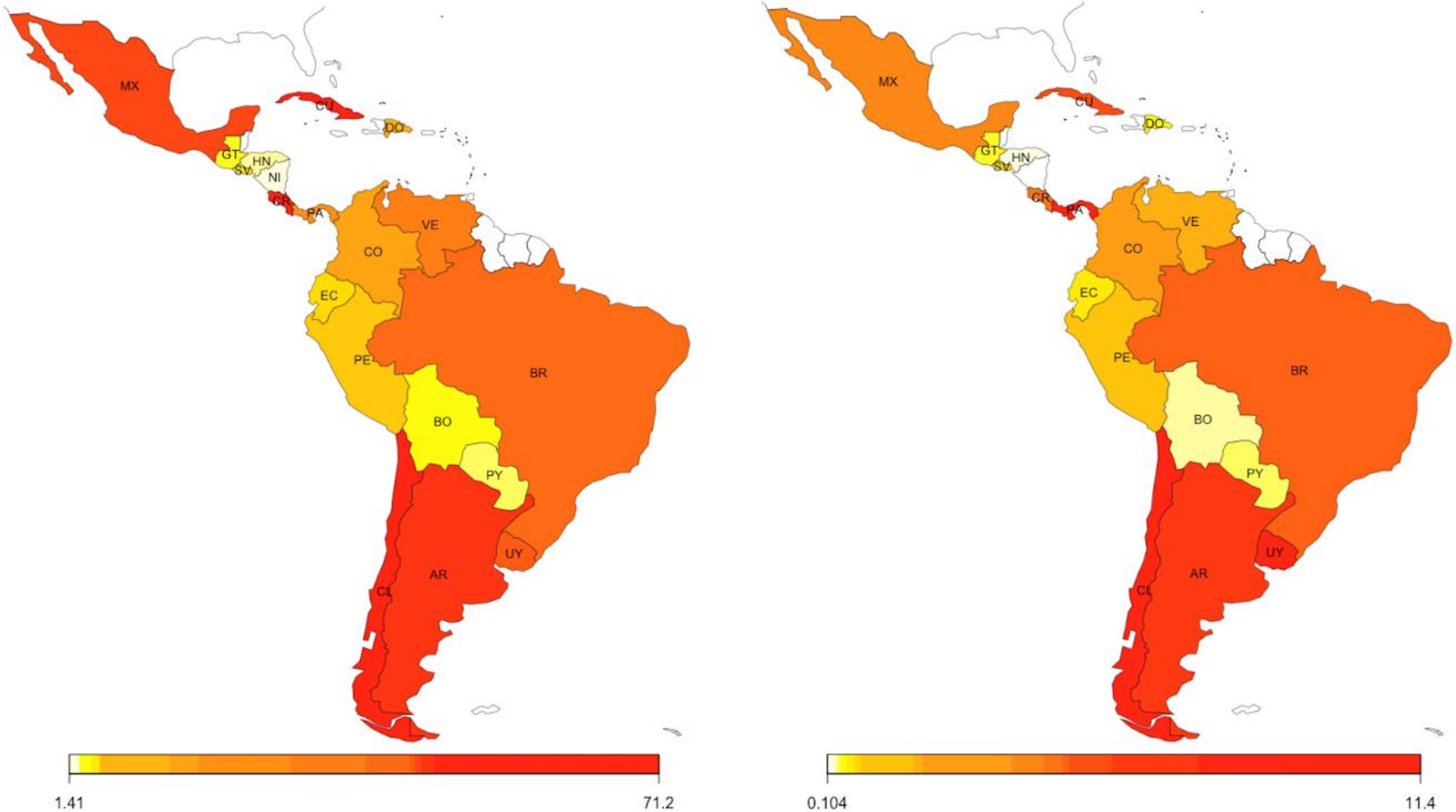
This process resulted in the distribution of locations of our assignees presented in the following table.

Table A1. Patent assignees in the databases

	number	%
Assignees (total)	4,735	*100.0*
Assignees with one location	4,649	*98.2*
of which, located in Latin America	2,152	*46.3*
Assignees with two locations	86	*1.8*
of which, both locations are in Latin America	5	*0.1*

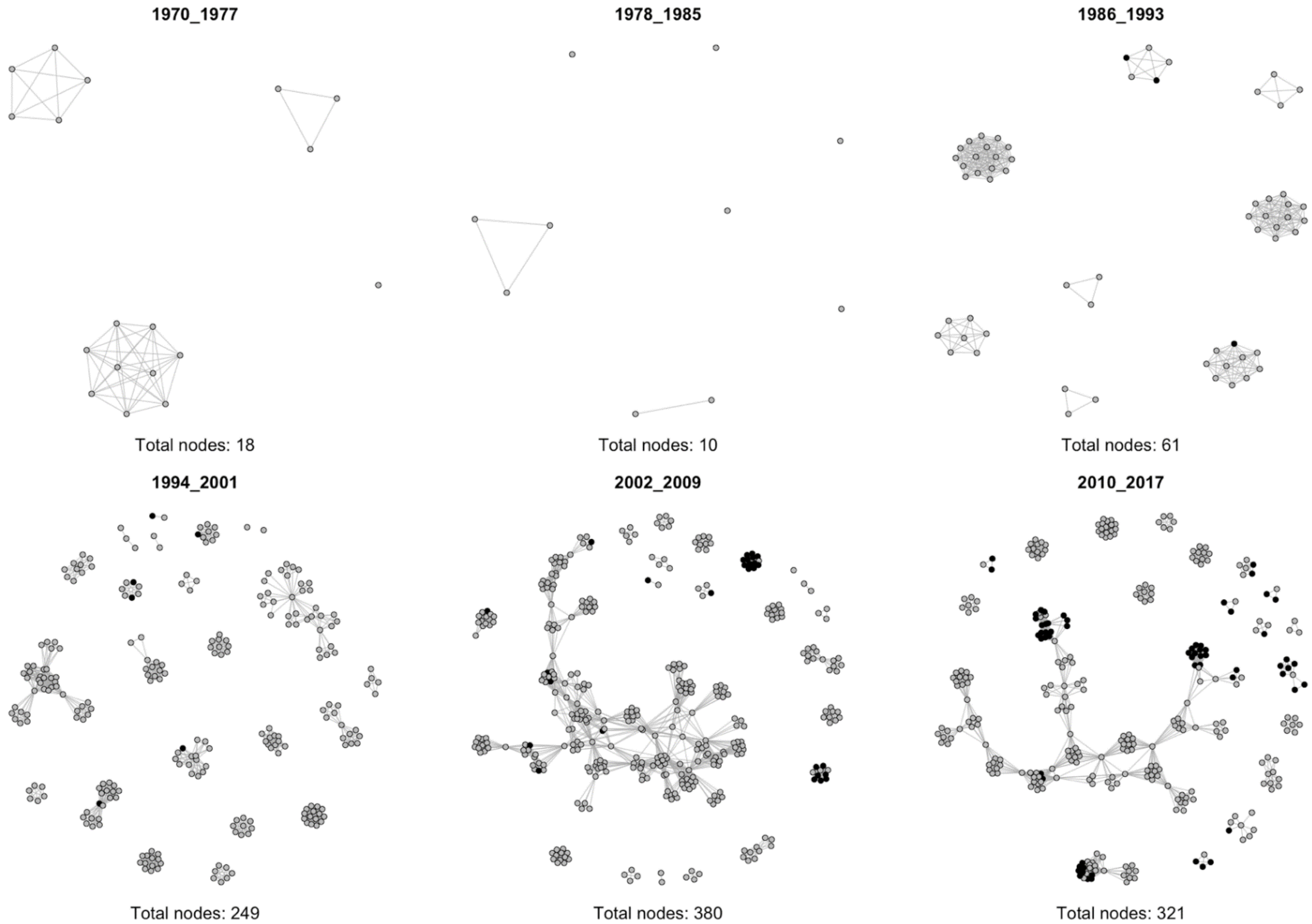
Source: authors based on PatentsView data.

Annex B. Inventors (left) and innovators (right) per million inhabitants (1970-2017)



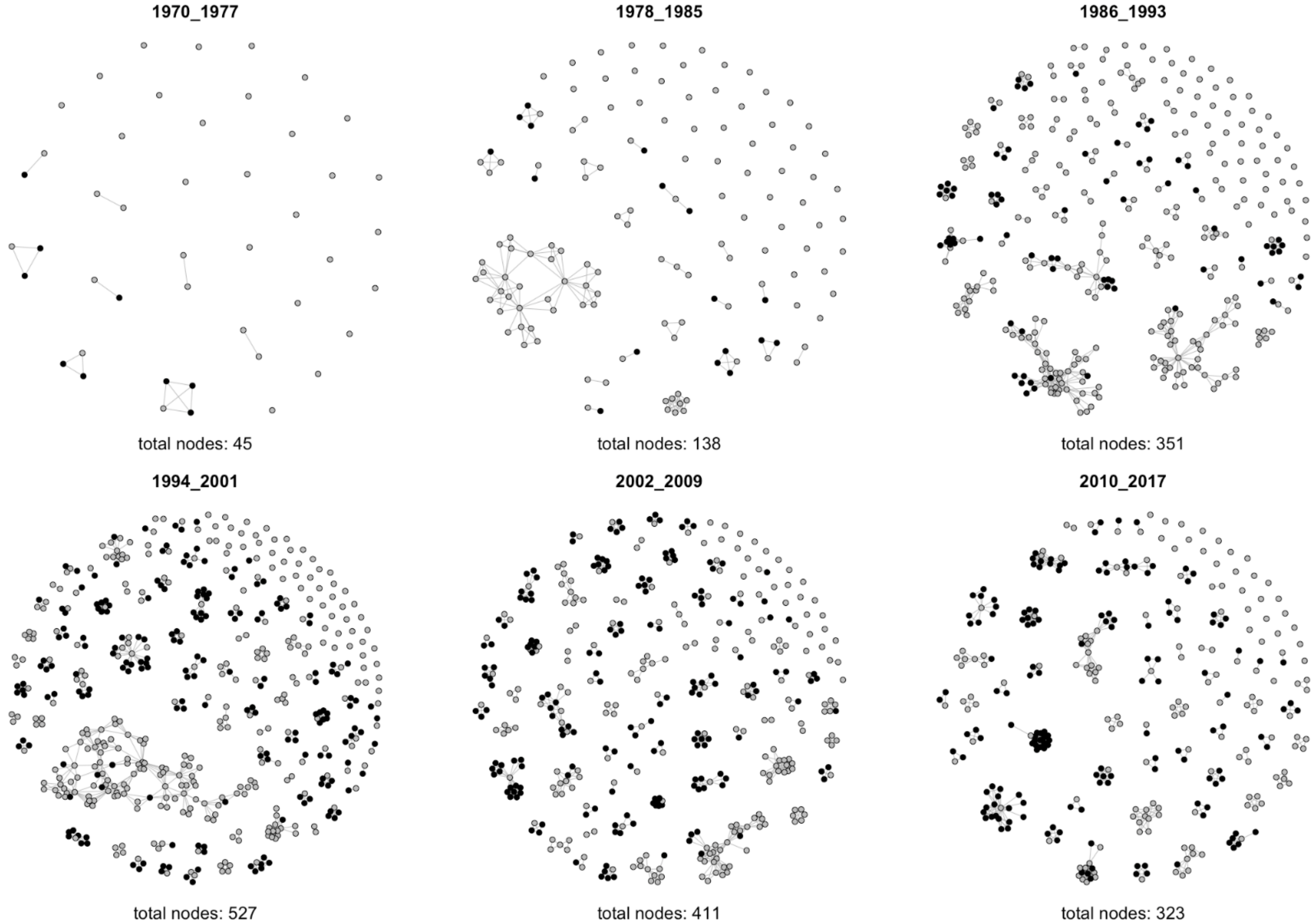
Source: authors based on PatentsView data.

Annex C. Evolution of inventor networks in Cuba



Source: authors based on PatentsView data.

Annex D. Evolution of inventor networks in Venezuela



Source: authors based on PatentsView data.