

Patent Collaboration Networks in Latin America: Extra-regional Orientation and Core-Periphery Structure

Carlos Bianchi, Pablo Galaso*, Sergio Palomeque

Universidad de la República, Facultad de Ciencias Económicas y de Administración, Instituto de Economía, URUGUAY.

ABSTRACT

This paper analyzes international collaboration networks associated with invention and patenting in Latin America between 1970 and 2017. We use data from US patent records retrieved from the Patents View platform. We select patents with actors located in Latin American countries and create networks where nodes are countries and links represent collaboration among inventors and among patent owners located in different countries. We apply various social network analysis methods. First, we calculate whole-network indicators with the aim of comparing interaction dynamics on a regional scale with extra-regional connections. Second, we test the existence of a core-periphery structure and identify core and peripheral countries in the network. Results show a clear extra-regional orientation of links, evidencing 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, like Brazil, Mexico and, to a lesser extent, Argentina, Chile or Colombia, monopolize most of the international collaborative links which connect them mainly to Europe, Asia and the US. Meanwhile, the rest of the Latin American countries remain almost disconnected from each other. These findings seem to reveal two important weaknesses of the regional innovation system in Latin America: first, innovation processes developed in the region are excessively dependent on collaborations with countries outside Latin America; second, there is a waste of potential sub-regional collaborations between neighboring countries that could be sharing research projects and complementing their capacities and resources to improve innovation processes.

Keywords: International collaboration, Patents, Social network analysis, Latin America, Invention, Core-periphery.

Correspondence

Pablo Galaso

Facultad de Ciencias Económicas y de Administración, Instituto de Economía, Gonzalo Ramírez 1926, Montevideo 11200, URUGUAY.
Email id: pgalaso@iecon.ccee.edu.uy

Received: 28-10-2020

Revised: 29-01-2021

Accepted: 12-03-2021

DOI: 10.5530/jscires.10.1s.22

INTRODUCTION

International collaboration networks connecting actors involved in innovation processes are increasingly relevant. Although most interactions associated with innovation occur among actors located in the same territory, global networks are crucial for the innovation process. These international connections function as major channels or global pipelines that transfer knowledge from one place to another, introducing novel ideas into local networks and cooperating to prevent lock-in situations.^[1]

Previous studies have analyzed collaborative innovation networks on a global scale using different data sources such as patent records, scientific articles and R&D projects.^[2] There is also some research that studies the dynamics of international collaboration among European countries from a regional

perspective.^[3] However, in the case of Latin America, there is no previous research that analyzes collaborative networks for innovation among the countries of the region.

Our article aims to fill this gap by studying international collaboration networks associated with invention and patenting processes in Latin America between 1970 and 2017.¹ In this work, we follow a regional perspective, focusing on understanding interactions among Latin American countries, as well as the connections of the region with other countries in the world. The research question that guides our work is: *what are the main features of international collaboration networks associated with invention and knowledge ownership in Latin America?* In particular, we are interested in examining two structural characteristics of the networks: first, the extent to which countries either maintain strong intra-regional links or focus their collaborations towards countries located in other regions of the world; second, the (possible) presence of a core-periphery

Copyright

© The Author(s). 2021 This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

1 This article is based upon a previous working paper (Bianchi et al. 2020),^[4] where we present preliminary results of the research project entitled "Collaboration and invention networks in Latin America: empirical evidence from patent data", funded by the National Agency of Research and Innovation, Uruguay (ANII, FMV_3_2018_1_148242).

structure, in which a group of highly connected countries (the core) co-exist with a larger group of disconnected countries (the periphery).

To answer our question, we use data from US patent records retrieved from the PatentsView platform. We select patents with inventors located in Latin American countries and develop networks where nodes are countries and links represent collaboration among inventors and among patent owners located in different countries. Subsequently, we apply various social network analysis techniques that allow us to test the two structural characteristics mentioned above.

Results show a clear extra-regional orientation of links, evidencing 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 countries remain almost disconnected from each other

This study makes two major contributions to the previous literature. First, it provides novel empirical evidence with unique information on international collaboration patterns at the Latin American level during a long and relevant period of time, which allows analyzing the main regional trends in the light of the large research background on invention and development from this region. Second, it performs a categorization of Latin American countries in terms of patent collaborations, identifying core and peripheral countries in addition to pointing out the extra-regional countries collaborating with each of these groups.

The rest of the article is structured as follows. Section two presents the theoretical framework and our research hypotheses. Section three describes the data and methods used in the paper. The results are discussed in section four. Finally, section five concludes with the implications of our findings.

Theoretical framework

The globalization process of knowledge is a structural feature of the expansion of capitalism.^[5] Several studies have shown that this process has been deeply rooted in the creation, use and appropriation of knowledge to transform the environment. This unprecedented expansion of technical and scientific knowledge over the last centuries has been associated with several globalization waves. While this process boosts dissemination of technical knowledge worldwide, it also defines strong demarcations between cores and peripheries within the world knowledge system.^[6,7] Moreover, Latin American researchers have identified learning divides associated with the structural persistence of core-periphery insertion in knowledge-based capitalism.^[8]

Recent studies using patent data have analyzed the process of knowledge internationalization.^[9,10] They describe a sort of international division of in the knowledge production, driven by multinational companies and associated with migration streams, consisting mostly of highly qualified workers.^[10] Moreover, other works identify different features of core-periphery structures in the world knowledge production and diffusion, where knowledge dynamics, economic performance and public policies critically determine changes and persistence in the role that different cores and peripheries play at global and regional levels.^[11]

Inbound and outbound openness is a critical requisite for knowledge system functioning. However, while inbound openness to global knowledge fluxes is crucial for periphery countries to access and absorb new knowledge, it is not so relevant for countries with strong national capacities in research and innovation.^[12] Empirical evidence shows that underdeveloped countries are poorly connected to global knowledge networks. For example, Miguelez *et al.*^[2] show how both Africa and Latin America are left out of the global networks of knowledge production. Furthermore, both Miguelez *et al.*^[2] and Nam and Barnett^[13] found that the weak international connections of developing countries tend to be oriented towards countries that lead innovation processes on a global scale (mainly in Europe, Asia and the United States). Accordingly, we propose our first hypothesis regarding patent collaboration networks in Latin America as follows:

H1. The network has an extra-regional orientation, with little collaboration among Latin American countries compared to a greater connection with countries located in other regions of the world, mainly in Europe, the United States and Asia.

This extra-regional orientation of developing countries corresponds to a highly centralized global network structure. In this structure, developed countries are located at the center of the network, while underdeveloped countries are on the periphery. The core-periphery relationship between developed and underdeveloped countries has been widely studied, particularly from the perspective of Latin American structuralism.^[13] More recent studies show how Latin American countries, as part of the global periphery, have great difficulty in retaining their gains in productivity, which ends up being transferred to the core countries as a result of differences in labor markets and the presence of multinational companies. The literature on macroeconomic networks has documented such centralized structure in different types of networks on a global scale, such as international trade networks,^[14] finance networks,^[15] migration networks^[16] or mergers and acquisitions networks.^[17]

However, from a more regional approach, the internal dynamics and heterogeneities within the networks of underdeveloped

regions have been scarcely analyzed. In the case of Latin America, some works have provided evidence of an uneven configuration of mergers and acquisitions networks.^[18] The authors found that the network has a core of Latin American countries and some external ones that are strongly linked to each other, while most countries in the region are located on a disconnected periphery. This network configuration has not yet been documented for innovation networks.

Furthermore, an extensive background on research and innovation activities in Latin America has widely shown the uneven accumulation process among countries and knowledge areas in the region. Although there have been imbalances and countermarches, the largest Latin American countries have built world-integrated scientific and technological capabilities since the second half of the 20th century.^[19] Additionally, some medium or small countries show incipient developments and little critical mass; yet, many countries in the region are almost excluded from the global knowledge system.^[20,21]

Moreover, several works have revealed that innovation systems in Latin America show unequal development of different subsystems. In this regard, knowledge production in the region is mostly concentrated in research institutes, mainly public ones.^[22] Meanwhile, industrial production of science-based knowledge remains scarce.^[23,24] Even in the most advanced economies of the region, the weak demand from productive actors and the idiosyncratic adaptation of appropriability regimes have characterized a rather weakly linked business sector.^[25,26]

These features of innovative activity in Latin America can be observed in the configuration of international collaborative networks. In particular, we can expect that cooperation links will not be distributed homogeneously within the region, with all countries participating equally in the network. On the contrary, we can expect a network configuration as proposed in our second hypothesis:

H2. Collaborations in Latin America are strongly concentrated in a few countries, which leads to a core-periphery network structure, where a group of well-connected countries (the core) coexist with a larger number of countries (the periphery) that are disconnected from each other and only maintain a few connections with the core.

Finally, it is important to understand the role different countries play in such network configuration, in particular, which countries will constitute the core of the network and which ones will integrate the periphery. According to the largely documented heterogeneity of Latin American countries regarding their innovation activities and the different technological and research trajectories, we can expect the core of the network to be composed of a few leading Latin American countries, which are larger and have more capacity and experience in innovation processes. Meanwhile, the network

periphery will include a great diversity of countries, from small, with very backward economies, to middle-income countries with difficulties in allocating resources to innovation activities. Furthermore, given the strong extra-regional orientation of the international collaboration network, we can expect a central role from some non-Latin American countries. This leads us to formulate our last hypothesis:

H3. The core of the network is composed of both the leading Latin American countries and some countries from outside the region that lead innovation processes on a global scale, while the periphery is made up of a wider and more heterogeneous group of countries.

METHODOLOGY

The data used in this study are USPTO patent records retrieved from the PatentsView platform (<https://www.patentsview.org/>). The use of patent data from a common IPR regime allows an adequate comparison of inventive activities among different countries. In this regard, USPTO data have been widely used in the literature in order to compare inventive activities in different regions of the world.^[27-31]

PatentsView database incorporates disambiguated inventor and assignees identifiers, which is critical for analyzing collaboration networks based on patent data since it allows determining whether or not inventors and assignees registered with the same name are indeed the same actor. We aim to focus on inventions that have been developed by Latin American actors; thus, we select patents with, at least, one inventor located in a Latin American country. 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).

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 USPTO database. Although, compared to more developed regions, Latin America performs poorly in STI indicators such as R&D expenditures, number of scientific papers, or number of researchers,^[32,33] this low percentage seems to indicate that the region lags even further behind in its patenting levels than in other STI indicators.

For each of the selected patents, we process and use information related to the name and country of residence of both inventors and owners, as well as the application date. We use this data to reconstruct international collaboration networks. The nodes in our networks are countries, and we trace two different types of links connecting them. First, we establish a link between two countries when at least one inventor residing

in one of them registers a patent together with an inventor located in the other country. Second, we trace another type of link when two different patent owners that are based in two different countries work with the same inventor. Thus, while in the first type of link, the patent represents collaboration among people from different countries, in the second type the inventor acts as a link connecting two owners.^[34,35] Since most of the owners are firms or research centers, we can state that the second type of links captures inter-organizational collaboration networks, while the first one represents inter-personal networks. A detailed explanation of the data selection and processing, as well as the methodologies employed for the construction of the networks, can be found in Bianchi *et al.*^[4]

It should be noted that a patent may have more than one inventor and, in patents with several inventors, these actors may reside in different countries. Therefore, although all our patents have at least one Latin American inventor, our database also includes actors from other countries to the extent that they collaborate with Latin American inventors. Appendix 1 provides detailed information on the patents in our database and the presence of Latin American and non-Latin American inventors. This allows us to observe not only intra-regional links, but also extra-regional connections. Therefore, the nodes of our networks will be both Latin American countries and some countries outside the region, where inventors and owners who collaborate with Latin American actors are located.

Given the nature of the collaborations we study here, the links in our networks are symmetrical, that is, there is no direction that indicates that the relationship arises in one country and is directed towards the other, but rather that the interaction is supposed to be bidirectional. Furthermore, our links are weighted, which reflects the intensity of collaboration between each pair of countries. In order to obtain the weighting (or strength) of the links, we take into account the number of collaborations among, on the one hand, inventors and, on the other hand, owners from both countries.

Since inventors and innovators are supposed to collaborate before and after the patent application date, we must assume that each link exists before and after the date of the patent application. In accordance with this assumption, and in line with the literature on patent networks,^[35,36] we consider time windows. In particular, we develop 8-year windows and, for each of them, we trace both types of networks, considering the links associated with the patents registered in the corresponding period.

Once we have created the networks, we analyze their structural properties. In order to test our first hypothesis (extra-regional orientation of the network), we start comparing interaction dynamics on a regional scale with extra-regional connections.

To this end, we calculate three indicators of network cohesion: average degree, percentage of isolate nodes and size of the largest component. We then remove non-Latin American countries from the networks (keeping only Latin American nodes) and calculate the same indicators again. According to our first hypothesis, we expect that extra-regional countries will be crucial for the cohesion of the network, so if we eliminate them, Latin American countries will remain disconnected from each other. We complete the empirical evidence about this first hypothesis calculating assortativity indexes. Such indicators allow us to measure the propensity of Latin American countries to interact with other countries from the region (i.e. positive assortativity), or with countries in different parts of the world (i.e. negative assortativity). Accordingly, we expect assortativity indexes to confirm an extra-regional orientation of international collaborations of Latin American countries.

In order to test our second hypothesis (core-periphery structure of the network), we estimate the existence of a power-law degree distribution in the networks. 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.^[37,38] The alpha parameter measures the degree of concentration of the links, and the *p*-value indicates whether we can dismiss the existence of a power-law distribution or not. *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.

Finally, we aim to determine which countries belong to the core and which ones are located on the periphery of the network, which will allow us to test our third hypothesis. 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.^[39] Countries with high levels of coreness are embedded in highly connected clusters. Therefore, by identifying the countries with the highest levels of coreness for each period, we can identify the group of countries that make up the core of the network (the rest being the periphery).

RESULTS

We begin by examining the graphical representations of the networks (Figures 1-4), which are consistent with our first hypothesis on the extra-regional orientation of international collaborations. As presented in the Figures, the intra-regional networks composed only of Latin American countries (Figures 2 and 4) are poorly connected compared to the networks that include extra-regional countries (Figures 1 and 3), especially in the first periods. This seems to indicate that Latin

America does not have a cohesive collaborative structure for patenting on a regional scale.

Assortativity indexes are always negative both in the co-invention (Table 1) and the co-ownership networks (Table 2), which also confirms H1, evidencing the tendency of Latin American countries to interact with non-regional actors instead of cooperating with other Latin American countries. However, there is a persistent reduction in this indicator, which reveals a progressive trend towards greater interaction among countries in the region during the last periods. This result is also in line with the evolution of connectivity in the intra-regional networks. Indeed, although these networks, composed only of Latin American countries, were disconnected during the initial periods, they progressively improve their connectivity (Tables 1 and 2): 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.²

The country to which most of the international collaborations are directed is the US. Two links connecting inventors are particularly strong. They involve the largest Latin American countries: US-Mexico and US-Brazil. Furthermore, as it was expected given their historic trajectories, while Mexico is clearly focused on collaboration with the US, Brazilian links are more diversified, since 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, Venezuela too. If we focus on networks connecting owners, 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.³

Regarding intra-regional collaborations, our findings are highly novel, by contributing with a longitudinal approach in the whole region. We observe that the network comprised only of 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 pairs of Latin American countries. This finding is verified both for the network composed of links between inventors, and for the network between owners. As of 1986, the international co-invention network experiences an important phenomenon:

- 2 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. A component is considered to be the giant component if it connects a non-trivial share of nodes (Jackson, 2008).^[40]
- 3 Regarding these results, it is worth considering that the owners' networks take the tax address of the firm, being several works that show how patent registration and tax strategies are intertwined in multinational corporations.^[41]

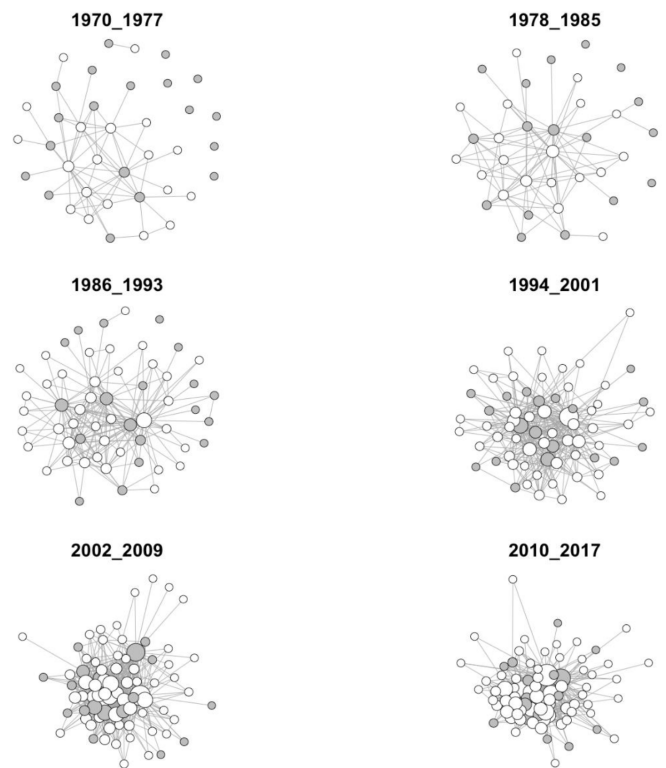


Figure 1: International co-invention networks of Latin American countries and other countries linked to the region. Note: grey nodes are Latin American countries; white nodes are non-Latin American countries. Source: authors based on PatentsView data.

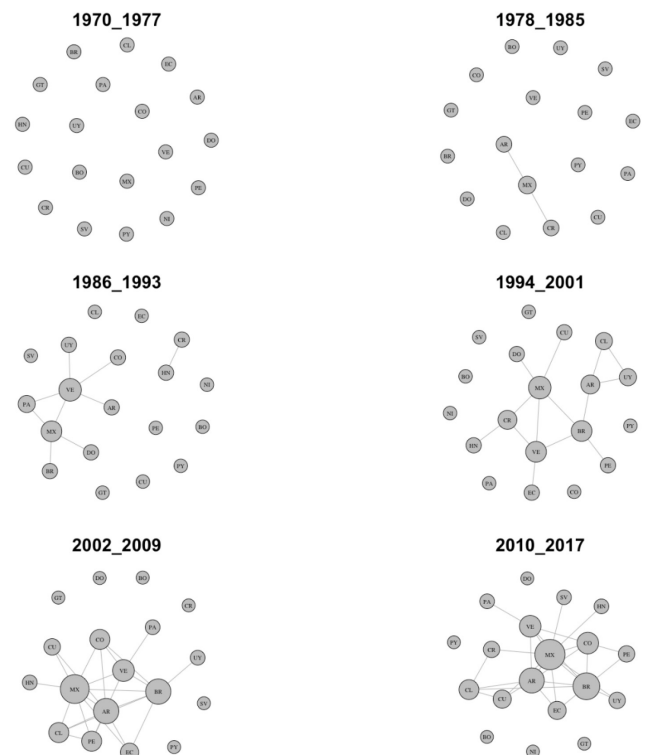


Figure 2: International co-invention networks of Latin American countries. Source: authors based on PatentsView data.

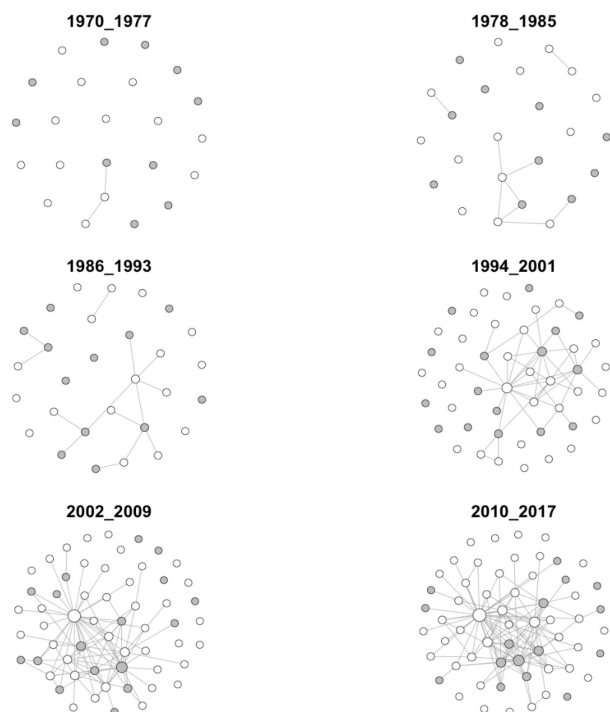


Figure 3: International co-ownership networks of Latin American countries and other countries linked to the region. Note: grey nodes are Latin American countries; white nodes are non-Latin American countries. Source: authors based on PatentsView data.

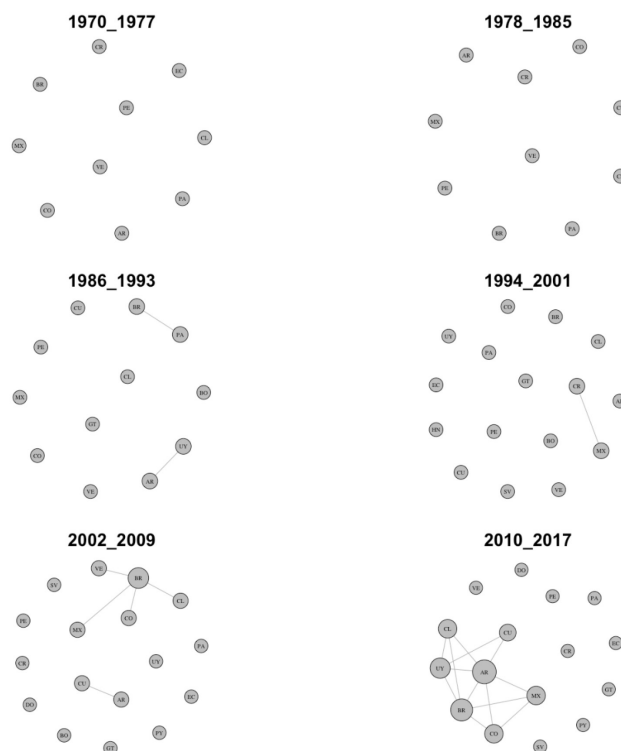


Figure 4: International co-ownership networks of Latin American countries. Source: authors based on PatentsView data.

Table 1: 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.

Table 2: Topology of international co-ownership 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.

the emergence of a giant component. This component is a group of interconnected countries that remain grouped until the end of the period. Furthermore, it could reflect certain –albeit weak– interaction and collaboration dynamics at the regional level.

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). The connection between Mexican and Brazilian inventors constitutes 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 some incipient subcontinental linkages in the South Cone (Argentina with Chile and Uruguay), and in the Andean region (Venezuela collaborating with Ecuador). This finding illustrates the fundamental role that Brazil and Mexico play in keeping the regional network relatively cohesive.

Regarding our second hypothesis, our findings corroborate 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 maintain a few links with the core. The visualization of network graphs allows obtaining a first impression of this structure, which is maintained throughout the period and appears when

considering the links between both inventors (Figure 1) and owners (Figure 3).

The high levels of centralization indexes, especially in the co-invention networks (Table 1), are consistent with the existence of a core-periphery structure. Network centralization persistently increases during the period (especially after 1985 and after 2009), revealing a tendency towards a concentration of links in few countries. When considering the network composed only of Latin American Countries, centralization is much lower but also shows a general upward trend.

We test this structural property by estimating the existence of a power-law degree distribution in both international co-invention and co-ownership networks. The results presented in Figure 5 confirm that the networks have a highly centralized structure in which a core-periphery model could fit. Yet, certain differences between co-invention and co-ownership networks can be identified. Concentration of links, measured with the alpha parameter is higher in the co-invention network, which indicates higher inequality in the distribution of links among countries in co-invention compared to co-ownership. However, *p*-values reveal that only the co-ownership network shows 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).

Our third and last hypothesis refers to the composition of the core and the periphery of the network. To test it, we analyze the *k*-cores and calculate the coreness levels of each country.

As presented in Table 3, the core of the network is made up of both Latin American and non-Latin American Countries. Regarding Latin American actors, Brazil and Mexico are always in the core while Argentina, Chile and Venezuela became part of the core as of 1978. It is also interesting to note that Colombia and Panama appear in the core of the co-ownership 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 have belonged to the core since 1978. Spain and Belize join this core group of countries in the case of co-ownership networks.

According to our hypothesis, we are interested in doing a detailed analysis of the position of each Latin American country in the network. To do so, we use two well-known indicators of network centrality: degree and strength centrality.⁴ Degree centrality measures the number of links adjacent to each node, that is, the number of countries with which it links directly. Strength, meanwhile, weighs these links according to the intensity of the collaborations, measured by the number of collaborations among inventors (in the co-invention network) and among owners (in the co-ownership network).

Results presented in Figure 6 show that Brazil is the most prominent country both in co-invention and co-ownership networks. The leading position of Brazil is also consistent for the two centrality indicators. Furthermore, according to the strength centrality indicator, we find an important divergence

Table 3: 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-ownership 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.

starting in the 1990s when the leading nations, especially Brazil, pulled away from the rest of the countries in the region.

However, when analyzing the countries that rank below Brazil, certain differences can be observed depending on 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 below Brazil. But in co-ownership networks, Chile has grown rapidly in recent periods and has managed to outdo Mexico and catch up with Argentina, according to its degree centrality. This finding may reflect the interactive co-ownership associated with the innovative dynamics in countries adopting trade agreements related to intellectual property rights.^[42]

Finally, we compare the position that countries occupy in co-invention vs. co-ownership networks. In particular, we are interested in studying the degree centrality of the countries in both networks, which allows us to observe the relative prominence of each country depending on the type of links considered. As presented in Figure 7, there is a positive relationship between the positions occupied by each country in both networks. However, some countries appear to be relatively more central in one network than in another, for example, the cases of Brazil, Mexico and Panama, which are relatively more central in the co-invention network. In these countries, local inventors seem to be more dynamic in terms of establishing international collaborations than patent owners.

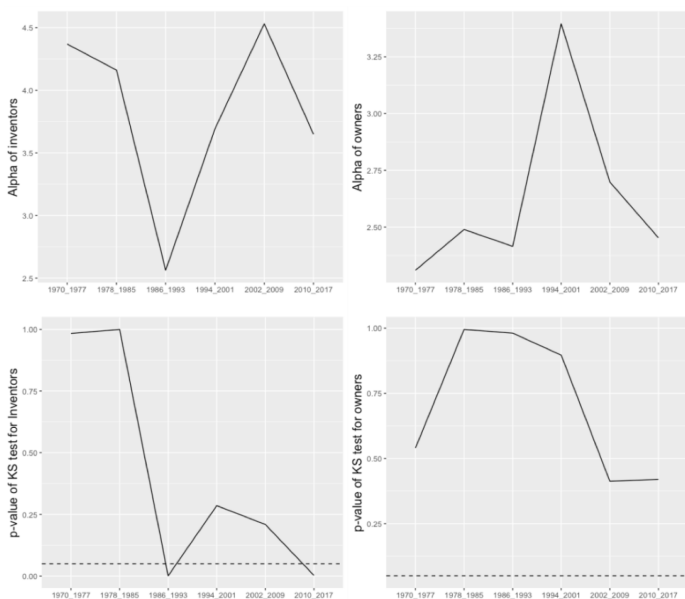


Figure 5: Results of the Kolmogorov-Smirnov test on power-law distribution of international collaboration networks of Latin American networks. Source: authors based on PatentsView data.

⁴ Other centrality indicators, such as eigenvector or reach centrality, have also been calculated. Their results, which do not differ essentially from those analyzed below, can be found in Appendix 2.

DISCUSSION AND CONCLUSION

This article uses data from patents registered at the USPTO to study the international collaborative networks associated with inventions developed in Latin American countries. In addition to reconstructing such networks for the first time, our study allows identifying their two essential structural properties: first, the extra-regional orientation, that is, the propensity of Latin American countries to establish international connections with countries outside the region rather than with other Latin American countries; second, the configuration of a core-periphery network structure, in which a small group of Latin American countries together with leading economies in innovation from outside the region conform a strongly interconnected core, while the rest of the countries in the region (a large and heterogeneous group), located on a periphery, are disconnected from each other and maintain collaborations only with the core.

What are the implications of these network properties? In particular, what can we conclude from these two structural properties about the processes of innovation in Latin America? First, the extra-regional orientation of the networks may reveal an important weakness of the regional innovation system in Latin America. The scarcity of intra-regional links shows the absence of Latin American collaboration dynamics and, thus, reveals that knowledge does not flow from one country to another in the region, which makes it very difficult to generate new innovations based on knowledge originated from Latin American countries. Furthermore, this feature may reveal a high dependence on external actors. Our networks seem to corroborate that innovation processes developed in Latin America depend excessively on links with other countries outside the region.

Regarding the second distinctive feature of the networks, their core-periphery structure, the literature on innovation networks has shown that this type of configuration is efficient in terms of knowledge dissemination since the average distance between their nodes is usually small.^[43] Additionally, core-periphery networks enhance coordination mechanisms among the different actors.^[44] However, in highly centralized networks links are unevenly distributed and too concentrated in a small proportion of nodes (i.e. the countries in the core), which may provide them with monopoly power over the flow of information and may reduce the collective results of innovation processes.^[45] In our network, the core-periphery structure seems to reveal a strong disparity of innovative activity, with large countries like Brazil, Mexico and, to a lesser extent, Argentina, Chile or Colombia monopolizing most of the international collaborative links, while most of the region remains disconnected from each other. This could be reflecting a waste of potential sub-regional collaborations between neighboring countries that could be sharing research

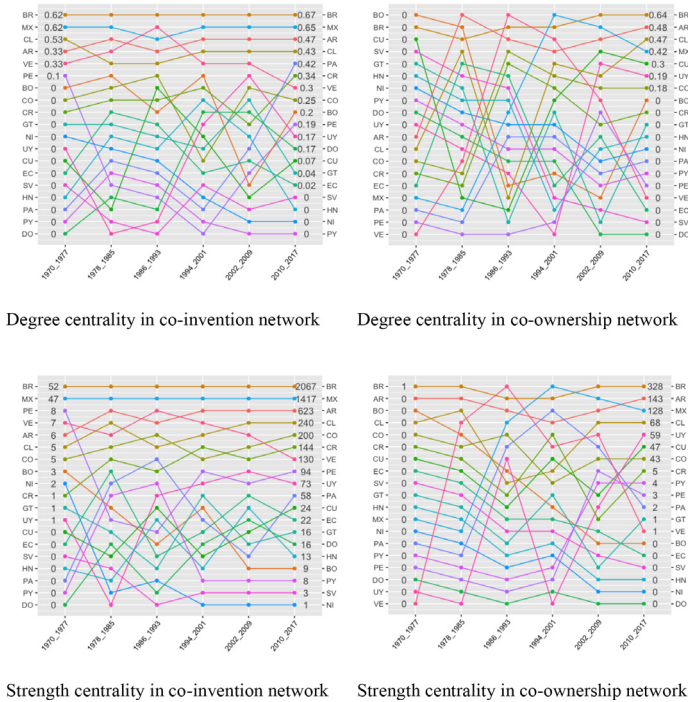


Figure 6: Ranking of Latin American countries according to their centrality indexes in international collaboration networks. Note: indicator values are shown for the first and last periods. Source: authors based on PatentsView data.

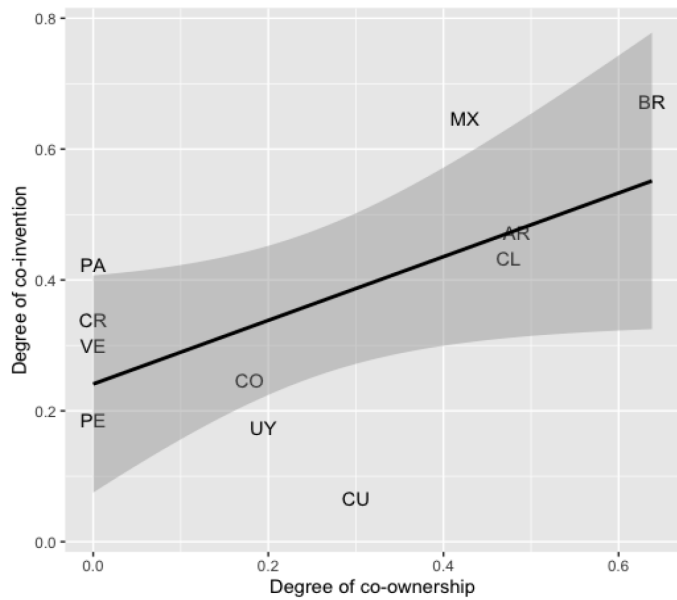


Figure 7: Degree centrality in international co-invention vs. co-ownership networks of Latin American countries. Source: authors based on PatentsView data.

On the other hand, countries such as Chile, Colombia, Uruguay and Cuba are relatively more prominent in the co-ownership network. Thus, such countries show a greater relevance of international collaborations carried out by patent owners than those carried out by their inventors.

projects, complementing their capacities and resources to improve innovation processes. Our results seem to reflect the loss of interactive learning spaces, which have been early signaled as a chronic failure of knowledge systems in under-development conditions.^[9]

Finally, regarding the presence of extra-regional countries in the core of the network, this feature seems to corroborate the great dependence of Latin America on the leading countries in the innovation processes. In particular, the US, China and some European countries appear persistently in the core of the Latin American network, interacting strongly with the leading countries of the region, and also operating as brokers between the small and medium-sized economies of Latin America that are located on the periphery of the network. Once again, we highlight the novelty of this empirical finding, since it measures the whole regional system and allows observing a very significant influence of the world leaders in the region's innovation processes and in the sustainability of the intra-regional linkages. Such influence seems excessive if a potentially more integrated Latin American system is pursued.

The understanding of these network dynamics offers clues for national innovation agencies and public policy actors that aim to promote or encourage innovation activities in collaboration with other countries as much as they help them to know how to better insert each country in the Latin American network. Furthermore, at a regional level, the design of mechanisms for strengthening a regional innovation system should take into account this form of interaction presented by the countries of the region, promoting intra-regional collaborations and the insertion of intermediate and medium-sized economies in the core of the Latin American collaboration networks for invention and innovation.

Our work also opens other avenues for future research, for example, the study of international collaborative networks with a sectoral focus, identifying the industries of greatest relevance to Latin America. In addition, there are interesting opportunities for analyzing networks with a different territorial approach, identifying relationships among cities or different territories at the sub-national level, which could provide more detail on the dynamics of collaboration in the region. Finally, although there are some previous studies that analyze innovation networks on a micro scale (e.g. networks of inventors), these works have focused on studying country cases, but there is no background to micro networks on a Latin American scale yet. Future research can contribute to complementing our findings with advances in these lines.

CONFLICT OF INTEREST

The authors declare no Conflict of interest.

REFERENCES

- Gazni A, Sugimoto CR, Didegah F. Mapping world scientific collaboration: Authors, institutions, and countries. *Journal of the American Society for Information Science and Technology*. 2012;63(2):323-35.
- Migueluez E, Raffo J, Chacua C, Coda-Zabeta M, Yin D, Lissoni F, Tarasconi G. Tied in: The Global Network of Local Innovation. In *Cahiers du GREThA (2007-2019)* (No. 2019-16; Cahiers Du GREThA (2007-2019)). Groupe de Recherche en Economie Théorique et Appliquée (GREThA). 2019. <https://ideas.repec.org/p/grt/wpegrt/2019-16.html>
- Balland PA, Boschma R, Ravet J. Network dynamics in collaborative research in the EU, 2003-2017. *European Planning Studies*. 2019;27(9):1811-37. DOI: 10.1080/09654313.2019.1641187
- Bianchi, C., Galaso, P., & Palomeque, S. (2020). Invention and collaboration networks in Latin America: evidence from patent data. *Serie Documentos de Trabajo (Working Papers) 04/20*. Instituto de Economía. <https://ideas.repec.org/p/ulr/wpaper/dt-04-20.html>
- Freeman C. The 'National System of Innovation' in historical perspective. *Cambridge Journal of Economics*. 1995;19(1):5-24.
- Reinert E. How rich nations got rich: Essays in the history of economic policy. Working Paper. 2004.
- Chang HJ. *Bad Samaritans: The guilty secrets of rich nations and the threat to global prosperity*. Random House. 2008.
- Arocena R, Sutz J. Knowledge, innovation and learning: Systems and policies in the north and in the south. In: Cassiolato JE, Lastres HMM, and Maciel ML. (Eds.). *Systems of Innovation and Development: Evidence from Brazil*. Edward Elgar Publishing. 2003;291-310.
- Danguy J. Globalization of innovation production: A patent-based industry analysis. *Science and Public Policy*. 2017;44(1):75-94. DOI: 10.1093/scipol/scw025
- Bergquist K, Fink C, Raffo J. Identifying and ranking the world's largest science and technology clusters. In *World Intellectual Property Organization (WIPO). The Global Innovation Index 2018: Energizing the World with Innovation*. WIPO. 2018.
- Chen Z, Guan J. The core-peripheral structure of international knowledge flows: Evidence from patent citation data. *R&D Management*. 2016;46(1):62-79.
- Nam Y, Barnett GA. Globalization of technology: Network analysis of global patents and trademarks. *Technological Forecasting and Social Change*. 2011;78(8):1471-85.
- Rodríguez O. Sobre la concepción del sistema centro-periferia. *Revista de la CEPAL*. 1977;3:203-48.
- Fagiolo G, Reyes J, Schiavo S. The evolution of the world trade web: A weighted-network analysis. *Journal of Evolutionary Economics*. 2009;20(4):479-514. DOI: 10.1007/s00191-009-0160-x
- Schiavo S, Reyes J, Fagiolo G. International trade and financial integration: A weighted network analysis. *Quantitative Finance*. 2010;10(4):389-99. <https://doi.org/10.1080/14697680902882420>
- Fagiolo G, Mastrorillo M. Does Human Migration Affect International Trade? A Complex-Network Perspective. *Plos One*. 2014;9(5):e97331. DOI: 10.1371/journal.pone.0097331
- Galaso P, Diez SA. Core-periphery relations in the international mergers and acquisitions network. *Applied Econometrics and International Development*. 2020;20(1):23-34.
- Sánchez Díez A, Galaso P, de la Cruz GJM. Mergers and acquisitions carried out by Spanish firms in Latin America: A network analysis study. *CEPAL Review*. 2017;2016(120):51-69. <http://repositorio.cepal.org/handle/11362/41255>
- Montobbio F, Sterzi V. Inventing together: Exploring the nature of international knowledge spillovers in Latin America. *Journal of Evolutionary Economics*. 2011;21(1):53-89.
- WIPO. *World Intellectual Property Indicators 2018*. Geneva: World Intellectual Property Organization. 2018.
- Delvenne P, Thoreau F. Dancing without listening to the music: Learning from some failures of the 'national innovation systems' in Latin America. In Kuhlman S and Ordoñez-Matamoros G. *Research Handbook on Innovation Governance for Emerging Economies*. Edward Elgar Publishing. 2017.
- Lundvall BÅ. Innovation as an Interactive Process: From User Producer Interaction to National systems of Innovation. In Dosi G, *Technical Change and Economic Theory*. Pinter Publishers; 1988.
- Chaves CV, Rapini MS, Suzigan W, de A. Fernandes AC, Domingues E, Martins Carvalho SS. The contribution of universities and research institutes to Brazilian innovation system. *Innovation and Development*. 2016;6(1):31-50.
- Confraria H, Vargas F. Scientific systems in Latin America: Performance, networks, and collaborations with industry. *The Journal of Technology Transfer*. 2019;44(3):874-915.
- Arocena R, Sutz J. Weak knowledge demand in the South: learning divides and innovation policies. *Science and Public Policy*. 2010;37(8):571-82.
- Cimoli M, Primi A, Rovira S. National innovation surveys in Latin America: Empirical evidence and policy implications. In: *National innovation surveys in Latin America: empirical evidence and policy implications*. Santiago: ECLAC.

- 2011;7-14.
27. CEPAL. Ciencia, tecnología e innovación en la economía digital: La situación de América Latina y el Caribe. Naciones Unidas, CEPAL. 2016.
 28. Gao Y, Zang L, Roth A, Wang P. Does democracy cause innovation? An empirical test of the popper hypothesis. *Research Policy*. 2017;46(7):1272-83. DOI: 10.1016/j.respol.2017.05.014
 29. Guan J, Zhang J, Yan Y. The impact of multilevel networks on innovation. *Research Policy*. 2015;44(3):545-59. DOI: 10.1016/j.respol.2014.12.007
 30. Huang Z, Chen H, Chen Z, Roco MC. International nanotechnology development in 2003: Country, institution, and technology field analysis based on USPTO patent database. *Journal of Nanoparticle Research*. 2004;6(4):325-54. DOI: 10.1007/s11051-004-4117-6
 31. Valera MRM, Sifontes DA. Las patentes como resultado de la cooperación en I+D en América Latina: Hechos y desafíos. *Investigación y desarrollo: revista del Centro de Investigaciones en Desarrollo Humano*. 2014;22(1):2-18.
 32. Huggett S. The rise of Latin American science. *Research Trends*. 2012;31:15-8.
 33. Lemarchand GA. Latin America. In UNESCO, UNESCO science report: Towards 2030. Unesco Publishing; 2015.
 34. Cantner U, Graf H. The network of innovators in Jena: An application of social network analysis. *Research Policy*. 2006;35(4):463-80.
 35. Galaso P, Kovarik J. Collaboration Networks, Geography and Innovation: Local and National Embeddedness. *Papers in Regional Science*. 2020;1-28. DOI: 10.1111/pirs.12578
 36. Andersson DE, Galaso P, Saiz P. Patent Collaboration Networks in Sweden and Spain during the Second Industrial Revolution. *Industry and Innovation*. 2019;26(9):1075-102. DOI: 10.1080/13662716.2019.1577720.
 37. Clauset A, Shalizi CR, Newman MEJ. Power-Law Distributions in Empirical Data. *SIAM Review*. 2009;51(4):661-703. DOI: 10.1137/070710111
 38. Newman MEJ. Power laws, Pareto distributions and Zipf's law. *Contemporary Physics*. 2005;46(5):323-51. DOI: 10.1080/00107510500052444
 39. Seidman SB. Network structure and minimum degree. *Social Networks*. 1983;5(3):269-87. DOI: 10.1016/0378-8733(83)90028-X
 40. Jackson MO. *Social and Economic Networks*. Princeton University Press; 2008.
 41. Griffith R, Miller H, O'Connell M. Ownership of intellectual property and corporate taxation. *Journal of Public Economics*. 2014;112:12-23.
 42. Campi M, Dueñas M. Intellectual property rights, trade agreements, and international trade. *Research Policy*. 2019;48(3):531-45.
 43. Schilling MA, Phelps CC. Interfirm Collaboration Networks: The Impact of Large-Scale Network Structure on Firm Innovation. *Management Science*. 2007;53(7):1113-26. DOI: 10.1287/mnsc.1060.0624
 44. Crespo J, Suiire R, Vicente J. Network structural properties for cluster long-run dynamics: Evidence from collaborative R&D networks in the European mobile phone industry. *Industrial and Corporate Change*. 2016;25(2):261-82. DOI: 10.1093/icc/dtv032
 45. Shi Y, Guan J. Small-world network effects on innovation: Evidences from nanotechnology patenting. *Journal of Nanoparticle Research*. 2016;18(11):329. DOI: 10.1007/s11051-016-3637-1

APPENDIX

Appendix 1. Latin American patents registered at USPTO by number and residence of inventors (1970-2017)

	1970-1977		1978-1985		1986-1993		1994-2001		2002-2009		2010-2017	
	#	%	#	%	#	%	#	%	#	%	#	%
Total patents	529	100.0	975	100.0	1486	100.0	3331	100.0	4674	100.0	6947	100.0
Patents with one inventor ^a	364	68.8	631	64.7	785	52.8	1314	39.4	1393	29.8	1565	22.5
Patents with more than one inventor ^b	165	31.2	344	35.3	701	47.2	2017	60.6	3281	70.2	5382	77.5
of whom all are from LA	62	11.7	175	17.9	358	24.1	899	27.0	1381	29.5	2205	31.7
of whom at least one is from LA and one from non-LA	103	19.5	169	17.3	343	23.1	1118	33.6	1900	40.7	3177	45.7

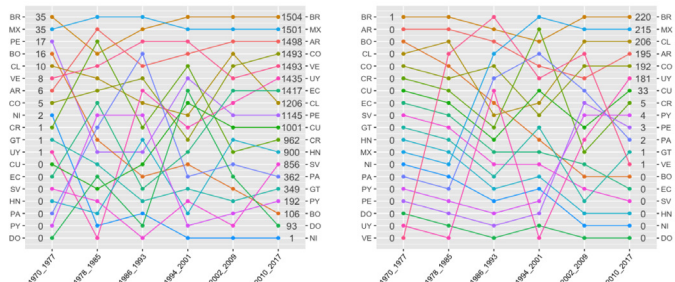
Notes:

a) All inventors in patents that have only one inventor are from Latin America (LA).

b) In patents with more than one inventor, at least one of them is from LA, while the rest can be either from LA or from outside LA (non-LA).

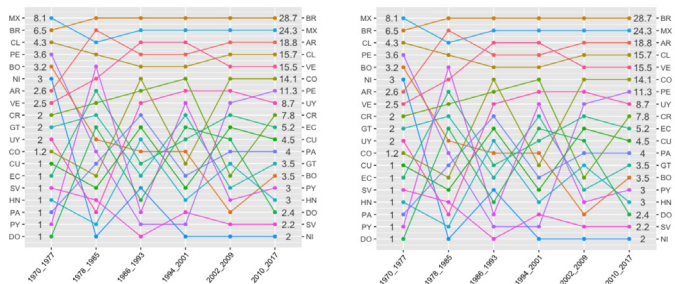
Source: authors based on PatentsView data.

Appendix 2. Centrality indicators of Latin American countries in patent collaboration networks



Eigenvector centrality in co-invention network

Eigenvector centrality in co-ownership network



Weighted reach centrality in co-invention network

Weighted reach centrality in co-ownership network

Note: indicator values are shown for the first and last periods.

Source: authors based on PatentsView data.